MARINE CONSERVATION: KNOWLEDGE, EXPERIENCE AND TOOLS FOR CHANGE

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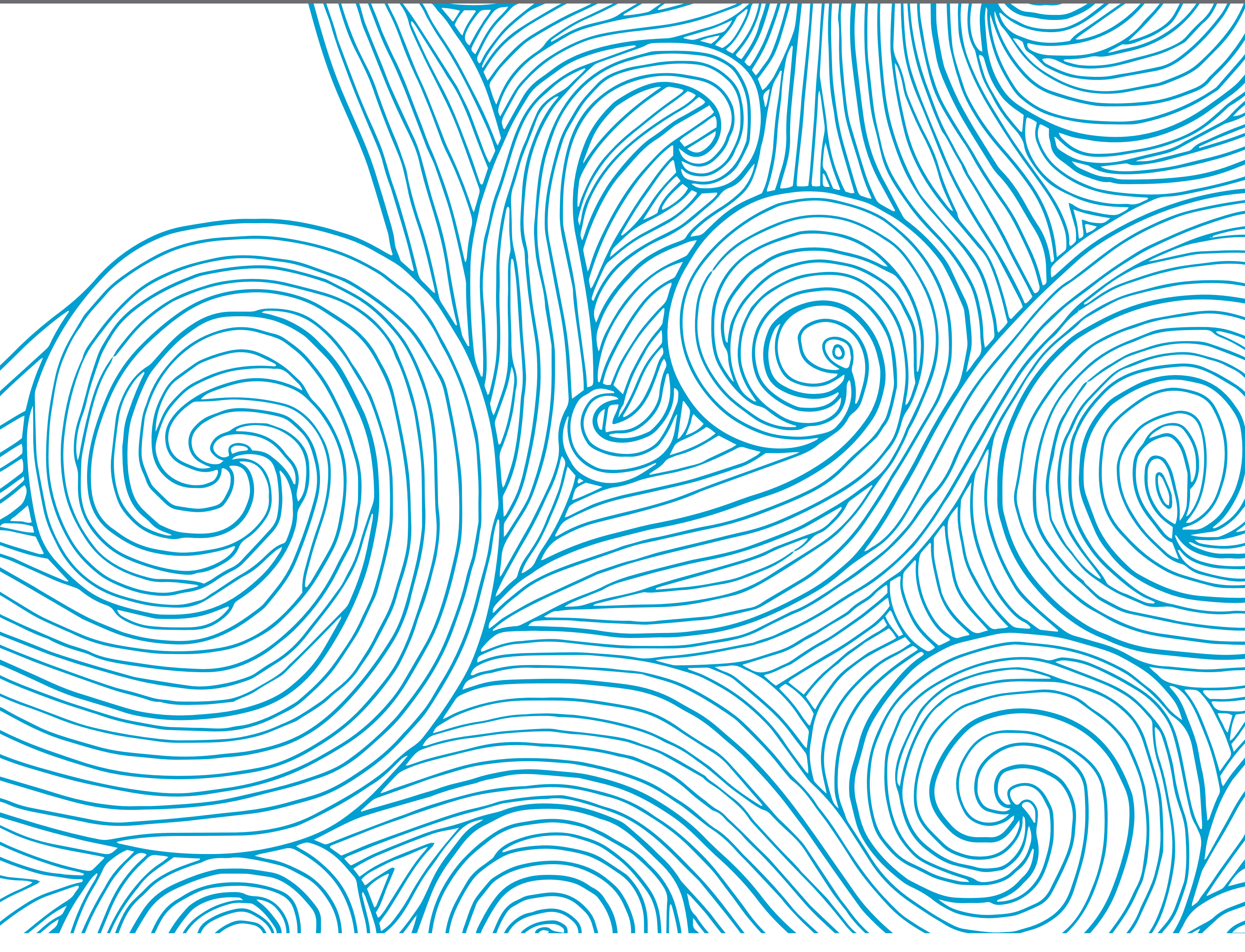

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MARINE CONSERVATION: KNOWLEDGE, EXPERIENCE AND TOOLS FOR CHANGE

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Better for Whom? Leveling the Injustices of International Conferences by Moving Online

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International conferences are an important component of the professional calendar of scientists and practitioners in many fields, and are valued as opportunities to establish, create and foster networks, wellbeing and knowledge. The 2020 global pandemic, in prohibiting large gatherings and travel, has provided an opportunity to test the feasibility and implications of a shift from in-person to online conference formats. Avoiding international travel and associated bureaucracy, time and expense could overcome many of the historic injustices preventing many from participating in and benefiting from international conferences, and also avoid the emissions associated with international air travel. However, prior to 2020, there has been resistance to moving these events online because of the perception that the value of conferences cannot be cultivated online. Here, we use the example of the 6th International Marine Conservation Congress (IMCC6), which moved online in response to the COVID-19 pandemic, to explore participants' perceptions and experiences of an online conference and the potential effects on access and inclusion. Our results show that moving online substantially increased the accessibility of the conference for those who would be unable to attend an in-person event for financial or personal reasons. Results also indicate that the online experience was able to recreate some of the benefits of in-person events, and that many participants are interested in attending online or virtual events in the future. However, the degree of enjoyment experienced or perceived 'value' likely relates to the frame of reference of the individual participant and a commitment to actively engage in the program. Reflecting on the success of IMCC6, we conclude that holding international conferences online, or at least including an online element as part of a 'hybrid' model, is a significant improvement in the capacity of conferences to meet the moral imperatives of the conservation community by addressing the climate crisis and some of the systemic injustices within the field.

Keywords: conference, sustainability, COVID, professional development, equity in access, diversity equity and inclusion, knowledge exchange, carbon emissions

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INTRODUCTION

The global COVID-19 pandemic has pushed much of professional life online in 2020. This includes the usual outlets for networking, knowledge production and exchange such as international conferences, which are highly valued by the scientific community and other communities of practice (Oester et al., 2017). The exchanges facilitated by international conferences where participants convene in a single destination are recognized as important for professional development, wellbeing, and advancing knowledge (Fraser et al., 2017; Edelheim et al., 2018; Timperley et al., 2020). Furthermore, international conferences have become big business, supporting tourism and local communities (Biletska, 2011; Rogerson, 2015). Despite the importance of these events, they are not without controversy and are commonly criticized as being unsustainable and exclusive (Holden et al., 2017; Hook, 2018; Arend and Bruijns, 2019; Jäckle, 2019; Timperley et al., 2020). Moving international conferences, or an element of international conferences, online has been raised as the solution to these concerns. However, there has been a reluctance to change format due to concerns over being able to create the value of in-person formats, much of which arises from informal networking opportunities outside of the formal conference program (Oester et al., 2017). COVID-19 has pushed all events online out of necessity. This, coupled with the global goodwill of a world in 'lockdown' (Morgan, 2020), has provided an opportunity to understand the significance of moving a conference online when considered through the lenses of equity, justice and sustainability for the post-pandemic world (Niner et al., 2020).

Issues of Equity and Justice

Access to Funding

International conferences are exclusive events due to high registration fees and required travel expenses. Registration fees often reflect the high cost of hosting an in-person event, as the costs associated with venue hire, catering and administration of large events are not insignificant (e.g., McKeown, 2017). Whilst many international conferences offer tiered registration fees to account for the potential income of a delegate via proxies such as career stage (i.e., student status) or location (e.g., low income country), without financial support, registration plus the other costs required to attend and participate are frequently prohibitive (Fullick, 2016; Arend and Bruijns, 2019). Funding for attendance has also been shown to be dependent on career-stage, professional role and sector (Timperley et al., 2020). For example, those in early career positions may be fortunate and have access to funds as part of their training programs, but this is more common for students with strong institutional support (Lundy, 2016; Timperley et al., 2020). It is recognized that in academia, in the early years post-Ph.D., it is increasingly challenging to obtain funds for conference attendance. This is attributed to the lack of ownership of funds, which are often awarded to more senior colleagues and also a higher proportion of teaching commitments and therefore fewer funds (and hours) allocated to research communication (Timperley et al., 2020).

International conferences are also inaccessible to many outside of academia, such as those based in government, industry, NGOs or community groups. While the coproduction of knowledge with both users and scientists is increasingly valued (Gross and Fleming, 2011; Edelheim et al., 2018), attendance of practitioners is often limited by institutional support for the necessary financial and time commitments that accompany in-person attendance (Timperley et al., 2020).

Funding to support attendance is often limited and highly competitive; personal experience of the authors has highlighted that fundraising for the purposes of travel grants is challenging with funding for more 'visible' purposes more popular (Niner et al., 2020). Even when available, travel grant programs and reduced registration fees do not necessarily cover the costs of attendance. Given the degree that the location of a conference determines who can attend (Arend and Bruijns, 2019), it is unlikely that financial support will be sufficient to address the overarching issue of equity in access for international conferences.

Systemic Barriers

Systemic barriers, such as those restricting equal participation on the basis of gender or ethnicity also reinforce those posed by access to funding. Gendered barriers to equality in academia have been well-documented. For example, Timperley et al. (2020) in their analysis of gender and ethnic inequality in early career conference attendance describe how women are excluded from conferences. Their findings support established understanding that women are less likely to be keynote (plenary) speakers (Walters, 2018) and are less likely to actively participate (Jones et al., 2014; Eden, 2016; Hinsley et al., 2017). The authors describe how these issues combine with wider inequalities faced by women, such as managing childcare and maintaining perceptions of professionalism, and also harassment in the field (Macdonald, 2020) and at conferences (Henderson, 2015; Mair and Frew, 2018; Sapiro and Campbell, 2018; Jackson, 2019; Timperley et al., 2020).

Similarly, systemic issues restricting participation are also experienced by underrepresented groups. These relate to the culture of 'Othering,' described as inherent to international conferences (Dervin, 2012), whereby perceived differences in social identities influence how a group or individual is treated and can lead to an unwelcoming environment in the context of a conference (King et al., 2018). This is signaled through a lack of representation of both women and people of color in visible and important roles, such as keynote speakers (Mukandi, 2017; King et al., 2018). Further cues of a lack of belonging signaling otherness reported at conferences include the use of gendered language, aggressive questioning, or a higher degree of audience distraction when women and people of color are presenting, and a propensity for men to take more time when giving a presentation or asking a question (King et al., 2018). Cumulatively, these cultures undermine aims of diverse participation in science and draw lines of who and what behavior are expected, valued, and welcome at a conference and its associated community of practice (Henderson, 2015; King et al., 2018; Timperley et al., 2020).

Issues of Sustainability

Sustainability is a particular concern for conferences serving the environmental science and practice community, as much of the work presented is centered around how to protect and ensure the long-term health of natural systems and the services they provide for society (MEA, 2005). There are examples of conferences moving toward "plastic free" (Sinclair et al., 2019) status, providing sustainable food options and comprehensive waste plans (Sarabipour et al., 2020). The carbon emissions associated with the international travel of participants to a single destination are more difficult to address. This is a particular issue for organizations and conferences in the environmental sector, where these groups have made a commitment to addressing climate change as one of the biggest threats to the healthy functioning of our natural world and the planet (Harley et al., 2006; Thuiller, 2007).

In recognition of the direct contribution of traditional in-person conference formats to carbon emissions from international travel, carbon offsetting (Holden et al., 2017) has become synonymous with aims of climate 'neutrality.' Carbon offsetting describes an exchange, whereby an organization, individuals or conferences organizers financially contribute to a scheme that is projected to either remove atmospheric carbon dioxide or achieve additional reduction activity that equals the emissions under question. However, carbon offsetting is often described as greenwashing (Hyams and Fawcett, 2013), whereby the moral boundaries of a damaging activity are eroded by framing it as an exchange (Ives and Bekessy, 2015). Further criticism relates to the technicalities and ethics of offsetting, commonly relating to legitimacy of measuring and accounting carbon reductions and the inequities and injustices of global trading (Hyams and Fawcett, 2013). Most significantly for conference organizers and delegates, however, is the carbon management hierarchy. This hierarchy dictates how offsetting should be appropriately applied and stipulates that the use of offsets should only be considered as a tool of last resort after all options to avoid and minimize emissions have been taken (Hyams and Fawcett, 2013). This hierarchy recognizes the huge uncertainties of emissions reduction or carbon drawdown and the significance of the risks posed by climate change. Moving online does not remove all carbon emissions, as demonstrated by projections for Internet-related emissions to grow in excess of the aviation industry (Boston Consulting Group, 2012; Malmodin and Lundén, 2018). However, avoiding emissions by not flying means that online conferences meet the demands of the carbon management hierarchy.

Is Moving Online the Solution?

Prior to the pandemic, there have been calls for international conferences to provide online access to address issues of access and sustainability (Welch et al., 2010; Fraser et al., 2017). There has historically been a resistance to these calls, largely on the premise that recreating the true value of these events was challenged by moving online (Oester et al., 2017) and also by the technological challenges of creating a seamless hybrid online/in-person event. Furthermore, the authors' experience of seeking to support remote attendance while organizing several international conferences prior to 2020, found the funding landscape for options, such as hub conference models, sparse. Moving online, as required in response to the COVID-19 global pandemic, offers an opportunity to reduce or remove the cost of participation through lower registration fees, and no requirement to travel. However, it is not a panacea for the myriad injustices posed by international conferences.

The issue of access remains when you move online. Whilst the financial burden may be removed, access to the infrastructure and technology necessary for online participation is known to be unequal across society. Many delegates will have adequate access to the infrastructure and technology that supports active participation. However, groups that have been historically and continue to be structurally marginalized, particularly those from low-income countries, are likely to disproportionately experience the digital divide (Niner et al., 2020). Inequities in access to the Internet or technology are mitigated for those associated with governmental, higher education, and some private institutions. Where access to these facilities is restricted, such as during the COVID-19 'lockdowns', or unavailable, such as for those not associated with such institutions and based in rural locations, users rely on in-home or mobile Internet and home-based technology.

Other challenges of shifting large networking events online include the creation of similar cues and norms for communication that are commonly described as essential for the full value of in-person events (Erickson et al., 2011). Often, the informal elements of in-person conferences, such as spontaneous connections occurring in a coffee break or over a meal, are reported as being the most valued output of an event (Gross and Fleming, 2011; Edelheim et al., 2018). This informal communication is traditionally reliant on physical proximity, which supports 'chance encounters', interpretation of body language and also a more visible demonstration of interpersonal relationships of several people in a group (Fish et al., 1993). All of this provides situational information that supports professional networking and the development of knowledge fueled by discussions across disciplines, experiences and geographies. This proximity is challenged by remote participation where many of these cues remain invisible or less easily detected (Fish et al., 1993; Erickson et al., 2011) and is described as leading to a degradation of politeness in communication (Hardaker, 2010). If not addressed during conference organization, these issues could exacerbate existing barriers to participation through unintended exclusion or through tendencies for nepotism toward familiar people and networks that they already know and trust, perhaps those developed and nurtured through previous international conferences.

Moving online will not solve the challenges set by aims of environmental sustainability or equity. However, a change in format addresses many of the fundamental injustices posed by the need to travel internationally to a single destination. The global pandemic in 2020 has pushed many events online, and the goodwill toward virtual opportunities to connect with the wider world whilst travel-restricted has been documented (Morgan, 2020). This goodwill is also evidence of the demand for international networking events. 2020 may be the first time many are able to participate in an international conference purely because it is online. However, for those that have historically been able to attend, the perceived or real diminished value of online formats may lead to a rebound back to business-as-usual, destination in-person conferences post pandemic.

Here, we consider the Sixth International Marine Conservation Congress (IMCC6) as a case study to explore the experiences of an online international conference. We specifically explore what effect moving this conference online had in increasing the accessibility of the event and the experiences of conference participants. As a growing area of interest for the field of knowledge exchange and production this case study provides a snapshot on which future reviews and research can build to consider how international conferences in the future might learn from the lessons of the online transition forced by COVID-19.

MATERIALS AND METHODS

Case Study and Background: The International Marine Conservation Congress

The International Marine Conservation Congress (IMCC) is a biennial meeting hosted by the Society for Conservation Biology Marine Section (SCB Marine), a professional society serving the marine conservation community. Prior to 2020 IMCC has been held in Washington, DC, United States; Victoria, Canada; Glasgow, Scotland; St John's, Canada; Kuching, Malaysia. IMCC6 was planned to be held in Kiel, Germany but in response to the global COVID-19 pandemic, it was held online over the 17–28th August 2020.

SCB Marine has recognized the inequities in participation and access to IMCCs and in 2016 introduced a code of conduct for the meeting (Favaro et al., 2016), and employed a 'safety officer' to ensure adherence to the code of conduct and to mediate any conflict. Additionally, to support the findings of Sardelis and Drew (2016) they incentivized female leadership with preferential fees to encourage increased female representation and participation. SCB Marine like many other organizations, rotates the country and region hosting each event. In theory this changes or shares the accessibility of IMCC, where proximity and the cost of travel is a known barrier to participation. However, 2020 is the first time that remote access to IMCC has been made available.

Data Collection and Analysis

The data analyzed were collected via several methods. Participants (n = 1103) of IMCC6 and those that submitted an abstract to participate in IMCC6 in Kiel but did not participate in IMCC6 online (n = 252) were invited to complete a survey about their experiences of IMCC6 online. The survey included open and closed-ended questions on delegate demographics, career level, experiences of conference attendance and that relating to IMCC6 (see **Supplementary Information** for full survey). Prior to circulation on the final day of the conference, the survey was piloted with a number of participants to refine the flow and clarity of questions. The survey was open for 22 days, and in total 329 people completed the survey representing a return rate of 25 percent.

Survey data was supplemented by anonymized data from the IMCC6 abstract submission and registration platform, the hosting platform and application for IMCC6 and Twitter. This included the number and type (e.g., poster, talk, speed talk) of presentation and the patterns of engagement in the conference. Limited data was available relating to the attendance and experience of previous IMCCs. This is restricted to high level numbers relating to the demographics and overall attendance gathered at the point of registration. Where this information is available this has been included.

For open-ended survey questions, responses were analyzed using N-Vivo (QSR International Pty Ltd., 2018). Response text was uploaded into N-Vivo and then coded inductively to explore the themes present in survey answers. These themes and coded text were then reanalyzed and refined to reduce or remove overlap.

All data was collected, anonymized, analyzed, and stored securely in accordance with the ethics approval obtained from the University of Plymouth.

RESULTS

IMCC6 Attendance and Survey Responses

A total of 1103 people registered for IMCC6, a significant increase from previous registration numbers for IMCCs. IMCC3 in Glasgow, Scotland had 769 delegates. IMCC4 in St. Johns, Newfoundland had 638 delegates (Oester et al., 2017) from 53 countries. IMCC5 in Kuching, Malaysia had 635 delegates from 56 countries. For IMCC6, the registered delegates were also more geographically diverse, from 77 countries, with the largest number of delegates from the USA (23.6%).

Registration for IMCC6 followed a tiered pricing structure, with suggested amounts determined by career stage and the income of the country of residence, following the World Bank classifications (World Bank, 2019) and the United Nations Educational, Scientific and Cultural Organisation (UNESCO) list of Small Island Developing States (UNESCO, 2017). The €10 option, suggested for delegates from middle-income countries, small island states, and for students, was chosen most often (37.2%), followed by the €25 option (33.8%), which was suggested for delegates from high-income countries (**Table 1**).

TABLE 1 | Registrations for IMCC6 by price bracket and the indicative description for each bracket.

Price bracket description	Price	Number
Price covers two registrations – subsidize attendance for others	€50	80
Delegates from high-income countries	€25	373
Delegates from middle-income countries, small island states, and students	€10	410
SCB Members and delegates from low-income countries	€0	240

Definitions for country income and for small island states followed the World Bank and UNESCO definitions (UNESCO, 2017; World Bank, 2019).

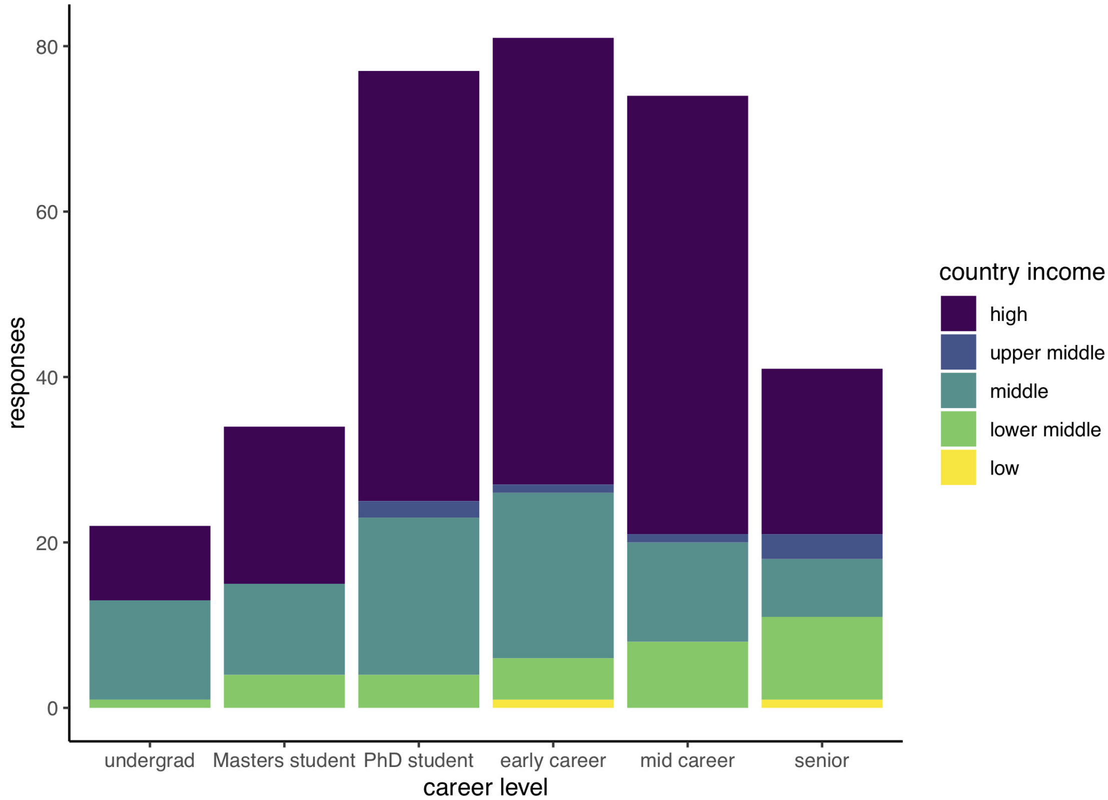

FIGURE 1 | Distribution of survey respondents by career stage and the World Bank definition for the income of the country of residence (World Bank, 2019).

The survey received 329 responses, representing 25% of potential respondents which included those that submitted an abstract to attend in Kiel but selected not to participate when IMCC6 moved online. Of those that responded, 93.3% attended IMCC6 online and 6.7% did not attend. Respondents were from 49 countries, with the largest number from the USA (21%), followed by the United Kingdom (10.6%), and South Africa (7.6%). 70.5% of survey respondents identified as women and 26.7% identified as men, with 2.7% preferring to self-describe or not to say.

The majority of respondents were employed full-time (51.8%), with 30.2% currently students. Most respondents were Ph.D. students (23.4%), early career (23.4%; defined as up to five years since graduation), or mid-career (21.3%), with 11.9% of respondents identifying as senior, 10.3% as Masters students, and 5.2% as undergraduate students (**Figure 1**). 41.9% of respondents were employed in academia, followed by 25.3% in non-governmental organisations (NGOs), 13.2% in government, 12.4% in education, and 2.2% in business (**Figure 2**). The majority of IMCC6 attendees did not present, with speakers and session/workshop/focus group chairs representing 40% of the total attendees. Of the survey respondents, 48.8% attended but did not present and 4.9% did not attend. 26.1% of respondents had attended an IMCC previously. 51.1% had not attended an IMCC but had attended a different international conference previously, and for 22.8%, IMCC6 was their first international conference.

Modes of Attendance

60.6% of survey respondents submitted an abstract for a session, talk, poster, workshop, or focus group. Almost all respondents (96.9%) indicated that they would prefer to present in English, with the remaining respondents indicating Spanish, French, and Portuguese as preferred languages. The majority of survey respondents (70.3%) had not intended to attend IMCC6 in Kiel, Germany. The majority of respondents (81.2%) who did submit an abstract, submitted before March 2020 with the intention of attending in Kiel. Of those who had submitted before March 2020, 252 authors withdrew their abstracts when the conference was moved online, and 66.2% of those who withdrew attended the online conference. Of those who did not submit an abstract for the in-person conference, 28.8% indicated that the cost of travel was why they did not submit, with cost of registration indicated by 20.3%.

The main mode of transportation for those who had planned on attending IMCC6 in Kiel was plane (77.2%), followed by the train (14.6%). 30.6% of respondents had applied for a grant to attend in-person, and 17% were concerned about visa requirements.

Almost all respondents used the desktop app (56.6%) and/or the mobile app (42.4%) to access IMCC6. Three respondents indicated that they dialed in via telephone (0.6%). The majority of respondents (59.2%) did not experience any technical problems when accessing and engaging in IMCC6. Of those who did

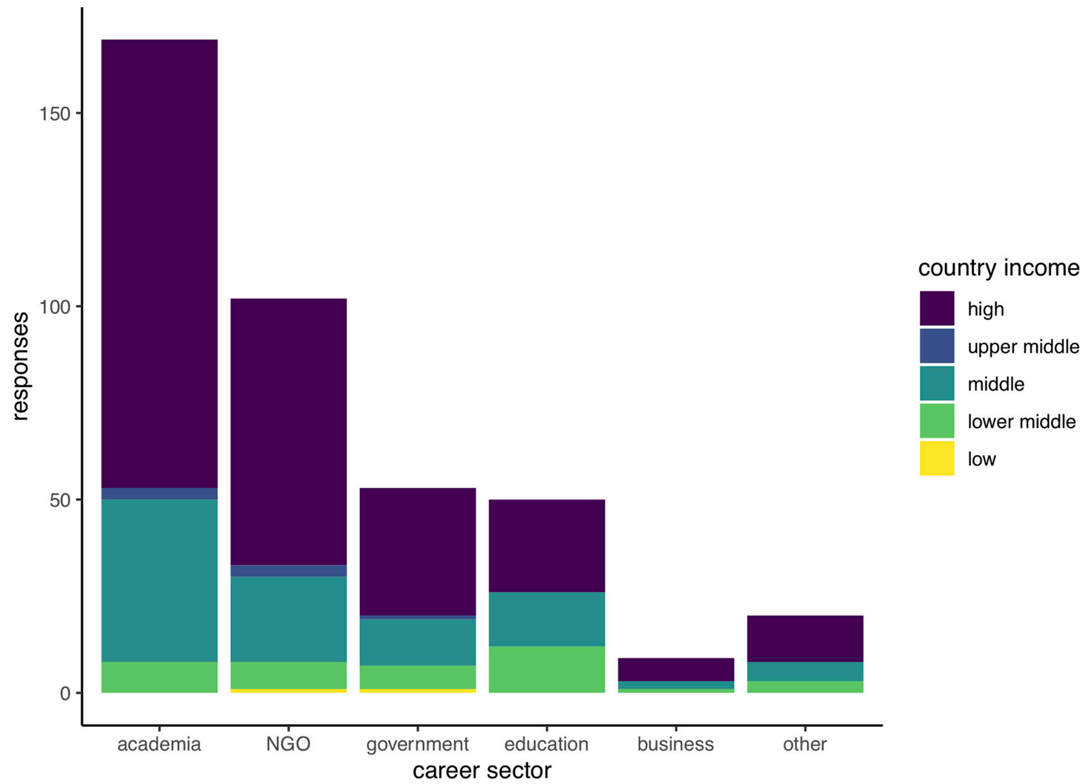

FIGURE 2 | Distribution of survey respondents by career sector and the World Bank definitions for the income of the country of residence (World Bank, 2019).

have issues, access to WiFi and mobile data was the largest issue (**Figure 3**; 35.8%), followed by browsers not functioning (**Figure 3**; 19.2%).

Most respondents had a strong (48.7%) or good (39.5%) internet connection, allowing them to follow talks and engage with limited problems. 11.4% of respondents indicated that their internet was patchy, meaning it was difficult to follow talks and to engage at times.

The Online Experience

Overall, respondents had a positive (51.3%) or extremely positive (33%) experience and felt that IMCC6 was better (52.6%) or much better (24.8%) than expected (**Figure 4**). Respondents indicated that the most useful parts of the conference were the formal program (47.5%), the conference app community (23.8%), and the focus groups & workshops (18.8%). The majority of respondents (72.1%) were able to form professional connections at IMCC6, mostly through the formal program (40.8%). Most respondents, however, indicated that it was more difficult to form professional (57.5%) and personal (66.7%) connections online than in-person.

Most respondents engaged with IMCC6 between 30 minutes and two hours per day (52.6%) and the majority predominantly engaged with the live talks (**Figure 5**; 53.1%). 74.5% of respondents watched the recorded talks and 84% indicated that they intended to watch the recorded talks after IMCC6 closed. The IMCC6 recordings were watched for a total of 1,461 hours, with 4873 plays across 78 uploaded videos (with each video representing a 1–1.5 hour session), with an average of 62.5 plays per video, ranging between 3 and 259 plays per video, and an average of 23.9% of each video watched. Aside from the conference app and website, 45.2% of respondents indicated that they used Twitter to follow the conference activity, with 11.3% indicating that they used Facebook. IMCC6 obtained over 275k tweet impressions within August 2020, a 2% increase in impressions obtained for IMCC5 and a 10% increase in impressions over the month leading up to the conference as compared to a similar timeframe for IMCC5.

Work commitments was the most common answer (28.7%) for what prevented further engagement with IMCC6, followed by time zones & scheduling (23.4%), personal commitments (19%), and 'Zoom fatigue' (13.4%).

The survey included several open-ended questions to inductively gather themes that described perceptions and experiences of those that participated in IMCC6 online. These questions were optional and as such response rate varied. 266 respondents answered the question on what they liked about IMCC6 and 247 answered the question about what they disliked, 16% of respondents indicated explicitly that they did not dislike any aspect of the conference. In contrast, 29% of question respondents described how online conferencing does not adequately replace all of the benefits of in-person formats, as described by one respondent and echoed by others "*it is just not the same. . .*." The reasons described for this perception include an inability to "*protect*" the time from personal or

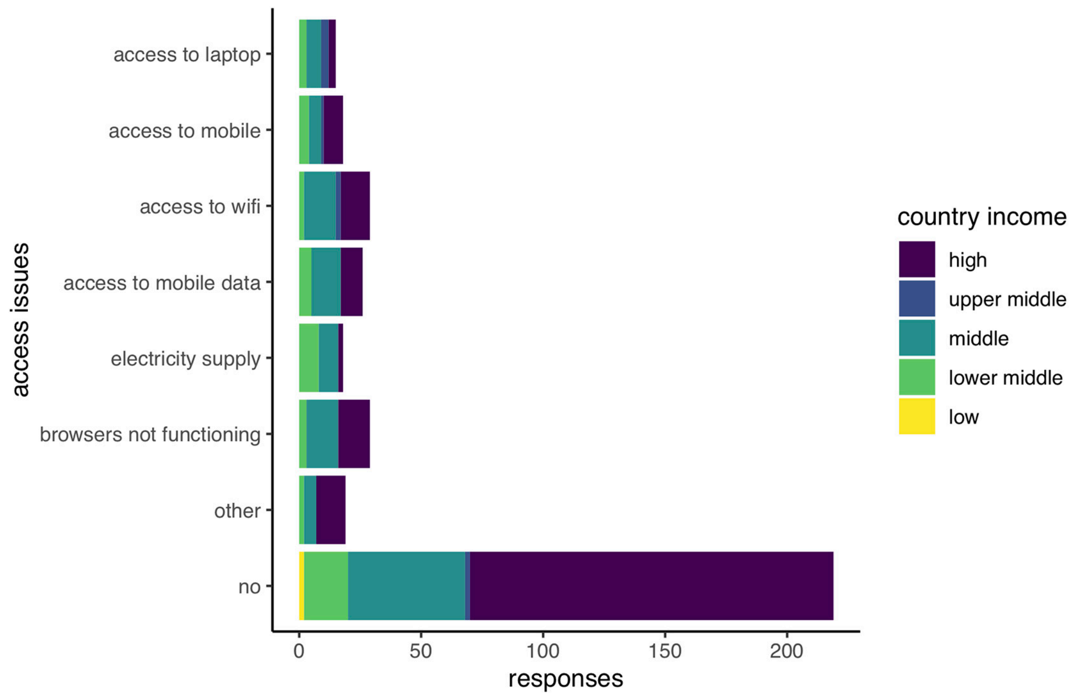

FIGURE 3 | Reported access issues for survey respondents (respondents could choose multiple options), and the World Bank definitions for the income of the country of residence (World Bank, 2019) for the respondents.

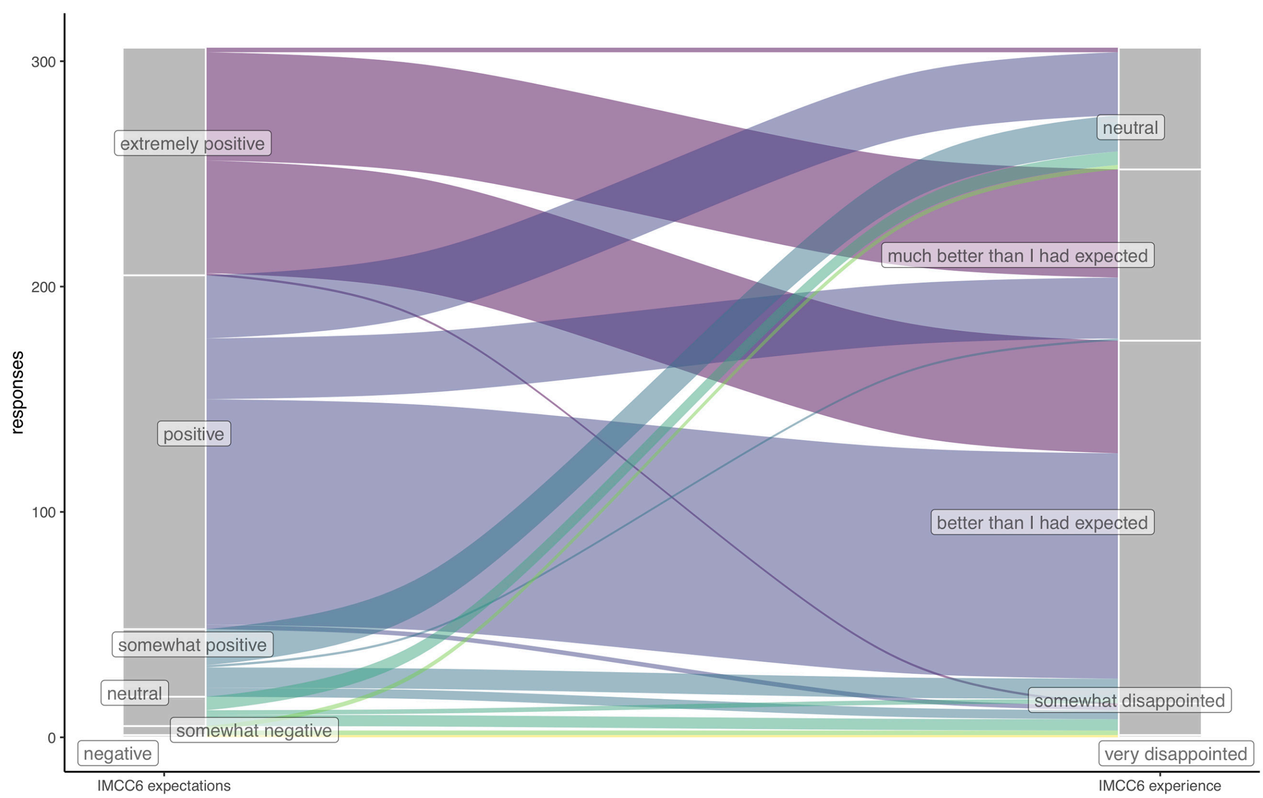

FIGURE 4 | Comparison of survey respondents' expectations for IMCC6 and respondents' IMCC6 experience.

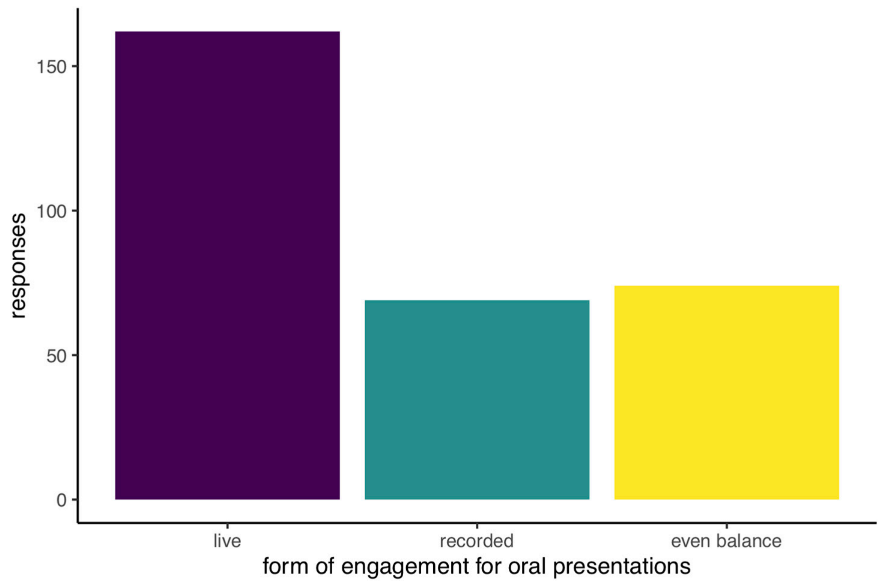

FIGURE 5 | Distribution of the majority of survey respondents' engagement with the oral presentations.

work commitments to engage fully with the conference (20%), a perceived lack of opportunity for informal interactions (14%) or networking to establish meaningful connections (13%) outside of the formal scientific program.

The organization of the event was explicitly described positively by 19% of question respondents while only 2% described elements of conference organization that they disliked. The technological platforms were viewed positively and well-suited to the event by 23% of respondents, with 15% experiencing troubles, most notably issues of poor desktop app functionality and inabilities to download the mobile app because it was unsupported by older technology.

> *"my phone was too old so I had to borrow a phone so that I could access all the features of the app"*

When commenting on what they liked about the conference, 26% of respondents described how access to recorded material allowed them to engage at their own pace or in their own time zone. The restriction of recorded talk availability to a week after the event was described as a frustration by 9% of respondents, however 17% expressed regret that they were unable to engage with the live talks due to inconvenient scheduling for their time zone. As expressed by one respondent, they perceived there was "*Little interaction with other participants due to time-zone overlap*." A further 10% of participants described how they enjoyed engaging flexibly with IMCC6 such as being able to easily take breaks and to participate from their desks alongside work, while doing chores, or "*with my child and cutting vegetables*."

The low cost of the event was referenced explicitly by 23% of respondents, with the affordability of fees (6%) and reduced travel costs (5%) arising as key themes. Some respondents (2%) also described how they missed the opportunity to travel for a conference. Of those reflecting on the costs associated with IMCC6, 42% of question respondents (9% of total respondents) specifically outlined that they would not have been able to attend IMCC6 in Kiel owing to the high associated costs, a further 12% (3% of total respondents) indicated their support for increasing access for those who are excluded as a result of costs. The perception of increased global representation at IMCC6 was described positively by 20% of question respondents, and 25% described how they enjoyed the quality of talks and the range of topics. Contrasting this, 2% of respondents outlined concerns about a lack of diversity and inclusion of conference participants.

Several themes arose with respect to the perceived social presence at IMCC6. A perceived sense of "*incredible community*" arising from a friendly and welcoming atmosphere was described by 8% of respondents. Contrasting this, 2% of respondents outlined a perception of poor behavior or aggression. The accessibility of talks was commented on by several respondents as contributing to this.

> *"The topics were not too complicated even for a stranger to marine conservation/biology. It appeared and was pretty welcoming"*

Engagement, communication and networking with content and other IMCC6 delegates was viewed by 17% of respondents as easy or easier online. This was described by 5% of respondents as stemming from a welcoming environment provided by friendly and helpful communication from organizers and conference facilitators.

> *"I have never had the confidence to ask a question at a conference and at IMCC I felt great asking a question. The community felt more welcoming online for some reason and it felt safer to ask a question behind a screen. At conferences I'm always intimidated by the big scientists."*

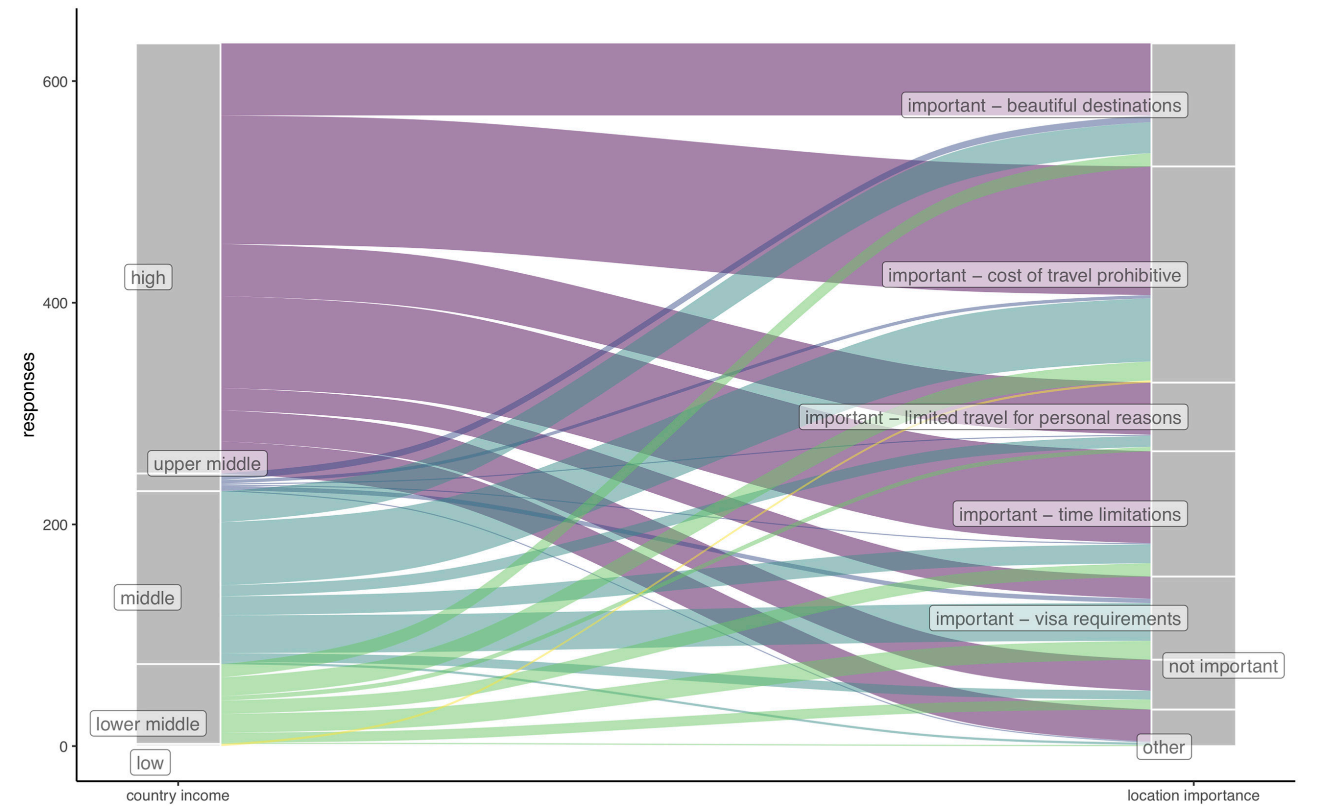

FIGURE 6 | Comparison of the income of the country of residence of respondents, from the World Bank definitions (World Bank, 2019), and the importance of future conference location. Respondents could choose multiple options.

Climate

Almost all respondents indicated that the scientific community should reduce its carbon emissions in line with the Paris agreement (United Nations, 2015), with 64.4% responding that the community should do more than it already does. When asked if they expected scientific societies, research, and conservation organizations to lead these efforts, 93.9% responded "yes." When asked how important the location of IMCC was, however, 17.5% indicated that it was very important because they like to go to beautiful destinations (**Figure 6**). 9.8% indicated that location was very important because they choose to limit their travel due to personal reasons (**Figure 6**). Eight respondents mentioned climate as an "other" option, stating that climate change is "*not a 'personal' reason to avoid unnecessary travel,*" that they "*feel guilty traveling by air, for work or privately,*" for example. In reference to their preferred conference format, two mentioned climate as a reason to move away from in-person conferences, and one person mentioned that their attendance either in-person or online at a hybrid event would depend on whether they had "*already exceeded [their] carbon for that year.*" However, when considering positive perceptions of IMCC6 online only 6% of respondents referenced climate change or a reduction in carbon emissions as something they liked.

The Future of International Conferences

The majority of respondents indicated that they would prefer a hybrid conference model (65.3%), followed by in-person (22.8%), and then by online (11.9%). When asked how they would imagine they would attend a hybrid option, the vast majority (82.3%) indicated "both in-person & online - it depends." Only 8.4% selected exclusively in-person, and 7.4% selected exclusively online.

Only 157 responses were received in relation to the question asking for detail on what a hybrid model for IMCC might look like, and of these responses 129 answered the question directly. Broadly, suggestions related to ensuring that either the entirety or elements of the in-person conference were made available online, to ensure that remote delegates were able to present and ask questions. Other suggested models included smaller, more topic-focused conferences held online complemented by a broader in-person event hosting plenary speakers, the application of a hub model either for the conference or to access an online IMCC, or restricting the travel allowed to attend the in-person event while circulating the conference location with a focus on the southern hemisphere. A limited number of participants raised concerns of adequate integration between in person and online events to ensure that "*the online is organized to cater to the advantages of online not just be a lesser extension of in person.*" Suggestions to address this included holding specific 'online only' social events and regional hub 'dial-ins'. One respondent mooted the opinion that "*a fully hybrid model might not work well*" and instead that every two years, IMCC should alternate between dedicated in-person and online formats. Another respondent indicated that the use of a hybrid model is likely only a phase in the natural transition toward online conferences and suggested that "*the pandemic was just a catalyst to this process*."

When providing suggestions or ideas for improving online conferences, 157 were received. Of these, 24% explicitly outlined that they had no suggestions for improvements, either because IMCC6 "*worked unbelievably well*" or because of a lack of interest in online conferences, as with one respondent who chose to withdraw their abstract when IMCC6 moved online because they "*can interact online with people at any time and do not need a conference for that.*" Another common theme within responses was that online conferences are relatively new to most and that there are criteria that encourage efficient and effective attendance. The suggested concepts criteria included understanding the time commitment required to effectively engage to meet personal aims, the need for coordinators to actively engage in session planning, and an understanding of the "*netiquette of virtual interactions.*" In addition to this, suggested included ways to encourage more informal interaction between and among participants such as through open 'rooms' for people to join, small ice-breakers, speed-dating type events to encourage networking, and other informal events such as cooking demonstrations. Various technological platforms were suggested as a way to make the online conference more immersive to encourage informal interaction. In relation to IMCC's aims of diversity and inclusion, suggestions included the use of translators, closed captioning, and the creation of non-English language-based discussion groups or rooms.

DISCUSSION

Access to IMCC6

Attendance at IMCC6 increased by 74%, compared to IMCC5 in Kuching, Malaysia, notably corresponding to a 38% increase in the number of countries represented. This increase is similar as compared to patterns of attendance at IMCC4 in St Johns, Canada. Results here indicate that moving online increased the access to IMCC6 for those that would have been unable to attend an in-person event in Kiel, Germany, and perhaps also for those who had never been able to participate in an international professional conference. The survey results suggest that the low cost of the event, both as a result of the tiered registration fee and the removal of requirements for travel, increased the accessibility of the conference. In line with previous analysis (Wilson and Biggs, 2016), further barriers to attendance in person related to concerns over obtaining a visa for travel and also the time associated with both traveling and attending the event were avoided via online participation.

There are barriers to access beyond travel costs, however, including access to technology and English language proficiency. Access to technology is a barrier that is unlikely to be adequately captured by the results presented in this study, as it is unlikely that those who have limited access to data, internet infrastructure or technology such as laptops or smartphones, were able to register for or participate in IMCC6. As an indication of the uneven distribution of these services and technologies, 23.4% of urban households in India have access to a computer (Government of India, 2018) and in Africa, only 39.3% of the total population in March 2020 had access to the Internet, as compared to 62.9% of the rest of the world (Ngware, 2020). For many, particularly those in rural areas, the cost of mobile data, a primary source of access to online learning and conferences, is unaffordable; in South Africa the proportion of smartphone users for whom data is unaffordable is estimated at a third (Gedye, 2020).

Results here do provide some indication that limited technological access is a prevalent issue, such as that for some, downloading the smart phone app, one of the primary platforms on which IMCC6 was hosted, was not supported because of the age of several delegates' phones. Further, difficulties participating in IMCC6 as a result of internet quality appear to fall disproportionately on low-income countries. However, our personal experience was that the overall ability of people to actively participate and present work was much better than expected. A colleague anecdotally reported how in an IMCC6 session he was chairing, a delegate successfully delivered their talk via a mobile phone, in the field in remote Sri Lanka (pers comm Dr. David Shiffman, August 2020). The survey results also suggest that for those able to attend, the technology was largely useable. Most of the software and services used were contracted before the conference was moved online, and some problems arose through retrofitting the new needs of an online conference. These problems included interfacing between platforms and discrepancies between the online and web-based apps, whereby full functionality was not available on both platforms. This highlights the importance of intentional and careful planning to ensure not only that the selection of technology facilitates engagement in the event, but also that is compatible with older devices and low data availability to reduce this barrier to access.

Language is another potential barrier to access and participation. English is the international language of scientific communication (Montgomery, 2004), which holds true for the survey results presented here, where the majority of survey respondents indicated that they had a high level of English fluency and would prefer to present in English. However, the survey results reflect the perceptions, preferences and experiences of those already engaged to some degree with IMCC6 and the international marine conservation community and are unlikely to include those for whom communicating in English is a barrier. The scientific community acknowledges that there is a "diversity crisis" whereby participation is commonly dominated by English-speaking countries (Smith et al., 2017). Bridging this language gap is even more important when conferences are moved online because they open up the possibility of participation for many who may be excluded from in-person, location-based events. While the call for abstracts was available in languages other than English, including Japanese, Russian, Bengali, Italian and French, and abstracts were accepted in any language, communication and outreach about the conference were almost entirely in English. The transition of IMCC6 from in-person to online was both rapid and unexpected. This restricted the considered 'lead in' to the conference, including wide promotion using other channels across a range of languages to an audience beyond the established IMCC and SCB Marine community, that could have lead to a more diverse delegate profile.

Inclusion at IMCC6

Adapting an in-person conference program to an online setting necessitated a change in format, especially to account for the many time zones of attendees. When planning the move of IMCC6 online, it was assumed that live, synchronous presentations were central to creating the social presence or 'buzz' that characterizes a successful in-person event (Tu and McIsaac, 2010). The resulting structure - extended over two weeks with fewer sessions per day but spread over a 24 h time period - was viewed by the organizers as the best option for encouraging live participation and avoiding 'Zoom fatigue' (Jiang, 2020). Furthermore, this structure sought to avoid disadvantaging presenters in less populated or represented time zones. Because live viewing of all content was unlikely to be possible for attendees, and recognizing the challenges of competing time pressures and the relatively new concept of 'conferencing from home,' all sessions were recorded and made available for one week beyond the live program. The recorded videos provided an opportunity for attendees to attend sessions asynchronously, and many survey respondents indicated that they would have liked the recordings to be available for more than one week beyond the end of the conference. The data from the recorded video platform suggest, however, that a minority of attendees actually watched the recordings.

Focusing on a live program was also aimed at encouraging networking and attempting to recreate some of the intrinsic value of IMCC. The IMCC community is an important part of the identity of the conference (Oester et al., 2017), and the survey respondents noted that the conference was inviting and open, and that the live sessions were more engaging than the recorded sessions. A small minority of respondents mentioned issues with social aggression at the conference, highlighting the continued necessity of a code of conduct and safety officer for online conferences. A degradation in politeness has been recognized in online communication (Hardaker, 2010), and cultural insensitivity and impoliteness has been indicated as leading to lower levels of minority representation in academia (Louque and Thompson, 2005). With the diverse geographical and cultural backgrounds represented at IMCC6, there is a risk that some communication is made more difficult and can exacerbate existing inequities, such as through the pronouncement or distortion of accents (Gibson et al., 2014) or a slower response time for those participants for whom English is a second language. This risks a perceived domination by native or confident English speakers and has the potential to disadvantage inexperienced and minority attendees more so than in person where non-verbal cues are less easily detected (Fish et al., 1993; Niner et al., 2020).

Future of Conferences

Privilege of Preferring an In-Person Option

Both the survey results and the authors personal experience indicate a feeling from some attendees that online conferences do not provide the same experience as in-person conferences, especially for IMCC where the community is central. This is contrasted sharply with the respondents and attendees who expressed their excitement at being able to participate in an IMCC because it was online and therefore accessible to them. For many delegates, IMCC6 was their first international conference, and the survey responses show that some of the respondents were very aware of the fact that their attendance would not be possible for any in-person IMCCs in the future. Reflecting on hybrid conferences, one respondent described how they would never be able to attend in-person, but that "*my perspective is no less valid in this field just because I am poor.*" Another respondent commented "*I had the feeling that there were too [sic] kinds of attendees to the conference,*" that "*some saw the online version as a unique opportunity to be able to attend a conference,*" while others "*attended because there was no better option: better this than nothing. Some of them stressed several times that a face-to-face conference is better, but better for whom?*" These conflicting views of an online conference as an opportunity versus an inferior (and temporary) replacement hint at possible resistance to instating online conferences post-pandemic.

Conflict Between Conferences and Sustainability

Almost all survey respondents indicated that the scientific community should reduce their climate impacts, and that professional societies should lead in these efforts. However, this sentiment is not necessarily represented in the rest of the survey, with very low numbers referencing the issue throughout. These results show how the travel opportunities presented by conferences remain an important factor in their value creation. Carbon offset programs can provide benefits in terms of carbon reduction through various means, such as tree planting, support for technological innovation (e.g., renewable energy development), biodiversity conservation or activities such as the provision of efficient cooking stoves (Hyams and Fawcett, 2013). Carbon offsets to balance the emissions associated with flying are increasingly available, particularly in response to the growing pressures of flygskam or flight shame (Ambrose, 2019). They are also commonly employed by international conference organizers in acknowledgment of their contribution to global carbon emissions (Holden et al., 2017). However, for these financial contributions to be considered true offsets, their use needs to adhere to the carbon management hierarchy and they should only be applied as a last resort after all options for mitigation and avoidance of emissions have been explored (Hyams and Fawcett, 2013). This hierarchy recognizes the significance of emissions and their contribution to the climate crisis, and the uncertainties of offset success. As commonly applied, carbon offsets for international travel to attend a conference do not fit the 'last resort' criteria. These payments are made with the acknowledgment of the myriad consequences of carbon emissions for both current and future generations (Coelho, 2015). Carbon offsets are criticized for eroding the moral boundary of harmful activity and the impetus for technological and policy reform (Sandel, 2005; Anderson, 2012; Hyams and Fawcett, 2013). Their use is increasingly uncomfortable considering the unequal benefits accrued at the expense of emissions with only

4% of the global population taking an international flight in 2018 (Gössling and Humpe, 2020).

Given the overarching challenge of the climate crisis for the ocean (Harley et al., 2006), there is a moral onus on the marine science and conservation community to analyze their actions, and their personal and organizational responsibilities, accordingly. The push online afforded by the COVID-19 pandemic has shown that conferences can be held meaningfully online. Whilst online conference formats are not carbon neutral (Taylor, 2020) they do, through the total avoidance of travel emissions, meet the last resort criteria of the carbon management hierarchy.

Does an Ethical Hybrid Model Exist?

While the majority of survey respondents indicated that they'd prefer a "hybrid" conference model that includes both in-person and online elements, there is no clear consensus on the form of a hybrid conference. Common survey responses suggested that models would follow traditional in-person formats, with the possibility to present and view some presentations remotely. These suggestions fell short of providing solutions as to how to adequately integrate the two formats. In recognition of the difficulties of adequate integration and the "*risk that the online community would be disconnected from the in-person community and would get less out of it*," one respondent suggested the most appropriate and feasible hybrid model would be to alternate between in-person and online conferences. Results presented here show that the cost of travel is the main deterrent from attending an in-person conference. Accordingly, those likely to be disproportionately affected by inadequate integration and the prioritization of in-person elements of a hybrid event are attendees from low-income countries, students, and practitioners from outside the academy, potentially widening existing systemic inequities.

It should also be noted that while online conference models address some issues of inequity in access and participation, barriers remain for language, disability, and other potential sources of disadvantage in academic and professional communities. IMCC6 provided no support for vision and hearing-impaired attendees, nor any other disabilities. Technology for automatic captioning and no need for physically access to conference venues may mean that online conferences are more accessible for some (Tisdell and Loch, 2017), but moving online may present other challenges.

Improving Online Conference Formats

Survey results showed an overall positive perception of the online IMCC6 experience, and there were indications that social presence contributed to this. Feedback relating to regret that delegates were unable to participate in more live sessions suggests that creating a unique moment in time is important for creating conference value. Despite the clear indications of a preference for live engagement, there were calls from delegates to extend the availability of the recorded sessions beyond the single week after the close of the conference. However, these calls were not supported by recorded session views, which were much lower than when talks were presented live. If the value of an online conference is strongly contingent on live engagement, then this will require that delegates are available to actively engage at the times scheduled. Several survey respondents indicated that they struggled to "*set aside*" time to engage with the conference, owing to competing work demands that they were unable to step away from when attending a conference at home, instead of a location-based conference. Conversely, others enjoyed the flexibility of being able to dip in and out of the conference and to fit attendance around their commitments, many of which could prevent or challenge in-person attendance.

A common refrain heard throughout IMCC6 was that "*it's not the same*" indicating a bias linked to the expectations for online conferences to recreate an exact or very similar experience to traditional models. We agree with other critiques of online events this year (Elder-Vass and Carrigan, 2020) in that a shift in perception is required, where online is viewed as an improvement on a model that was inherently exclusionary. Participants did not raise any issue in relation to the effectiveness of delivering oral presentations online. However, reflecting on the survey results and the experience of organizing and facilitating the rapid pivot of IMCC6 online in response to the global pandemic of 2020, it is clear that both the technology and format of online conference will innovate over the coming months and years. For example, poster presentations could shift to video abstracts (e.g., Verbalize.science, 2020), interactive infographics or another form better suited to online engagement. Other suggestions involving virtual reality platforms were proposed, but the technology and infrastructure requirements for participants with a lesser degree of access should be borne in mind when considering how presentation formats might evolve.

Another key aspect that requires consideration is how to create informal spaces for networking, such as semi-structured sessions to actively encourage engagement that may precipitate into informal conversation and fruitful collaborations. Whilst a third of survey respondents indicated that they found actively engaging and networking easier remotely than at an in-person event, the majority indicated that they found it harder to form personal connections online. Informal engagement at IMCC6 was anecdotally much easier for those that had existing relationships. Whilst reinforcing such relationships is an important element of conferences, this should not be at the expense of including newcomers. This is particularly pertinent for online conferences that support a vast widening of a community of practice, particularly considering that an online conference might be the first time an individual is participating and that the usual forms of conference etiquette may not be known. This is not to say that all attendees should conform, but more that participants new and old should be cognizant of the different frames of reference of attendees and recognize the opportunities that this diversity brings to the field. As we all become more adept at organizing and participating in large online networking events, together we can seek to understand what netiquette of virtual interactions is most inclusive and effective for each community of practice.

Beyond program format, the business models for conferences will also require renovation in response to a full or partial shift online. In-person events can incur significant costs, arising from necessary services such as large venue hire and catering (e.g., McKeown, 2017), often leading to high registration fees. For IMCC6, moving online led to a reduction of costs, which coupled with sponsorship allowed us to pass these reductions onto delegates via highly reduced registration fees (**Table 1**). However, for some organizations and businesses, conferences and the profit raised by them are core sources of income. As such, some organizations will likely look to charge for future attendance or participation whether online or in-person. Much of the growing body of events and information being shared online is being made available free of charge (e.g., United Nations, 2020). In response, business models that seek to make profit from online conferences may be challenged and resist moving online. Online conferences do hold value, as demonstrated by results presented in this paper, and willingness to pay to attend an online conference will depend on the development of innovative formats that make these values clear. However, when considering the new business-models for such events, the myriad benefits of equity in access for knowledge exchange and production should be central to considerations of profit when registration fees are set. As the effects of the COVID-19 pandemic continue to be felt into 2021, more events will be pushed online. Further experiences and data from online and hybrid conferences will contribute to an understanding of how best to hold conferences that are effective, valued, and importantly sustainable, equitable and just.

CONCLUSION

Online conferences are a step toward leveling the inequities and injustices of access and sustainability posed by traditional in-person international conference models. These barriers are insurmountable for in-person conferences, as highlighted by the inadequate 'solutions' currently employed, including travel grants and offset payments. Hybrid events are heralded as the solution to these challenges, but there is no consensus on how to integrate in-person and online attendance in a way that does not exacerbate these barriers. While technical access remains a barrier to online participation particularly for those in low and middle income countries, holding conferences online is a key step toward equalizing access and inclusion in scientific and professional fields. However, our results and trends in air travel prior to 2020 indicate that whilst the climate crisis and the Paris Agreement is recognized as important, the disincentives for traveling to an in-person conference are not sufficient to drive change. Whilst at an individual level it is possible to opt out of traveling to in-person conferences (Anderson, 2012) such a stance could disadvantage some and for others 'opting in' is not an option. Accordingly, whilst at a personal level active and positive engagement in online events will be essential to realize the full range of benefits afforded by international conferences, the onus for change should not be on the individual but on the society or organization.

It remains to be seen whether the shift to online formats in 2020, while necessitated by the global pandemic, will be the impetus for an overall shift to more inclusive formats. This year has highlighted that online conferences can be valuable, inclusive and an opportunity to address many of the moral dilemmas posed by traditional conference models, particularly for the marine conservation community and others working in the fields of environmental or sustainability science and management. If organizations neglect the lessons learned from the pandemic and fail to embrace the opportunities of remote conference attendance, they knowingly exclude people. On an individual level, those of us able to attend a conference no matter where it is held should be cognizant of the fact that the option to prefer an in-person conference is predicated on the ability to attend one.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the manuscript/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Plymouth. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Both authors have contributed equally to this work and share first authorship.

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SUPPLEMENTARY MATERIAL

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REFERENCES

Ambrose, J. (2019). *Can Carbon Offsets Tackle Airlines'. Emissions Problem? Guard*. Available online at: https://www.theguardian.com/environment/2019/nov/19/can-carbon-offsets-tackle-airlines-emissions-problem (accessed November 27, 2020).

Anderson, K. (2012). The inconvenient truth of carbon offsets. *Nature* 484:7.

Arend, M. E., and Bruijns, S. R. (2019). Disparity in conference registration cost for delegates from low- and middle-income backgrounds. *Afr. J. Emerg. Med.* 9, 156–161. doi: 10.1016/j.afjem.2019.01.016

Biletska, I. (2011). Business tourism in the context of international tourism development. *J. Eur. Econ.* 10, 182–191.

Boston Consulting Group (2012). *GeSI SMARTer 2020: The Role of ICT in Driving a Sustainable Future*. Available online at: https://www.bcg.com/publications/2012/energy-environment-technology-industries-smarter-2020-role-ict-driving-sustainable-future.aspx (accessed May 5, 2020).

Coelho, R. S. (2015). *The High Cost of Cost Efficiency*. Coimbra: Faculdade de Economia da Universidade de Coimbra.

Dervin, F. (2012). "Cultural identity, representation, and othering," in *The Routledge Handbook of Language and Intercultural Communication*, ed. J. Jackson (London: Routledge), 181–194.

Edelheim, J. R., Thomas, K., Åberg, K. G., and Phi, G. (2018). What do conferences do? What is academics' intangible return on investment (ROI) from attending an academic tourism conference? *J. Teach. Travel Tour.* 18, 94–107. doi: 10.1080/15313220.2017.1407517

Eden, D. (2016). Women's participation in academic conferences in Israel. *J. High. Educ. Policy Manag.* 38, 406–421. doi: 10.1080/1360080X.2016.1181887

Elder-Vass, D., and Carrigan, M. (2020). *Online Conferences Don't Have to Feel like Substitutes. 4 Considerations for Making Yours Better than the 'Real Thing.'* LSE Impact Blog. Available online at: https://blogs.lse.ac.uk/impactofsocialsciences/2020/09/14/online-conferences-dont-have-to-feel-like-substitutes-4-considerations-for-making-yours-better-than-the-real-thing/ (accessed December 7, 2020).

Erickson, T., Sadat Shami, N., Kellogg, W. A., and Levine, D. W. (2011). "Synchronous interaction among hundreds: an evaluation of a conference in an avatar-based virtual environment," in *Proceedings of Conference on Human Factors in Computing Systems*, Vancouver, BC, 503–512. doi: 10.1145/1978942.1979013

Favaro, B., Oester, S., Cigliano, J. A., Cornick, L. A., Hind, E. J., Parsons, E. C. M., et al. (2016). Your science conference should have a code of conduct. *Front. Mar. Sci.* 3:103. doi: 10.3389/fmars.2016.00103

Fish, R. S., Kraut, R. E., Root, R. W., and Rice, R. E. (1993). Video as a technology for informal communication. *Commun. ACM* 36, 48–61. doi: 10.1145/151233.151237

Fraser, H., Soanes, K., Jones, S. A., Jones, C. S., and Malishev, M. (2017). The value of virtual conferencing for ecology and conservation. *Conserv. Biol.* 31, 540–546. doi: 10.1111/cobi.12837

Fullick, M. (2016). *It's Time to Rethink Academic Conference Funding*. Univ. Aff. Available online at: https://www.universityaffairs.ca/opinion/speculative-diction/its-time-to-re-think-academic-conference-funding/ (accessed May 28, 2020).

Gedye, L. (2020). *Covid-19 Turns Learning into Costly Data Exercise*. Johannesburg: New Frame.

Gibson, C. B., Huang, L., Kirkman, B. L., and Shapiro, D. L. (2014). Where global and virtual meet: the value of examining the intersection of these elements in twenty-first-century teams. *Annu. Rev. Organ. Psychol. Organ. Behav.* 1, 217–244. doi: 10.1146/annurev-orgpsych-031413-091240

Gössling, S., and Humpe, A. (2020). The global scale, distribution and growth of aviation: implications for climate change. *Glob. Environ. Chang.* 65:102194. doi: 10.1016/j.gloenvcha.2020.102194

Government of India. (2018). *Key Indicators of Household Social Consumption on Education in India: NSS 75th Round*. Delhi: Government of India.

Gross, N., and Fleming, C. (2011). "Academic conferences and the making of philosophical knowledge," in *Social Knowledge in the Making*, eds C. Camic, N. Gross, and M. Lamont (Chicago, IL: University of Chicago Press), 151–180.

Hardaker, C. (2010). Trolling in asynchronous computer-mediated communication: from user discussions to academic definitions. *J. Politeness Res.* 6, 215–242. doi: 10.1515/JPLR.2010.011

Harley, C. D. G., Hughes, A. R., Hultgren, K. M., Miner, B. G., Sorte, C. J. B., Thornber, C. S., et al. (2006). The impacts of climate change in coastal marine systems. *Ecol. Lett.* 9, 228–241. doi: 10.1111/j.1461-0248.2005.00871.x

Henderson, E. F. (2015). Academic conferences: representative and resistant sites for higher education research. *High. Educ. Res. Dev.* 34, 914–925. doi: 10.1080/07294360.2015.1011093

Hinsley, A., Sutherland, W. J., and Johnston, A. (2017). Men ask more questions than women at a scientific conference. *PLoS One* 12:e0185534. doi: 10.1371/journal.pone.0185534

Holden, M. H., Butt, N., Chauvenet, A., Plein, M., Stringer, M., and Chadès, I. (2017). Academic conferences urgently need environmental policies. *Nat. Ecol. Evol.* 1, 1211–1212. doi: 10.1038/s41559-017-0296-2

Hook, G. (2018). *Academic Conferences: Overrated, Exclusionary and Compulsory for Sole Parent Postgraduates*. Conf. Inference. Available online at: https://conferenceinference.wordpress.com/2018/05/07/guest-post-by-genine-hook-academic-conferences-overrated-exclusionary-and-compulsory-for-sole-parent-postgraduates/ (accessed October 12, 2020).

Hyams, K., and Fawcett, T. (2013). The ethics of carbon offsetting. *Wiley Interdiscip. Rev. Clim. Chang.* 4, 91–98. doi: 10.1002/wcc.207

Ives, C. D., and Bekessy, S. A. (2015). The ethics of offsetting nature. *Front. Ecol. Environ.* 13:568–573. doi: 10.1890/150021

Jäckle, S. (2019). WE have to change! The carbon footprint of ECPR general conferences and ways to reduce it. *Eur. Polit. Sci.* 18, 630–650. doi: 10.1057/s41304-019-00220-6

Jackson, L. (2019). The smiling philosopher: emotional labor, gender, and harassment in conference spaces. *Educ. Philos. Theory* 51, 693–701. doi: 10.1080/00131857.2017.1343112

Jiang, M. (2020). *The Reason Zoom Calls Drain Your Energy*. London: BBC.

Jones, T. M., Fanson, K. V., Lanfear, R., Symonds, M. R. E., and Higgie, M. (2014). Gender differences in conference presentations: a consequence of self-selection? *PeerJ* 2:e627. doi: 10.7717/peerj.627

King, L., MacKenzie, L., Tadaki, M., Cannon, S., McFarlane, K., Reid, D., et al. (2018). Diversity in geoscience: participation, behaviour, and the division of scientific labour at a Canadian geoscience conference. *Facets* 3, 415–440. doi: 10.1139/facets-2017-0111

Louque, A. C., and Thompson, G. L. (2005). *Exposing the "Culture of Arrogance" in the Academy: A Blueprint for Increasing Black Faculty Satisfaction in Higher Education*. Sterling, VA: Stylus Publishing.

Lundy, C. (2016). *Free the Academic Conference*. Res. Whisperer. Available online at: https://researchwhisperer.org/2016/07/12/free-the-academic-conference/ (accessed October 9, 2020).

Macdonald, C. (2020). *The Dark Side of Being a Female Shark Researcher*. Sci. Am. Available online at: https://www.scientificamerican.com/article/the-dark-side-of-being-a-female-shark-researcher/ (accessed October 9, 2020).

Mair, J., and Frew, E. (2018). Academic conferences: a female duo-ethnography. *Curr. Issues Tour.* 21, 2160–2180. doi: 10.1080/13683500.2016.1248909

Malmodin, J., and Lundén, D. (2018). The energy and carbon footprint of the global ICT and E & M sectors 2010-2015. *Sustainability* 10:3027. doi: 10.3390/su10093027

McKeown, S. (2017). *How much does it Cost to Organise a Developer Conference?* Humanmade. Available online at: https://humanmade.com/2017/05/22/how-much-does-it-cost-to-organise-a-developer-conference/ (accessed December 7, 2020).

MEA (2005). *Ecosystems and Human and Well-Being: Synthesis*. Washington, DC: Island Press.

Montgomery, S. (2004). Of towers, walls, and fields: perspectives on language in science. *Science* 303, 1333–1335.

Morgan, C. (2020). *As Coronavirus Shrinks Our World, Resurgent Community Spirit Offers Hope*. Guard. Available online at: https://www.theguardian.com/society/2020/apr/21/community-spirit-hope-coronavirus-public-services (accessed May 28, 2020).

Mukandi, B. (2017). *Black Issues in Philosophy: Australian Continental Philosophy*. Am. Philos. Assoc. Available online at: https://blog.apaonline.org/2017/12/26/black-issues-in-philosophy-australian-continental-philosophy/ (accessed October 12, 2020).

Ngware, M. (2020). *Delivering Education Online: Coronavirus Underscores What's Missing in Africa*. Conversat. Available online at: https://theconversation.com/

delivering-education-online-coronavirus-underscores-whats-missing-in-africa-134914 (accessed May 28, 2020).

Niner, H. J., Johri, S., Meyer, J., Wassermann, S. N., and Meyer, J. (2020). The pandemic push: can COVID-19 reinvent conferences to models rooted in sustainability, equitability and inclusion? *Soc. Ecol. Pract. Res.* 2, 253–256. doi: 10.1007/s42532-020-00059-y

Oester, S., Cigliano, J. A., Hind-Ozan, E. J., and Parsons, E. C. M. (2017). Why conferences matter—an illustration from the international marine conservation congress. *Front. Mar. Sci.* 4:257. doi: 10.3389/fmars.2017.00257

QSR International Pty Ltd. (2018). *NVivo Qualitative Data Analysis Software*. Doncaster, VIC: QSR International Pty Ltd.

Rogerson, C. M. (2015). The uneven geography of business tourism in South Africa. *S. Afr. Geogr. J.* 97, 183–202. doi: 10.1080/03736245.2015.1028984

Sandel, M. J. (2005). "Should we buy the right to pollute?," in *Public Philosophy: Essays on Morality in Politics*, ed. M. J. Sandel (Harvard, MA: Harvard University Press), 93–96.

Sapiro, V., and Campbell, D. (2018). Report on the 2017 APSA survey on sexual harassment at annual meetings. *Polit. Sci. Polit.* 51, 197–206. doi: 10.1017/S1049096517002104

Sarabipour, S., Schwessinger, B., Mumoki, F. N., Mwakilili, A. D., Khan, A., Debat, H. J., et al. (2020). Evaluating features of scientific conferences: a call for improvements. *bioRxiv* [Preprint]. doi: 10.1101/2020.04.02.022079 bioRxiv:2020.04.02.022079

Sardelis, S., and Drew, J. A. (2016). Not "pulling up the ladder": women who organize conference symposia provide greater opportunities for women to speak at conservation conferences. *PLoS One* 11:e0160015. doi: 10.1371/journal.pone.0160015

Sinclair, E., Birkmanis, C., and Pemberton, R. (2019). *We Organised a Conference for 570 People Without Using Plastic. Here's How it Went.* Conversat. Available online at: https://theconversation.com/we-organised-a-conference-for-570-people-without-using-plastic-heres-how-it-went-120157 (accessed October 8, 2020).

Smith, N. S., Côté, I. M., Martinez-Estevez, L., Hind-Ozan, E. J., Quiros, A. L., Johnson, N., et al. (2017). Diversity and inclusion in conservation: a proposal for a marine diversity network. *Front. Mar. Sci.* 4:234. doi: 10.3389/fmars.2017.00234

Taylor, A. R. E. (2020). *Why Going Digital in Pandemic Times might not be as Green as You Think.* Corona Times. Available online at: https://www.coronatimes.net/going-digital-not-as-green-covid-19/ (accessed May 29, 2020).

Thuiller, W. (2007). Biodiversity: climate change and the ecologist. *Nature* 448, 550–552. doi: 10.1038/448550a

Timperley, C., Sutherland, K. A., Wilson, M., and Hall, M. (2020). He moana pukepuke: navigating gender and ethnic inequality in early career academics' conference attendance. *Gend. Educ.* 32, 11–26. doi: 10.1080/09540253.2019.1633464

Tisdell, C., and Loch, B. (2017). How useful are closed captions for learning mathematics via online video? *Int. J. Math. Educ. Sci. Technol.* 48, 229–243. doi: 10.1080/0020739X.2016.1238518

Tu, C., and McIsaac, M. (2010). The relationship of social presence and interaction in online classes the relationship of social presence and interaction. *Communication* 16, 131–150. doi: 10.1207/S15389286AJDE1603

UNESCO (2017). *Small Island Developing States (SIDS)*. Paris: UNESCO.

United Nations (2015). *Paris Agreement*. Available online at: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

United Nations (2020). *World Ocean Week: 8 to 12 June 2020*. New York, NY: United Nations.

Verbalize.science (2020). *Audio Abstracts For Conferences*. Available online at: https://verbalize.science/for_conferences (accessed December 7, 2020).

Walters, T. (2018). Gender equality in academic tourism, hospitality, leisure and events conferences. *J. Policy Res. Tour. Leis. Events* 10, 17–32. doi: 10.1080/19407963.2018.1403165

Welch, C. J., Ray, S., Melendez, J., Fare, T., and Leach, M. (2010). Virtual conferences becoming a reality. *Nat. Chem.* 2, 148–152. doi: 10.1038/nchem.556

Wilson, J. W., and Biggs, D. (2016). *Innovation and Research Suffer When Visa Rules Keep Scientists at Home.* Conversat. Available online at: https://theconversation.com/innovation-and-research-suffer-when-visa-rules-keep-scientists-at-home-66055 (accessed November 22, 2020).

World Bank (2019). *World Bank Country and Lending Groups*. Available online at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519#Low_income (accessed December 7, 2020).

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A Rising Tide Does Not Lift All Boats: Intersectional Analysis Reveals Inequitable Impacts of the Seafood Trade in Fishing Communities

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Seafood is the world's most traded food commodity, and the international trade in seafood is promoted as a development strategy in low-income coastal communities across the globe. However, the seafood trade can drive negative social and environmental impacts in fishing communities, and whether the benefits of trade actually reach fishers is a subject of ongoing scholarship. Furthermore, scholars and policymakers have tended to treat fishing communities as homogeneous, assuming that trade policies will impact all members equally. Yet individual community members have different roles, statuses, and entitlements according to their intersecting identities, meaning that different fishers will be differently impacted by the seafood trade. In particular, women occupy different positions than men in seafood value chains and in fishing communities. There are also important within-group differences among men and among women depending on their nationality, marital status, and other identity markers. Through 205 surveys, 54 interviews, and ethnographic field methods conducted in fifteen rural Palauan fishing communities between November 2019 and March 2020, this case study of the sea cucumber trade in Palau brings together theories of gender, intersectionality, and access to answer the question, "How are the harms and benefits of the seafood trade distributed in fishing communities?" In this case, men benefited more than women from the export of sea cucumbers by leveraging access to technology; knowledge; and authority, and the trade depleted resources relied on primarily by women for their food security and livelihoods. An intersectional analysis revealed that marital status and nationality determined access among women, with married women having greater access than unmarried women and immigrant women having greater access than immigrant men, demonstrating the importance of intersectionality as an analytical tool.

Keywords: seafood trade, gender, small-scale fisheries, equity, intersectionality

INTRODUCTION

As the global seafood trade rapidly expands (Gephart and Pace, 2015), the export of high-value fisheries products from coastal communities to luxury markets is promoted as a vehicle for poverty alleviation (Barclay et al., 2019). Whether the benefits of trade actually reach fishers is a subject of ongoing scholarship (e.g., Béné et al., 2010; Crona et al., 2015; O'Neill et al., 2018), and case studies from across the globe show that trade can have harmful impacts on fishing communities and their resources (e.g., Porter et al., 2008; Campling, 2012; Fabinyi et al., 2018; Nolan, 2019). Moreover, scholars and policymakers have tended to treat fishing communities as homogenous groups, assuming that policies will affect all fishing community members equally (Agrawal et al., 1997; Agrawal and Gibson, 1999, 2001; Allison and Ellis, 2001). But we know that fishing communities are diverse across many dimensions, including gender (Harper et al., 2020), ethnicity (Lau and Scales, 2016), power and class (Colwell et al., 2017), religious denomination and place of birth (Rohe et al., 2018), and nationality (Yingst and Skaptadóttir, 2018), as well as other identity markers, which intersect with one another (Hooks, 1984; Collins, 1986; Crenshaw, 1989, 1991). Fishers' identities shape their access to marine resources and their interactions with globalized seafood markets (Porter et al., 2008; Fabinyi et al., 2018; O'Neill et al., 2018). In this paper, I examine whether and how different fishers are impacted differently by the seafood trade according to their intersecting identities.

The trade in dried sea cucumbers, also known as *bêche-de-mer*, epitomizes many of the social and environmental challenges of high-value export fisheries. Driven by the growing demand for luxury seafood products in China (Fabinyi, 2012; Purcell et al., 2014), cases of "boom-bust" fishery collapse have been documented across the Pacific and Indian Oceans, in a pattern of serial depletion (Anderson et al., 2011; Purcell et al., 2013; Eriksson et al., 2015). There has been rapid geographic expansion to meet increasing demand from China, with sea cucumber fisheries serving the Chinese market now operating within countries cumulatively spanning over 90% of the world's tropical coastlines (Eriksson et al., 2015), with the Western Central Pacific being the most important exporting region (Conand, 2017). Sea cucumbers are highly vulnerable to overfishing due to their slow growth, late age of maturity, ease of capture, and reproductive strategy (Uthicke et al., 2004). Markets for new and lower-value species, such as *Stichopus herrmanni*; *Bodaschia vitiensis*; and *Holothuria fuscopuntata*, are growing as the highest-value species are becoming depleted at an alarming rate (Purcell et al., 2013, 2018).

The sea cucumber trade may also fail to deliver the hoped-for economic development. Sea cucumber fisheries are generally characterized by patron-client relationships, defined by socioeconomic asymmetries (Ferrol-Schulte et al., 2014), which result in disproportionate wealth capture by exporters and other middlemen, particularly for the highest-value species (Purcell et al., 2017). Where targeted species are important for local consumption and not easily substituted, export can exacerbate food security challenges for poor community members by increasing prices (Crona et al., 2016). And the rapid overexploitation of fisheries resources threatens fishers' livelihoods and ways of life in the long-term (Christensen, 2011).

Furthermore, the seafood trade does not impact all fishers equally (Crona et al., 2016). For instance, there is evidence that men displace women in areas where locally consumed resources become commoditized, limiting women's access to trade benefits (Porter et al., 2008; Pinca et al., 2010; Williams, 2015). We therefore cannot understand the processes that shape relations to the seafood trade without first understanding the identities that shape fishers' relations to one another and to marine resources.

Gender is a central organizing identity for marine resource use globally and in the Pacific. In many Pacific island nations, women are the customary harvesters of sea cucumbers and dominate local markets for sea cucumber products (Matthews, 1991; Williams, 2015). Using minimal technologies to collect sea cucumbers in the nearshore environment at low tide, a fishing practice known as "gleaning," women in the Pacific contribute critically to household food security and income (Weeratunge et al., 2010; Rohe et al., 2018; De Guzman, 2019). Across the Pacific, women's harvesting activities, including gleaning, account for approximately 56% of the total catch in small-scale fisheries (Harper et al., 2013).

Yet women are frequently overlooked in fisheries research (Kleiber et al., 2015). As a result, we understand little about how women are impacted by the seafood trade. Recent reviews have highlighted the need to include gender as a key variable in our understanding of fishing communities and economies, as women participate in—and often dominate—many aspects of the seafood production chain (Bennett, 2005; Williams, 2008; Weeratunge et al., 2010; Harper et al., 2013, 2020; Kleiber et al., 2015). In the context of the ever-expanding reach of the global seafood trade and global commitments to achieving gender equality (UN General Assembly, 2015), it is important to examine not only the roles women play in seafood value chains, but also the role of the global seafood trade in shaping gender inequalities among fishers.

Critically, gender is not the only—or necessarily the principal—identity that shapes fishers' relations to marine resources. In this analysis, I also examine how two locally relevant identities, nationality and marital status, intersect with gender to produce unique relations to the seafood trade in Palau.

Gender and Intersectionality

The terms "gender" and "sex" mean different things to different feminist theorists, and neither is easy or straightforward to characterize. In this paper, I use "gender" to refer to sociocultural, political, and behavioral attributes that are typically associated with "men" and "women"—though there is significant variation and complexity beyond this binary—in contrast to "sex," which refers to biological attributes such as chromosomes and reproductive organs. Constructions of gender are neither uniform across societies nor historically static, and they interact with other identity markers, such as ethnicity, race, and age, to produce unique positions within the social hierarchy (Crenshaw, 1989, 1991). It should be noted that the dominant binary construction of gender is itself culturally contextualized, and many Pacific cultures have customarily recognized gender variance including third gender constructions (Presterudstuen, 2019).

Feminist political ecologists have examined the importance of nature in producing gender and gendered power relations (Gururani, 2002; Harris, 2006; Nightingale, 2006, 2011), arguing that gender and other social identities emerge through "everyday, embodied activities" such as agro-forestry (Nightingale, 2011). Gendered power relations are revealed not only in the division of labor and resources between women and men, but also in the ideas and representations of women and men as having different abilities, attitudes, desires, personality traits, behavior patterns, etc., often in opposition to one another (Agarwal, 1997). Gendered power relations are constructed through differentiated relations with the environment, based on gendered work patterns, access to and rights over resources, cultural concepts regarding masculinity and femininity, and belief systems (e.g., Singh and Burra, 1993; Krishna, 1998; Vedavalli and Anil Kumar, 1998; Sillitoe, 2003; Gurung and Gurung, 2006; Kelkar, 2007). Gender and gendered power relations are thus critical variables shaping processes of ecological change (Elmhirst and Resurreccion, 2008), and ecological change, in turn, shapes gendered power relations (Agarwal, 1997; Gururani, 2002; Nightingale, 2011).

While researchers have tended to examine social inequities along only a single axis (e.g., gender, nationality, or marital status), feminist scholars have critiqued single-axis frameworks that consider gender in isolation from other social identities and have highlighted the value of intersectional approaches that account for the interdependent nature of identities (Crenshaw, 1989, 1991). Intersectionality is a framework that "promotes an understanding of human beings as shaped by the interaction of different identity markers (e.g., "race"/ethnicity, indigeneity, gender, class, sexuality, geography, age, disability/ability, migration status, religion) [which] occur within a context of connected systems and structures of power" (Hankivsky, 2014, p. 2). Intersectionality can deepen our understanding of fishers and fishing communities by revealing how different forms of social difference (e.g., gender and nationality, or gender; nationality; and marital status) interact to produce unique positions within power structures governing resource access and use, moving away from models that assume homogeneity among fishers, or among women fishers.

Researchers have increasingly applied intersectionality within the context of natural resources, highlighting the role of natural resource systems in producing and maintaining social differences and power hierarchies (Nightingale, 2006; Valentine, 2007). Recent studies have examined how gender interacts with ethnicity (Lau and Scales, 2016), class (Colwell et al., 2017), individual decision-making (Kusakabe and Sereyvath, 2014), religious denomination and place of birth (Rohe et al., 2018), and nationality (Yingst and Skaptadóttir, 2018) to shape fishers' access to and control of marine resources. In this paper, I examine how the harms and benefits of the seafood trade are distributed among fishers, focusing on gender as it intersects with nationality and marital status, in the context of the sea cucumber trade in Palau.

Sea Cucumber Fishing in Palau

The Republic of Palau comprises more than 340 islands across over 475,000 km^2, eight of which are inhabited (**Figure 1**). Palau is renowned for its high marine biodiversity, the health of its coral reef and seagrass systems (Golbuu et al., 2005), and its leadership in marine conservation (Gibbens, 2017). The town of Koror is the economic center of Palau, where two-thirds of the population resides and the majority of commercial activity is located.

Sixty-eight percent of Palau's 17,661 residents are Palauan citizens; citizenship is only available to those who can trace their lineage to Indigenous Palauan ancestors, meaning that nationality, indigeneity, and power are closely linked (Palau Const. art. III, 1994). The remaining residents are immigrants: the majority of women immigrants (60%) are from the Philippines, and men immigrants originate from a diversity of countries including Bangladesh, the United States, China, Japan, and the Federated States of Micronesia (Palau Bureau of Planning and Statistics, 2015).

In 1994, Palau regained its sovereign status after enduring three centuries of colonial rule by Spain, Germany, Japan, and the United States. Today, Palau maintains a close relationship with the United States according to the Compact of Free Association, the treaty that established Palau as an independent nation "freely associated" with the United States. The Compact grants the United States military control of Palau in exchange for economic aid to Palau, freedom of Palauan residency in the United States, and the possibility for Palauans to serve in the U.S. military (Compact of Free Association, 1994).

Palauan culture has been fundamentally re-shaped by the values of colonizers and renegotiated to meet modern challenges, notably with respect to fisheries management and gender. Colonial policies created a centralized, democratic governance system that has undermined traditional leaders' powers, challenging customary natural resource management practices that once relied on enforcement by local chiefs (Graham and Idechong, 1998). Meanwhile, the import of highly efficient fishing technologies and the marketization of the Palauan economy created the means and incentives to overfish (Graham and Idechong, 1998).

Colonization also shifted relations between men and women, both through the introduction of Christianity and through the privileging of Palauan men in positions of power within the patriarchal Japanese and American administrations of the islands (Wilson, 1995). Though Palauan women still enjoy a relatively high degree of authority within traditional governance systems, they are highly underrepresented in elected positions.

In Palau, the use of marine resources is customarily gendered, with men "fishing" finfish and women "gleaning" marine invertebrates, including sea cucumbers. These activities require different technologies and knowledges. Men typically use motorboats and gears such as spearguns and fishing poles to access their resources. Boys are taught to freedive, including long breath holds, from a young age. Men's ecological knowledge is thus associated with reef habitats and deeper waters. Though sea cucumbers are found in these waters—in fact, the largest species are found there—men rarely collect them. Women, on the other hand, typically wade into shallow waters on foot or use man-powered boats (e.g., kayaks, bamboo rafts) to access nearshore invertebrates in waters typically less than 1 m deep. Girls typically do not learn to freedive. Women's ecological knowledge is associated with seagrasses and shallow water habitats.

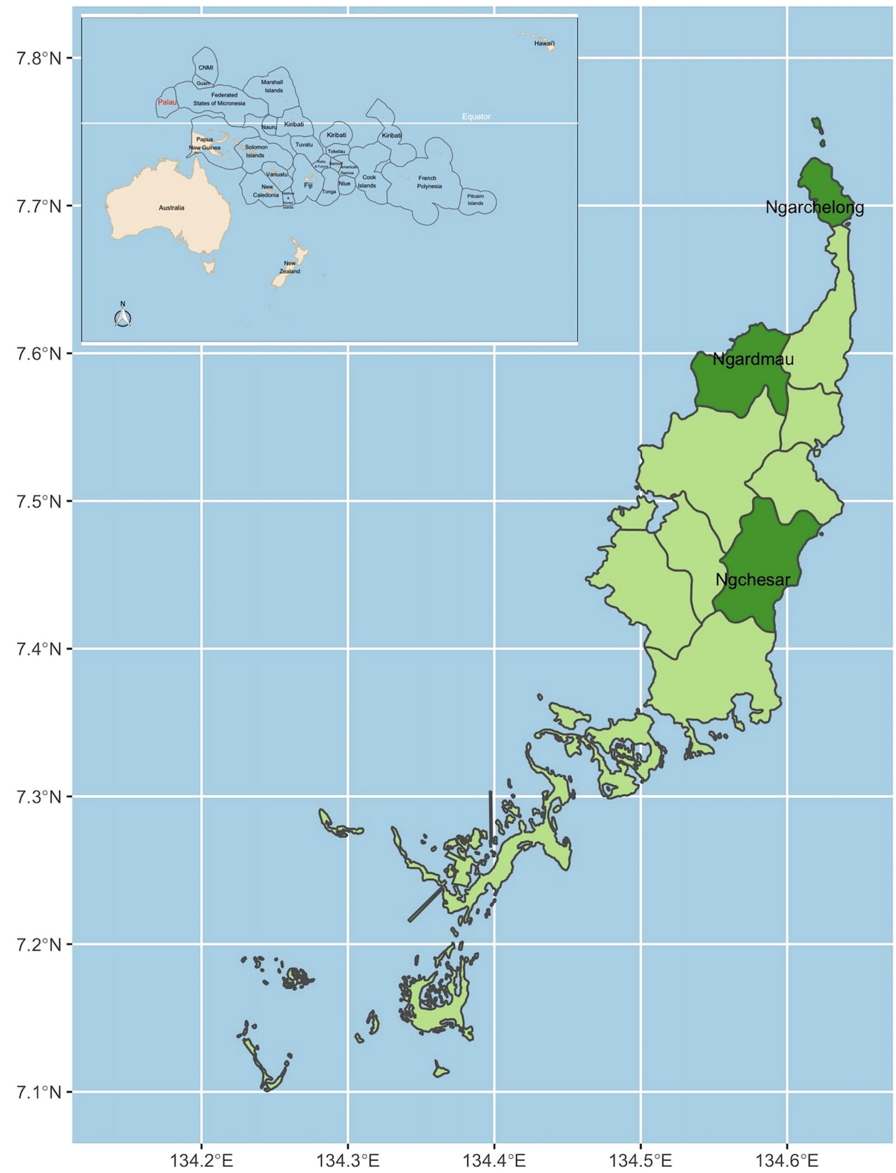

FIGURE 1 | Map of mainland Palau. Study sites are shown in dark green.

This traditional gender division of marine resources remains widespread but is evolving. The norm against women fishing is apparently stronger than the norm against men gleaning. In a 2020 nationwide survey, 86% of spearfishers in Palau were men and 57% of gleaners were women, with 72% of sea cucumber gleaners being women (Ferguson and Singeo, unpublished data). Ota (2006) explored the significance of spearfishing to Palauan masculine identity, arguing that fishermen prefer to use tools and techniques that create physical challenges because it allows them to express particular notions of masculinity. Ota also noted the common narrative provided by Palauan fishermen that spearfishing is too difficult for women to practice. The cultural construction of spearfishing as being highly masculine at least partially explains women's lack of participation, while gleaning, which is physically less demanding, is feminized and done primarily by women. This gendered pattern of marine resource use is not uncommon in the Pacific or other geographies (Kleiber, 2014). Previous scholarship has found that women's labor is spatially constrained by their responsibilities in the home (Gustavsson, 2020). Indeed, children in Palau often accompany women while they glean.

Palauans regularly consume twenty species of sea cucumbers, 12 of which are valuable for the *bêche-de-mer* trade (Pakoa et al., 2009; Purcell et al., 2018). Pacific nations including Palau have been producing *beĉhe-de-mer* for Chinese consumers for over a century (Conand and Sloan, 1989); however, mounting concerns about the social and environmental sustainability of the fishery eventually led to a moratorium on the export of sea cucumbers from Palau Marine Protection Act (1994).

In 2011, exporters and their Palauan partners circumvented this moratorium to export cherumrum (Latin: *Actinopyga miliaris, A. mauitania,* and *A. lecanora*; English: hairy blackfish, surf redfish, white-bottomed sea cucumber), as well as other species illegally (Pakoa et al., 2014). For six months, five foreign companies exported unprecedented volumes of sea cucumbers from Palau for the *bêche-de-mer* trade, before national legislation forced the companies to shutter operations in early 2012 (Pakoa et al., 2014). During those six months, fishers were allowed to harvest and sell an unlimited amount of sea cucumbers on Mondays and Thursdays, from 6 am to 6 pm (Pakoa et al., 2014). In just forty-eight total legal fishing days, approximately 1,160,392 kg (1,279 tons) of sea cucumbers were landed and sold at an estimated total value of US$1.3 million (Pakoa et al., 2014).

Once national action banned the export of all sea cucumbers, the exporters left Palau. Sea cucumber harvesting then returned to pre-export levels, with most of the collection being done by women for subsistence and small local markets. However, the environmental impacts of the export period were immediately felt and have proven to be long-lasting: a report produced by the Palau International Coral Reef Center in April 2012 demonstrated an 88% decline in the target species from pre-export levels (Golbuu et al., 2012), and recent monitoring indicates further decline in fished areas (Ferguson and Singeo, unpublished data). The ban on exporting sea cucumbers is still in place today. Thus, the special events of 2011 offer an opportunity to study how fishers quickly leverage their assets and social relations to access seafood trade benefits under new and short-term trade conditions.

MATERIALS AND METHODS

I used a mixed methods single case study approach over multiple visits to the fifteen study communities between September 2019 and March 2020. In total, I spent 3 months in Palau during this period, based in Ollei village in Ngarchelong State. The research question, "How were the harms and benefits of the sea cucumber trade distributed among fishers in Palau?" was developed after a 1-year period of preliminary, unstructured interviews with Palauan fishers, marine scientists, fisheries management professionals, and conservationists from June 2018 to June 2019 based on frequently cited concerns and areas of research interest. Data were collected by me and five Palauan field assistants. Access theory (Ribot and Peluso, 2003) was chosen as an analytical frame to identify how individual fishers accessed the benefits of the sea cucumber trade. In the following sections, I justify site selection, provide a brief background on access theory, followed by a detailed description of each data collection method, and a summary of how data were analyzed. More detail is provided in **Supplementary Material**.

Site Selection

The fifteen rural villages included in this study represent every village in Ngardmau, Ngarchelong, and Ngchesar states (**Figure 1**). These small communities are all engaged in gleaning sea cucumbers for food security and income, particularly but not exclusively among women. Ngardmau was the most intensive site of harvest for the *bêche-de-mer* trade and is the site known throughout Palau for the quality and abundance of its sea cucumbers. Ngarchelong was intensely engaged in the harvest for the last month of the trade. Ngchesar, which is physically distant from the other states, was largely uninvolved in the trade, providing perspectives from fishers who rely heavily on the resource but who were impacted relatively little by the trade. At the 2015 census, the total population of these three states was 792, including 77 non-Palauan immigrants (Palau Bureau of Planning and Statistics, 2015).

Access Theory

Access theory is a political ecology approach to understanding how individual actors "derive benefits from things" (Ribot and Peluso, 2003), with a focus on natural resources as the "things". Ribot and Peluso (2003) placed differential relations among actors and the "things" they want to benefit from at the center of their theory. They were informed by the popular critique that the common property literature is ahistorical and apolitical (Peters, 1993; Cleaver, 2002; Forsyth and Johnson, 2014). "A Theory of Access" took the notion of access as being associated chiefly with enforceable rights and expanded it to encompass a broader range of actors, structures, and social relations, including the illicit (Myers and Hansen, 2020). Ribot and Peluso (2003) focused on access as an ability, including but not limited to rights. They identified eight structural and relational "access mechanisms" (technology, capital, markets, labor, knowledge, authority, identities, and social relations) in addition to two rights-based mechanisms (legal and illegal access). Survey questions were structured by these mechanisms to understand individual fishers' abilities to derive benefits from the sea cucumber trade.

Data Collection

Survey

To be able to make generalizable and quantifiable conclusions, I used a random sampling approach. I stratified the sample by gender to ensure near-equal representation of women and men. Survey data collection was done by four Palauan field assistants, in Palauan and English depending on the preference of the respondent. Survey respondents were randomly selected by knocking on every other door in each study community on weekends and evenings, when people were most likely to be home and available to respond. In order to capture the greatest possible diversity of respondents, enumerators surveyed as many people within the household as were willing and able. We continued to survey until we reached a sample achieving a 95% confidence interval with a 10% margin of error. In total, we surveyed 100 women and 105 men, including 11 non-Palauan immigrant women and 19 non-Palauan immigrant men.

Recognizing that gender and other identities are socially constructed, we asked respondents to self-identify their gender, nationality, marital status, age, level of education, employment status, and whether they held a customary title (a locally relevant measure of power and status). Although we offered multiple gender responses, including "transgender," "non-binary," and "other," 100% of respondents self-identified as "woman" or "man." Thus, results are reported in alignment with these categories. In addition to these identity questions, the survey included questions related to gleaning and local marketing of sea cucumbers, questions related to participation in the 2011 *bêche-de-mer* trade (e.g., "Did you participate?," "Which species did you target?" with at least 1 question addressing each of the 10 access mechanisms identified by access theory), as well as observations of environmental changes. At the end of each survey, we asked respondents whether they would be interested in being contacted for a follow-up interview.

Interviews

To develop a more in-depth understanding of individual experiences and attitudes, I purposively sampled interview participants from the pool of survey respondents, as well as seven Palauan experts on women's fisheries. Interviews were conducted by me, with the support of a Palauan field assistant and translator. Interviews ranged from ten to ninety min and were conducted in English or in Palauan, whichever was preferred by the respondent. Most Palauans today are fluent in English, and some younger Palauans are more comfortable speaking English than Palauan. A limitation of this study is that interviews with non-Palauans were all conducted in English due to a lack of appropriate translators of other languages, so some nuances may have been lost. I selected individuals to interview based on their level of experience gleaning, their participation in the *bêche-de-mer* harvest, their role in management and decision-making (i.e., state rangers and traditional leaders), and their intersecting identities, with the goal of hearing perspectives from people representing a diversity of social positions. In total, I interviewed 26 women and 23 men, including 4 non-Palauan immigrant women. Interviews were audio recorded and transcribed in English. In the case of interviews conducted in Palauan, I have not used direct quotes due to the imperfect nature of translations.

Semi-structured interviews focused in greater detail on fishers' access mechanisms to sea cucumbers during the 2011 *bêche-de-mer* harvest, attitudes toward the *bêche-de-mer* trade, and ecological knowledge related to local sea cucumber populations. Questions related to the precise details of catch amounts and prices were generally avoided due to the eight year gap between the event and this investigation. Such details were thoroughly documented by managers and researchers during and shortly after the trade was closed, which were used to verify information recalled by fishers (Pakoa et al., 2014; Barr et al., 2016). Each interview included an opportunity for the participant to ask questions and provide informed consent, following ethical guidelines and approval from the Stanford University Institutional Review Board.

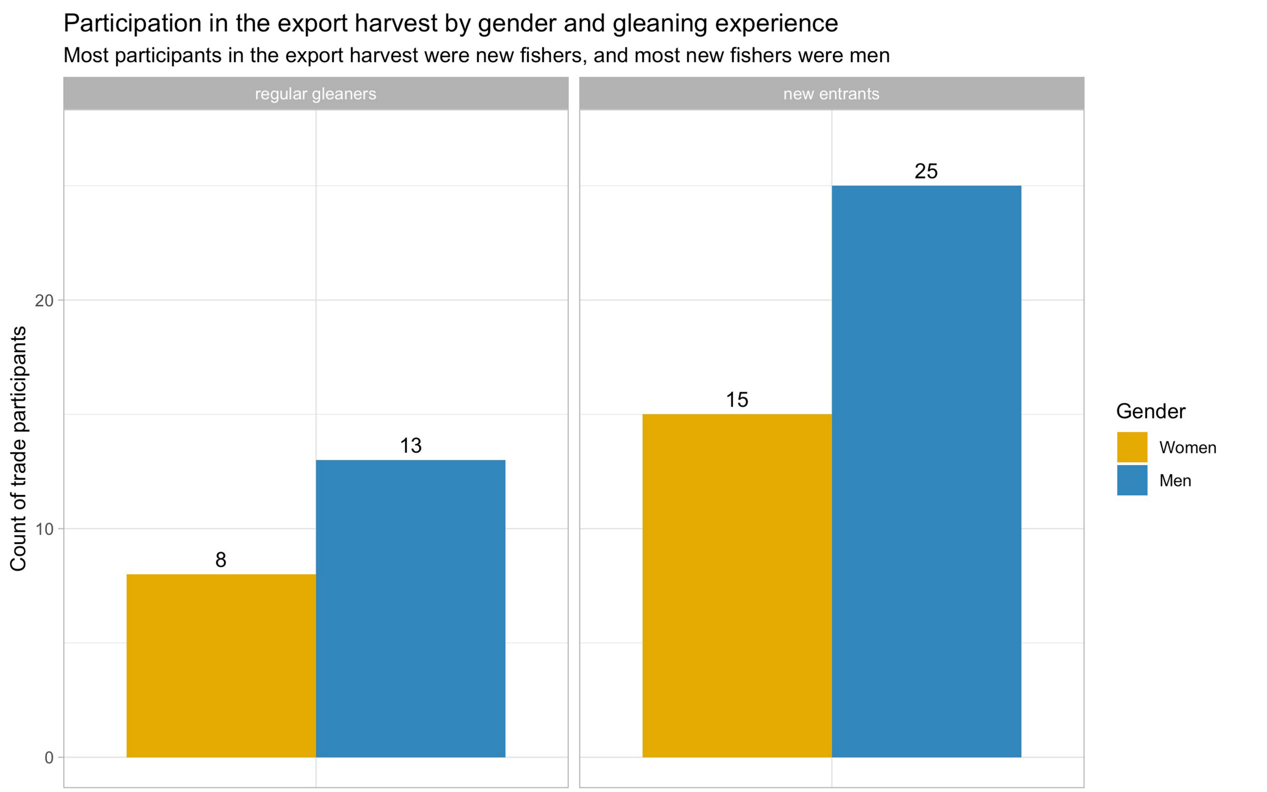

FIGURE 2 | Most fishers who participated in the trade were new entrants, and most new entrants were men. Whether or not a regular gleaner participated in the trade depended on their gender, with men gleaners more likely to participate.

Data Analysis

Identifying Mechanisms of Access

To identify key mechanisms of access, I first coded interview data deductively in the Dovetail app[1] using the access theory framework. After coding all interviews, "technology," "knowledge," and "authority" arose as the most common and explanatory access mechanisms. I then cross-referenced this finding with survey data, examining how fishers responded to questions on those access mechanisms.

Assessing the Distribution of Benefits and Harms

To assess the distribution of benefits and harms, I first coded interview data deductively in the Dovetail app (see text footnote 1) using the intersectionality framework. After coding all interviews, gender, marital status, and nationality arose as the most explanatory identities. I then used survey respondents' self-identified identity markers (e.g., woman, Palauan, 40–45 years old, married, no title, etc.) to assess which actors had the ability to leverage key mechanisms of access during the trade, using Pearson chi-square tests for independence. Significance level was set at $p < 0.05$.

Finally, to understand the distribution of harms, I asked survey respondents about changes in local sea cucumber populations since the trade. I also coded interviews for any reference to "environmental harm." This included references to resource degradation, difficulty finding sea cucumbers, and associated challenges obtaining food and income from gleaning.

RESULTS

Distribution of Access to the Benefits of Trade

The sea cucumber fishery transformed swiftly during the export period from a low-tech, low volume gleaning activity done primarily by Palauan and immigrant women to a capital-intensive, high volume activity dominated by Palauan men. I use "gleaner" to describe the harvesters using traditional gleaning methods and "fisher" to describe the harvesters using these "new" methods normally reserved for harvesting finfish. I use "harvester" generically to refer to people harvesting sea cucumbers using any method.

Men largely displaced women in the trade. Under normal (i.e., non-trade) conditions, women in the study communities participate in sea cucumber gleaning at a significantly higher rate than men, representing 58% of gleaners, X^2 (1, N = 206) = 6.0, p = 0.0140. However, during the export period in 2011, women represented only 38% of harvesters, participating significantly less than men X^2 (1, N = 206) = 4.1, p = 0.0423.

Most of the harvesters (66%) who participated in the trade (N = 61) were new entrants to the sea cucumber fishery, not gleaners who utilize sea cucumber resources under normal conditions (**Figure 2**). 63% of these new harvesters (N = 40) were men. Men gleaners were also significantly more likely (57%) to continue harvesting than women gleaners (25%) during the trade, X^2 (1, N = 55) = 5.6, p = 0.0176.

The disproportionate and, according to some, culturally inappropriate role of men in the sea cucumber trade was noted by community members. One middle-aged Palauan woman gleaner in Ngarchelong remembered,

> *"It was the men, not the women. I remember sitting there, asking the men in our community, "Excuse me, it belongs to the women. Why are you encroaching?" It's about money. It's not about the people or the culture, it's really just about money."*

Men justified their participation in the otherwise feminized, "easy" practice of sea cucumber harvesting by referencing the financial rewards. A middle-aged Palauan fisherman in Ngarchelong explained,

> *"It's easy fishing, that's why only women do it. But during that time, the buyer is here with a sack of money, then we ain't waiting for our women, yeah? We got to go help them, get out the boat, you know? So, it was a different thing. . .. It was just money waiting."*

While gender was highly explanatory of which fishers participated in the trade, nationality was even more deterministic. 100% of people who reported participating in the trade (N = 61) were Palauan; none of the non-Palauans in the sample (N = 21), including the subset (N = 4) who glean under normal conditions, participated. Reasons for not participating varied among individuals in this group, and I was not able to interview all of them. Two Filipina women reported that they were working full-time in 2011 and unable to take time off to collect; it is likely that similar restrictions imposed by work visas applied to some other immigrants.

Mechanisms of Access

Access to Technology: Motorboats

Motorboats proved to be a critical technology for accessing and storing large volumes of sea cucumbers during the export period. Because gleaners do not typically collect in waters deeper than about a meter (3.28 feet), harvesters explained that deeper water populations of all species, further from shore, tended to be more abundant and home to larger individuals. Motorboats enabled access to these populations. Furthermore, harvesters without motorboats were more limited in how many sea cucumbers they could collect before returning to the port with full buckets. Only those harvesters with access to motorboats were able to store sea cucumbers in large volumes.

A middle-aged fisherman from Ngarchelong described the spectacle of fishing boats at Ngerkeklau, an island 2.7 km (1.7 miles) from the village, known for its abundance of sea cucumbers. He remembered with excitement, "The place looked like this new city, new village over there. Really! More than 40 lights every night," referring to the lights of boats. The distance to Ngerkeklau and other unfished sites was too great to swim or paddle, meaning fishers without motorboats were harvesting in already exploited areas.

[1] Dovetailapp.com

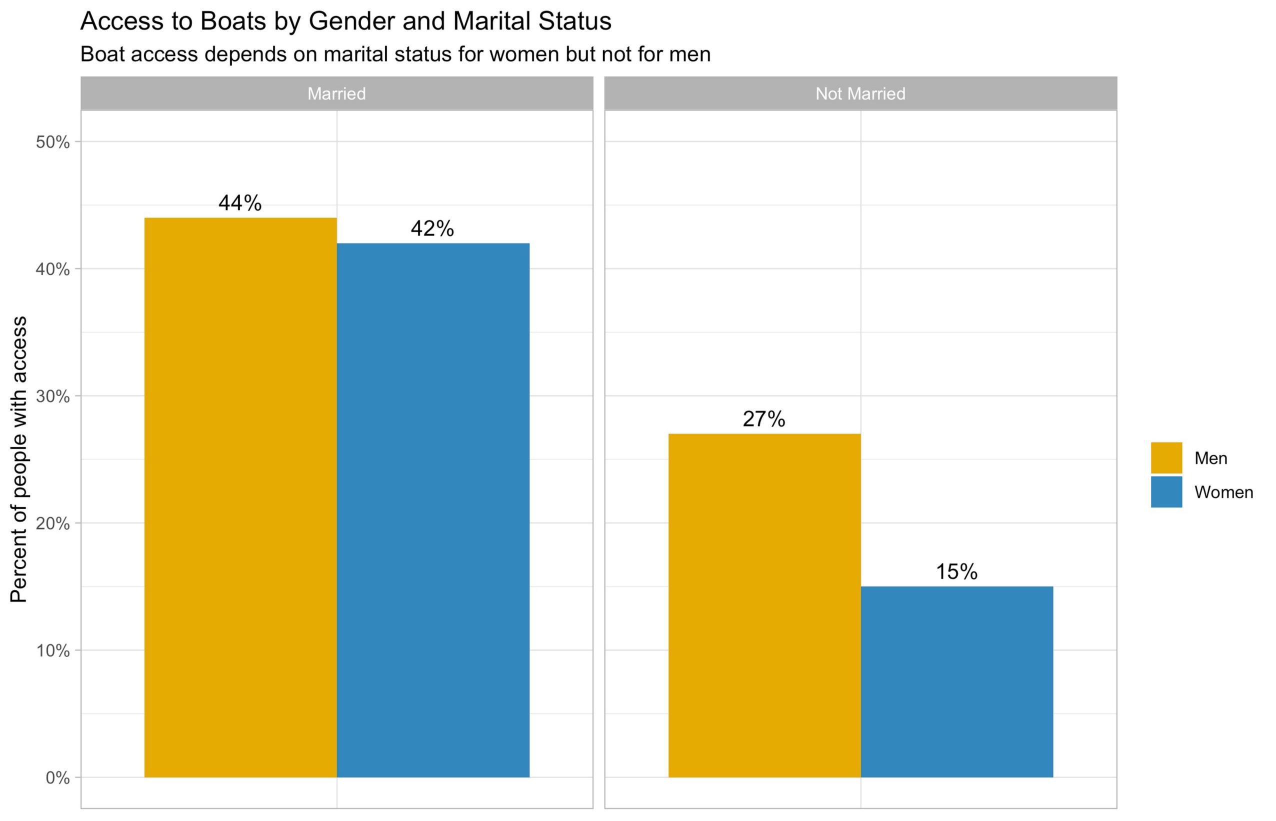

FIGURE 3 | Marital status determines access to boats for women but not for men.

Among those who did not own boats, men reported significantly higher access to motorboats than women, with 81% of men and 69% of women in the sample reporting that they had access to a motorboat, X^2 (1, N = 205) = 4.1, p = 0.0438. When asked whose motorboat a respondent had access to, 96% of gendered responses (N = 83) were male (e.g., brother, husband, male friend), indicating that the vast majority of those who control access to motorboats are men.

Both nationality and marital status profoundly shaped which women had close relations to Palauan men and thus had access to motorboats.

Among women in the sample who did not own boats, married women had significantly more access to motorboats than unmarried women, X^2 (1, N = 63) = 7.3, p = 0.0071 (**Figure 3**). Meanwhile, among men in the sample, marital status had no significant effect on motorboat access, X^2 (1, N = 69) = 1.9, p = 0.1632.

Among Palauans in the sample who did not own boats (N = 124), 66% reported having access to one; among immigrants (N = 20), fewer than half (45%) reported having access. Among non-Palauans, women actually had more access to motorboats than men, representing 56% of those with access (**Figure 4**). All of these women (N = 5) were married to Palauan men. However, the sample size of immigrants with access to motorboats was small, and the difference between immigrant men and immigrant women was not statistically significant.

Access to Knowledge: Freediving, Gendered Ecological Knowledge, and Night Fishing

Knowledge of both freediving as a practice and of the deeper water habitats associated with this practice placed Palauan men in a better position to capitalize on the sea cucumber trade than other harvesters. A middle-aged Palauan fisherman from Ngarchelong explained,

> *"The guys that made the big bucks were the real fishermen. You know, they can stay down there ten minutes, they have like ten buckets. They're faster and have more air to stay down and collect, collect."*

As a result of the gender division of marine resource use in Palau, marine ecological knowledge is gendered. Sea cucumber gleaners—primarily Palauan women—are the most knowledgeable about nearshore sea cucumber habitats and behaviors and thus might have been best positioned to capitalize on the sea cucumber trade. However, harvesting in these nearshore areas proved less efficient than harvesting in the deeper waters where spearfishers—primarily Palauan men—had more applicable ecological knowledge.

Though sea cucumbers are not their target species, fishermen's extensive ecological knowledge of deeper water areas includes an awareness of sea cucumber habitats and behaviors that could be called upon when it became profitable. For example, bakelungal (Latin: *Holothuria fuscogilva* and *H. whitmaei*; English: white

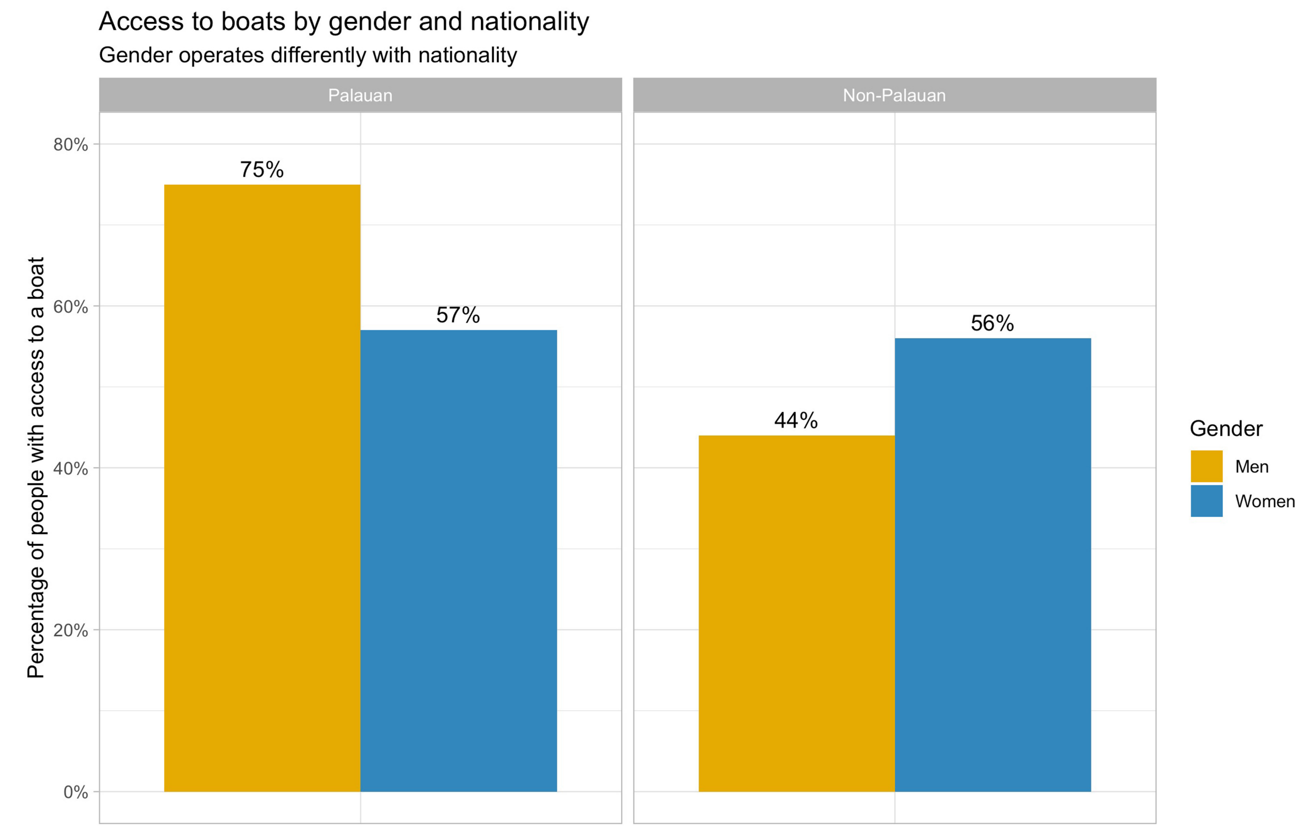

FIGURE 4 | Gender operates differently depending on a harvester's nationality, with immigrant women having greater access to boats than immigrant men.

teatfish and black teatfish), the largest and highest-value species for *bêche-de-mer* in Palau, is found only in deeper waters, where typically only Palauan men fish. An elder Palauan fisherwoman and expert explained, "The men dive when they go fishing, so they know where to collect bakelungal. The women don't collect those." A middle-aged Palauan fisherman from Ngarchelong echoed this claim, "We [men] know where to find [bakelungal] from spearfishing and also net fishing."

Ecological knowledge of Palauan marine environments is not only gendered but is also associated with being Palauan. A Yapese immigrant woman married to a Palauan man explained that sea cucumbers are not eaten in Yap and that she learned to glean them from her husband's family when she moved to Palau. She said that, because she had not grown-up gleaning sea cucumbers, she had less knowledge of the animals and their habitats than Palauan women. To the extent that she does have ecological knowledge of sea cucumbers, she attributes it in large part to her marriage to a Palauan man.

Knowledge of nighttime fishing also proved advantageous and is also gendered in Palau. A middle-aged Palauan fisherman from Ngarchelong explained the advantage of night fishing thusly, "You know, at night [the sea cucumbers] come out. So it's much easier. And once the tide gets lower, they're just right there. You're just walking, picking them up. Quick, quick money." This nighttime behavior of sea cucumbers was noted by several participants in the study and is widely known by gleaners. However, nighttime fishing is not practiced by gleaners under normal conditions, who prefer to collect in the early morning, when "the sea cucumber hasn't eaten yet so the intestines are clean," according to an elder fisherwoman and expert. But because sea cucumbers are processed differently (i.e., smoked and dried) for *bêche-de-mer*, the cleanliness of the intestines was not a relevant quality criterion for the trade. An elder Palauan woman chief from Ngarchelong commented on the unusual and gendered nature of nighttime fishing for sea cucumbers, stating, "These people collected during nighttime. The [sea cucumber] comes out at night. And women don't dive at night... it was a very different way of collecting."

Access to Authority: State Rangers

State rangers are responsible for enforcing fisheries regulations within state waters in Palau. State rangers are overwhelmingly Palauan men. Eighty percentage of those in the study who had ever served as a state ranger ($N = 20$) were men and 100% were Palauan.

Palauan law required that exporting companies have a Palauan business partner to obtain a license, and all five exporting companies partnered with state rangers in this capacity. These partners were compensated with percentages of profits, with one ranger estimating he received over US$50,000 from the partnership (for comparison, the median annual income in rural areas in Palau is around US$12,870, Palau Office of Planning and Statistics, 2014). As business partners, these rangers gained early access to the market, weeks or even months before other fishers knew of the buyers' presence. One ranger, a Palauan fisherman from Ngardmau who partnered with one of the companies, explained that, "Actually, the harvest was [going on for] more than a year," with fishers who knew of the buyers' presence collecting illegally for the first 6 months. Another Palauan fisherman, who was a state ranger in Ngarchelong at the time, reported that he kept the buyers' presence a secret initially because, in his determination, prices were too low,

> *"I [was] the first one who went to collect. But I never told anybody because I wanted to see if they're really buying at a good price... But they were buying really cheap. Ten cents per [sea] cucumber. So, I went one time, I deliver, and then I see it's not worth it. I'm already killing my resources, my water, I'm killing it... So, I told them off. Okay, either you raise the price or I'm going to stop. So, I stopped and then they went to the other [state rangers]."*

In their capacity as state rangers, a highly gendered position of authority restricted to Palauans, a small number of Palauan men benefited especially greatly from the trade.

Distribution of the Harms of Trade

After 6 months, legislation at the national level ended the legal harvest of sea cucumbers for export to the *bêche-de-mer* trade. Fishing quickly returned to normal conditions, with primarily women (58%) gleaning sea cucumbers using low-tech practices. An elder Palauan fisherman in Ngarchelong commented that he no longer collects since the exporters left because prices are too low and because he considers gleaning to be women's work.

Predictably, severe decline in sea cucumber populations resulted from the trade. When asked how sea cucumber populations have changed in the past 10 years, 73% of survey respondents (N = 161) reported a decline since 2009. Fishers and gleaners connected this decline directly to the *bêche-de-mer* harvest. An elder fisherwoman from Ngardmau said the export harvest, "totally wiped them out, and fast."

For gleaners, the decline in sea cucumbers is experienced as a decrease in their catch per unit effort. Nearly every active gleaner in the study commented on the decline in sea cucumbers, and a few former gleaners shared that they had stopped gleaning altogether because of the difficulty finding sea cucumbers. One elder Palauan woman and former gleaner from Ngardmau complained, "Nowadays, it's too much walking around and looking." As a result of resource degradation from the trade, gleaners—mostly Palauan and immigrant women—must work harder for longer to collect the same number of sea cucumbers as before the trade, resulting is less food and income for the same effort.

DISCUSSION

This empirical case study demonstrates that the seafood trade does not impact all fishers equally and can serve to reinforce or exacerbate local power inequities. Fishers' intersecting identities shaped how the benefits and harms of the sea cucumber trade were distributed among them in Palau. Palauan men benefited most while Palauan and immigrant women bear a disproportionate share of the short- and long-term harms. This result is surprising in light of the feminized nature of sea cucumber harvesting in Palau and represents a case of masculinization, in which women were largely displaced by men in the harvesting of their customary resources when those resources became more profitable. Masculinization has been documented under similar circumstances in the octopus trade in Tanzania (Porter et al., 2008) and invertebrate fisheries in the Pacific (Pinca et al., 2010; Williams, 2015). Today, the burden of resource degradation associated with the trade is borne primarily by women. It is thus critical that seafood trade policies consider local power dynamics, evaluate possible unintended consequences, and ensure that benefits are distributed equitably in fishing communities, while also managing environmental impacts that may affect less powerful fishers disproportionately.

While gender explains much of the difference in how harvesters interacted with the sea cucumber trade, results highlight the relevance of intersectionality as an analytical tool (Crenshaw, 1989, 1991). In particular, marital status and nationality both shaped which men and which women benefited. Married women benefited more than unmarried women, Palauan women benefited more than non-Palauan women, and non-Palauan men benefited least of everyone, undermining a simplistic interpretation of outcomes based on gender alone.

The literature on women in fisheries tends to conceptualize women as either being deprived of agency or having full agency (Gustavsson, 2020). However, this case demonstrates that women (and men) have limited agency within a given historical, spatial, and political context. In this case, less powerful actors leveraged their relationships with more powerful and resourced actors to access trade benefits; for example, married women gained access to motorboats through their husbands. Such nuances in the distribution of benefits would have been masked by an analysis that narrowly focused on gender and therefore highlights the importance of intersectional analysis in small-scale fisheries contexts (e.g., Kusakabe and Sereyvath, 2014; Lau and Scales, 2016; Colwell et al., 2017; Lokuge and Hilhorst, 2017; Rohe et al., 2018; Yingst and Skaptadóttir, 2018; Gustavsson, 2020). Furthermore, while many women in Palau may have accrued indirect financial benefits from their men family members' earnings from the sea cucumber trade, such indirect benefits do not yield the same advancements in gender equality (U.N. Women., 2018), economic development and resilience (IMF., 2018), freedom from domestic violence (Conner, 2013), and political participation (Bari, 2005). In order to achieve global commitments to gender equality (UN General Assembly, 2015), it remains crucial that women enjoy individual economic empowerment within their households and in their communities. By definition, women's economic empowerment "includes women's ability to participate equally in existing markets; their access to and control over productive resources..." (U.N. Women., 2018). It is thus critical that trade policies account not only for benefits flowing to households but also to individuals, with consideration not only of their gender but also of their intersecting identities.

The harms of the trade were distributed in almost the opposite pattern of benefits. The majority of Palauan fishermen, who benefited most from the trade, only collected sea cucumbers in 2011, when exporters were paying very high prices, and do not collect anymore. They are therefore quite unimpacted by the decline in the fishery associated with overexploitation during the export period. Meanwhile, the women gleaners who benefited relatively little from the trade or—in the case of immigrant women—not at all must work harder and longer to collect even a fraction as many sea cucumbers as before the export period. This has direct impacts on their livelihoods, food security, cultural identity, and well-being (Grantham et al., 2020).

This case provides further support for the argument of feminist political ecologists that gendered power relations are constructed through relations with the environment (e.g., Agarwal, 1997; Gururani, 2002; Elmhirst and Resurreccion, 2008; Nightingale, 2011). In Palau, the preexisting gender division in access to and use of marine resources, with women primarily gleaning using minimal technologies and men primarily freediving for reef fish using motorboats, set the stage for the sudden masculinization of the sea cucumber fishery upon the arrival of exporters. Furthermore, the inequitable distribution of trade benefits and harms between women and men served to reinforce gendered power dynamics. Results also indicate that power hierarchies based not only on gender but also on intersecting identities are critical determinants of how actors interact with the environment and how resource degradation, in turn, shapes local power dynamics.

Nightingale (2011) argues that social inequalities are constantly shifting yet surprisingly resilient to major reconfigurations. In this case, the opening of the sea cucumber fishery to exporters was a monumental shift in how the fishery operated, presenting an opportunity for an unsettling and restructuring of local power hierarchies. Given the feminized nature of sea cucumber harvesting in Palau, one might have predicted that opening the trade would create an opportunity for women's economic empowerment and the advancement of gender equality. Yet preexisting power hierarchies appear to have been further entrenched, rather than challenged, by the sea cucumber trade. This resilience of social inequalities in fishing communities and the configurations of fisheries management and practices that disrupt or entrench them warrants further study.

CONCLUSION

Fishing communities are not homogeneous, and fisheries policies do not impact all fishing community members equally. Fisheries policies and development strategy should carefully account for and include in decision-making a diversity of actors across intersecting lines of identity to assess and anticipate possible unintended consequences. This case study demonstrates that a failure to account for these intersections can lead to the unintended exclusion of the most vulnerable groups and risks entrenching inequities in fishing communities.

Small-scale fisheries around the globe are increasingly subject to global market forces that can have severe short- and long-term impacts on fishing communities and their resources. While increased connectivity through trade has the potential to deliver economic development, it also poses sustainability and equity challenges. This case provides one of many examples of resource degradation resulting from the seafood trade (Crona et al., 2015)—an issue that is particularly common in sea cucumber fisheries (Anderson et al., 2011; Purcell et al., 2013)—and expands our understanding of the longer-term impacts of resource degradation on the (re)production of social inequities. Policymakers and community-level decision-makers should therefore adopt a precautionary and inclusive approach when addressing new market opportunities for locally utilized marine resources.

It is critically important to increase understanding and consideration of how the intersecting identities of actors in fisheries, aquaculture, and other socio-ecological systems shape their access to and use of resources, and how resource degradation in turn may serve to entrench inequities. Paying attention to resource users' intersecting identities has profound implications for designing processes and policies that promote equity in socio-ecological systems across the globe.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Stanford University Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CF was the sole author of this manuscript. CF developed the research question and protocol, conducted data collection and analysis, and wrote the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.625389/full#supplementary-material

REFERENCES

Agarwal, B. (1997). "Bargaining" and gender relations: within and beyond the household. *Feminist Eco.* 3, 1–51. doi: 10.1080/135457097338799

Agrawal, A., and Gibson, C. C. (2001). *Communities and the environment: ethnicity, gender, and the state in community-based conservation*. New Brunswick, NJ: Rutgers University Press.

Agrawal, A., and Gibson, C. C. (1999). Enchantment and disenchantment: the role of community in natural resource conservation. *World Dev.* 27, 629–649. doi: 10.1016/s0305-750x(98)00161-2

Agrawal, A., Smith, R. C., and Li, T. (1997). *Community in conservation: beyond enchantment and disenchantment*. Gainesville, FL: Conservation & Development Forum.

Allison, E. H., and Ellis, F. (2001). The livelihoods approach and management of small-scale fisheries. *Marine policy* 25, 377–388. doi: 10.1016/s0308-597x(01)00023-9

Anderson, S. C., Flemming, J. M., Watson, R., and Lotze, H. K. (2011). Serial exploitation of global sea cucumber fisheries. *Fish Fisheries* 12, 317–339. doi: 10.1111/j.1467-2979.2010.00397.x

Barclay, K., Fabinyi, M., Kinch, J., and Foale, S. (2019). Governability of high-value fisheries in low-income contexts: a case study of the sea cucumber fishery in papua new guinea. *Hum. Ecol.* 47, 381–396. doi: 10.1007/s10745-019-00078-8

Bari, F. (2005). *Women's political participation: Issues and Challenges. In United Nations Division for the Advancement of Women Expert Group Meeting: Enhancing Participation of Women in Development through an Enabling Environment for Achieving Gender Equality and the Advancement of Women*. Bangkok: Division for the Advancement of Women.

Barr, R., Ullery, N., Dwight, I., and Bruner, A. (2016). *Palau's sea cucumber fisheries: the economic rationale for sustainable management*. Washington DC: Conservation Strategy Fund.

Béné, C., Lawton, R., and Allison, E. H. (2010). "Trade matters in the fight against poverty": narratives, perceptions, and (lack of) evidence in the case of fish trade in africa. *World Dev.* 38, 933–954. doi: 10.1016/j.worlddev.2009.12.010

Bennett, E. (2005). Gender, fisheries and development. *Marine Policy* 29, 451–459.

Campling, L. (2012). The tuna 'commodity frontier': business strategies and environment in the industrial tuna fisheries of the western indian ocean. *J. Agrarian Change* 12, 252–278. doi: 10.1111/j.1471-0366.2011.00354.x

Christensen, A. E. (2011). Marine gold and atoll livelihoods: the rise and fall of the bêche-de-mer trade on ontong java, solomon islands. *Nat. Res. Forum* 35, 9–20. doi: 10.1111/j.1477-8947.2011.01343.x

Cleaver, F. (2002). Reinventing institutions: Bricolage and the social embeddedness of natural resource management. *Eur. J. Dev. Res.* 14, 11–30. doi: 10.1080/714000425

Collins, P. H. (1986). Learning from the outsider within: the sociological significance of black feminist thought. *Soc. Prob.* 33, s14–s32.

Compact of Free Association (1994). *Republic of Palau*. Available online at: https://pw.usembassy.gov/wp-content/uploads/sites/282/2017/05/rop_cofa.pdf

Colwell, J. M. N., Axelrod, M., Salim, S. S., and Velvizhi, S. (2017). A gendered analysis of fisherfolk's livelihood adaptation and coping responses in the face of a seasonal fishing ban in Tamil Nadu & Puducherry, India. *World Dev.* 98, 325–337. doi: 10.1016/j.worlddev.2017.04.033

Conand, C. (2017). Expansion of global sea cucumber fisheries buoys exports. *Revista de Biología Tropical* 65, S1–S10.

Conand, C., and Sloan, N. A. (1989). "World fisheries for echinoderms," in *Marine invertebrate fisheries: their assessment and management*, ed. J. F. Caddy, (Hoboken, NJ: Wiley).

Conner, D. H. (2013). Financial freedom: women, money, and domestic abuse. *Wm. Mary J. Women L.* 20:339.

Crenshaw, K. (1989). Demarginalizing the intersection of race and sex: a black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. *U. Chi. Legal F.* 1, 139–167.

Crenshaw, K. (1991). Mapping the margins: Identity politics, intersectionality, and violence against women. *Stanford Law Rev.* 43, 1241–1299. doi: 10.2307/1229039

Crona, B. I., Basurto, X., Squires, D., Gelcich, S., Daw, T. M., Khan, A., et al. (2016). Towards a typology of interactions between small-scale fisheries and global seafood trade. *Marine Policy* 65, 1–10. doi: 10.1016/j.marpol.2015.11.016

Crona, B. I., Van Holt, T., Petersson, M., Daw, T. M., and Buchary, E. (2015). Using social–ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Global Environ. Change* 35, 162–175. doi: 10.1016/j.gloenvcha.2015.07.006

De Guzman, A. B. (2019). Women in subsistence fisheries in the philippines: the undervalued contribution of reef gleaning to food and nutrition security of coastal households. *SPC Women Fisheries Bull.* 29, 34–40.

Elmhirst, R., and Resurreccion, B. P. (2008). *Gender, Environment and Natural Resource Management: New Dimensions, New Debates. Gender and Natural Resource Management: Livelihoods, Mobility and Interventions*, 3–22. doi: 10.4324/9781849771436

Eriksson, H., Österblom, H., Crona, B., Troell, M., Andrew, N., Wilen, J., et al. (2015). Contagious exploitation of marine resources. *Front. Ecol. Environ.* 13:435–440. doi: 10.1890/140312

Fabinyi, M. (2012). Historical, cultural and social perspectives on luxury seafood consumption in china. *Environ. Conserv.* 39, 83–92. doi: 10.1017/s0376892911000609

Fabinyi, M., Dressler, W. H., and Pido, M. D. (2018). Moving beyond financial value in seafood commodity chains. *Marine Policy* 94, 89–92. doi: 10.1016/j.marpol.2018.04.033

Ferrol-Schulte, D., Ferse, S. C., and Glaser, M. (2014). Patron–client relationships, livelihoods and natural resource management in tropical coastal communities. *Ocean Coastal Manag.* 100, 63–73. doi: 10.1016/j.ocecoaman.2014.07.016

Forsyth, T., and Johnson, C. (2014). Elinor Ostrom's legacy: Governing the commons and the rational choice controversy. *Dev. Chan.* 45, 1093–1110. doi: 10.1111/dech.12110

Gephart, J. A., and Pace, M. L. (2015). Structure and evolution of the global seafood trade network. *Environ. Res. Lett.* 10:125014. doi: 10.1088/1748-9326/10/12/125014

Gibbens, S. (2017). *This Small Island Nation Makes a Big Case For Protecting Our Oceans*. Washington, DC: National Geographic.

Golbuu, Y., Andrew, J., Koshiba, S., Mereb, G., Merep, A., Olsudong, D., et al. (2012). *Status of sea cucumber population at Ngardmau State, Republic of Palau*. Koror: Palau International Coral Reef Center, 11–12.

Golbuu, Y., Bauman, A., Kuartei, J., and Victor, S. (2005). The state of coral reef ecosystems of palau. *State Coral Reef Ecosyst. U S Pacific Freely Assoc. States* 2005, 488–507.

Graham, T., and Idechong, N. (1998). Reconciling customary and constitutional law: managing marine resources in palau, micronesia. *Ocean Coastal Manag.* 40, 143–164. doi: 10.1016/s0964-5691(98)00045-3

Grantham, R., Lau, J., and Kleiber, D. (2020). Gleaning: beyond the subsistence narrative. *Maritime Stud.* 19, 509–524. doi: 10.1007/s40152-020-00200-3

Gurung, C., and Gurung, N. (2006). *The social and gendered nature of ginger production and commercialization: a case study of the Rai, Lepcha and Brahmin-Chhetri in Sikkim and Kalimpong, West Bengal, India*. Ottawa, CA: International Development Research Centre.

Gururani, S. (2002). Forests of pleasure and pain: Gendered practices of labor and livelihood in the forests of the Kumaon Himalayas, India. *Gender Place Cult. J. Femin. Geogr.* 9, 229–243. doi: 10.1080/0966369022000003842

Gustavsson, M. (2020). Women's changing productive practices, gender relations and identities in fishing through a critical feminisation perspective. *J. Rural Stud.* 78, 36–46. doi: 10.1016/j.jrurstud.2020.06.006

Hankivsky, O. (2014). *Intersectionality 101*. Vancouver, CA: Institute for Intersectionality Research & Policy, SFU, 1–34.

Harper, S., Adshade, M., Lam, V. W., Pauly, D., and Sumaila, U. R. (2020). Valuing invisible catches: estimating the global contribution by women to small-scale marine capture fisheries production. *PloS One* 15:e0228912. doi: 10.1371/journal.pone.0228912

Harper, S., Zeller, D., Hauzer, M., Pauly, D., and Sumaila, U. R. (2013). Women and fisheries: contribution to food security and local economies. *Marine Policy* 39, 56–63. doi: 10.1016/j.marpol.2012.10.018

Harris, L. M. (2006). Irrigation, gender, and social geographies of the changing waterscapes of southeastern anatolia. *Environ.Plan. D Soc. Space* 24, 187–213. doi: 10.1068/d03k

Hooks, B. (1984). *Feminist theory: From margin to center*. London, UK: Pluto Press.

IMF. (2018). *Pursuing Women's Economic Empowerment*. Washington, DC: International Monetary Fund.

Kelkar, M. (2007). Local knowledge and natural resource management: a gender perspective. *Ind. J. Gender Stud.* 14, 295–306. doi: 10.1177/097152150701400205

Kleiber, D. (2014). *Gender and small-scale fisheries in the Central Philippines* .Doctoral dissertation. Columbia: University of British Columbia.

Kleiber, D., Harris, L. M., and Vincent, A. C. (2015). Gender and small-scale fisheries: a case for counting women and beyond. *Fish Fisheries* 16, 547–562. doi: 10.1111/faf.12075

Krishna, S. (1998). *Gender Dimensions in Biodiversity Management*. Arunachal Pradesh, IND: Sage Publication, 148–181.

Kusakabe, K. Y. O. K. O., and Sereyvath, P. R. A. K. (2014). Women fish border traders in cambodia: what shapes women's business trajectories. *Asian Fisheries Sci.* 27, 43–57.

Lau, J. D., and Scales, I. R. (2016). Identity, subjectivity and natural resource use: How ethnicity, gender and class intersect to influence mangrove oyster harvesting in the gambia. *Geoforum* 69, 136–146. doi: 10.1016/j.geoforum.2016.01.002

Lokuge, G., and Hilhorst, D. (2017). Outside the net: Intersectionality and inequality in the fisheries of trincomalee, Sri Lanka. *Asian J. Women Stud.* 23, 473–497. doi: 10.1080/12259276.2017.1386839

Matthews, E. (1991). *The role of women in the fisheries of Palau*. Corvallis,USA: Oregon State University.

Nightingale, A. (2006). The nature of gender: work, gender, and environment. *Environ. Plan. D Soc. space* 24, 165–185. doi: 10.1068/d01k

Nightingale, A. J. (2011). Bounding difference: Intersectionality and the material production of gender, caste, class and environment in Nepal. *Geoforum* 42, 153–162. doi: 10.1016/j.geoforum.2010.03.004

Nolan, C. (2019). Power and access issues in Ghana's coastal fisheries: A political ecology of a closing commodity frontier. *Marine Policy* 108:103621. doi: 10.1016/j.marpol.2019.103621

Myers, R. and Hansen, C. P. (2020). Revisiting a theory of access: a review. *Soc. Nat. Resour.* 33, 146–166. doi: 10.1080/08941920.2018.1560522

O'Neill, E. D., Crona, B., Ferrer, A. J. G., Pomeroy, R., and Jiddawi, N. S. (2018). Who benefits from seafood trade? a comparison of social and market structures in small-scale fisheries. *Ecol. Soc.* 23:26799136.

Ota, Y. (2006). Fluid bodies in the sea: an ethnography of underwater spear gun fishing in palau, micronesia. *Worldviews Global Rel. Cul. Ecol.* 10, 205–219. doi: 10.1163/156853506777965811

Pakoa, K., Friedman, K., Moore, B., Tardy, E., and Bertram, I. (2014). *Assessing tropical marine invertebrates: A manual for Pacific Island resource managers*. Noumea, NC: Secretariat of the Pacific Community, 118.

Pakoa, K., Lasi, F., Tardy, E., and Friedman, K. (2009). *The status of sea cucumbers exploited by Palau's subsistence fishery*. Noumea, NC: Secretariat of the Pacific Community.

Palau Bureau of Planning and Statistics. (2015). *2015 Census of Population and Housing*. Palau: Office of Planning & Statistics.

Palau Const. art. III (1994). *Palau's Constitution of 1981 with Amendments through 1992*. Available online at: https://www.constituteproject.org/constitution/Palau_1992.pdf?lang=en

Palau Office of Planning and Statistics. (2014). *2014 Household Income and Expenditure Survey*. Koror, Palau: Economics Departments, Institutes and Research Centers in the World.

Palau Marine Protection Act (1994). *RPPL No. 4-18*. Available online at: http://extwprlegs1.fao.org/docs/pdf/pau38135.pdf

Peters, P. E. (1993). Is "rational choice" the best choice for Robert Bates? An anthropologist's reading of Bates's work. *World Dev.* 21, 1063–1076. doi: 10.1016/0305-750X(93)90062-E

Pinca, S., Kronen, M., Friedman, K., Magron, F., Chapman, L., Tardy, E., et al. (2010). *Regional assessment report: Profiles and results from survey work at 63 sites across 17 Pacific Island Countries and Territories. Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish/C/ CoFish)*. Noumea, New Caledonia: Secretariat of the Pacific Community, 512.

Porter, M., Mwaipopo, R., Faustine, R., and Mzuma, M. (2008). Globalization and women in coastal communities in tanzania. *Development* 51, 193–198. doi: 10.1057/dev.2008.4

Presterudstuen, G. H. (2019). "Understanding sexual and gender diversity in the Pacific Islands," in *Pacific Social Work: Navigating Practice, Policy and Research*, eds J. Ravulo, T. Mafile'o, and D. B. Yeates, (Abingdon, VA: Routledge), 161–171. doi: 10.4324/9781315144252-15

Purcell, S. W., Crona, B. I., Lalavanua, W., and Eriksson, H. (2017). Distribution of economic returns in small-scale fisheries for international markets: a value-chain analysis. *Marine Policy* 86, 9–16. doi: 10.1016/j.marpol.2017.09.001

Purcell, S. W., Mercier, A., Conand, C., Hamel, J. F., Toral-Granda, M. V., Lovatelli, A., et al. (2013). Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing. *Fish Fisheries* 14, 34–59. doi: 10.1111/j.1467-2979.2011.00443.x

Purcell, S. W., Polidoro, B. A., Hamel, J. F., Gamboa, R. U., and Mercier, A. (2014). The cost of being valuable: predictors of extinction risk in marine invertebrates exploited as luxury seafood. *Proc. R. Soc. B Biol. Sci.* 281:20133296. doi: 10.1098/rspb.2013.3296

Purcell, S. W., Williamson, D. H., and Ngaluafe, P. (2018). Chinese market prices of beche-de-mer: implications for fisheries and aquaculture. *Marine Policy* 91, 58–65. doi: 10.1016/j.marpol.2018.02.005

Ribot, J. C., and Peluso, N. L. (2003). A theory of access. *Rural Soc.* 68, 153–181.

Rohe, J., Schlüter, A., and Ferse, S. C. (2018). A gender lens on women's harvesting activities and interactions with local marine governance in a south pacific fishing community. *Maritime Stud.* 17, 155–162. doi: 10.1007/s40152-018-0106-8

Sillitoe, P. (2003). The gender of crops in the papua new guinea highlands. Women and plants. *Gender Relat. Biodivers. Manag. Conserv.* 2003, 165–180.

Singh, A. M., and Burra, N. (1993). *Women and wasteland development in India*. New Delhi: Sage Publications.

U.N. Women. (2018). *Facts and Figures: Economic Empowerment Benefits of Economic Empowerment*. New York, NY: UN Women.

UN General Assembly (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. New York, NY: UN General Assembly.

Uthicke, S., Welch, D., and Benzie, J. A. H. (2004). Slow growth and lack of recovery in overfished holothurians on the great barrier reef: evidence from DNA fingerprints and repeated large-scale surveys. *Conserv. Biol.* 18, 1395–1404. doi: 10.1111/j.1523-1739.2004.00309.x

Valentine, G. (2007). Theorizing and researching intersectionality: a challenge for feminist geography. *Prof. Geogr.* 59, 10–21. doi: 10.1111/j.1467-9272.2007.00587.x

Vedavalli, L., and Anil Kumar, N. (1998). "Wayanad, Kerala," in *Gender dimensions in biodiversity management*, ed. M. Swaminathan (Delhi: Konark Publishers Pvt. Ltd.), 96–106.

Weeratunge, N., Snyder, K. A., and Choo, P. S. (2010). Gleaner, fisher, trader, processor: understanding gendered employment in fisheries and aquaculture. *Fish Isheries* 11, 405–420. doi: 10.1111/j.1467-2979.2010.00368.x

Williams, M. J. (2008). Why look at fisheries through a gender lens? *Development* 51, 180–185. doi: 10.1057/dev.2008.2

Williams, M. J. (2015). Pacific invertebrate fisheries and gender–Key results from PROCFish. *SPC Women Fisheries Inf. Bull.* 26, 12–16.

Wilson, L. B. (1995). *Speaking to power: Gender and politics in the Western Pacific*. East Sussex, UK: Psychology Press.

Yingst, A., and Skaptadóttir, U. D. (2018). Gendered labor in the Icelandic fish processing industry. *Maritime Stud.* 17, 125–132. doi: 10.1007/s40152-018-0099-3

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Knowledge Pluralism in First Nations' Salmon Management

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There is growing interest in the "integration" of knowledge and values held by Indigenous peoples with Western science into natural resource governance and management. However, poorly conducted integration efforts can risk harming Indigenous communities and reifying colonial legacies. In this regard, dichotomous conceptualizations of Indigenous and scientific knowledges are problematic. In this research, we focus on the role of indigenous and scientific knowledges in the management of coho salmon (*Oncorhyncus kisutch*) on the west coast of Vancouver Island, British Columbia (BC) in a governance context featuring contested authority among First Nations (Indigenous peoples) and the government of Canada. We discuss an example from a particular Indigenous community, Tla-o-qui-aht First Nations (TFN), that has worked with other management bodies to establish practices for the restoration, enhancement and harvest of *cuẃit* (coho). After outlining relevant Tla-o-qui-aht values, knowledges and decision-making processes, we consider the pluralistic approach to Indigenous and scientific knowledges in Tla-o-qui-aht management of *cuẃit* and show that pluralistic, co-constitutive, and multiplicative understandings of Indigenous and scientific ways of knowing may provide better grounding for addressing challenges in integration efforts. We also emphasize the importance of engagement with FN community liaisons and deferral to FN leadership to align management efforts with FN structures of knowledge production and governance, maintain ethical engagement, recognize Indigenous agency, and support effective conservation, and management efforts.

Keywords: knowledge pluralism, Indigenous knowledge, fisheries management, fisheries governance, knowledge integration, western science, salmon, pacific northwest

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INTRODUCTION

There is growing interest in the "integration" of Western science with the knowledge and values held by Indigenous peoples into natural resource governance and management. The stated intents of these efforts to "bridge" or "integrate" IK with western science include enriched ecological knowledge, improved decision-making processes and outcomes in conservation and management, and empowerment of Indigenous peoples (Berkes, 2009; Weiss et al., 2013; Mistry and Berardi, 2016; Ban et al., 2018; Whyte, 2018; Thompson et al., 2019, 2020; Wheeler and Root-Bernstein, 2020; Reid et al., 2020). Some of this work has cautioned against "integration" efforts that feature an artificial dichotomization of these knowledge systems, appropriation of one knowledge into another based on perceived utility to western scientific management objectives, or conditional validation where non-scientific knowledges are only accepted as legitimate if they match assumptions in western science (Weiss et al., 2013; Mistry and Berardi, 2016; Reid et al., 2020). Such integration efforts serve to echo harmful colonial histories, displace Indigenous values and worldviews, limit the agency of Indigenous peoples and marginalize their own decision-making processes, precipitate negative ecological and socio-cultural outcomes, and contribute to Indigenous peoples' distrust of Federal governments (Whyte, 2013; Coombes et al., 2014; Muller et al., 2019). In this article, we build on work that challenges this legacy and pushes toward equitable, just, and decolonized practices in resource management.

In the academic literature, Indigenous knowledge (IK), often termed traditional ecological knowledge (TEK), broadly refers to environmentally oriented ways of knowing which are place-based, adaptive, acquired experientially and intergenerationally, and held by Indigenous peoples (Berkes, 2012; Ban et al., 2018; Wheeler and Root-Bernstein, 2020). IK is contextualized by specific worldviews and cultural practices and formed through close relationships with the local environment and with community (Berkes, 2012; Thompson et al., 2020). There is no single IK system, and IK cannot be selectively described through discrete pieces of information; knowledge is embedded within the worldview and traditional practices of an Indigenous community (Wheeler and Root-Bernstein, 2020). English language and academic articulation of IK/TEK originated in international development and adaptive governance literature (Agrawal, 1995; Whyte, 2013). These definitions are sometimes embedded in controversy and tend to privilege non-Indigenous and scientific agendas or frame IK/TEK as a way to fill gaps in scientific knowledge through assimilation (Whyte, 2013; Reid et al., 2020).

In seeking a clear definition of IK/TEK and an articulation of the differences and relationships between science and IK/TEK, Indigenous and scientific ways of knowing are often treated dichotomously. Mistry and Berardi (2016) among others (Whyte, 2013; Weiss et al., 2013; Reid et al., 2020) note that science has been framed as superior in accuracy, rigor, objectivity, modernity and reliability. Some academic literature has specified science as different from IK/TEK through its systematic processes and positivist or reductionist perspectives and in noting that science is perceived, if erroneously, to be more objective and less culturally embedded than Indigenous ways of knowing (Weiss et al., 2013; Muller et al., 2019). Hypothesis and experiment-driven science and (especially quantitative) data is often contrasted with place-based, relationally-driven, experiential knowledge shared through storytelling, ceremony, and other oral traditions (Ban et al., 2018; Wheeler and Root-Bernstein, 2020). However, these differentiations are not absolute, nor do they inherently make science more accurate or relevant. There are also clear epistemic similarities in these knowledge systems. Both scientific and Indigenous ways of knowing rely on observation, occur through culturally embedded processes, develop through integration of new technologies, and can seek to understand ecological systems and the impacts of human behavior (Kimmerer, 2013a; Weiss et al., 2013; Ban et al., 2018). Differences between Indigenous and scientific ways of knowing are more ontologically grounded; for example Indigenous ways of knowing center relational worldviews (Datta, 2015) and a focus on connection, compared to practices of categorization or separation in western knowledge traditions (Muller, 2012).

Indigenous scholars Marshall (Bartlett et al., 2012), Kimmerer (2013a,b), and Whyte (2013, 2018), among others, reject ideas of a hierarchical division between science and IK, the supposed objectivity of western science, and the categorization of IK as antiquated, lacking rigor, or dependent on myth. They argue that dichotomous views of Indigenous and scientific ways of knowing preclude collaborative relationships and shared understanding between Indigenous peoples and environmental scientists and conservation practitioners. Further, recognition of IK as valid alongside rather than mediated or subjugated by science is important for disrupting colonial legacies in resource governance and for more effectively integrating knowledges into management efforts (Whyte, 2013; Muller, 2014; Reid et al., 2020).

The challenges of knowledge integration efforts are exemplified in salmon fisheries of the west coast of Vancouver Island, BC, Canada (WCVI) where governance features contested sovereignty between Canada and First Nations (Indigenous peoples). In this paper, we discuss an example from Tla-o-qui-aht First Nations (TFN) and the management of coho salmon (*Oncorhynchus kisutch*) on WCVI. We describe TFN's management priorities for coho, contextualized through Tla-o-qui-aht worldview, and consider the roles of western science and IK in TFN's salmon governance and management. We demonstrate a practice of integration that enacts knowledge pluralism embedded in the salmon governance and management of TFN. In this case, knowledge pluralism refers to the idea that Indigenous and scientific knowledges are fluid, evolving ways of knowing that are mutually informative and may be concurrently mobilized. We conceptualize knowledge plurality by drawing on epistemic pluralism (Carter, 2017) and on Indigenous frameworks for knowledge coexistence which reflect a philosophy and practice of embracing collaborative knowledge generation, recognizing strengths in Indigenous and scientific knowledges, and rejecting dichotomous definitions between knowledge systems (Whyte, 2013; Reid et al., 2020). Our use of the term "pluralism" is reflective of ontological multiplicities discussed by Mol (1999) and Howitt and Suchet-Pearson (2003, 2006) and requires attention to Indigenous diversity and particularities (Howitt et al., 2009).

The specific details in this article directly stem from a 6 year research project entitled EPIC4[1] that utilizes western science and is intended to support application of conservation tools and technology to coho salmon management. EPIC4 itself grew out of a long-term engagement between authors on this project through multiple research-oriented projects spanning close to 15 years that have built considerable trust, identified shared areas of interest and that have collectively sought to maintain

[1]EPIC4 (Enhanced Production in Coho: Culture, Community, Catch) is an ongoing research project, funded from outside of the Tla-o-qui-aht community, seeking to address challenges in coho salmon conservation and management through genomics. This paper does not explicitly consider genomics. It is part of one section of EPIC4 focused on First Nations' knowledge mobilization and project impacts to community well-being.

ethical engagement with First Nations' governance structures and uphold First Nations' agency. The specific goals of this article are to illuminate Tla-o-qui-aht values, worldviews and knowledge development and decision-making processes relevant to the management of coho and to demonstrate the strengths of a practice of knowledge pluralism that differs from most western scientific management or academic approaches of knowledge integration.

METHODS

Case Study: Tla-o-qui-aht First Nations

The traditional territory (*hahouthli*) of the Tla-o-qui-aht First Nations (TFN) is on the west coast of Vancouver Island and encompasses Clayoquot Sound, three Tla-o-qui-aht communities, and the Canadian town of Tofino. TFN is one of fourteen language-sharing Nuu-chah-nulth First Nations who have lived along the west coast of Vancouver Island for thousands of years. The history between Nuu-chah-nulth people and Canada following white settlement includes violent displacement, forced assimilation, resource disputes, and contested sovereignty. First Nations have well-established structures of resource governance but have historically been subjugated by *de jure* and *de facto* practices of Canadian governance systems (Truth and Reconciliation Commission, 2015; Ban et al., 2019). The history of conflict over territory and resource use rights between Canada and First Nations complicates tense and often antagonistic negotiations over fishery management decisions.

Canada attempts to accommodate asserted food, social, and ceremonial (FSC) fishing rights of each Nuu-chah-nulth First Nation and, after lengthy and ongoing struggles in the courts, recently recognized the commercial fishing rights of five Nations, including Tla-o-qui-aht (CanLII, 2018). T'aaq-wiihak (fishing with the permission of the chiefs) and Ha'oom Fisheries Society were developed to coordinate negotiating and implementing these rights. T'aaq-wiihak negotiates with Fisheries and Oceans Canada (DFO) to determine catch allocations, season openings and lengths, and other restrictions. Ha'oom works collaboratively with each of the five Nations to implement the results of negotiations through managing demonstration commercial fisheries and establishing local practices for the catch monitoring, restoration, enhancement, and harvest of salmon populations. Recent modification of the Fisheries Act (Bill C-68, 2019) includes a directive for DFO to incorporate Indigenous rights and knowledge into fishery management practices and to strengthen obligations to build partnerships with First Nations. While Federal strategies toward meeting this legislative mandate are evolving, Tla-o-qui-aht and other FNs have developed their own strategies of applying traditional and scientific knowledges in territorial resource governance and management. TFN hopes to eventually hold full agency over the management of fish stocks within their traditional territories.

The five species of Salmon (*Oncorhynchus* spp.) native to BC waters hold high economic value to many coastal BC communities and are integral to the well-being of Nuu-chah-nulth First Nations on Vancouver Island (George, 2003; Atleo, 2011; Price et al., 2017). Wild salmon populations across British Columbia (BC) have not recovered from drastic declines despite fishery closures and population supplementation through hatchery propagation (Price et al., 2017). Recent escapement surveys estimate coho numbers in the Tla-o-qui-aht watersheds to be at a fraction of the 12 year average, and some river surveys report returning coho numbers in the single digits (DFO, 2019a,b, 2020). Management is complicated by a limited ability to differentiate wild from hatchery fish, identify spawning origins of wild fish, prevent genetic introgression, and to easily identify wild fish as part of specific Conservation Units (Price et al., 2017). With these challenges in mind, First Nations and DFO are highly invested in salmon conservation and management using both Indigenous knowledges (IKs) and scientific tools.

Information and Analysis

Our approach used ethnographic traditions grounded in critical theory within a western research paradigm that was also informed by the growing literature on indigenous methodologies. A western research paradigm is limited in its ability to account for and incorporate Indigenous worldviews, so we referred to Smith (2012) and the reflections of Coombes et al. (2014), and Reid (2020) on the praxis of appropriately engaging in critical research with an Indigenous community, especially regarding the importance of Indigenous leadership. Further, we centered relational ontologies in our conceptual framework (Datta, 2015) and placed ethics and reciprocity as central to the methodology (Kovach, 2010).

We prioritized direction by and meaningful engagement with TFN, building on a 15 year history of work together. TFN representatives led our conversations toward developing research objectives and we followed TFN's formal permission guidelines to conduct the research and write about Tla-o-qui-aht knowledge, governance, and management practices. All research objectives, methods of data collection, and agreements on data and research ownership were first reviewed and approved by TFN through the Tla-o-qui-aht Traditional Research Council (TRC). We collaborated with the TFN administration and Ha'oom Fisheries Society in collecting data. In developing the results presented here, we synthesized information provided through the review of relevant documents (e.g., post-season reports, management protocols), 12 individual conversations with TFN resource managers, administrators, and Elders between August 2018 and November 2019, two TRC meetings in 2018 and 2019, co-development of written records of TFN *cuẃit* (coho) management protocols with TFN's natural resources manager, and observation of five Salmon Roundtable[2] meetings between November 2018 and February 2021. Most stories by elders were shared in a group during the TRC meetings. Individual conversations were held at the TFN offices, following introduction by a community liaison. Documents were acquired either through publically available records or were provided

[2]The WCVI Salmon Roundtables are bi-annual meetings between First Nations, commercial and recreational fishers, DFO, and other stakeholders to address salmon research, restoration, enhancement, and harvest planning efforts through co-management processes. Meetings are coordinated and moderated by West Coast Aquatic.

directly by a TFN archivist, whose work was financially supported in part by this research. TFN leaders discussed and verified research findings with the authors. All research efforts were guided by a community liaison supported by the project who is listed as the fourth author on this paper.

Positionality and Limitations

The first and third authors are non-Indigenous researchers with white settler lived experience. The second author is Indigenous (Xwchíýò:m) and works with T'aaq-wiihak in negotiations and with Ha'oom in implementation. The fourth author is also Indigenous (Tla-o-qui-aht) and is a Tla-o-qui-aht Councillor, TFN Parks Project Coordinator, and plays a crucial role as a liaison and guide in this research. Other Tla-o-qui-aht collaborators have expressed support and approval of this paper and have for their own reasons chosen to not be listed as individual authors though we do work together to produce other allied research products of direct interest and value to TFN. We write with the intent to act as ethical allies to our Tla-o-qui-aht colleagues but not to speak for their experiences or interests. We extend gratitude for their leadership and guidance in this research.

When reviewing Nuu-chah-nulth values, sacred principles and relationships with salmon, we do not provide a complete summary or speak for Nuu-chah-nulth experience. As the first three authors are not Nuu-cha-nulth people, we cannot explain Nuu-chah-nulth worldviews or experience with complete accuracy, nor is it our rightful place to do so. Instead, we recommend the reader refer to work by Nuu-chah-nulth scholars (George, 2003; Atleo, 2004, 2011; Atleo C., 2008; Atleo M. R., 2008; Coté, 2019).

RESULTS

We separate our results into broad categories (worldview, management priorities, knowledge pluralism, and external relationships) to illuminate the key aspects of how knowledge is produced, valued, and deployed toward the management of *cuẃit* and other salmon in TFN.

Nuu-chah-nulth Relational Worldview and Traditional Practices

TFN managers and Elders emphasized that all aspects of resource governance are informed by values grounded in the Nuu-chah-nulth worldview and that decisions regarding the enhancement, restoration, and harvest of salmon populations are bound by these traditional values and principles. This includes ways of collecting, sharing, and using knowledge as well as processes of decision-making. Elders and managers stress that external partners learn about Tla-o-qui-aht values and worldview when engaging with Tla-o-qui-aht resource governance, especially in any attempts to connect western science and management with Tla-o-qui-aht practices. Here, we offer some broad descriptions of this worldview, focusing on what Tla-o-qui-aht Elders and fishery managers identified to be of key importance for non-Nuu-chah-nulth practitioners to understand about salmon management in the Tla-o-qui-aht *hahouthli*.

The Nuu-chah-nulth worldview is grounded in the concepts of *His-shuk-nish-t'sa-waalk,* or "everything is one" and *Iisaak*, or "respect with caring" (Atleo, 2004, 2011). In this relational worldview, all components of the physical and spiritual worlds are understood as intimately connected; everything impacts everything else through close knit and sacred relationships (Atleo, 2004, 2011). Recognition, Respect, and Reciprocity are core principles in the Nuu-chah-nulth value system that honor and maintain these relationships (Atleo, 2011; TFN, 2020). Salmon, including *cuẃit* (coho), hold a particular relational value within the Nuu-chah-nulth worldview. Traditional stories, for example, tell of the Salmon people as "blood relatives" and as sacred knowledge holders with whom the people hold an important reciprocal relationship: salmon offer themselves as food in exchange for the people's celebration by public ritual and for the care and guardianship of the rivers (Atleo, 2011). Following this tenet, much of Tla-o-qui-aht's management for salmon is focused on habitat restoration through traditional river guardianship to address the lasting detrimental impacts of forestry practices on freshwater habitat (DFO, 2002; TFN, 2020).

In addition to honoring valued relationships through respect and reciprocity in ceremony, habitat restoration, and harvest, Nuu-chah-nulth worldview guides traditional governance practices in political oversight of salmon management. For example, TFN's administrative natural resource management plans require approval of the Council of *Hawił* (hereditary chiefs). The *Hawił* review management plans to ensure that they follow *His-shuk-nish-t'sa-waalk* and *Iisaak,* uphold Tla-o-qui-aht's values, and honor traditional practices (TFN, 2020).

Priorities: Enhancement, Restoration, Harvest

Tla-o-qui-aht's protection of salmon is organized into three strategic programs: restoration of key habitat to improve salmon survivorship, enhancement of fish populations through Tla-o-qui-aht owned hatcheries, and careful harvest management that upholds traditional practices and relationships without further threatening the fish stock. Restoration and enhancement programs support stock health and abundance, annual rates of return, and reproduction in salmon populations. Harvest programs address both home[3] fisheries and commercial salmon fishing, though *cuẃit* populations are currently too low to support commercial harvest within the *hahouthli* (TFN, 2020). Strategic programs are intended to "reinvigorate and maintain important relationships between *cuẃit* and the Tla-o-qui-aht community," and support continued traditional practices in river guardianship, fish harvest, and ceremony (TFN, 2020). According to TFN resource managers and Elders, these strategies are maintained for multiple additional reasons including protecting culture, identity, and knowledge, honoring sacred relationships, abiding by Nuu-hah-nulth worldview, and enacting Tla-o-qui-aht sovereignty in the *hahouthli.*

[3]TFN refers to FSC fisheries as "home" fisheries.

Tla-o-qui-aht recognize that dwindling numbers of *cuẃit* and other salmon threaten a food source and the sacred, reciprocal relationships between people, salmon, and rivers. All of TFN's *cuẃit* management programs are designed to prioritize abundance and genetic diversity of coho. Only then does the maintenance of home fisheries follow, with commercial harvest as a long-term goal. This order of priorities was explained to us by a Tla-o-qui-aht fishery manager as: "putting the health and abundance of the fish first, so our relationship . . . supports productive and healthy fish." River habitat restoration and enhancement of wild *cuẃit* populations follows tenets of respect and care for the salmon. Harvest would enable salmon to perform their side of the relationship, but cannot be supported without proper respect, recognition and reciprocity through Tla-o-qui-aht guardianship. To prioritize harvest over restoration and enhancement would further harm *cuẃit* populations. One Elder carefully differentiated this approach from sustainability frameworks in scientific fishery management: "We understand the concept of sustainability, but the way you [white people] use it frames the fish only in how they are useful to people. Sustainability sets our goals low rather than high enough to support both our needs and the fish's needs." In a Traditional Resource Council meeting, an Elder called this approach, "abundability." This order of priorities stands following the affirmation of TFN's commercial fishing rights. TFN intends to eventually hold full authority over a commercial *cuẃit* fishery within the *hahouthli*, developed and managed through this philosophy, but does not plan to open a terminal commercial fishery in the *hahouthli* until *cuẃit* populations have substantially increased (TFN, 2020).

Knowledge Pluralism

Although Nuu-chah-nulth worldview and traditional practices are central in Tla-o-qui-aht governance and management, scientific knowledge also plays an important role in informing decisions and monitoring management efforts. TFN works toward achieving management goals through application of the "best available knowledge" (TFN, 2020). TFN considers "best available knowledge" to include both Nuu-chah-nulth and scientific approaches to such tasks as stock assessments, river surveys, and monitoring environmental change. TFN's staff includes an Aboriginal Fishery Manager (AFM) and a Salmon Enhancement Manager (SEM), who are trained as traditional Guardians[4] and are well versed in scientific data collection and interpretation in the context of fisheries biology and management. Guardians hold important Indigenous knowledge of river systems and fish populations, abide by traditional practices of river stewardship according to Nuu-chah-nulth values, and guide traditional river walks to assess habitats, among other duties. They also coordinate their work with external collaborators, consulting with fishery biologists from other management agencies such as Ha'oom and non-profits such as the Clayoquot Biosphere Trust. TFN Guardians oversee stock assessments, escapement surveys, and other scientific monitoring projects conducted by fishery biologists in their waters. They communicate with Tla-o-qui-aht fishers about the dates of salmon runs and the patterns of return to collect experiential knowledge of salmon populations in the rivers. Information from scientific surveys, river walks, and fisher consultation are utilized together in TFN's decision-making and development of restoration, enhancement, and harvest plans (TFN, 2020).

TFN's administration values this synthesis of traditional and scientific approaches to knowledge production for well-informed management, particularly with regards to restoration and enhancement projects. Emerging scientific technology that may be useful for improving management strategies is considered positively, but carefully guided through Nuu-chah-nulth worldview and TFN authority when applied with traditional knowledge practices to well-informed management plans. For example, the SEM and AFM expressed interest in the possibility of utilizing genomics to improve enhancement efforts. Important to this application, however, is that such tools are used concurrently to Tla-o-qui-aht knowledges and alongside traditional practices, and that their application is overseen by Tla-o-qui-aht AFM, SEM and other relevant TFN staff or Guardian.

External Governance Relationships

Tla-o-qui-aht's pluralistic approach to knowledges is further evident in their external relationships. Clayoquot sound and coastal waters are shared with multiple stakeholders, including non-Indigenous commercial and recreational coho fishers. TFN currently does not have unilateral decision-making power in their watersheds. External collaborations with Ha'oom, T'aaq-wiihak, and local research and conservation groups are important in navigating this reality. The *Hawił* and elected Chief and Council appointed a Lead Negotiator to work with T'aaq-wiihak and Canada in reconciliation efforts. Ultimately, DFO oversees the conservation efforts regarding WCVI salmon, sets limits to total allowable catch across all harvest, and determines allocation of catch to recreational, commercial, and First Nations fisheries. In this context, it is advantageous to First Nations' to demonstrate their understanding of scientific reports and language while advocating for inclusion of their interests and knowledge in DFO management plans. When communicating with local DFO representatives during bi-annual Salmon Roundtables, for example, TFN's fishery managers use storytelling to convey Tla-o-qui-aht knowledge and advocate for Nuu-chah-nulth principles in addition to discussing scientific data sets presenting stock assessments, pathogen rates, and other statistics gathered and presented by DFO representatives through scientific methodologies. TFN considers such quantitative data alongside traditional knowledge when responding to DFO's draft regional management plans. Continuing research is contextualizing TFN's fishery management with external federal governance relationships and considering how the knowledge integration strategies employed by Ha'oom and DFO might compare to those used internally by TFN.

[4]TFN Guardians represent the Nations' interests with regard to the *hahouthli*. In traditional Tla-o-qui-aht governance, individual keepers are trained from a young age as guardians and knowledge holders of specific systems (eg. river keepers or *c̓ac̓ałuk*). In the absence of active *c̓ac̓ałuk*, TFN Guardians currently fill those missing roles (A. Jackson, personal communication, February 11, 2021).

DISCUSSION

Tla-o-qui-aht's management of rivers and salmon reflects a robust use of Indigenous and scientific ways of knowing, applied together to strategic management programs informed by an Indigenous worldview that honors relationships with salmon. IK and science are not treated as separate bodies of knowledge requiring translation of static pieces of information. Instead, they are actively co-constructed and mobilized together. Specific structures and individuals within TFN salmon governance and management facilitate this approach. TFN managers and Guardians—often the same person - play multiple roles, using different ways of knowing and communicating, enacting and guiding the ontological pluralities that shape TFN's river and fishery management practices. TFN's governance structures allow for the sharing of multiple knowledges in decision-making, guide traditional and scientific practice in *cuẃit* management, and help to make the data or knowledge gathered legible to both traditional leaders and to external collaborators. Overall, TFN's *cuẃit* management is grounded in Nuu-chah-nulth worldviews, protects Tla-o-qui-aht identity through maintenance of traditional practices, employs scientific methods, is guided by intergenerational knowledge, requires internal political approval, and is communicated strategically to navigate multiple and ontologically diverse internal and external governance relationships.

Our findings reinforce that productive, meaningful, and ethical use of Indigenous and scientific knowledges doesn't necessitate separation of and translation between knowledge bases and instead benefits from collaborative and pluralistic strategies. Whyte (2013) proposes a philosophical shift to conceptualizing Indigenous knowledges as collaborative practice and notes that many definitions of IK fit this framework which facilitates "cross-cultural and cross-situational collaboration among actors working for Indigenous and non-Indigenous institutions of environmental governance." Reid et al. (2020) point out that "it is the actions taken that matter most, rather that the words used to describe them" when considering pluralistic integration strategies through Indigenous frameworks like "Two-Eyed Seeing" or *Etuaptmumk* (Mi'kmaw). Epistemic plurality (Carter, 2017) is not the use of discrete pieces of information from multiple sources to understand a single reality, but rather the engagement with multiple perspectives, understandings, and ways of being to navigate shared and differentially experienced environmental realities which are highly context-specific. There is no singular "correct" approach to these strategies in praxis; Indigenous diversity and specificity must inform knowledge pluralism through particularities of local contexts (Howitt et al., 2009). Well-documented Indigenous frameworks include "Two Row Wampum" or *Kaswentha* (Haudenosaunee), "Double Canoe" or *Waka-Taurua* (Māori) and "Two Ways" or *Ganma* (Yolngu), all subject to contextual specificities (Bartlett et al., 2012; Muller, 2012; Maxwell et al., 2020; Reid et al., 2020). Along with these authors, we challenge dichotomous approaches to science and IK/TEK and instead point to Indigenous conceptualizations of collaborative, co-productive, multiplicative, or other congruent pluralistic strategies of knowledge production and application.

Indigenous leadership in facilitating the use of multiple knowledges within Indigenous territories is especially important. Indigenous leadership in knowledge integration supports Indigenous autonomy in environmental governance. This is important for improved local management outcomes and adaptive capacity in responding to environmental stressors such as climate change (Thompson et al., 2020; Whitney et al., 2020). Further, Indigenous leadership and self-determination are key to disrupting colonial legacies and harmful relationships of power (Reid et al., 2020). Resource governance implicates colonial pasts when western science takes precedence over or selectively uses IKs according to a western scientific management agenda and in the absence of Indigenous leadership (Muller et al., 2019). Rather than "integration" strategies that subsume Indigenous wisdoms into western paradigms, Indigenous leadership in strategies such as the above frameworks are necessary to "remedy. . .existing power relations, respect differences. and uphold, as opposed to diminish, their unique strengths"(Reid et al., 2020). Even the best intentioned knowledge integration efforts uphold colonial legacies and harmful power dynamics if directed within an Indigenous space by non-Indigenous peoples through hierarchical divisions of knowledges (Howitt et al., 2009; Coombes et al., 2014; Muller, 2014; Muller et al., 2019). In this case study, our collaborators emphasize that TFN leadership in research and management within the *hahouthli* supports TFN's agency and efforts toward self-determination. Throughout our research, our liaisons have guided us through traditional customs, deferral to TFN leadership in determining management objectives, and respectful consultation of Elders. They express that such engagement, following TFN's protocols of research permissions, better aligns the application of scientific methods and tools with First Nations' interests.

CONCLUSION

In this case study, Indigenous governance demonstrates effective pathways for applying science and Indigenous knowledges (IKs) to local salmon management efforts through pluralistic knowledge mobilization and ontological multiplicity. These pathways, coordinated and led by Indigenous peoples, reduce the frictions presented in dichotomous approaches to knowledge integration for locally scaled conservation and management efforts. The exact strategies identified in this study are contextually specific and not necessarily transferable to other Indigenous communities. However, the philosophical approach embedded in the practices where Indigenous and scientific knowledges are recognized as multiple concurrent ways of knowing and being is more broadly informative. This epistemic pluralism, through Indigenous leadership, enables Indigenous governance to direct knowledge production and application, disrupts colonial legacies, and resists scientific dominance in local practice without compromising accuracy of data or quality of management practices. We hope this illumination is helpful for researchers and managers seeking to concurrently apply

Indigenous and scientific knowledges to fishery governance and management in a meaningful, ethically responsible, and effective manner. Ultimately, this shift in "integration" away from translation or assimilation and toward epistemic pluralism better supports Indigenous agency, empowers indigenous governance, and recognizes IKs as valid in efforts to improve efficacy and equity of fishery management.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available. Most data used in this article are existing documents referenced within the text and were made available to the authors by Tla-o-qui-aht First Nations, Ha'oom Fisheries, or West Coast Aquatic. Original data includes notes from conversations or observations of meetings and a few quotes from these data are included in the text. These notes are part of data under formal agreements made with research collaborators (Tla-o-qui-aht First Nations and Ha'oom Fisheries) wherein the authors would not distribute raw data without explicit permission by Tla-o-qui-aht First Nations. These agreements were made to ensure that Tla-o-qui-aht First Nations may retain ownership of Tla-o-qui-aht knowledge and the ability to determine how and when this knowledge is shared. These agreements were approved during ethics review by the Duke Campus IRB. Requests to access the datasets should be directed to JAB, julia.bingham@duke.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Duke University Campus Institutional Review Board. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

JAB, SM, GM, and TD designed the methodologies and developed the project with the permission and help of TFN collaborators. JAB and SM collected and analyzed the data. JAB led the writing of the manuscript. SM and GM provided substantial edits. SM and TD participated as experts in the elicitation process. All authors contributed critically to drafts and gave final approval for publication.

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REFERENCES

Agrawal, A. (1995). Dismantling the divide between indigenous and scientific knowledge. *Dev. Change* 26, 413–439. doi: 10.1111/j.1467-7660.1995.tb00560.x

Atleo, C. (2008). *From Indigenous Nationhood to Neoliberal Aboriginal Economic Development: Charting The Evolution of Indigenous-Settler Relations In Canada*. Toronto, ON: Canadian Social Economic Hub.

Atleo, M. R. (2008). Watching to see until it becomes clear to you: metaphorical mapping – a method for emergence. *Int. J. Qual. Stud. Educ.* 21, 221–233. doi: 10.1080/09518390801998338

Atleo, R. E. (2004). *Tsawalk: A Nuu-Chah-Nulth Worldview*. Vancouver, BC: UBC Press.

Atleo, R. E. (2011). *Principles of Tsawalk: An Indigenous Approach to Global Crisis*. Vancouver, BC: UBC Press, doi: 10.5860/choice.50-0799

Ban, N., Wilson, E., and Neasloss, D. (2019). Strong historical and ongoing indigenous marine governance in the northeast pacific ocean: a case study of the kitasoo/xai'xais first nation. *Ecol. Soc.* 24:10. doi: 10.5751/ES-11091-240410

Ban, N. C., Frid, A., Reid, M., Edgar, B., Shaw, D., and Siwallace, P. (2018). Incorporate indigenous perspectives for impactful research and effective management. *Nat. Ecol. Evol.* 2, 1680–1683. doi: 10.1038/s41559-018-0706-0

Bartlett, C., Marshall, M., and Marshall, A. (2012). Two-eyed seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. *J. Environ. Stud. Sci.* 2, 331–340. doi: 10.1007/s13412-012-0086-8

Berkes, F. (2009). Indigenous ways of knowing and the study of environmental change. *J. R. Soc. New Zeal.* 39, 151–156. doi: 10.1080/03014220909510568

Berkes, F. (2012). *Sacred Ecology*, Third Edn. New York, NY: Rutledge.

Bill C-68 (2019). *An Act to Amend the Fisheries Act and Other Acts in consequence. SC 2019, c 14*. Ottawa, ON: CanLII.

CanLII (2018). *Ahousaht Indian Band and Nation v Canada (Attorney General). BCSC 633 2018*. Ottawa, ON: CanLII.

Carter, J. A. (2017). "Epistemic pluralism, epistemic relativism and "hinge" epistemology," in *Epistemic Pluralism. Series: Palgrave Innovations in Philosophy*, eds A. Coliva and N. J. L. L. Pedersen (London: Palgrave), 229–252. . doi: 10.1007/978-3-319-65460-7_9

Coombes, B., Johnson, J. T., and Howitt, R. (2014). Indigenous geographies III: methodological innovation and the unsettling of participatory research. *Prog. Hum. Geogr.* 38, 845–854. doi: 10.1177/0309132513514723

Coté, C. (2019). hishuk'ish tsawalk—everything is one. Revitalizing place-based indigenous food systems through the enactment of food sovereignty. *J. Agric. Food Syst. Community Dev.* 9, 37–48. doi: 10.5304/jafscd.2019.09A.003

Datta, R. (2015). A relational theoretical framework and meanings of land, nature, and sustainability for research with Indigenous communities. *Local Environ.* 20, 102–113. doi: 10.1080/13549839.2013.818957

DFO (2002). *West Coast Vancouver Island Coho. DFO Science Stock Status Report D6-06*. Nanaimo, BC: Fisheries and Oceans Canada.

DFO (2019a). *South Coast Salmon Bulletin #13: 2019 Escapement Summary, All Salmon Species – Area 24: Clayoquot Sound*. Nanaimo, BC: Fisheries and Oceans Canada.

DFO (2019b). *South Coast Salmon Escapement Bulletin #9: West Coast of Vancouver Island Stock Assessment for 15 November 2019 – All Salmon Species*. Nanaimo, BC: Fisheries and Oceans Canada.

DFO (2020). *South Coast Salmon Escapement Bulletin #1: West Coast of Vancouver Island Stock Assessment for September 18, 2020 – All Salmon Species*. Nanaimo, BC: Fisheries and Oceans Canada.

George, E. M. (2003). *Living on the Edge: Nuu-Chah-Nulth History From an Ahousaht Chief's Perspective*. Winlaw, BC: Sononis Press.

Howitt, R., Muller, S., and Suchet-Pearson, S. (2009). "Indigenous geographies," in *International Encyclopedia of Human Geography*, eds N. Thrift and R. Kitchin (Amsterdam: Elsevier), 358–364. doi: 10.1016/B978-008044910-4.00705-7

Howitt, R., and Suchet-Pearson, S. (2003). "Ontological pluralism in contested cultural landscapes," in *Handbook of Cultural Geography*, eds K. Anderson, M. Domosh, S. Pile, and N. Thrift (Thousand Oaks, CA: SAGE Publications), 557–569. doi: 10.4135/9781848608252.n41

Howitt, R., and Suchet-Pearson, S. (2006). Rethinking the building blocks: ontological pluralism and the idea of "management." *Geogr. Ann. Ser. B* 88, 323–335. http://www.jstor.org/stable/3878377

Kimmerer, R. W. (2013a). *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants*. Minneapolis, MN: Milkweed Editions.

Kimmerer, R. W. (2013b). "The fortress, the river, and the garden: a new metaphor for cultivating mutualistic relationship between scientific and traditional ecological knowledge," in *Contemporary Studies in Environmental and Indigenous Pedagogies: A Curricula of Stories and Place*, eds A. Kulnieks, D. R. Longboat, and K. Young (Rotterdam: Sense Publishers), 49–76.

Kovach, M. (2010). *Indigenous Methodologies: Characteristics, Conversations, and Contexts*. London: University of Toronto Press.

Maxwell, K. H., Ratana, K., Davies, K. K., Taiapa, C., and Awatere, S. (2020). Navigating towards marine co-management with Indigenous communities on-board the Waka-Taurua. *Mar. Policy* 111:103722. doi: 10.1016/j.marpol.2019.103722

Mistry, J., and Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science* 352, 1274–1275. doi: 10.1126/science.aaf1160

Mol, A. (1999). Ontological politics. a word and some questions. *Sociol. Rev*. 47, 74–89. doi: 10.1111/j.1467-954x.1999.tb03483.x

Muller, S. (2012). "Two ways': bringing indigenous and non-indigenous knowledges together," in *Country, Native Title and Ecology*, ed. J. K. Weir (Canberra, ACT: ANU E Press), 59–79.

Muller, S. (2014). Co-motion: making space to care for country. *Geoforum* 54, 132–141. doi: 10.1016/j.geoforum.2014.04.011

Muller, S., Hemming, S., and Rigney, D. (2019). Indigenous sovereignties: relational ontologies and environmental management. *Geogr. Res.* 57, 399–410. doi: 10.1111/1745-5871.12362

Price, M. H. H., English, K. K., Rosenberger, A. G., Macduffee, M., and Reynolds, J. D. (2017). Canada's wild salmon policy: an assessment of conservation progress in British Columbia. *Can. J. Fish. Aquat. Sci.* 74, 1507–1518. doi: 10.1139/cjfas-2017-0127

Reid, A. J., Eckert, L. E., Lane, J.-F., Young, N., Hinch, S. G., Darimont, C. T., et al. (2020). "Two-Eyed Seeing": an indigenous framework to transform fisheries research and management. *Fish Fish.* 22, 243–261. doi: 10.1111/faf.12516

Reid, B. (2020). Positionality and research: "Two-Eyed Seeing". With a rural ktaqmkuk mi'kmaw community. *Int. J. Qual. Methods* 19, 1–12. doi: 10.1177/1609406920910841

Smith, L. T. (2012). *Decolonizing Methodologies: Research and Indigenous Peoples*, Second Edn. London: Zed Books.

TFN (2020). "Decision support tool for management of cuẃit (coho salmon)," in *Tla-o-qui-aht First Nations Lands and Resources*, eds J. Bingham and S. Masso (Vancouver, BC: TFN).

Thompson, K. L., Lantz, T. C., and Ban, N. C. (2020). A review of indigenous knowledge and participation in environmental monitoring. *Ecol. Soc.* 25, 1–27. doi: 10.5751/ES-11503-250210

Thompson, K. L., Reece, N., Robinson, N., Fisher, H. J., Ban, N. C., and Picard, C. R. (2019). "We monitor by living here": community-driven actualization of a social-ecological monitoring program based in the knowledge of indigenous harvesters. *Facets* 4, 293–314. doi: 10.1139/facets-2019-0006

Truth and Reconciliation Commission (2015). *Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada*. Ottawa, ON: Truth and Reconciliation Commission.

Weiss, K., Hamann, M., and Marsh, H. (2013). Bridging knowledges: understanding and applying indigenous and western scientific knowledge for marine wildlife management. *Soc. Nat. Resour.* 26, 285–302. doi: 10.1080/08941920.2012.690065

Wheeler, H. C., and Root-Bernstein, M. (2020). Informing decision—making with Indigenous and local knowledge and science. *J. Appl. Ecol.* 57, 1634–1643. doi: 10.1111/1365-2664.13734

Whitney, C. K., Frid, A., Edgar, B. K., Walkus, J., Siwallace, P., Siwallace, I. L., et al. (2020). "Like the plains people losing the buffalo": perceptions of climate changimpacts, fisheries management, and adaptation actions by Indigenous peoples in coastal British Columbia, Canada. *Ecol. Soc.* 25, 1–17. doi: 10.5751/ES-12027-250433

Whyte, K. (2013). On the role of traditional ecological knowledge as a collaborative concept: a philosophical study. *Ecol. Process.* 2:7. doi: 10.1186/2192-1709-2-7

Whyte, K. (2018). "What do indigenous knowledges do for indigenous peoples?," in *Traditional Ecological Knowledge*, eds M. K. Nelson and D. Shilling (Cambridge: Cambridge University Press), 57–82. doi: 10.1017/9781108552998.005

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Reducing Data Deficiencies: Preliminary Elasmobranch Fisheries Surveys in India, Identify Range Extensions and Large Proportions of Female and Juvenile Landings

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Chondrichthyes, an ancient and diverse class of vertebrates, are crucial to the health of marine ecosystems. Excessive demand for chondrichthyan products has increased fishing pressure, threatening ∼30% of species with extinction in recent decades. India is the second-largest shark landing nation globally and the province of Gujarat, is the largest contributor to its shark exports. Despite their significant contribution to global fish supplies, chondrichthyan fisheries in Gujarat remain understudied and many species, data deficient, posing challenges to the conservation of remaining populations in the region. Here, we report results from taxonomic assessment of elasmobranchs at four key landing sites in Gujarat. We identified thirty-one species of sharks and rays with a significant bias toward capture of females and juveniles by fisheries. Our data indicate the presence of nursery areas for species such as *Sphyrna lewini* and *Rhynchobatus laevis* in the neritic areas off Gujarat. Further, we discovered extensions of the current distribution range for three species -*Torpedo sinuspersici*, *Carcharhinus sorrah,* and *Rhinobatos punctifer*. Taxonomic identities for a subset of species were confirmed using genomic analyses conducted with portable DNA sequencing tools. We present assessments for six data deficient species in the region – *Rhinobatos annandalei*, *Rhinoptera jayakari*, *Maculabatis bineeshi, Pateobatis bleekeri, T. sinuspersici,* and *Carcharhinus amboinensis.* Our investigation underscores species with urgent conservation needs and reduces data deficiencies. These data will inform and pivot future scientific and conservation efforts to protect remaining populations of some of the most vulnerable Chondrichthyes in the Arabian Seas Region.

Keywords: sharks, rays, fisheries, conservation, India, Arabian Sea, Gujarat, data-deficiency

INTRODUCTION

Chondrichthyes (sharks, rays, skates, and chimeras) have been extant for 420 million years and comprise one of the most diverse and ubiquitous group of vertebrates (Dulvy et al., 2014). Chondrichthyan species occupy diverse ecological niches and are selective of their habitats (Compagno, 1990; García et al., 2008). Most species play a crucial role as apex or meso predators in marine and freshwater ecosystems, by maintaining ecosystem health through regulation of population dynamics at all trophic levels (Dulvy et al., 2014). Chondrichthyes have slow life histories, long generation times, and low fecundity, because of which populations present a slow growth rate (Cortés, 2000; Stevens, 2000; García et al., 2008; Hutchings et al., 2012). Consequently, the population abundance of such species is less than that of lower trophic level organisms (Hutchings et al., 2012) and are extremely vulnerable to fishing pressure (Stevens, 2000). Incidental and targeted catch due to a growing demand for chondrichthyan products over the past few decades has increased fishing pressure and overexploitation of many species (Dulvy et al., 2014, 2017; Jabado et al., 2017, 2018; FAO, 2021). As a result, chondrichthyan populations have had significant declines, with some species showing declines of up to 90% (Jabado et al., 2017) and pushed to the brink of extinction. As such, an estimated 18% of chondrichthyan species are categorized as Critically Endangered, Endangered, or Vulnerable by IUCN (FAO, 2019, 2020). The decrease in abundance of Chondrichthyes as apex predators has led to damaging direct and indirect effects on oceanic ecosystems around the world (Bornatowski et al., 2014; Johri et al., 2019).

Globally, the decline of teleost fisheries in combination with technological advances in fishing methods have made elasmobranchs an attractive alternative resource for food and revenue (Lack and Sant, 2011; Dent and Clarke, 2015). Paradoxically, there is marginal investment in the management of elasmobranch stocks due to the presumably small proportion of elasmobranchs caught in fisheries and limited understanding of the ecology, distribution, and population health of the species (Rose, 1998; Castro et al., 1999; Musick et al., 2000; Barker and Schluessel, 2005; Dent and Clarke, 2015). A significant portion of elasmobranch landings are non-targeted fisheries catch and as a result, are often discarded, recorded as bycatch or unidentified shark/ray species, or not recorded at all (Barker and Schluessel, 2005). As a consequence elasmobranch landings are often underreported, making estimates of global catches difficult and inaccurate (Lack and Sant, 2011). A recent estimate places the actual number of catches as double that of the recorded value (Barker and Schluessel, 2005). Further, a majority of shark fishing nations do not report species composition of their catch to the World Food and Agriculture Organization of the United Nations (FAO) (Lack and Sant, 2011; Karnad et al., 2020), restricting assessments of stocks or fishing pressure on specific species and populations. The highly migratory nature of many chondrichthyan species places them in international territories, making country specific protections, when existent, only partially effective (Stevens, 2000). Additionally, national or international regulations protecting migratory species are difficult to enact when information on species distributions are limited or non-existent, as in the case of many Chondrichthyes (Dulvy et al., 2014, 2017). As a result of the many shortfalls in accountability listed above, chondrichthyan stocks are being depleted at a rampant rate while management policies are scarcely implemented or are often too inadequate to be effective. The absence of accurate and comprehensive datasets, management, and political will are significant barriers impeding the design and implementation of conservation measures for Chondrichthyes. This is reflected by the fact that only 13 of the 20 major shark fishing nations worldwide have developed a National Plan of Action for sharks (NPOA), and its implementation is extremely variable in each of the 13 nations with NPOAs (Bräutigam et al., 2020).

The Arabian Seas Region (ASR), bordered by 20 nations, is regarded as a global hotspot for marine biodiversity (Stein et al., 2018) and provides habitat for ∼15% of all chondrichthyan species (Jabado et al., 2017). While the ASR is prolific in fish resources, it is also one of the most over-exploited marine environments globally (Jabado and Spaet, 2017; Jabado et al., 2018). Several teleost species in the ASR have been over—exploited in the last two decades causing extreme threats to the teleost fisheries, with reported declines of 40–80% (FAO, 2007). At the same time demand for Chondrichthyes is growing primarily due to their high economic value in the fin trade and more recently, to suffice issues of food security through provision of animal protein from shark and ray meat (Lack and Sant, 2011; Dent and Clarke, 2015). Both targeted and incidental catches of elasmobranchs are being tapped to supply this demand (FAO, 2007; Henderson et al., 2016). The ASR is recognized for having the largest number of chondrichthyan fishers and traders in the world (Dent and Clarke, 2015; Dulvy et al., 2017; Jabado and Spaet, 2017). Within this region the top fishing nations are India, Iran, Pakistan, Oman, Yemen, Somalia, and Sri Lanka, respectively (Dent and Clarke, 2015; Jabado and Spaet, 2017). Regional reported landings of chondrichthyans in 2015 represented 9.62% of global landings, despite seven countries in the region not reporting their chondrichthyan catches (FAO, 2017). Despite the extreme pressures on fisheries and population declines of up to 90% in some elasmobranchs (Jabado et al., 2017, 2018), understanding of the extent of declines at the species level and the contributing factors remains poor. These knowledge gaps stem from the fact that approximately 19% of elasmobranch species in the ASR are data deficient (DD) (Dulvy et al., 2014).

India, the largest shark fishing nation in the ASR and second largest in the world (Dent and Clarke, 2015), contributes 74,000 metric tons of an estimated 831,460 metric tons of global chondrichthyan exports annually (FAO Yearbook, 2020). Chondrichthyan exports from India thus account for ∼ 9% of global and ∼ 93% of ASR exports of the species. While the FAO reports a 20% decline in global recorded landings of sharks and rays since 2003 (FAO, 2021), India has seen 20–60% declines in landings despite a simultaneous doubling of trawling effort during the same time period (Raje and Zacharia, 2009; Kizhakudan et al., 2015). Batoid landings in India have fared even worse with declines of up to 86% (Raje and Zacharia, 2009; Kyne et al., 2020b). The reduction in catch per unit effort (CPUE) has led to intensification of mechanized fishing efforts into off shore waters, further jeopardizing chondrichthyan populations previously protected from commercial fishing (Raje and Zacharia, 2009; Mohamed and Shettigar, 2016; Jabado and Spaet, 2017). Overexploitation in Indian fisheries has pushed 55% of its elasmobranch species to the brink of extinction with 3% categorized as Critically Endangered (CE), 5% as Endangered (EN), 26% as Vulnerable (VU), and 21% as Near Threatened (NT). In addition, 37% are data-deficient (DD) or not evaluated (Akhilesh et al., 2014).

The significantly high levels of threat and data deficiency in Chondrichthyes in India are a consequence of almost non-existent management measures for the species, and poor enforcement of existing measures at the state and national levels (Karnad et al., 2020). Chondrichthyan stock assessments remain absent, and as a result, catch limits on chondrichthyan landings are only imposed for species protected under Schedule I of the Wild Life (Protection) Act (1972) which includes the Whale shark *Rhincodon typus*, Pondicherry shark *Carcharhinus hemiodon*, and Giant guitarfish *Rhynchobatus djiddensis* (FAO, 2007; Karnad et al., 2020). Species-specific protections have repeatedly proven inadequate with the exception of whale sharks (Jabado et al., 2018; Karnad et al., 2020). India is the largest contributor to global seafood supplies and millions of fishermen livelihoods in India depend on commercial fisheries (Kizhakudan et al., 2015). The current rate of unsustainable shark fisheries in India is likely to cause further declines in commercial fisheries due to trophic effects. The lack of fisheries regulation in the Indian sub-continent, therefore not only threatens the diversity of Chondrichthyes, but could disrupt global food supply chains and diminish India's national GDP (Jabado et al., 2017). India is ranked as the number one country, with the greatest need for conservation of sharks and rays, among the 20 largest shark fishing nations of the world (Dulvy et al., 2017).

The state of Gujarat, which accounts for 26% of fisheries landings (FAO, 2007) and 40% of all chondrichthyan landings (Kizhakudan et al., 2015) in India, has suffered significant declines in CPUE (Kizhakudan et al., 2015) and we have prioritized this region for our assessment. Gujarat comprises 1/5th of India's total coastline, the longest in the country, and supports habitats such as mangroves, salt marshes, coral reefs, and seagrasses (Raje et al., 2007; Worldbank, 2020). A significant portion of Gujarat's continental shelf area falls in the depth range of 0–50 m and supports commercially important species found at shallow depths including *Carcharhinus limbatus, Carcharhinus falciformis, Rhizoprionodon acutus, Rhizoprionodon oligolinx,* and *Sphyrna lewini* (Devadoss et al., 1989; Spaet and Berumen, 2015). Gujarat's state economy relies heavily on fishing and comprises 15% of the total export economy of India (Devadoss et al., 1989). Despite a strong reliance of state and national economies on fisheries in Gujarat, it is lacking in adequate fisheries assessments by national or state agencies and is ranked 4th by the FAO among regions with the greatest need for research and conservation of Chondrichthyes (Dulvy et al., 2017; Nagle, 2019). The lack of scientific investigations of fisheries in Gujarat, suggest a lack of stock assessments and a subsequent lack of management measures to protect Chondrichthyes. Consequently, further declines in commercial fisheries can be expected with a potentially catastrophic effect on the state and national GDP, fishermen livelihoods and global seafood supply chain.

Gujarat's significant contribution to Indian and global fisheries and its extreme paucity of chondrichthyan biodiversity assessments call for an urgent inquiry into chondrichthyan species distributions, ecology, and fishing practices in the area. Although excessive stretches of shallow coastal areas intermixed with mangrove and seagrass habitats along the coast of Gujarat are likely favorable habitats for juvenile sharks and rays (Spaet et al., 2012), local nursery areas remain unidentified within the region. A high number of recorded landings identified as immature elasmobranchs from the neighboring Red Sea region, suggest that juveniles are at a higher risk from fishing in the ASR (Spaet and Berumen, 2015), including in Gujarat. Because some species aggregate by age, sex, or reproductive state, their population numbers could be more vulnerable to fishing pressure than others (Barker and Schluessel, 2005), and habitats harboring these species, if present in Gujarat, should be identified and protected expediently. To address the knowledge gaps described here, we designed a fisheries dependent survey to assess elasmobranch biodiversity and fisheries in Gujarat. We hypothesized that fisher communities in Gujarat encounter a rich biodiversity of elasmobranchs as targeted or incidental catch, and that a survey of the fisheries will provide a proxy measure of elasmobranchs biodiversity and distribution, as well as fisheries' catch composition in the area. We focused our studies in ports known to be the primary fishing and export hubs for elasmobranchs in Gujarat.

In the current report, we present assessments of seasonal elasmobranchs biodiversity obtained via fisheries dependent surveys at four major landing ports in Gujarat. Elasmobranch specimens were photographed at landing sites, fish markets and salting factories at the port cities of Veraval, Mangrol, Porbandar, and Okha in Gujarat. We report the identification and occurrence of 31 elasmobranchs species in Gujarat, including six data deficient species and three species reported for the first time in the region. In the current report, we therefore provide the first expansive assessment of elasmobranchs and their vulnerability to fisheries in Gujarat.

MATERIALS AND METHODS

Sampling

Four primary areas along the western coast of Gujarat, India - Veraval (20.9159° N, 70.3629° E), Mangrol (21.1172° N, 70.1158° E), Porbandar (21.6417° N, 69.6293° E), and Okha (22.4649° N, 69.0702° E) (**Figure 1**), were chosen as sites for sample collection due to their high volume of elasmobranch landings. Landing sites, fish markets, and salting factories were surveyed by a single researcher at Veraval (26 days), Mangrol (3 days), Porbandar (3 days), and Okha (6 days), for a total of 38 days over 5 months (April, May, August 2017, and March–May 2018) in 2017–2018. The number of sampling days in Veraval was highest due to increased sampling accessibility in markets facilitated by established relationships of the fisher communities with the

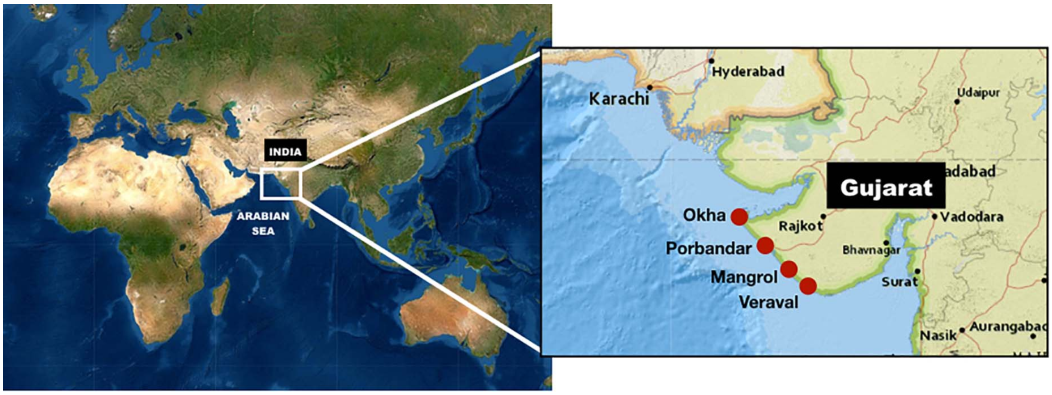

FIGURE 1 | Sampling sites located along the western coast of Gujarat, India. The four sampling locations -Okha, Veraval, Mangrol, and Porbandar – were selected due to the high volume of elasmobranch landings reported previously in the region.

College of Fisheries located in Veraval. Each day the researcher would enter the market, talk with fishers, and ask about the elasmobranchs that were caught, and each specimen would be photographed, including close-up photos of the head, mouth, eyes vulva/claspers, and body of the complete or dismembered elasmobranch specimen. Tissue samples were taken for genomic sequencing using methods described in Johri et al. (2019).

Morphological Identification

Photographic identification of each specimen was conducted following protocols described in Ebert et al. (2013) and Last et al. (2018). For each sample, photographs were uploaded to the species identification database iNaturalist[1], where expert observers in the field assigned research-grade identifications for our samples, in parallel to our own taxonomic identification.

Genomic and Phylogenetic Analyses

Genomic sequencing and phylogenetic assessment of select specimens was conducted following methods described by us previously in Johri et al. (2019, 2020a,b,c).

We searched for and downloaded relevant sequences from GenBank which are detailed in **Supplementary Table 1** and aligned them using MUSCLE v.3.8.31 (Edgar, 2004). We constructed five alignments: one for the COI gene for genus *Rhinobatos* using *Glaucostegus formosensis* and *Acroteriobatus annulatus* as outgroups, two for genus *Torpedo* for COI and ND2 separately using *Narcine brasiliensis* and *Narcine bancroftii* as outgroups, one for the mitochondrial genome for the genera *Mobula* using *Rhinoptera steindachneri* as an outgroup, and one for the mitochondrial genome for genus *Carcharhinus* (inclusive of *Prionace glauca*) using *Galeocerdo cuvier* as an outgroup. We used the PartitionFinder2 v2.1.1 tool (Lanfear et al., 2016) on CIPRES (Miller et al., 2010) to assess partitioning schemes. We used best-fitting partitioning schemes identified by PartitionFinder2 to generate phylogenies in RAxML v8.2.12 (Stamatakis, 2014) and MrBayes v3.2.7a (Ronquist et al., 2012) on CIPRES. All RAxML runs used four starting trees, GTRGAMMA models for all partitions, and generated 1000 bootstrap replicates. All MrBayes runs were run in triplicate and used GTR + 4Γ models for all partitions and ran for 1,000,000,000 MCMC steps. Convergence of MrBayes runs was assessed by eye in Tracer v1.7.1 (Rambaut et al., 2018).

[1]iNaturalist: https://www.inaturalist.org (accessed March, 2021).

Maturity and Sex Determination

Sex was determined by assessing the presence of claspers or vulva for each intact specimen.

Morphological measurements -Total length (TL) for sharks, and TL or Disc Width (DW) for batoids, weight measurements (collected when available), and the presence of calcification of claspers in males and young or eggs in females' uterus were used to identify maturity for each specimen. Specimens that were less than the gender specific measurements at maturity described for each species in the literature (Ebert et al., 2013; Last et al., 2018; Froese and Pauly, 2020; IUCN Red List, 2021; Pollerspöck and Straube, 2021; referenced in **Table 1**) were considered to be immature. Similarly, specimens greater than the gender specific measurements at maturity and showing hardened claspers and presence of young or eggs were assessed as mature.

For *Pateobatis bleekeri*, DW at maturity was unavailable, and hence, maturity for the specimen could not be determined. Similarly, for *Glaucostegus granulatus*, species specific information on TL at maturity was unavailable. We therefore based our assessment of maturity on other taxa in the Glaucostegidae or Giant Guitarfish family (Last et al., 2018) and followed specifications for Rhinidae/Glaucostegidae maturity assessments (Rhinidae – IUCN Red List).

Conservation Status

Conservation status of species was determined using the International Union for Conservation of Nature (IUCN) (IUCN Red List, 2021) to assess the impact of fisheries in Gujarat on priority concern species. Conservation categories defined by IUCN were used and include Critically Endangered (CE), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data deficient (DD).

TABLE 1 | Total Length (TL) or Disc Width (DW) (cm) threshold used to determine maturity for each species are listed below.

Species	Reference species TL or DW at maturity (cm)	References for TL/DW at maturity
Carcharhinus amboinensis	198–223 TL	https://www.fishbase.se/summary/Carcharhinus-amboinensis.html
Carcharhinus brevipinna	170–266 TL	https://www.fishbase.se/summary/Carcharhinus-brevipinna
Carcharhinus falciformis	202–260 TL	https://www.fishbase.de/summary/Carcharhinus-falciformis.html
Carcharhinus leucas	180–230 TL	https://www.fishbase.se/summary/carcharhinus-leucas.html
Carcharhinus limbatus	120–194 TL	https://www.fishbase.se/summary/Carcharhinus-limbatus.html
Carcharhinus macloti	70–89 TL	https://www.fishbase.se/summary/Carcharhinus-macloti
Carcharhinus sorrah	130 TL	https://www.fishbase.se/summary/Carcharhinus-sorrah
Rhizoprionodon acutus	70–80 TL	https://www.fishbase.se/summary/899
Rhizoprionodon oligolinx	32–65 TL	https://www.fishbase.se/summary/902
Scoliodon laticaudus	33–35	https://www.fishbase.se/summary/Scoliodon-laticaudus
Sphyrna lewini	140–273	https://www.fishbase.se/summary/912
Lago omanensis	55.7 TL	https://www.fishbase.se/summary/5929
Alopias pelagicus	260–292 TL	https://www.fishbase.se/summary/5891
Chiloscyllium arabicum	45–54 TL	https://www.fishbase.se/summary/Chiloscyllium-arabicum.html
Aetobatus flagellum	50–74.6 DW	https://www.shark-references.com/species/view/Aetobatus-flagellum
Aetobatus ocellatus	150–160 DW	https://www.fishbase.de/summary/12600
Brevitrygon walga	16.7 DW	https://www.fishbase.de/summary/15484
Himantura leoparda	70–80 DW	https://www.fishbase.de/summary/Himantura-leoparda.html
Himantura uarnak	82–84 DW	https://www.fishbase.se/summary/Himantura-uarnak
Maculabatis bineeshi	>51–66 DW	https://doi.org/10.11646/zootaxa.4144.3.3
Maculabatis gerrardi	64–? DW	https://www.fishbase.se/summary/15483
Pateobatis bleekeri	range?–? DW	https://www.fishbase.de/summary/13148
Pteroplatytrygon violacea	40–50 DW	https://www.fishbase.de/summary/pteroplatytrygon-violacea.html
Mobula mobular	200–220 DW	https://www.iucnredlist.org/species/110847130/110847142
Mobula tarapacana	198–250 DW	https://www.iucnredlist.org/species/60199/124451161
Glaucostegus granulatus	?–280 TL	https://www.iucnredlist.org/species/pdf/2382420/attachment#:$\sim$:text=
Rhynchobatus laevis	∼130 TL	https://shark-references.com/species/view/Rhynchobatus-laevis
Rhinobatos annandalei	60–65 TL	http://eprints.cmfri.org.in/14336/1/IJF_2020_G%20B%20Purushottama_Biological%20observations%20on%20the%20Bengal%20guitarfish%20Rhinobatos%20annandalei.pdf
Rhinobatos punctifer	<71–77 TL	https://www.iucnredlist.org/species/161447/109904426#habitat-ecology
Rhinoptera jayakari	?–78 DW	https://www.fishbase.se/summary/27176
Torpedo sinuspersici	30–?	https://www.fishbase.se/summary/Torpedo-sinuspersici.html

Distribution

The occurrence for each species at sampling locations was assessed to determine differences in species distribution across sampling sites. Range extensions were discovered by comparing the location of specimen landing site with geographic ranges previously reported for respective species on the IUCN Red List database (IUCN Red List, 2019).

We obtained depth ranges where species normally occur from the IUCN and FishBase databases (IUCN Red List, 2019; FishBase, 2020). We divided depth ranges into four categories by adopting the classical subdivision which considers 200 m of depth as a limit of the continental shelf, and considering that species which populate the continental shelf and beginning of the continental slope could be very different. The four depth categories are: 0–200 m, 201–600 m, >600 m, or no available information. We binned the species of sharks and rays' samples into the depth categories listed above, based on published information about the species.

RESULTS

Species Identification

The surveys conducted at four fish markets and landing sites within Gujarat state (**Figure 1**) culminated in ∼1000 photographs of elasmobranchs. A total of 157 elasmobranchs were sampled opportunistically, including species from the superorder Selachimorpha (sharks) and Batoidea (rays). Within the superorder Selachimorpha, we identified fourteen species comprising three orders, five families, and seven genera (**Table 2** and **Figure 2**), while within the superorder Batoidea we identified seventeen species, comprising four orders, eight families, and twelve genera (**Table 2** and **Figures 3**, **4**). Additional specimen photographs and research grade identifications for each specimen can be found at iNaturalist: https://www.inaturalist.org/observations?place_id=any&subview=grid&user_id=shaili&verifiable=any&view=species. Note that 71 specimens for which taxonomic identities remained unknown are not included in **Table 2**.

TABLE 2 | Information about taxonomy, number of specimens, collection site, gender, maturity, TL/DW (cm) for mature and immature specimens, and binned depth range (in meters) for each species sampled.

Superorder	Order	Family	Genus	Species	Common name	Conservation status	No. of samples	Veraval	Mangrol	Porbandar	Okha	Males	Females	Young	TL or DW (cm)	Mature adults	TL or DW (cm)	Reference species TL/DW range at Maturity (cm)	Binned depth range (m)
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus amboinensis*	Pigeye Shark	Data Deficient	2	0	0	0	2	1	1	1	84	1	208	198–223	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus brevipinna*	Spinner Shark	Near Threatened	1	0	0	1	0	0	1	0		1	Approximate 193–241, pregnant female	170–266	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus falciformis*	Silky Shark	Vulnerable	2	1	0	0	1	0	2	1	84	0		202–260	201–600
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus leucas*	Bull Shark	Near Threatened	1	0	0	0	1	0	1	1	90	0		180–230	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus limbatus*	Common Blacktip Shark	Near Threatened	2	2	0	0	0	1	1	2	68.58–100	0		120–194	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus macloti*	Hardnose Shark	Near Threatened	3	1	0	1	1	0	2	0		2	70–76	70–89	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Carcharhinus*	*Carcharhinus sorrah*	Spot tail shark	Near Threatened	4	2	0	2	0	2	2	4	58–100	0		130, range ?–?	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*	*Rhizoprionodon acutus*	Milk Shark	Least Concern	2	1	0	1	0	1	1	1	60	1	81.28	70–80	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Rhizoprionodon*	*Rhizoprionodon oligolinx*	Gray Sharpnose Shark	Least Concern	5	3	1	0	1	2	3	1	18	2	32–80	32–65	0–200
Selachimorpha	Carcharhiniformes	Carcharhinidae	*Scoliodon*	*Scoliodon laticaudus*	Spadenose Shark	Near Threatened	11	9	1	0	1	2	9	1	25	10	30–53.34	33–35	0–200
Selachimorpha	Carcharhiniformes	Sphyrnidae	*Sphyrna*	*Sphyrna lewini*	Scalloped Hammerhead	Endangered	5	4	0	1	0	2	3	5	50–66.04	0		140–273	0–275
Selachimorpha	Carcharhiniformes	Triakidae	*Lago*	*Lago omanensis*	Bigeye Houndshark	Least Concern	4	2	1	1	0	0	4	2	34	2	45–64	55.7, range ?–?	>600
Selachimorpha	Lamniformes	Alopiidae	*Alopias*	*Alopias pelagicus*	Pelagic Thresher Shark	Vulnerable	3	0	0	0	3	2	1	2	204–220	1	300	260–292	0–200
Selachimorpha	Orectolobiformes	Hemiscylliidae	*Chiloscyllium*	*Chiloscyllium arabicum*	Arabian Carpet Shark	Near Threatened	2	1	0	0	1	1	1	1	43	1	60	45–54	0–200
Batoidea	Myliobatiformes	Aetobatidae	*Aetobatus*	*Aetobatus flagellum*	Longheaded Eagle Ray	Endangered	1	1	0	0	0	0	1	0		1	76.2	50–74.6	No information
Batoidea	Myliobatiformes	Aetobatidae	*Aetobatus*	*Aetobatus ocellatus*	Whitespotted Eagle Ray	Vulnerable	3	1	0	0	2	2	1	2	32–40	1	170	150–160	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Brevitrygon*	*Brevitrygon walga*	Arabian Dwarf Whipray	Near Threatened	7	4	1	1	1	5	1	1	15	4	16.5–21.34	16.7, range?–?	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Himantura*	*Himantura leoparda*	Leopard Whipray	Vulnerable	1	1	0	0	0	0	1	1	58	0		70–80	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Himantura*	*Himantura uarnak*	Reticulate Whipray	Vulnerable	2	1	0	0	1	1	1	1	30	0		82–84	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Maculabatis*	*Maculabatis bineeshi*	Shorttail Whipray	Data Deficient	5	5	0	0	0	2	0	2	33–40 DW	0		>51–66 DW	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Maculabatis*	*Maculabatis gerrardi*	Whitespotted Whipray	Vulnerable	1	1	0	0	0	1	0	0		0		range 64–?	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Pateobatis*	*Pateobatis bleekeri*	Bleeker's Whipray	Data Deficient	1	1	0	0	0	0	1	0		0		range?–?	0–200
Batoidea	Myliobatiformes	Dasyatidae	*Pteroplatytrygon*	*Pteroplatytrygon violacea*	Pelagic Stingray	Least Concern	2	2	0	0	0	2	0	1	34 DW	1	40 DW	40–50	201–600
Batoidea	Rajiformes	Mobulidae	*Mobula*	*Mobula mobular*	Spinetail Devil Ray	Endangered	1	0	0	0	1	1	0	1	110 TL, 193 DW	0		200–220 DW	>600
Batoidea	Rajiformes	Mobulidae	*Mobula*	*Mobula tarapacana*	Sicklefin Devil Ray	Vulnerable	1	0	0	0	1	1	0	0		1	140 TL, 240 DW	198–250 DW	>600
Batoidea	Rhinopristiformes	Glaucostegidae	*Glaucostegus*	*Glaucostegus granulatus*	Granulated Guitarfish	Critically Endangered	2	1	0	0	1	0	2	2	≤120	0		?–280	0–200
Batoidea	Rhinopristiformes	Rhinidae	*Rhynchobatus*	*Rhynchobatus laevis*	Smoothnose Wedgefish	Critically Endangered	8	7	0	1	0	1	7	6	50.8–111.76	1	150	∼130	0–200
Batoidea	Rhinopristiformes	Rhinobatidae	*Rhinobatos*	*Rhinobatos annandalei*	Annandale's Guitarfish	Data Deficient	3	2	0	1	0	0	3	2	36–43	1	62	60–65	0–200
Batoidea	Rhinopristiformes	Rhinobatidae	*Rhinobatos*	*Rhinobatos punctifer*	Spotted Guitarfish	Near Threatened	4	2	0	1	1	1	3	3	54–71	1	85	<71–<77	0–200
Batoidea	Rhinopristiformes	Rhinopteridae	*Rhinoptera*	*Rhinoptera jayakari*	Oman Cownose Ray	Data Deficient	1	1	0	0	0	1	0	1	31.75 DW	0		?–78 DW	No information
Batoidea	Torpediniformes	Torpedinidae	*Torpedo*	*Torpedo sinuspersici*	Variable Torpedo Ray	Data Deficient	1	0	0	1	0	1	0	0		1	30	30–?	0–200

FIGURE 2 | Representative pictures of species sampled in the superorder Selachimorpha. **(A)** *Chiloscyllium arabicum* (Arabian carpetshark), **(B)** *Iago omanensis* (Bigeye houndshark), **(C)** *Carcharhinus leucas* (Bull shark), **(D)** *Carcharhinus limbatus* (Common Blacktip shark), **(E)** *Rhizoprionodon oligolinx* (Gray Sharpnose shark), **(F)** *Carcharhinus macloti* (Hardnose shark), **(G)** *Rhizoprionodon acutus* (Milk shark), **(H)** *Alopias pelagicus* (Pelagic Thresher shark), **(I)** *Carcharhinus amboinensis* (Pigeye shark), **(J)** *Sphyrna lewini* (Scalloped Hammerhead), **(K)** *Carcharhinus falciformis* (Silky shark), **(L)** *Scoliodon laticaudus* (Spadenose shark), **(M)** *Carcharhinus brevipinna* (Spinner shark), and **(N)** *Carcharhinus sorrah* (Spottail shark).

Taxonomic identity of specimens from five species were confirmed by sequencing and phylogenetic analyses in the current study. Phylogenetic analyses of the species are presented in **Supplementary Figure 1** and the sequence data are available on GenBank using the listed accession numbers. We constructed four gene trees, one for each of the following genera of elasmobranchs: (1) 13 of 22 *Rhinobatos* species, (2) seven of 25 *Torpedo* species, (3) all 12 *Mobula* and *Manta* species, and (4) 14 of 34 *Carcharhinus* species. All Bayesian inference (BI) phylogenies converged within 1 billion steps. SRA Accession # SRR13587043 was placed within the *Rhinobatos* tree with 100/100 bootstrap support for *Rhinobatos punctifer* (**Supplementary Figure 1A**). SRA Accession # SRR13660201 was placed within *Torpedo* ML or BI trees, but relationship of our contig to any other known taxon was not resolved with high confidence and extremely short branch lengths occurred throughout the tree (**Supplementary Figure 1B**). SRA Accession # SRR13587044 was confidently placed with high confidence in both BI and ML *Carcharhinus* trees and identified as *Carcharhinus sorrah* (**Supplementary Figure 1C**). SRA Accession # SRR13587041 and SRA Accession # SRR13587042 were confidently placed in the *Mobula/Manta* trees identified as *Mobula japanica* + *Mobula mobular* and *Mobula tarapacana*, respectively (**Supplementary Figure 1D**).

There were differences in distribution of species across the four sampling locations. *Scoliodon laticaudus* was the most frequently sampled species (n = 11) among sharks and *Rhynchobatus laevis* was the most frequently sampled batoid (n = 8) (**Supplementary Figure 2A**). *Alopias pelagicus, Carcharhinus amboinensis*, *Carcharhinus leucas*, *M. mobular,* and *M. tarapacana*, were sampled only in Okha (**Supplementary Figure 2A**). *Carcharhinus brevipinna* and *Torpedo sinuspersici* were sampled only in Porbandar (**Supplementary Figure 2A**), whereas the *Carcharhinus limbatus*, *Aetobatus flagellum*, *Pteroplatytrygon violacea*, *Himantura leoparda*, *Rhinoptera jayakari*, *Maculabatis gerrardi*, and *Pateobatis bleekeri* were sampled only in Veraval (**Supplementary Figure 2A**). The difference in species sampled at the four locations may indicate distinct ecology and distribution patterns of the respective species, as well as distinct habitats in this part of the Arabian Sea region.

Elasmobranch species were identified across all conservation categories in the four sampling locations in Gujarat. Of the 31 species identified in our study, 12 (38.7%) are in the threatened

FIGURE 3 | Representative pictures of species sampled in the superorder Batoidea. **(A)** *Brevitrygon walga* (Arabian Dwarf Whipray), **(B)** *Pateobatis bleekeri* (Bleeker's Whipray), **(C)** *Torpedo sinuspersici* (Variable Torpedo ray), **(D)** *Maculabatis gerrardi* (Whitespotted Whipray), **(E)** *Himantura leoparda* (Leopard Whipray), **(F)** *Aetobatus ocellatus* (Whitespotted Eagle ray), **(G)** *Mobula mobular* (Spinetail Devil ray), **(H)** *Mobula tarapacana* (Sicklefin Devil ray), **(I)** *Pteroplatytrygon violacea* (Pelagic Stingray), **(J)** *Aetobatus flagellum* (Longheaded Eagle ray), **(K)** *Rhinoptera jayakari* (Oman Cownose Ray), **(L)** *Himantura uarnak* (Reticulate Whipray), and **(M)** *Maculabatis bineeshi* (Short-tail Whipray).

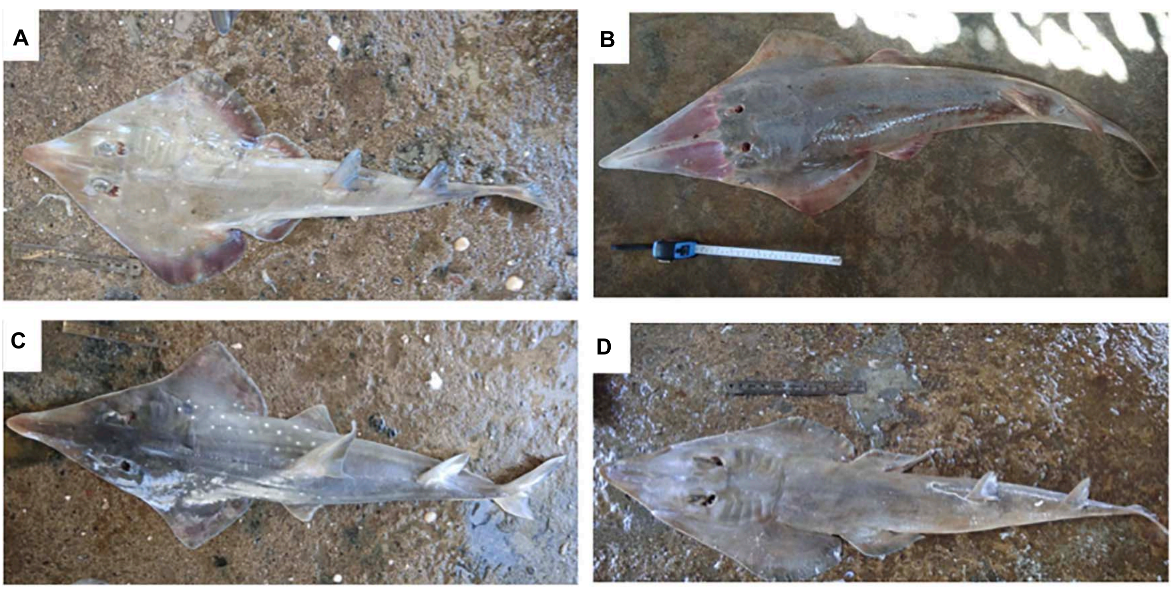

FIGURE 4 | Representative pictures of species sampled in the order Rhinopristiformes. **(A)** *Rhinobatos annandalei* (Annandale's guitarfish), **(B)** *Glaucostegus granulatus* (Granulated guitarfish), **(C)** *Rhynchobatus laevis* (Smoothnose wedgefish), and **(D)** *Rhinobatos punctifer* (Spotted guitarfish).

categories of CE, EN, and VU (**Table 2** and **Supplementary Figure 2B**), 9 (29%) are Near Threatened, 4 (13%) are Least concern and 6 (19%) are Data Deficient. A majority of shark species are in the Near Threatened category, whereas a majority of batoids sampled are either Threatened (CE, EN, VU) ($n = 9$) or Data deficient ($n = 5$) (**Table 2** and **Supplementary Figure 2B**).

Assessment of Gender, Maturity and Depth Distribution in Specimens

Of a total of 157 specimens, 127 samples were sufficiently intact for gender determination. Of these 127 samples, 63% were female ($n = 80$), and 37% were male ($n = 47$) (**Figure 5A**). There was a significant difference in the number of shark specimens that were female (68% or 48/71), compared to males (32% or 23/71) (**Figure 5B**, $p = 0.03$). For batoids, the difference was not significant with 57% or 32/55 female specimens and 43% or 23/55 male (**Figure 5B**). When gender ratios were compared across sampling locations, Veraval had a significantly higher proportion of female vs. male specimens ($p = 0.02$), whereas there was no significant difference between occurrence of male and female specimens at other locations (**Figure 5C**). Note that 41 specimens for which the taxonomic identities remained unknown, but gender was determined are included in the 127 male/female specimens. However these 41 specimens are not included in **Table 2**.

Morphological measurements were analyzed to determine the maturity of specimens. Of the 157 total specimens, sufficient data was available for 78 samples to determine maturity. Immature young comprised 58% ($n = 45$) of total specimens, while mature adults made up 42% ($n = 32$), as shown in **Figure 5D**. For all shark specimens with distinguishable life stages 51% ($n = 22$), were immature and 49% ($n = 21$) were mature adults (**Figure 5E**). Maturity was determined for 35 batoids of which, 65% were immature and 34% were mature adults ($n = 23$ and $n = 12$, respectively) (**Figure 5E**). There was no significant difference in the total number of mature vs. young specimens at the four sampling locations (**Figures 5E,F**).

For numerous species of sharks and batoids the gender ratio was skewed toward females. For instance, nine of eleven *S. laticaudus* ($p = 0.05$), seven of eight *R. laevis*, and all four *Iago omanensis* sampled were females (**Table 2** and **Figure 5G**). Whereas for species like *Brevitrygon walga* the ratio was skewed towards males, with five of six total specimens being male (**Table 2** and **Figure 5G**). Total distribution of males vs. females across all species had a significant difference ($p < 0.0001$, **Figure 5G**). Similarly, several species had a higher skew towards immature specimens including *Sphyrna lewini*, *C. sorrah*, *R. laevis,* and *R. punctifer* (**Table 2** and **Figure 5H**). Conversely for *S. laticaudus*, 10 specimens were mature adults and only one was immature (**Table 2**). The total number of mature vs. immature specimens across all species (except *S. laticaudus*) was significantly different ($p < 0.05$, **Figure 5H**).

For *Glaucostegus granulatus,* species specific information on TL at maturity was unavailable. However, both specimens in our collection were female at ≤120 cm TL and 2–4 kg in weight. Since mature females in closely related species such as *Glaucostegus typus* and *Glaucostegus cemiculus*, are expected to have TL > 150 cm at maturity (Last et al., 2018, Rhinidae – IUCN Red List), we assessed *G. granulatus* specimens in our collection to be at an immature life history stage.

In our depth assessments, 78% ($n = 24$) of sampled species inhabited a depth range of 0–200 m, three species were in the range of 201–600 m and three species were in the >600 m range (**Table 2** and **Supplementary Figure 3**). Coastal or neritic species found at 0–200 m were the most frequently sampled across all four locations (**Supplementary Figure 3**), suggesting that these species had a higher likelihood of capture in the sampled fisheries. For depth ranges between 0–200 m and 201–600 m, the frequency of shark and ray species was even, with 12 species each of sharks and rays at 0–200 m and 1 each at 201–600 m. At >600 m depth only one shark (*I. omanensis*) and two ray species (*M. mobular* and *M. tarapacana*) were found (**Table 2**). For the species *A. flagellum* and *R. jayakari* no depth information is available.

Geographic Range Extensions and Verifications

The high rate of data deficiencies and aggregated, non-species specific assessments among Chondrichthyes (Dulvy et al., 2014) mean that geographic ranges are not accurately documented for many elasmobranch species. Our sampling of fisheries, which catch mainly coastal elasmobranch species via targeted or incidental means, provided an opportunity to investigate the current geographic range of sampled coastal specimens. Of the 31 species, three were found at landing sites located outside of their previously reported ranges which are based on landing data (Dent and Clarke, 2015; IUCN Red List, 2020b; Park University, 2020). *C. sorrah* is listed as extant along the southwestern and eastern coast of India, in addition to its global distribution, as shown in **Supplementary Figure 4A**. We report four sightings of this species along the northwestern coast of India, specifically in Veraval ($n = 2$) and Porbandar ($n = 2$) (**Supplementary Figure 4A**), and taxonomic identity of these specimens was confirmed at species level through phylogenetic (**Supplementary Figure 1C**) and morphological assessments (**Figure 2N**). *T. sinuspersici* was reported to be found along the eastern coast of Africa, and Saudi Arabia based on landings data, and has not been reported in India previously (Jabado and Spaet, 2017; Kyne, 2019). We report its presence for the first time in Porbandar ($n = 1$), Gujarat, northwestern India, as shown in **Supplementary Figure 4B** and confirmed its taxonomic identity at the genus level phylogenetically (**Supplementary Figure 1B**) and at the species level morphologically (**Figure 3C**). A third species, *R. punctifer*, is known to be extant in the Arabian Seas Region from the northern Red Sea to the Sea of Oman (Ebert et al., 2017). Ours is the first study to report four specimens of the species landed in India, specifically, at the ports of Veraval ($n = 2$), Porbandar ($n = 1$), and Okha ($n = 1$) (**Supplementary Figure 4C**). The taxonomic identification of the specimens was confirmed to the species level through phylogenetic (**Supplementary Figure 1A**) and morphological assessments (**Figure 4D**).

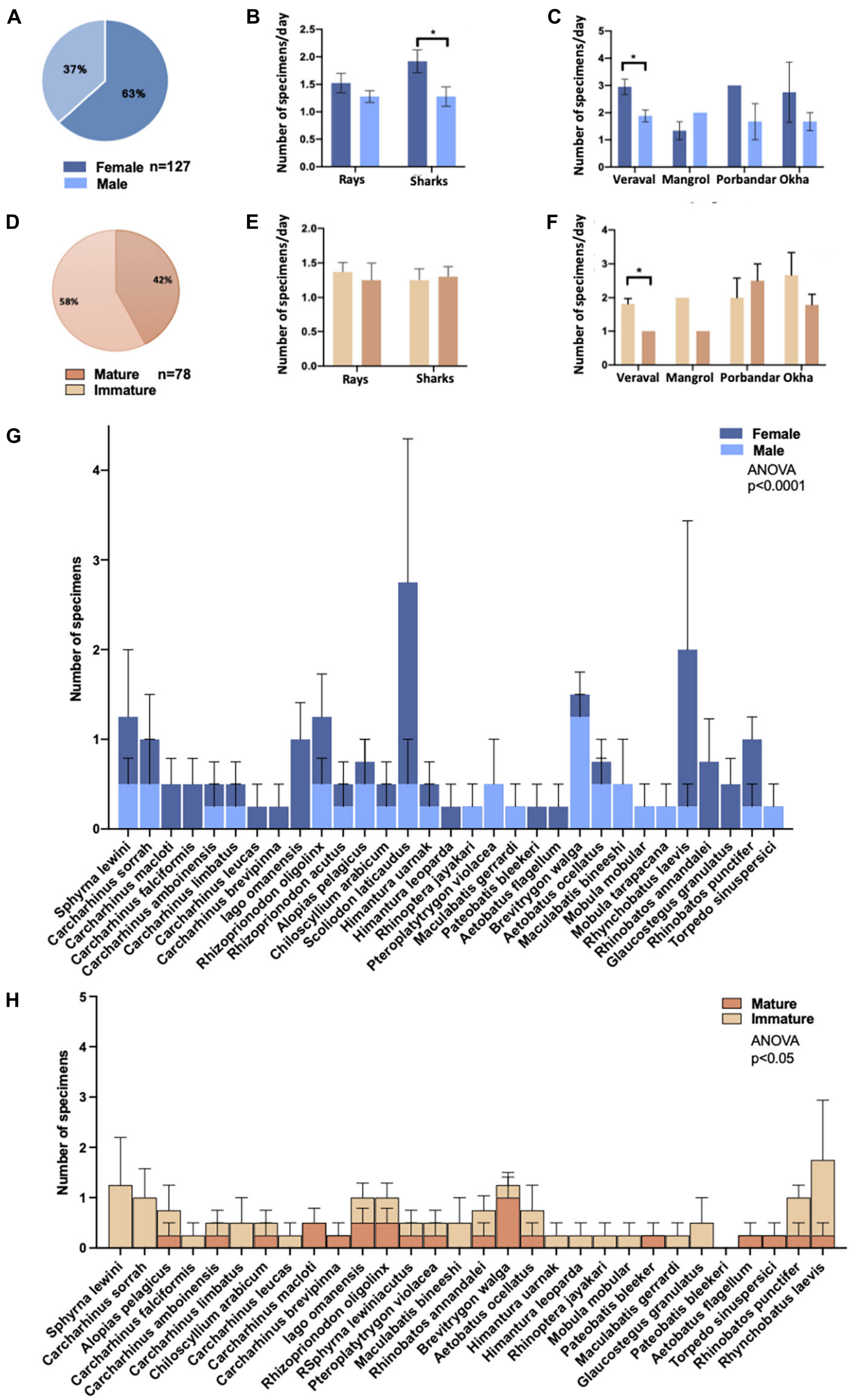

FIGURE 5 | Frequency distribution of sharks and the rays by sex and maturity across sampling locations. Sex determination of **(A)** all samples (n = 117) in which determination could be made, including samples with no species identification, **(B)** by shark and ray specimens, and **(C)** by sampling location. A comparison of the ratio of young to mature adults **(D)** among all specimens (n = 77), **(E)** between sharks and rays, and **(F)** between sampling locations. Comparison of male and female specimens in all species in **(G)** and comparison of mature and immature specimens of each species except *Scoliodon laticaudus* in **(H)**. Two-way ANOVA with multiple comparisons between the respective groups was performed in **(B,C,E–H)**. Asterisk * denotes a significant difference ($p \leq 0.05$) and *** denotes a highly significant difference ($p \leq 0.0005$) between groups. We compared total population distribution of males vs. females in **(G)** and mature vs. immature specimens in **(H)**. Distribution of males vs. females and of mature vs. immature individuals was significantly different as indicated by respective p values. *S. laticaudus* was identified as an outlier and removed from analyses in **(H)**.

DISCUSSION

Systematic evaluation of the distribution, population health and threats adversely affecting Chondrichthyes is vital to drive the management and conservation of remaining populations and limit extinctions in the Arabian Seas Region. Here we have conducted an elasmobranch biodiversity assessment in Gujarat, India, one of the most prolific fishing region in the ASR. Our assessment identified 31 species of elasmobranchs from 157 specimens collected in just 38 days. The survey complements global and regional (Jabado et al., 2017; FAO, 2019) efforts at chondrichthyan status assessments and the very few scientific investigations into elasmobranch biodiversity, distribution, and fisheries in India (Raje and Zacharia, 2009; Akhilesh et al., 2014; Bineesh et al., 2017; Jabado et al., 2018; Kumar et al., 2018; Pradeep et al., 2018), and Gujarat (Sutaria et al., 2015; Johri et al., 2019, 2020b,c). Among the elasmobranch species sampled in our study ∼39% are in the ICUN Threatened categories and ∼20% in the data deficient category. We demonstrate that Gujarat is a biodiverse elasmobranch habitat and the fishery is exploiting (via targeted and incidental catch) ecologically important species at an alarming rate. We also alleviate the data deficiency of elasmobranchs (Dulvy et al., 2014; Jabado et al., 2017) by extension and confirmation of the geographic range of species and by documenting the catch of 31 different species with skewed gender and age ratios in the catch.

Our sequencing and phylogenetic analyses in the current study corroborates the taxonomic classification of five species (*R. punctifer*, *T. sinuspersici*, *C. sorrah*, *M. mobular,* and the *M. tarapacana*) in the sample set. Taxonomic identifications for *Carcharhinus falciformis* (Johri et al., 2019), *Rhynchobatus laevis* (Johri et al., 2020c), and *Glaucostegus granulatus* (Johri et al., 2020b) were confirmed previously by us. It should be noted that the low posterior probabilities or bootstrap support values in case of *T. sinuspersici*, Bayesian and maximum likelihood analyses are due to the lack of enough genetic data available for this clade of species in public databases. This again highlights the data deficiency with respect to genomic information on elasmobranchs and our current work is aimed at reducing these knowledge gaps.

A significantly high number of female and juvenile elasmobranchs are being captured by fisheries in Gujarat, suggesting the presence of a previously unknown nursery ground in coastal waters off Gujarat. *S. lewini, R. laevis, C. sorrah, Rhinobatos annandalei,* and *Aetobatus ocellatus* specimens were almost exclusively females (16 out of 26) and juveniles (21 out of 25). In Veraval, nearly all landings were females and juveniles. In addition, species found at shallow depths of 0–200 m were abundantly landed at all locations, with the exception of Okha and Porbandar which had a higher number of species found at deeper depths. Fishers in Veraval have high-capacity mechanized boats which are used for fishing in offshore waters several hundred nautical miles away from the coast (pers. comm. with fisher communities). However, at landing sites and fish markets we identified and sampled auctions of catch from smaller, coastal fishing vessels, which account for 25% of total fisheries catch in Veraval (pers. comm. with fisher communities). These fishers engage in daily fishing and landing activities in coastal and neritic zones as opposed to month long expeditions in offshore areas by larger vessels (pers. comm. with fisher communities). Consequently, catch from these fishers, was sampled heavily in the current study, represents species individuals caught close to shore. These data are indicative of the predominantly coastal fisheries in Veraval targeting coastal and neritic species and potentially nursery areas with a large proportion of females and juveniles for several species. Our findings support a potential nursery area for *S. lewini, R. laevis, C. sorrah, R. annandalei,* and *A. ocellatus*- all species with majority juvenile landings along the coast of Gujarat, which should be the target of future research.

Our results are consistent with observations of higher landing volumes for juvenile scalloped hammerhead sharks in other parts of the ASR (Henderson et al., 2016; FAO, 2021). *S. lewini*, a Critically Endangered, CITES (Pacoureau et al., 2020) listed species has had a >50% regional decline in the ASR (Jabado et al., 2017), in part due to its slow life history traits (Hazin et al., 2001; Harry et al., 2011). *R. laevis* which is a Critically Endangered, CITES (Peter Kyne, 2020) listed species, is similarly vulnerable to fishing pressure due to its slow life history traits (Compagno, 1990; García et al., 2008; Hutchings et al., 2012) and has suffered declines of 50–80% throughout the ASR (Kyne et al., 2020b; FAO, 2021). In general, the population growth rate of Chondrichthyes is limited by slow life history traits, long gestation periods, and low fecundity (Cortés, 2000; Hutchings et al., 2012). Overfishing of juveniles and sexually mature females as seen in our study, further exacerbates the recovery potential of overexploited species populations. Our findings thus identify priority concern species and their nursery grounds in the ASR and call for expedient management measures to conserve and protect remaining populations.

We extended the geographic ranges of three species that were previously unreported in northwest India or in two cases unreported in the Indian subcontinent. These species include *T. sinuspersici*, which is a Data Deficient species, and *C. sorrah* and *R. punctifer*, both of which are Near Threatened. Our observations are significant in establishing the geographic range of the species, understanding species ecology, and in evaluating species biodiversity of the Gujarat coast. Since each of these species has a coastal distribution range within 0–200 m, the specimens we report were potentially fished in coastal waters off of the respective landing sites in Gujarat. The fishing of these specimens in distant international/national coastal zones and subsequent landing in Gujarat is extremely unlikely due to national fishing restrictions within exclusive economic zones (EEZs) and provincial fishing restrictions within India. We are therefore confident that the range extensions reported here are accurate, but suggest dedicated sampling efforts are conducted to describe the distribution of the species in Gujarat, elsewhere in India and the ASR.

T. sinuspersici is a species complex (Dent and Clarke, 2015; Park University, 2020) and warrants investigation to resolve the component species. The spotted guitarfish *R. punctifer*, a second range extension, is commonly mistaken with the Annandale's guitarfish *R. annandalei,* and thus its distribution in the area has been questionable (Ali et al., 2021). The spotted guitarfish was sampled four times in the current study confirming, for the first time, that the species is extant in India. The repeated landings also suggest extreme vulnerability of the species to capture by fisheries all along the coast of Gujarat and are concerning for a species with a declining population trend. The third species was the spottail shark *C. sorrah*, for which we identified four specimens caught at two different ports in Gujarat, thus extending the geographic range of the species to northwestern India. The species has been previously reported on the eastern coast and up to the southwestern coast of India, along with its wide range in the tropical Indo-West Pacific, the Indian Ocean, Southeast Asia, and Australia (IUCN Red List, 2020b). Our observations suggest a high vulnerability of the spottail shark to fisheries in Gujarat. Future genetic studies of the species are warranted and will assist in determining its population trend, which currently remains unknown. Our findings on the three species found in neritic marine zones significantly contribute to the current knowledge on species distributions, and will be instrumental in defining areas on the continental shelf that warrant protection from the prolific and exploitative fisheries in Gujarat.

Numerous species sampled in our study such as *S. lewini*, *A. pelagicus*, *C. falciformis*, *C. brevipinna*, *C. leucas, C. limbatus*, as well as *M. mobular, M. tarapacana,* and *A. ocellatus* are migratory in nature (The IUCN Red List, 2019). These species potentially cross international maritime boundaries with high frequency and call for special consideration by the Convention for Migratory Species (CMS), along with an international coalition for protection from fisheries, including those in India.

We have reduced the data deficiency of five batoids – *Rhinobatos annandalei*, *R. jayakari, Maculabatis bineeshi*, *P. bleekeri,* and *T. sinuspersici*. Batoid fisheries and trade receive even less attention and monitoring than true shark landings, and batoid specimens are often not reported (Bräutigam et al., 2020). Two of the sampled species, *M. bineeshi* and *P. bleekeri* have declined by >50% (Jabado et al., 2017) and have potentially undergone heavy exploitation by fisheries in Gujarat due to their habitation of in-shore coastal areas (Jabado et al., 2017). *R. annandalei* is frequently misidentified with the spotted guitarfish (*R. punctifer*), and therefore often goes unreported (Jabado et al., 2017). All three specimens of the species collected in Veraval and Porbandar were juvenile, suggesting nursery areas for the species close to the sampling sites. *Carcharhinus amboinensis* was the only DD shark species sampled in our study. Low fecundity of the species, deterioration in its habitat quality due to heavy coastal pollution and large scale development in Gujarat and elsewhere in the ASR (Jabado et al., 2017) are concerning for the species' status which is expected to have a 30–50% decline in its population (IUCN Red List, 2020a). The high frequency of juvenile and female specimens captured from DD species, raises the concern that populations will be depleted through exploitation by fisheries, before we have an opportunity to enact conservation measures by assessing the species' distribution and ecology. Our studies provide timely indicators of the species' distribution, ecology and catch rate in fisheries, to enable specific investigations which will ultimately facilitate enactment of protective measures for the species.

There is an increasing trend toward mechanization of fishing vessels in the ASR (Raje and Zacharia, 2009; Jabado and Spaet, 2017). Mechanized fishing fleets explore deeper off shore environments as nearshore resources are depleted (Akhilesh et al., 2011; Jabado et al., 2018; Kyne et al., 2020b), thus expanding fishing capacity into territories with inadequate or absent oversight and management (Nagle, 2019). Chondrichthyes inhabiting deep water environments are adapted to colder and potentially resource limited environments, have slower than average growth rates and consequently are more vulnerable to fishing pressure than nearshore species (Nagle, 2019). However, an estimated 35% of chondrichthyan species are found in deep-water environments and are considered a low priority for fisheries management (Bräutigam et al., 2020). Thus, mechanization and offshore fishing exposes vulnerable species which were earlier protected in deep water refuges. Mechanized vessels found in the Indian EZZ use trawl nets, gill nets, and long line gear and are therefore likely to engage in indiscriminate fishing in the absence of observers or alternate monitoring mechanisms (Nagle, 2019). In addition offshore fisheries in India engage in overfishing of species which have a limited geographic range and extremely low fecundity, resulting in up to 99% declines in population abundance of species (Akhilesh et al., 2011; Kyne et al., 2020a; Pogonoski and Pollard, 2020; White, 2020). Thus, increased capacity for fishing in deeper waters in Gujarat is likely going to drive further species declines and extinctions, unless directed and expedient measure are taken to manage deep water fisheries at a national and regional level in the ASR.

Reporting of most fisheries occurs by aggregating species in higher groups such as orders and families, which masks declines of individual species (Dulvy et al., 2014; Nagle, 2019). Lack of species identification makes management of stock and protected species difficult or impossible. We provided species-specific assessments of landing sites along with the age or gender groups captured as targeted or incidental catch for 31 elasmobranch species in the fisheries of Gujarat. Thus, we provide critical information on priority species of concern impacted by fisheries in the area. While we acknowledge that the number of specimens recorded for each species was highly variable and very low in some cases, the data were obtained through opportunistic samplings of fish markets which offer no control on the type and number of specimens. However, we used these specimens to sequence the partial genome of a chondrichthyan species, *C. falciformis* (Johri et al., 2019), and reported the first mitogenomes for *G. granulatus* (Johri et al., 2020b), and *R. laevis* (Johri et al., 2020c), providing the first species specific assessments for these taxa in the ASR and demonstrating the power of molecular taxonomy in species assessments of wildlife trade and fisheries.

CONCLUSION

The ineffectiveness of protection and management measures in the ASR is represented by the decline in chondrichthyan stocks over the past few decades. To increase sustainability and effectiveness of conservation strategies, efforts should be directed at identification of priority concern species through ecological and threat assessments of chodnrichthyan populations in areas with high fishing volumes. Second, community partnerships should be forged to enact management measures to their full potential and to develop a sustainable conservation program with shared cross-sectoral responsibilities and beneficiaries. The current report bridges crucial knowledge gaps with regards to elasmobranch fisheries in India, the largest shark fishing nation in the ASR and second largest in the world. We expect that the data presented here will pivot the direction of conservation measures to protect priority concern species and underline the impending urgency of these efforts. We also expect to leverage community partnerships built during the current work to assist in co-designing and implementation of cross-sectoral management and conservation programs in India.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: BioProject: PRJNA698050 and at iNaturalist: https://www.inaturalist.org/observations?place_id=any&subview=grid&user_id=shaili&verifiable=any&view=species.

AUTHOR CONTRIBUTIONS

SJ conceptualized and designed the study, wrote the manuscript and contributed to sampling and DNA sequencing. IL contributed to writing and data analyses. AT conducted sampling and surveys. JS organized sampling trips and facilitated liaisons with fisher communities. AB and IM helped with data analyses, organization, outreach, and education materials. SF conducted phylogenetic analyses of samples. MD assisted with sampling. ED helped with study design and writing of the manuscript. All authors edited the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.619695/full#supplementary-material

Supplementary Figure 1 | Bayesian and maximum likelihood estimates of phylogenetic relationships among elasmobranch species using mitochondrial protein coding genes for *Rhinobatos punctifer* **(A)**, *Torpedo sinuspersici* **(B)**, *Carcharhinus sorrah* **(C)**, *Mobula mobular* and *Mobula tarapacana* **(D)**. The unknown sequence contig for each of the five specimens clusters with their taxonomically assigned identities and thus confirms their taxonomic classification based on morphology. Numbers at nodes are posterior probabilities for BI trees and bootstrap support values are the numbers at nodes in ML trees.

Supplementary Figure 2 | A comparison of species distribution across sampling locations. **(A)** Frequency of species by sampling location, with 31 total species of elasmobranchs positively identified from 157 samples. **(B)** Percentage of species for sharks and rays sampled in each conservation category.

Supplementary Figure 3 | Depth range of 24 species sampled and described across all four sample locations.

Supplementary Figure 4 | Comparison of previously reported geographic ranges and landing site locations for three species from the current study indicated as: Okha (blue arrow), Porbandar (red arrow) and Veraval (black arrow). **(A)** Geographic range of Carcharhinus sorrah on the IUCN Redlist Database, and landing sites for the species in Porbandar and Veraval, **(B)** Geographic range of Torpedo sinuspersici on the IUCN Redlist Database, and landing site for the species in Porbandar, and **(C)** Geographic range of Rhinobatos punctifer on the IUCN Redlist Database, and landing sites for the species in Okha, Porbandar and Veraval.

Supplementary Table 1 | List of taxa, genetic loci and accession numbers used to assess phylogenetic relationships described in **Supplementary Figure 1**.

REFERENCES

Akhilesh, K. V., Bineesh, K. K., Gopalakrishnan, A., Jena, J. K., Basheer, V. S., and Pillai, N. G. K. (2014). Checklist of chondrichthyans in Indian waters. *J. Mar. Biol. Assoc. India* 56, 109–120. doi: 10.6024/jmbai.2014.56.1.01750s-17

Akhilesh, K. V., Ganga, U., Pillai, N. G. K., Vivekanandan, E., Bineesh, K. K., Rajool Shanis, C. P., et al. (2011). Deep Sea fishing for chondrichthyan resources and sustainability concerns-a case study from Southwest Coast of India. *Indian J. Geo Mar. Sci.* 40, 347–355.

Ali, M., Akhilesh, K. V., and Khan, M. (2021). *IUCN Red List of Threatened Species: Rhinobatos Punctifer*. Available online at: https://www.iucnredlist.org/en (accessed February 9, 2021)

Barker, M. J., and Schluessel, V. (2005). Managing global shark fisheries: suggestions for prioritizing management strategies. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 15, 325–347. doi: 10.1002/aqc.660

Bineesh, K. K., Gopalakrishnan, A., Akhilesh, K. V., Sajeela, K. A., Abdussamad, E. M., Pillai, N. G. K., et al. (2017). DNA barcoding reveals species composition of sharks and rays in the Indian commercial fishery. *Mitochondr. DNA A DNA Mapp. Seq. Anal.* 28, 458–472. doi: 10.3109/19401736.2015.1137900

Bornatowski, H., Navia, A. F., Braga, R. R., Abilhoa, V., and Corrêa, M. F. M. (2014). Ecological importance of sharks and rays in a structural foodweb analysis in Southern Brazil. *ICES J. Mar. Sci.* 71, 1586–1592. doi: 10.1093/icesjms/fsu025

Bräutigam, A., Callow, M., and Campbell, I. R. (2020). *Global Priorities for Conserving Sharks and Rays?: A 2015-2025 Strategy*. Available online at: https://portals.iucn.org/library/sites/library/files/documents/2016-007.pdf (accessed June 3, 2020).

Castro, J. I., Woodley, C. M., and Brudek, R. L. (1999). *A Preliminary Evaluation of the Status of Shark Species*. Rome: Food & Agriculture Organisation.

Compagno, L. J. V. (1990). Alternative life-history styles of cartilaginous fishes in time and space. *Environ. Biol. Fishes* 28, 33–75. doi: 10.1007/BF00751027

Cortés, E. (2000). Life history patterns and correlations in sharks. *Rev. Fish. Sci.* 8, 299–344. doi: 10.1080/10408340308951115

Dent, F., and Clarke, S. (2015). *State of the Global Market for Shark Products*. Rome: FAO, 196.

Devadoss, P., Kuthalingam, M. D. K., and Thiagarajan, R. (1989). *The Present Status and Future Prospects of Elasmobranch Fishery in India. Sessions I&II*. Kochi: Central Marine Fisheries Research Institute.

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., et al. (2014). Extinction risk and conservation of the World's sharks and rays. *eLife* 3:e00590. doi: 10.7554/eLife.00590

Dulvy, N. K., Simpfendorfer, C. A., Davidson, L. N. K., Fordham, S. V., Bräutigam, A., Sant, G., et al. (2017). Challenges and priorities in shark and ray conservation. *Curr. Biol.* 27, R565–R572. doi: 10.1016/j.cub.2017.04.038

Ebert, D., Fowler, S., and Compagno, L. (2013). *Sharks of the World: A Fully Illustrated Guide*. Plymouth: Wild Nature Press Ltd.

Ebert, D. A., Khan, M., Ali, M., Akhilesh, K. V., and Jabado, R. W. (2017). *Rhinobatos punctifer. The IUCN Red List of Threatened Species*. Available online at: doi.org/10.2305/IUCN.UK.2017-2.RLTS.T161447A109904426.en (accessed December 6, 2019).

Edgar, R. C. (2004). MUSCLE: multiple sequence alignment with high accuracy and high throughput. *Nucleic Acids Res.* 32, 1792–1797. doi: 10.1093/nar/gkh340

FAO (2007). "Review of the state of world marine capture fisheries management. Pacific Ocean," in *FAO Fisheries Technical Paper*, ed. C. De Young (Rome: Food and Agriculture Organization of the United Nations).

FAO (2017). *FAO Fisheries & Aquaculture - FishStatJ - Software for Fishery and Aquaculture Statistical Time Series*. Available online at: http://www.fao.org/fishery/statistics/software/fishstatj/en (accessed June 3, 2020)

FAO (2019). *2019 IUCN RL Update*. Available online at: https://www.iucnssg.org/2019-iucn-rl-update.html (accessed February 5, 2021)

FAO (2020). *2020_03RedList*. Available online at: https://www.iucnssg.org/2020_03redlist.html (accessed February 5, 2021)

FAO (2021). *Overview of World Elasmobranch Fisheries*. Available online at: http://www.fao.org/3/v3210e/V3210E01.htm#ch1. (accessed January 24, 2020)

FAO Yearbook (2020). *Fishery and Aquaculture Statistics 2018/FAO Annuaire. Statistiques Des Pêches et de l'aquaculture 2018/FAO Anuario. Estadísticas de Pesca y Acuicultura 2018*. Rome: FAO.

FishBase (2020). *Search FishBase*. Available online at: https://www.fishbase.in/search.php (accessed January 22, 2020)

Froese, R., and Pauly, P. (2020). *FishBase. World Wide Web Electronic Publication*. Available online at: https://www.fishbase.de/summary/citation.php (accessed February 24, 2021)

García, V. B., Lucifora, L. O., and Myers, R. A. (2008). The importance of habitat and life history to extinction risk in sharks, skates, rays and chimaeras. *Proc. R. Soc. B Biol. Sci.* 275, 83–89. doi: 10.1098/rspb.2007.1295

Harry, A. V., Macbeth, W. G., Gutteridge, A. N., and Simpfendorfer, C. A. (2011). The life histories of endangered hammerhead sharks (Carcharhiniformes, Sphyrnidae) from the East Coast of Australia. *J. Fish Biol.* 78, 2026–2051. doi: 10.1111/j.1095-8649.2011.02992.x

Hazin, F., Fischer, A., and Broadhurst, M. (2001). Aspects of reproductive biology of the scalloped hammerhead shark, Sphyrna Lewini, off Northeastern Brazil. *Environ. Biol. Fishes* 61, 151–159. doi: 10.1023/a:1011040716421

Henderson, A. C., Reeve, A. J., Jabado, R. W., and Naylor, G. J. P. (2016). Taxonomic assessment of sharks, rays and guitarfishes (Chondrichthyes: Elasmobranchii) from South-Eastern Arabia, using the NADH dehydrogenase subunit 2 (NADH2) gene. *Zool. J. Linn. Soc.* 176, 399–442. doi: 10.1111/zoj.12309

Hutchings, J. A., Myers, R. A., García, V. B., Lucifora, L. O., and Kuparinen, A. (2012). Life-history correlates of extinction risk and recovery potential. *Ecol. Appl.* 22, 1061–1067. doi: 10.1890/11-1313.1

IUCN Red List (2019). *The IUCN Red List of Threatened Species*. Available online at: https://www.iucnredlist.org/en (accessed December 17, 2019)

IUCN Red List (2020a). *IUCN Red List of Threatened Species: Pigeye Shark*. Available online at: https://www.iucnredlist.org/en (accessed June 11, 2020)

IUCN Red List (2020b). *IUCN Red List of Threatened Species: Spottail Shark*. Available online at: https://www.iucnredlist.org/ja (accessed June 7, 2020)

IUCN Red List (2021). *The IUCN Red List of Threatened Species. Version 2020-1*. Available online at: https://www.iucnredlist.org/en (accessed February 24, 2021)

Jabado, R. W., Kyne, P. M., and Pollom, R. A. (2017). *The Conservation Status of Sharks, Rays, and Chimaeras in the Arabian Sea and Adjacent Waters*. Bristol: Environment Agency.

Jabado, R. W., Kyne, P. M., Pollom, R. A., Ebert, D. A., Simpfendorfer, C. A., Ralph, G. M., et al. (2018). Troubled waters: threats and extinction risk of the sharks, rays and chimaeras of the arabian sea and adjacent waters. *Fish Fish.* 19, 1043–1062. doi: 10.1111/faf.12311

Jabado, R. W., and Spaet, J. L. Y. (2017). Elasmobranch fisheries in the Arabian seas region: characteristics, trade and management. *Fish Fish.* 18, 1096–1118. doi: 10.1111/faf.12227

Johri, S., Dunn, N., Chapple, T. K., Curnick, D., Savolainen, V., Dinsdale, E. A., et al. (2020a). Mitochondrial genome of the silvertip shark, carcharhinus albimarginatus, from the British Indian Ocean Territory. *Mitochondr. DNA Part B* 5, 2085–2086. doi: 10.1080/23802359.2020.1765210

Johri, S., Fellows, S. R., Solanki, J., Busch, A., Livingston, I., Mora, M. F., et al. (2020b). Mitochondrial genome to aid species delimitation and effective conservation of the sharpnose guitarfish (*Glaucostegus granulatus*). *Meta Gene* 24:100648. doi: 10.1016/j.mgene.2020.100648

Johri, S., Solanki, J., Cantu, V. A., Fellows, S. R., Edwards, R. A., Moreno, I., et al. (2019). 'Genome skimming' with the MinION hand-held sequencer identifies CITES-listed shark species in India's exports market. *Sci. Rep.* 9:4476. doi: 10.1038/s41598-019-40940-9

Johri, S., Tiwari, A., Kerr, E. N., and Dinsdale, E. A. (2020c). Mitochondrial genome of the smoothnose wedgefish *Rhynchobatus laevis* from the Western Indian Ocean. *Mitochondr. DNA Part B* 5, 2083–2084. doi: 10.1080/23802359.2020.1765209

Karnad, D., Sutaria, D., and Jabado, R. W. (2020). Local drivers of declining shark fisheries in India. *Ambio* 49, 616–627. doi: 10.1007/s13280-019-01203-z

Kizhakudan, S. J., Zacharia, P. U., Thomas, S., Vivekanandan, E., and Muktha, M. (2015). *Guidance on National Plan of Action for Sharks in India*. Kochi: Central Marine Fisheries Research Institute.

Kumar, R., Sasidharan, V., Akhilesh, K. V., Bineesh, K. K., and Pt, R. (2018). First report of four deep-sea chondrichthyans (Elasmobranchii and Holocephali) from Andaman Waters, India with an updated checklist from the region. *Acta Ichthyol. Piscat.* 3, 289–301. doi: 10.3750/AIEP/02336

Kyne, P., Huveneers, C., Ebert, D., and Bigman, J. (2020a). *IUCN Red List of Threatened Species: Western Gulper Shark*. Available online at: https://www.iucnredlist.org/en (accessed June 8, 2020).

Kyne, P. M. (2019). *Torpedo sinuspersici*. The IUCN Red List of Threatened Species 2019. Available online at: https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T60136A140820271.en. (accessed April 22, 2021).

Kyne, P. M., Jabado, R. W., Rigby, C. L., Dharmadi, Gore, M. A., Pollock, C. M., et al. (2020b). The thin edge of the wedge: extremely high extinction risk in Wedgefishes and Giant Guitarfishes. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 30, 1337–1361. doi: 10.1002/aqc.3331

Lack, M., and Sant, G. (2011). *The Future of Sharks: A Review of Action and Inaction*. Cambridge: TRAFFIC Global Office.

Lanfear, R., Frandsen, P. B., Wright, M. A., Senfeld, T., and Calcott, B. (2016). PartitionFinder 2: new methods for selecting partitioned models of evolution for molecular and morphological phylogenetic analyses. *Mol. Biol. Evol.* 34, 772–773. doi: 10.1093/molbev/msw260

Last, P., White, W., Carvalho, M., Seret, B., Stehmann, M., and Naylor, G. (2018). *Rays of the World, Peter Last, William White, Marcelo de Carvalho, Bernard Séret, Matthias Stehmann, Gavin Naylor, 9780643109131*. Available online at: https://www.publish.csiro.au/book/7053/ (accessed September 14, 2018)

Miller, M., Pfeiffer, W. T., and Schwartz, T. (2010). "Creating the CIPRES science gateway for inference of large phylogenetic trees," in *Proceedings of the Gateway Computing Environments Workshop: 14 Nov 2010*, Vol. 14, (New Orleans, LA), 1–8.

Mohamed, K., and Shettigar, V. (2016). How long does it take for tropical marine fish stocks to recover after declines?Case studies from the Southwest Coast of India. *Curr. Sci.* 110, 584. doi: 10.18520/cs/v110/i4/584-594

Musick, J. A., Burgess, G., Cailliet, G., Camhi, M., and Fordham, S. (2000). Management of sharks and their relatives (Elasmobranchii). *American Fisheries Society*, 25. Available online at: http://www.adfg.alaska.gov/static-sf/Region2/ground_fish/PDFs/AFSMarineStocksAtRisk31b_sharks.pdf (accessed March, 2000).

Nagle, C. (2019). *Shark Fishing in the Indian Seas: A Quantitative Risk Assessment of the Impacts of Longline Fishing on the Sustainability of Regional Shark Populations*. Ph. D. Thesis, Harvard Extension School, Cambridge, MA.

Pacoureau, N., Sherley, R., Liu, K.-M., Sul, R. B., Herman, K., Rigby, C., et al. (2020). *IUCN Red List of Threatened Species: Scalloped Hammerhead*. Available online at: https://www.iucnredlist.org/en (accessed June 11, 2020)

Park University (2020). *(Charles D., Coordinator), A./ I.S.S.R. IUCN Red List of Threatened Species: Gulf Torpedo*. Available online at: https://www.iucnredlist.org/en (accessed June 7, 2020)

Peter Kyne, R. J. (2020). *IUCN Red List of Threatened Species: Smoothnose Wedgefish*. Available online at: https://www.iucnredlist.org/en (accessed February 21, 2020)

Pogonoski, J. J., and Pollard, D. (2020). *IUCN Red List of Threatened Species: Little Gulper Shark*. Available online at: https://www.iucnredlist.org/en (accessed June 8, 2020)

Pollerspöck, J., and Straube, N. (2021). *Bibliography Database. Version 2021*. Available online at: https://www.shark-references.com/ (accessed February 24, 2021)

Pradeep, H., Shirke, S., Nashad, M., Sasidharan, V., Kumar, R., Sumitha, G., et al. (2018). First record and DNA barcoding of Oman Cownose Ray, Rhinoptera Jayakari Boulenger, 1895 from Andaman Sea, India. *Zoosystema* 40, 67–74. doi: 10.5252/zoosystema2018v40a4

Raje, S., and Zacharia, P. U. (2009). Investigations on fishery and biology of nine species of rays in Mumbai Waters. *Indian J. Fish.* 56, 95–101.

Raje, S. G., Sivakami, S., Mohanraj, G., Manojkumar, P. P., Raju, A., and Joshi, K. K. (2007). Atlas on the elasmobranch fishery resources of India. *CMFRI Spec. Publ.* 95, 1–253. doi: 10.7755/fb.114.1.1

Rambaut, A., Drummond, A. J., Xie, D., Baele, G., and Suchard, M. A. (2018). Posterior summarization in Bayesian Phylogenetics using tracer 1.7. *Syst. Biol.* 67, 901–904. doi: 10.1093/sysbio/syy032

Rhinidae – IUCN Red List. *Supplementary Information for wedgefishes (Rhinidae) and giant guitarfishes (Glaucostegidae)*. Available online at: https://www.iucnredlist.org/species/pdf/2382420/attachment. (accessed March 01, 2021).

Ronquist, F., Teslenko, M., van der Mark, P., Ayres, D. L., Darling, A., Höhna, S., et al. (2012). MrBayes 3.2: efficient bayesian phylogenetic inference and model choice across a large model space. *Syst. Biol.* 61, 539–542. doi: 10.1093/sysbio/sys029

Rose, D. A. (1998). *Shark Fisheries and Trade in the Americas*. Washington, DC: TRAFFIC North America.

Spaet, J. L. Y., and Berumen, M. L. (2015). Fish market surveys indicate unsustainable elasmobranch fisheries in the Saudi Arabian Red Sea. *Fish. Res.* 161, 356–364. doi: 10.1016/j.fishres.2014.08.022

Spaet, J. L. Y., Thorrold, S. R., and Berumen, M. L. (2012). A review of elasmobranch research in the Red sea. *J. Fish Biol.* 80, 952–965. doi: 10.1111/j.1095-8649.2011.03178.x

Stamatakis, A. (2014). RAxML Version 8: a tool for phylogenetic analysis and post-analysis of large phylogenies. *Bioinform. Oxf. Engl.* 30, 1312–1313. doi: 10.1093/bioinformatics/btu033

Stein, R. W., Mull, C. G., Kuhn, T. S., Aschliman, N. C., Davidson, L. N. K., Joy, J. B., et al. (2018). Global priorities for conserving the evolutionary history of sharks, rays and chimaeras. *Nat. Ecol. Evol.* 2, 288–298. doi: 10.1038/s41559-017-0448-4

Stevens, J. (2000). The effects of fishing on sharks, rays, and chimaeras (Chondrichthyans), and the implications for marine ecosystems. *ICES J. Mar. Sci.* 57, 476–494. doi: 10.1006/jmsc.2000.0724

Sutaria, D., Parikh, A., Barnes, A., and Jabado, R. W. (2015). First record of the Sandbar Shark, Carcharhinus Plumbeus, (Chondrichthyes: Carcharhiniformes: Carcharhinidae) from Indian Waters. *Mar. Biodivers. Rec.* 8, e126. doi: 10.1017/S1755267215001025

The IUCN Red List (2019). *The IUCN Red List of Threatened Species*. Available online at: https://www.iucnredlist.org/en (accessed August 22, 2019)

White, W. T. (2020). *IUCN Red List of Threatened Species: Leafscale Gulper Shark*. Available online at: https://www.iucnredlist.org/en (accessed June 8, 2020)

Wild Life (Protection) Act. (1972). *An Act to Provide for the Protection of Wild Animals, Birds and Plants and for Matters Connected Therewith or Ancillary or Incidental Thereto with a View to Ensuring the Ecological and Environmental Security of the Country*. Available online at: http://indiacode.nic.in/handle/123456789/1726 (accessed September 9, 1972).

Worldbank (2020). *Protecting India's Coastline: Gujarat*. Available online at: https://www.worldbank.org/en/news/feature/2012/10/11/protecting-indias-coastline-gujarat (accessed April 15, 2020)

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Flow of Economic Benefits From Coral Reefs in a Multi-Use Caribbean Marine Protected Area Using Network Theory

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Adaptation to changes in the delivery of ecosystem services while maintaining resilience of natural systems is one of the main challenges faced by multi-use marine protected areas (MPAs). To overcome this, it is crucial to improve our understanding of interdependencies among resource users and ecosystems. In this study we used networks to model the socio-ecological system of a multi-use MPA in the southern Caribbean. Using a mixed-method approach, we built a socio ecological network (SEN) from the flow of economic benefits that stakeholders obtain from coral reefs in Los Roques National Park. We specifically looked at how these benefits are distributed among stakeholder groups and how the structure and other network properties can inform management. For this, four networks (simple, weighted, directed and directed-weighted) were built from 125 nodes representing three services and six stakeholder groups, linked through 475 edges. The SEN structure indicated an open resource use pattern with reduced social capital, suggesting that community-based management could be challenging. Only 31% of the benefits from ecosystem services stay within the SEN. Regulation services, derived from the coral reef framework were the most important in terms of maintaining the flow of benefits through the SEN; however, most benefits depended on provisioning services. This approach, based on network theory allowed identification of inequalities in the access to benefits among groups, externalities in benefits derived from fisheries and trade-offs between provisioning and regulation services. Our results suggest that Los Roques might be falling into a socio-ecological trap. Improving access to benefits and increasing trust need be prioritized. Low-cost management intervention can help internalize financial benefits and reduce trade-offs affecting more vulnerable stakeholder groups. However, these would require changes in governance and institutions at the executive level.

Keywords: MPA, network, socio-ecological, fisheries, governance, tourism, coral reefs, Los Roques

INTRODUCTION

Marine protected areas (MPAs) have been championed as a tool to increase resilience of coral reefs (Bruno and Selig, 2010; Cinner et al., 2016; Bellwood et al., 2019). Area-based protection has been put in the forefront of the global conservation agenda as a strategy to halt the loss of marine biodiversity (Toonen et al., 2013; Zhao et al., 2020). Both the Convention on Biological Diversity and the Sustainable Development Goals (SDG) set targets to protect 10% of the ocean with the goal of "safeguarding both habitats and populations of species and for delivering important ecosystem services" (CBD, 2010; Strategic Plan 2011-2020) and to "conserve and sustainably use the oceans and marine resources for sustainable development" (SDG, 2015).

However, the mere land and water coverage of a marine protected area is not indicative of its conservation value or effectiveness in moving forward toward these goals (Mora et al., 2006; Bruno and Selig, 2010). The effectiveness of MPAs to conserve biodiversity depends on a myriad of factors. While some, such as the MPA's age and size affect their protection effectiveness (Claudet et al., 2008; Edgar et al., 2014; Strain et al., 2019), those related with how the MPA is managed can ultimately hinder the area's capacity to protect biodiversity (Guidetti et al., 2008; Giakoumi et al., 2018; Strain et al., 2019). Unlike fully protected marine reserves (i.e., no-take zones), multi-use MPAs encompass areas with different levels of protection or allowed uses, often with human settlements inside the boundaries of the MPA. Here, management effectiveness becomes more critical, because securing the well-being of local communities living in, or using the MPA is also indispensable for actors to use resources sustainably and ensure the provision of ecosystem services (Mumby et al., 2014).

Recognizing where and when to adapt management and conservation interventions for resilience or transformation is becoming increasingly important to maintain the delivery of ecosystem services under a changing climate (Darling et al., 2019; Woodhead et al., 2019; Peterson St-Laurent et al., 2021). Socioeconomic and cultural processes change in response to how the provision of ecosystem services also change (Bohan et al., 2016; Bellwood et al., 2019; Williams et al., 2019). Adjustment of these processes can thus modify how resources are used by either increasing or decreasing pressure from anthropogenic local drivers of change in natural systems (Barnes et al., 2017). In multi-use coral reef MPAs where resource users are more reliant on natural resources (Cinner et al., 2011; Coulthard, 2012), changes in cultural, socioeconomic, and institutional aspects can rapidly affect the way people use these resources (Bohan et al., 2016). The relative importance that these changes have in protecting coral reefs increases within multi-use MPAs, because the effective protection of these systems is highly dependent upon limiting extractive activities for restoring and maintaining the biomass of fish and key guilds through no-take zones and fishing regulations (Bellwood et al., 2012; Mumby et al., 2014). Therefore, understanding how resource users adapt in response to changes in both the social and the ecological components of the system is key for maintaining the conservation value of these MPAs.

Using a multi-use coral reef MPA in the southern Caribbean as a study case, we explore the use of networks to understand the distribution of benefits from ecosystems among stakeholders. Socio ecological networks (SEN) can significantly aid in understanding and monitoring change in socio-ecological systems (Sayles et al., 2019; Barnes et al., 2019a). Network theory can provide information about the structure and dynamics of systems in terms of the connectivity of their components (Boccaletti et al., 2014). For more than a decade, network theory has been used as a tool to assess interactions among people and the environment (Janssen et al., 2006; Norberg and Cumming, 2008; Sayles et al., 2019). Applications in various areas of environmental and resource management demonstrate how network analysis can be useful in identifying interdependencies among people, organizations, and institutions (Bergsten et al., 2014; Alonso Roldán et al., 2015; Maciejewski and Cumming, 2015). Here, we specifically used network theory to answer the following questions: (i) how equitably distributed are benefits derived from ecosystem services among stakeholders? (ii) is the structure of the SEN likely to facilitate adaptation to change? and (iii) what components of the SEN should be prioritized when managing for change in the delivery of ecosystem services?

MATERIALS AND METHODS

Governance and Management in Los Roques National Park

Los Roques is located off the north coast of Venezuela in the southern Caribbean (11°5′64″ N y 66°45′ W). The MPA encompasses more than 50 coralline cays protected by two barriers within an area of 221,120 hectares (Bisbal, 2008; **Figure 1**). Created in 1972 Los Roques was the country's first MPA and the second of Latin America (Zamarro 2002). However, it was not until 1991, that the master plan, including specific objectives and regulations, was officially published (Gaceta Oficial, 1991). This document, known as PORU for its Spanish acronym, establishes seven categories of use ranging from no-take zones to localized built areas in the islands of Gran Roque and Pirata where human settlements are allowed (**Figure 1**).

Los Roques has approximately 2,000 permanent residents (INE, 2014) and 60 registered lodges who operate under concessions (SATIM, 2015). Here main stakeholders are organized by trade. Community organizations include two cooperatives gathering all boaters working in tourism, one fisher's council and a tourism chamber composed mainly of lodges and dive shops. It should be noted that, the last two had not been granted official status by the government at the time of this study. As mandated by national law, there is also one general community council.

The National Park is managed by the National Parks Institute (INPARQUES), with an on-site superintendent who is responsible for drafting annual working plans, that serve as the MPA's management plan. Most fishing activities are regulated by the country's national-level fisheries authority INSOPESCA and monitored by on-site officers. In 2011, the Territorio Insular Francisco de Miranda (TIFM) was created by an executive act.

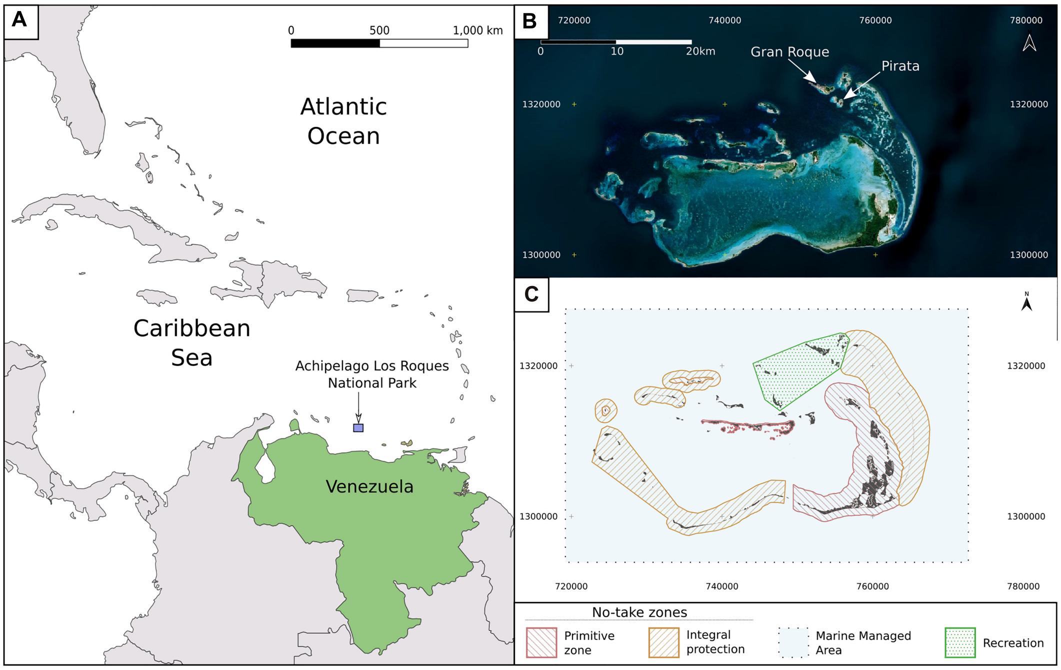

FIGURE 1 | Archipielago Los Roques National Park, a Venezuelan multi-use MPA in the southern Caribbean **(A)**. Stellite image of the MPA is shown in panel **(B)**, while the zoning, according to use regulations established in 1991 are shown in panel **(C)**. Based on allowed activities the marine zones from higher to lower protection are: Integral Protection (IPZ), Primitive Area (PA), Marine Managed Area (MMA – corresponding to the extent not included in the other zones) and Recreation (RZ). Image contains modified Copernicus Sentinel data [2020], processed by ESA. Datum: EPSG: 2202 – REGVEN/UTM 19N.

The decree establishes Gran Roque, within the National Park, as its capital and grants this new "territory" attributions that collide with the country's environmental and land planning body of laws, especially pertaining those involving resource management and law enforcement in MPAs (Gaceta Oficial, 2011). Its managing director is not elected but appointed by the president and since 2013 is the *de facto* higher authority in the MPA.

The Socio-Ecological Network

In a network, the nodes or vertices are the components of the system and the edges or links represent the connection among them (Newman et al., 2006). We represented stakeholders and ecosystem services as nodes in our socio-ecological system. Two or more nodes were linked when they either received or passed on a benefit from any of the ecosystem services included in the network. Stakeholder's represented as nodes were selected on three criteria: (1) they benefit directly (i.e., extracted goods that are sold such as fish) or indirectly (i.e., lodges reducing costs of protein by buying fish) from coral reef's ecosystem services, (2) the economic value of such benefits could be estimated, and 3) the benefits represent their main source of income (**Table 1**; see **Supplementary Materials** for full list). Under these criteria, a total of 125 nodeswith 475 links among them were identified. We defined the system's boundaries according to the MPA extension, obtaining a partially articulated SEN (*sensu* Sayles et al., 2019).

Seven different stakeholder groups related with tourism or local fisheries supply chain were assigned as attributes to the nodes. Three ecosystem services were also included as attributes. A weight was assigned to each of the network's links to build a weighted network based on the economic benefits obtained from these ecosystem services and transferred among stakeholders. Weights represent the gross benefit in US dollars that a node received either directly, or through another node. Depending on which node received and which passed on a benefit, a direction was assigned to both the simple and weighted links or edges. This directed network was used to characterize the flow of such benefits through the SEN according to the source (indegree) and target (outdegree) of the links between nodes (**Figure 2**).

Data Collection

To map the economic benefits obtained by stakeholders from ecosystem services in Los Roques we employed a mix-method approach (Dominguez and Hollstein, 2014). We conducted semi-structured interviews in several islands of the archipelago as part of a socio-economic assessment (Cavada-Blanco, 2018), triangulating the information obtained with key informants, discussion groups and participating observation. The sampling frame was established from the list of concessions and permits granted by the MPAs' authorities. We used convenience and snowball sampling to interview a total of 161 people: 33 lodge managers (53% of all lodges), 110 fishers (55% of licensed fishers), the only two local fish processors in the MPA, the owners and members of staff from all three dive shops, totaling 10 people, two fish carrier captains and four board members of the two boaters' cooperatives operating in the MPA. Interview guides were slightly modified for each stakeholder group,

TABLE 1 | Nodes within a Socio-Ecological Network (SEN) based on the flow of economic benefits derived from fisheries and tourism, the main human uses within Los Roques National Park, a multi-use MPA in the southern Caribbean.

Nodes	Node attribute	Description
Stakeholders	Lodges	Accommodation facilities within the MPA, ranging from 34 to 3 rooms capacity (*n* = 44).
	Fishers	Local fishers licensed. We used fishing boats as nodes because shares of catch among crew varied greatly depending on the gear and fishing season (*n* = 66).
	Fish processors	Locally known as "tableros," these are individuals who process the fish at the landing sites and sell it to lodges and residents (*n* = 2).
	Lobster nurseries	These are makeshifts nurseries kept by local fishers' families, where fishers' spiny lobster catch is kept alive until the authorities make an official "weighing" and certify the catch as compliant and ready to be sold to the authorized Fish carriers (*n* = 3).
	Fish carriers	Small (13-24 m LOA) trollers, longliners and decommissioned stern trawlers, which have been modified as wet and freeze fish carriers. There are only six carriers authorized to buy the MPAs catch that is not locally consumed (*n* = 2).
	Touristic boat cooperatives	We included the cooperatives as a node instead of individual boaters because work and payment are managed by the association and most boaters are also fishers (*n* = 2).
	Dive shops	Dive shops operating daily SCUBA trips from Gran Roque. Diving sites are fixed and authorized by the parks' authority (*n* = 3).
Services	Provisioning (fisheries)	Following Molberg and Folke (1999) and Mumby et al. (2014) we considered fisheries catch including the yearly Caribbean spiny lobster (*Panulirus argus*) as a provisioning service.
	Regulating (Structure and coastal protection)	We mapped the following activities to the maintenance and formation of cays and beaches and wave reduction: kitesurf, paddling and beaching, because >90% of interviewees revealed preferences included "calm water," "white sands" and "beach options provided by numerous cays." (Molberg and Folke, 1999; Mumby et al., 2014; Woodhead et al., 2019)
	Support (Biodiversity maintenance)	We mapped SCUBA diving and snorkeling activities to the maintenance of biodiversity, for >75% of interviewees revealed preferences included diversity of corals, fish and probability of sighting megafauna (sharks, eagle rays and sea turtles) (Molberg and Folke, 1999; Mumby et al., 2014; Woodhead et al., 2019)

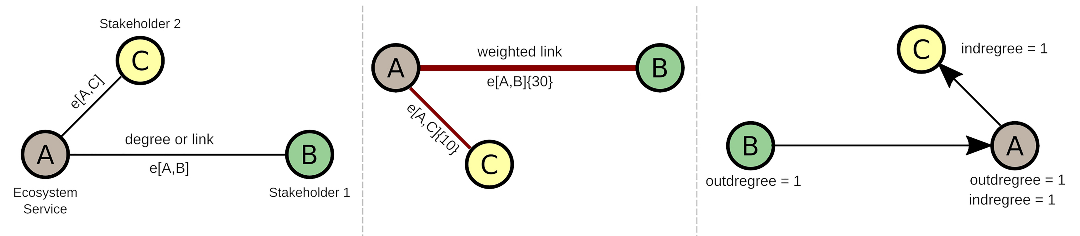

FIGURE 2 | Diagram of a minimum socio ecological network (SEN) configuration for simple, weighted and directed edges or links, where a link between two nodes is realized when each either obtains or transfers an economic benefit derived from an ecosystem service node.

but all contained a combination of closed and open-ended questions to capture quantitative and qualitative data about: (i) benefits directly and indirectly obtained from ecosystem services in the MPA, and (ii) knowledge and perception of the MPA management, resource governance and access rights (see **Supplementary Materials**).

As wholesale touristic packages can cause homogeneous groups of tourists to be found in the MPA for periods of weeks at a time, we designed questionnaires for tourists to be self-administered to better capture variability among tourist groups (i.e., people from the same country and with similar income might share the same values). After piloting the questionnaire ($N = 35$) and based on response time and clarification requests, a mix of closed and open questions were included to verify data on travel cost and get information on stated and revealed preference for recreational activities (see **Supplementary Materials**). A total of 250 questionnaires in both Spanish and English were left on the counter of several lodges and dive shops. Questionnaires were made available to tourists between August 2014 and January 2015 (high season) and were collected twice a week by two local key informants. In total only 124 questionnaires were fully completed and collected.

We also interviewed leaders of community associations (i.e., community council, fisher's council, the local schoolteachers, local tourism chamber heads) and on-site officers from INPARQUES, the fisheries authority (INSOPESCA) and the TIFM several times to: (1) assess management structures, resource governance, and conflict resolution mechanisms (2) verify information obtained through discussion groups and observation and (3) verify how working plans and regulations are implemented. Official and ancillary data (i.e., reports, ordinances, decrees and other documents) were used to increase our understanding on, and characterize, the management and institutional context of the MPA. Semi-structured interviews and unstructured group discussions took place after verbal consent was granted by all interviewees and participants. During verbal consent, participants were informed about the project, its purpose, and how the data would be stored and utilized. Participant's names were not recorded, except for key informants who requested to stay anonymous when disseminating results. Information was recorded through notetaking, transcribing rich-qualitative data verbatim when possible. Results were presented to the community between November 2015 and February 2016 through five workshops. This project was administered by Universidad Simón Bolívar, which does not have a Review Board for research ethics regarding social science surveys.

Estimation of Weights

After evaluating all the qualitative and quantitative data obtained, we were able to only map part of the benefits derived from provisioning, support and regulation, ecosystem services related with tourism and fisheries following Molberg and Folke (1999). The gross benefit in US dollars that each node received was calculated using a combination of methods (i.e., stated market value, income factors and travel and replacement cost following Mumby et al., 2014 and Koetse et al., 2015) for direct and indirect uses. The method applied depended on the ecosystem service being valued and the stakeholder's group each node in a pair belonged to (see **Table 2**). This was done to avoid double counting the contribution of any given service, as many ecological processes can be involved in the delivery of two or more of such services (Van Beukering *et al.,* 2015).

To partially control for this, we used weighted ranks when information was available to do so (i.e., on revealed preferences for activities related with tourism). When estimating the weights for benefits derived from fisheries, we allocated the same proportion of benefits to each of the ecosystem services nodes in our network. This was because the relative importance of processes responsible for the delivery of supporting and regulating ecosystem services on the provision of fish biomass is difficult to establish without site-specific information of ecological processes (Darling et al., 2017; Agudo-Adriani et al., 2019), which is not available for the study site. This approach might overestimate the economic benefits obtained by the MPA's stakeholders as it uses gross benefit for weighed links; however, it provides a good representation of the benefits obtained by stakeholders relative to each other. Therefore, allowing to investigate the structure of the SEN and the flow of such benefits. In recognition of this caveat, we present the results and discuss them in relative terms to the total economic benefits captured by our SEN.

Network Analysis

The SEN topology was assessed using a set of global metrics to better understand the structure of the system and how the benefits derived from the ecosystem services assessed above are shared among stakeholders. These metrics included the network's diameter (d), density (D), the average shortest path (l), the average degree per node, and assortativity (Newman, 2001). These were estimated for both the simple and weighted networks. The network's density reflects the relation between the number of existing links and the maximum possible links of the network (Janssen et al., 2006). Here, it provides information about efficiency and equality in the distribution of benefits. The diameter represents the maximum shortest geodesic path between any two nodes in the network and in a general sense, it provides information about the maximum number of people connected through benefits that can be mapped to ecosystem services. We used the average shortest path to estimate the average number of intermediaries in the flow of benefits.

A nodes' degree is the number of links it has with other nodes (Newman et al., 2006), and if weighted, represents the magnitude of benefits received from the ecosystem services nodes. A high value in a node's degree provides information about the different ways in which that node receives (indegree) and passes-on (outdegree) such benefits to other stakeholders. Finally, a network's degree assortativity is a scalar value that can take values between −1 and 1 and provides information on whether nodes with similar average degrees tend to be connected to each other. A network is disassortative when nodes with higher degree are, on average, connected to nodes with lower degree and assortative when nodes with similar average degrees are, on average, connected to each other (Noldus and Van Mieghem, 2015). Here, a disassortative weighted network would suggest that most stakeholders benefited from ecosystem services through various paths and are less dependent on just a few nodes.

To answer specific questions relating to management and adaptation to change in the delivery of the services included

TABLE 2 | Description of weight estimation for edges or links between nodes within a Socio-Ecological Network (SEN) in Los Roques National Park, a multi-use MPA in the southern Caribbean. Variables used and data sources are provided in **Supplementary Materials**.

Node pair	Edge's weight estimation
Ecosystem services –Fishers	Sum of total fish and lobster sold in 2014, after adjusting each by the number of fishers in the boat and their corresponding share.
Ecosystem services – Lodges	Structure, coastal protection and biodiversity maintenance: average gross income in 2014 based on number of guests and cost of accommodation, weighted by the rank of guests' revealed preferences. Provisioning: total spent in fish per Kg during 2014 multiplied by the average on-site cost per Kg of non-fish animal protein in the same period
Ecosystem services – Dive shops	Structure, coastal protection and biodiversity maintenance: average gross income in 2014 based on number and price of dives sold, weighted by the rank of divers' revealed preferences.
Ecosystem services – Boaters	Structure, coastal protection and biodiversity maintenance: average gross income in 2014 based on number and price of trips made, weighted by the rank of tourists' revealed preferences.
Fish processors, carriers, and lobster nurseries	Difference between market value of fish and lobster bought and market price of fish and lobster sold in 2014.

in our SEN, we calculated a group of metrics for node-level properties:

Key intermediaries

We calculated the intermediation centrality of each node to identify those stakeholders that are important intermediaries in the flow of benefits through the SEN. This metric estimates the number of possible paths in which the node participates. Additionally, the SEN centrality relative to the maximum number of intermediation centrality for each node was calculated to estimate the relative importance of these nodes in the flow of benefits. These metrics were estimated in both the simple and weighted networks.

Relative importance in the delivery of benefits

To determine from which of the mapped ecosystem service stakeholders obtained the most economic benefits, we normalized the total degree weight of the weighted network by the number of degrees for each ecosystem service. To explore if this relative importance is constant across stakeholder groups, the average distance between each ecosystem service node and each stakeholder node was calculated in both the simple and weighted networks and aggregated by stakeholder group. The rate of variation in the perceived benefit, or how the perceived benefit changes as it passes from one node to the other, was also estimated as the difference between the average weighted distance from the ecosystem service per stakeholder group and the average distance in intermediary nodes.

Vulnerable groups

We assessed which stakeholder would be most affected by a reduction in the total amount of benefits perceived, relative to each of the ecosystem services included in the SEN. For this we used alpha centrality, as it considers a given value that is exogenous to the node's attributes, which is then used in estimating the importance of a node relative to those it is connected to. A node is important if it is connected to others with many links *and* if it has a high exogenous value (Bonacich and Lloyd, 2001). The vector of exogenous values used to estimate alpha centrality was calculated by the difference between the weighted indegrees and the weighted outdegrees, both normalized by the total number of indegrees and outdegrees per node, respectively.

To identify which components of the SEN are key for the flow of benefits among stakeholders, the articulation of each node was calculated. This provides information of which nodes in the SEN reduce connectivity when removed, disrupting the flow of benefits through the network.

Cooperation among stakeholders

According to Barnes et al. (2019b) network closure can provide information about resource and knowledge sharing among stakeholders. Therefore, the number of triangles formed within a network, is a proxy of cooperation and knowledge sharing among stakeholders (Bodin et al., 2014). For common-pool resources, such as coral-reef fisheries, this cooperation is important in facilitating their adaptation to changes (Barnes et al., 2017). For the specific case of our networks, where links represent shared benefits from ecosystem services, network closure could facilitate a collective recognition of change in their provision. To investigate the potential for cooperation among stakeholders, we estimated the number of total triangles within the SEN and those formed by nodes with different attributes using the simple network.

Global and node-level metrics were calculated using the package igraph version 1.2.4.1 (Gabor Csardi, 2019) in R (R Core Team, 2018). The network data is available upon request in: https://github.com/fcavada/Network_analysis_SES/blob/main/README.md.

RESULTS

Los Roques economy is dependent on tourism and local small-scale fisheries. Lodges employ 20% of the local population, recreational activities provide income to 19% and fisheries to 18%. Local fishers or "*roqueños*" as they called themselves, composed 75.86% of respondents, while the other 20.69% who responded to the question on whether they lived in the MPA, were those who went to Los Roques to fish during specific seasons.

There are two main fishing seasons: between April and June fishers target various species of snappers (mainly *Lutjanus analis*, *L. griseus*, *L. vivanus* and *Ocyurus chrysurus*) and almost all dedicate the period between October and the end of January to the official Caribbean spiny lobster (*Panulirus argus*) season, when the season is officially open (G.O 40,279, 2013). Throughout the year, catch composition is dominated by barracuda (*Sphyraena barracuda*), cero mackerel (*Scomberomorus regalis*), jacks (*Caranx hippos*, *C. lugubris*), permit (T*rachinotus falcatus*), little tunny (*Euthynnus alletteratus*), several species of sharks (i.e., *Carcharinus limbatus*) and rays, mainly the spotted eagle ray (*Aetobatus narinari)*. A more detailed description about this small-scale fishery is provided in **Supplementary Materials**.

In 2014, a total of 38,094 tourists traveled to the MPA, 62% of which were national tourists. According to the MPA's entrance registration record, 57% of national tourists visited on full-day packages. We obtained responses from only 4.8% of the total tourists who entered the MPA and stayed at least one night within the period questionnaires were available. Due to this, only ranked revealed activities were used from the questionnaires to map the SEN links while benefits were calculated from INPARQUES records of entries and market prices (see **Supplementary Materials**). Length of stay ranged between one and 15 nights, with the response's frequency mode at four nights and the lodges' capacity, calculated as number of beds, ranged between eight and 38, with most (56%) having 16 or more. Most (40%) of the lodges in the MPA were owned by Europeans at the time of the study, with only 6% of all lodges interviewed owned by "*roqueños*". All tourists who responded to the questionnaires had a university level degree and the majority of international tourists were from south America, with Brazil (11%) and Argentina (34%) representing the two most frequent countries of origin. Twenty three percent of questionnaires were responded by Venezuelans. The rest were completed by people from six different countries in North America and Europe.

Network Metrics

The gross benefit received by the SEN's stakeholders from the ecosystem services considered here totaled just over USD $52 million with an average of USD $70,000 ± 24,000 received by node in 2014. The relative amount for each stakeholder ranged between $1,444.69 ± 103.7 year^{-1} obtained by fish processors to $157,524.07 ± 10,470 year^{-1} obtained by fish carriers (**Table 3**). To provide some perspective of the benefits derived from Los Roques' coral reefs, for the same year, the legal minimum salary was $645.00 year^{-1} when adjusted by the exchange rate[1]. However, these estimates should be analyzed in relative terms, as they do not represent net benefits. This is especially true for fish carriers whose benefit are realized once outside of the SEN.

The SEN formed one connected component (**Figure 3**). The average shortest path of the SEN was 2.1 (close to its diameter $d = 3$), suggesting that most stakeholders benefit directly from the ecosystem services or through one intermediary, and that, on average, only 19.14% of the total gross economic benefits flows through the SEN. This is reflected by the SEN assortativity (($\rho = -0.64$) and the degree distribution of the directed network. Forty eight percent of nodes had one or two indegrees (i.e., paths through which it receives benefits) and 37% had no outdegrees or paths to transfer the received benefits to other stakeholders inside the boundaries of the SEN. Based on the proportion of nodes without outdegrees, most (80.86%) of the economic benefits derived from the ecosystem services is kept by less than half of stakeholders in the SEN, or is transferred to stakeholders outside the MPA.

Key intermediaries

The highest values for intermediation centrality on both the simple and weighted networks, corresponded to the two fish processors, followed by one of the three dive shops, and all lobster nurseries (see **Supplementary Material**).

Relative importance in the delivery of benefits

Regulation services provided 50.24% of the average benefits obtained by stakeholders, followed by support (25.58%) and provisioning (24.16%). This importance varied among stakeholder groups (**Figure 4**). Accounting for both direct and indirect paths of obtaining a benefit, provisioning services provided most of the benefits obtained by fish carriers (95.3%) and lodges (38.5%), regulation services provided most of the benefits obtained by dive shops (43%) and concomitantly with support services to fishers (28 and 36%, respectively), nurseries (41 and 38.9%, respectively) and boaters (36.8 and 47.3%, respectively). The three services provided almost equal proportions of economic benefits to fish processors (**Figure 4**).

Vulnerable groups

The network's density (D = 0.0056) suggests that the flow of benefits through the SEN is not homogeneous among stakeholders. The average distance between the ecosystem service and stakeholders' nodes, indicated that the flow of benefits to fishers is direct only for provisioning services, with distance increasing on average to nearly three intermediaries for benefits coming from the support and regulation services (**Table 4**). Indeed, alpha centrality also suggested that fishers are the group most vulnerable to a decrease in the delivery of provisioning services (average ®-centrality = 0.014 ± 0.22).

Although provisioning services provided most of the benefits obtained by many stakeholders (lodges, fish carriers and directly benefiting fishers), regulation services were the most important in keeping the flow of all benefits through the SEN. This was the only node that completely disarticulated the network when its link with other nodes was removed.

Cooperation among stakeholders

In total there were 82 triangles in the SEN. Both fish carriers nodes participated in 28 triangles, the three dive shops nodes participated in 27, and a total of 12 fishers participated in 23 triangles. The other four triangles were formed by lobster nurseries and eight lodges. The number of triangles to which each node belongs indicated that connectivity among stakeholders, in terms of benefits transferred, is mediated by intermediaries. Fish carriers and dive shops were the nodes participating in most of the SEN's triangles.

DISCUSSION

Equitability in the Distribution of Benefits

As the most implemented approach in coral-reef MPAs (Maestro et al., 2019), ecosystem-based management is focused on the relationship between ecosystems and people, with management strategies aimed at securing the delivery of ecosystem service benefits (Barbier et al., 2008; Levin and Lubchenco, 2008). However, the way in which people benefit from ecosystem services depends on how they access them (Hicks and Cinner, 2014). Analysis of the directed, weighted SEN indicates that the proportion of economic benefits from the provisioning, regulation, and support services evaluated are unevenly distributed among stakeholders in Los Roques.

[1]Exchange rate used here is 90.95 bolivars per US dollar, estimated from the geometric mean of the monthly exchange rate accessible through the only alternatives currency market (non-government regulated).

TABLE 3 | Average gross economic benefit obtained by the main stakeholder's group from ecosystem services through tourism and fisheries in Los Roques National Park, a multi-use MPA in the southern Caribbean in 2014.

Stakeholder's group	Benefit in USD (average ± standard deviation)
Fish processors	1,444.69 ± 103.7
Fishers	1,892.17 ± 507.3
Lodges	70,645.19 ± 45,501
Fish carriers	157524.07 ± 10,470

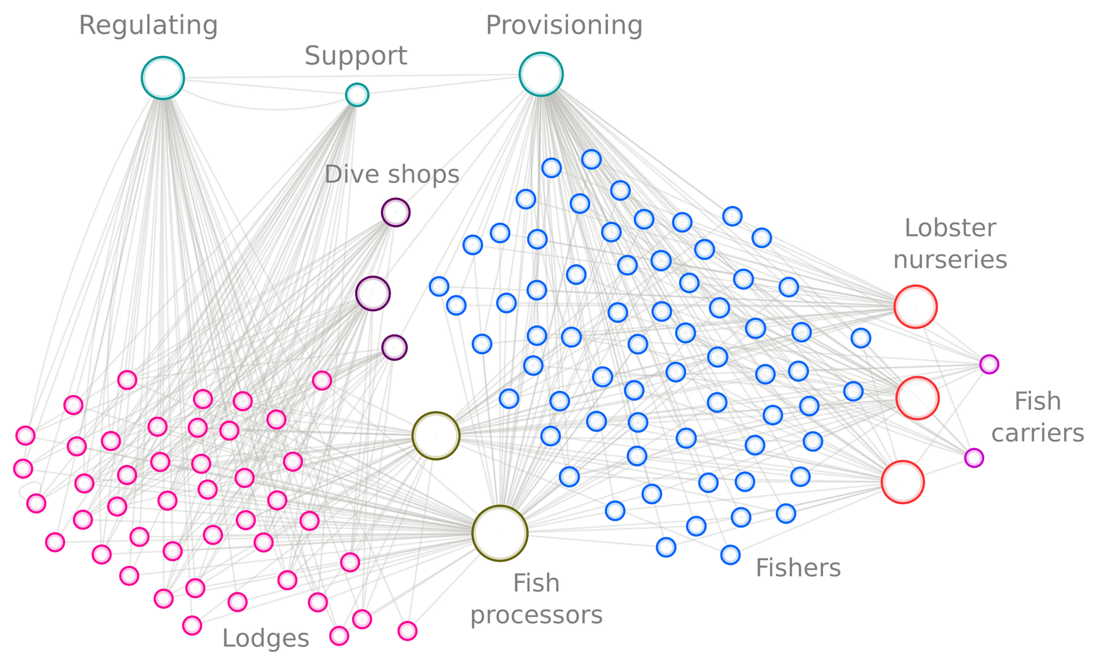

FIGURE 3 | Socio Ecological Network representing the flow of economic benefits through stakeholders in Los Roques National Park during 2014 and derived from ecosystem services through fisheries and tourism. The size of nodes represents its value of intermediation centrality.

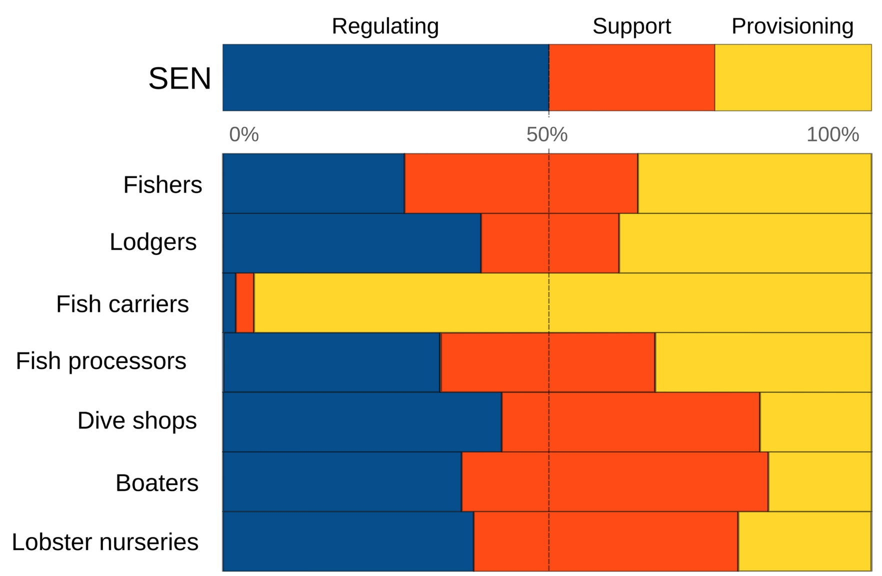

FIGURE 4 | Relative importance of the ecosystem services included within the socio ecological network (SEN) based on the amount of benefits flowing through the SEN and received by each stakeholder group.

Fish carriers and lodges obtain higher benefits from these services, benefiting the most from fisheries through indirect pathways. In contrast, fishers and fish processors are the group of stakeholders most vulnerable to a decrease in benefits from provisioning services within the MPA. Although fish carriers and lodges received the most benefit from provisioning services, their income is not directly dependent on this fishery. Fish carriers buy fish from other fisheries in the country, and lodges can transfer to customers the costs associated with substituting fish protein by alternative sources. In contrast, fishers and fish processors receive the lowest proportion of benefits from provisioning services, though their income is obtained directly from fisheries. This suggests that access mechanisms in the MPA could be causing

TABLE 4 | Average path length (± standard deviation) between each ecosystem service and stakeholder's group within Los Roques National Park's socio-ecological network (SEN).

	Stakeholder group (node attribute)						
Ecosystem Service	**Lodges**	**Dive shops**	**Fishers**	**Fish processor**	**Fish Carrier**	**Tourism Boaters**	**Nurseries**
Support	1.22 ± 0.03	2.00 ± 0.00	3.05	2.54 ± 0.05	2.00 ± 0.00	1.05 ± 0.23	4.62 ± 2.11
Regulating	2.00 ± 0.00	2.00 ± 0.00	3.00 ± 0.00	2.67 ± 0.02	3.00 ± 0.00	3.015 ± 0.81	3.54 ± 1.03
Provisioning	2.34 ± 0.02	1.00 ± 0.00	1.00 ± 0.00	2.00 ± 0.00	2.00 ± 0.00	4.21 ± 2.05	2.15 ± 0.02

externalities among stakeholder's groups (Costanza et al., 2014; Bouma, 2015).

The steep inequality in the benefits received from provisioning services between lodges and fish carriers compared to fishers and fish processors is caused by the economic and institutional mechanisms modulating how fishers can access economic benefits from fisheries. In Los Roques, fishers' access to provisioning services is mediated by regulations that can be enforced simultaneously by different government bodies controlling fishing areas and seasons, gear types, and catch composition. These regulations have also provided fish carriers, and to a lesser degree lodges, indirect control on how fishers access provisioning services through market prices. For example, fisheries production can only leave the archipelago through a few authorized fish carriers, in the specific case of spiny lobster, once the catch is weighted and minimum allowable catch size is verified by officers from three different authorities. Lodges constitute the local market, while fish carriers are the only mean to access national markets, therefore these stakeholders' can control the economic benefits that fishers receive from fisheries. For example, in 2015 fish carriers fixed the buying price for lobster 60% below that agreed by fishers and lobster's nurseries. According to representatives from the fisher's council interviewed at the time, fishers felt obliged to sell at loss having no access to other buyers and with a shrunken local economy due to the decline in outbound tourism and the increasing economic and political crisis in the country (Parnell and Parnell, 2019). This suggest that inequality in the access to ecosystem services benefits might be driving fishers in Los Roques into a socio-ecological trap (Cinner, 2011; Barnes et al., 2017).

Fishers and fish processors are the group of stakeholders most vulnerable to a decrease in benefits from provisioning services within the MPA. Although fish carriers and lodges received the most benefit from provisioning services, their income is not directly dependent on this fishery. Fish carriers buy fish from other fisheries in the country, and lodges can transfer to customers the costs associated with substituting fish protein by alternative sources. To compensate for changes in the access to these services, fishers can seek other access mechanisms to reduce their risk (Coulthard, 2012). Most local fishers interviewed (62%) told us they have started to sell most of their catch to fish carriers without reporting, which can be considered an illegal practice. The latter engage in transshipment as fish from the MPA was increasingly being sold to Bonaire and Aruba at higher prices and in foreign currency. To supply this demand, fishers have started to target smaller reef fish species. Fishing down these key species can create positive feedbacks through reef degradation (Mumby and Steneck, 2008) decreasing future options for adaptation to changes in the socio-ecological system driven by climate change (Cinner et al., 2018).

Adaptation to Change

The SEN's structure and closure showed that most benefits derived from ecosystem services are not shared among members of the same stakeholders' group, but instead are obtained directly as open resources (Fox et al., 2012). Due to centralized MPA access rights, rapid changes in resource governance driven by the imposition of the TIFM, have compromised common institutions and reduced social capital, which can lead to overexploitation (Basurto, 2005; Ostrom, 2009; Basurto et al., 2012).

Since 2011, when the TIFM was created, local stakeholders lost participatory and conflict resolution mechanisms, and experienced an overall loss of trust in other stakeholder groups. This has driven change in the ecological system as resource users have modified their patterns of use to reduce vulnerability (McLaughlin and Dietz, 2008). The rate at which societal and economic factors change, and the level of direct communication and trust among actors are important to achieve successful resource governance (Dietz et al., 2003; Ostrom, 2009; Folke et al., 2011). At the time we conducted interviews and informal discussions with fishers, the place where the fisher's council met, and all fishers got their supplies from, was shut down by the TIFM. Although this was presented as a temporary action, most fishers felt their ability to organize was severely affected. Discussions about relocating all landing sites and congregation points of fishers out of the main island of Gran Roque to improve the island's aesthetic undermined trust in the new authorities, and increased conflict among fishers, lodges, and boaters. A "coexistence law", put in place by the TIFM in late 2013, imposed many changes in local's daily lives within the island of Gran Roque. Simultaneously, illegal fishing by outsiders had increased with impunity and at least two people who complained publicly in community-council's assemblages were put in jail for a week. This further exacerbated the loss of social capital among stakeholders and increased conflict.

Changes in both access and constitutional rules might have decreased social capital among the different stakeholder's groups, compromising the system's resilience (Crona et al., 2011; Folke et al., 2011; Cinner et al., 2016; Pulver et al., 2018). Knowledge sharing and collective agency are more likely to happen in a SEN where links among actors sharing resources exist (Barnes et al., 2017; Dalege et al., 2017). In Los Roques SEN, fish carriers' nodes participated in most of the triangles formed, but only 20% of the fishers' nodes did. This configuration of the SEN could explain how Fish carriers adapted to the reduced local and national economy by supplying more lucrative near-by international markets. As they have control over how fishers' access economic benefits from fisheries and are in most the SEN triangles, fish carriers are able to better share knowledge and elicit collective action (Pelenc et al., 2013). Indeed, this "adaptation strategy" would not be possible acting alone, but with the cooperation of most fishers.

As argued by Coulthard (2012) actors can still make choices to adapt to change even if they reduce the overall resilience of the socio-ecological system. In all our informal discussions and interviews with fishers, they would acknowledge many "*other*" fishers were now fishing inside no-take zones and targeting parrotfishes, as carriers would only buy "*white meat*" fish which is "*scarce outside shallow reefs except during the snapper season*". Fishers treated this as a sensitive subject even though it is not illegal to catch parrotfishes in Venezuela, often acknowledging the importance of these fishes for the reef's health and adding they saw no other choice. Contrasting with lodge managers and owners, fishers had good knowledge and understanding of how reef's health is important for fisheries (Cavada-Blanco, 2018). Indeed, in the face of change, local economy can be a determinant factor in fishers' choices (Daw et al., 2012) with crisis historically increasing overexploitation and dependence on fisheries within the country (Rodríguez, 2000).

Though provisioning services was the most important of the three ecosystem services included in the SEN in terms of direct benefits, regulation services were responsible for keeping the flow of benefits among stakeholders. The shift towards smaller reef fish species in response to changes in access to benefits from provisioning services is generating a trade-off between these two services (Rodríguez et al., 2006; Brown and Mumby, 2014). Overexploitation, especially of herbivores can accelerate the degradation of coral reefs (Mumby and Steneck, 2008). However, as the benefits associated with regulation services in the SEN derive mostly from recreational activities dependent on reef framework and sanitation, a reduction in the delivery of this service will likely not affect its benefits at the pace it will those obtained from fisheries (Rogers et al., 2014; Roff et al., 2015; Kuffner et al., 2019).

This trade-off is important in maintaining future options for adaptation, as the capacity to keep reefs and other key ecosystems, such as mangroves and seagrass meadows, protected is also extremely reduced in Los Roques. Enforcement capacity has never been good in the MPA (Trujillo and Posada, 2007) and has been reduced abruptly in recent years. Previously less than ten rangers and four boats patrolled a little over 200,000 hectares of mostly open ocean, now that capacity has decreased to less than half. At the time of our interviews, INPARQUES had only three rangers on site, none of the patrol boats were in working conditions and most permanent surveillance points across the archipelago were unfit for use. Patrols had reduced from twice a month to once every three or four months excluding the southern barrier and north-west cays of the archipelago, which were too expensive to reach. The former harbors most of the MPAs' reefs in good and excellent condition (coral cover > 40 and 50% respectively; Cavada-Blanco et al., in revision) and potential reproductive aggregation sites for several species of groupers and snappers (Romero et al., 2011).

Low enforcement capacity seemed not to have compromised the MPAs' conservation value in the past. Los Roques is considered as one of the few healthy coral reefs in the Caribbean (Jackson et al., 2014). Abundance of key species such as parrotfishes was the highest of the region at the beginning of this century (Choat et al., 2003; Posada et al., 2003). Indeed, the MPA has several of the attributes identified as key for effective coral reef MPAs (Edgar et al., 2014): it is the oldest in the Caribbean, its area is > 100 Km^2, it can only be accessed by sea or air, and the effective area of human influence was small and localized. These factors have provided Los Roques high conservation value for threatened reef-building corals (Zubillaga et al., 2008; Cavada-Blanco et al., in revision) and key reef species (Posada et al., 2003; Trujillo and Posada, 2007; Tavares, 2009). However, signs of reef degradation due to bleaching and coral disease epizootic events (Cróquer et al., 2003, 2005; Bastidas et al., 2012; Croquer et al., 2016), decline of reef fish species (Agudo-Adriani et al., 2019) and overexploited stocks due to damaging fishing practices (i.e., depletion of Nassau grouper's reproductive aggregations; Boomhower et al., 2010) have been reported in recent years, signaling the potential loss of its value to conserve coral reefs and key threatened marine species.

Management

The opportunity cost of reef degradation and overfishing is high for Los Roques SEN. Two thirds of stakeholders are highly dependent on provisioning services and tourism-related activities provide income to half the local residents. Moreover, market distortions created by numerous government subsidies (i.e., fuel, staple food, household electronics, boats and offboard engines) in Los Roques can increase the vulnerability and livelihood dependence (Daw et al., 2012) of not only fishers but, as shown by our SEN, also lodges and other tourism-related actors who depend on provisioning and regulation services. Internalization of externalities produced by unequal taxation and budget allocation to maintain natural capital (Bennett and Dearden, 2014) could help increase management capacity. But caution must be taken, for the methods used here overestimate the net amount of benefits accessed by stakeholders. However, estimations of value made here are below others previously made. Spalding et al. (2017) reports a value in total dollars per km^2 of reef per year, considering only tourism and recreation of > \$352,000 for a third of Los Roques reef area[2]. That is almost the same value that the mean value per km^2 estimated for all reefs in the country (\$386,911) and is higher than those estimated for six island nations in the Caribbean (Spalding et al., 2017). Likewise, benefits from fisheries are high in Los Roques. For example, compared with Tobago, coral-reef associated fisheries in Los Roques produces three times the amount of economic benefits (Burke et al., 2008), though this is not standardized by fishing effort.

[2]www.oceanwealth.org

As shown by the average path length of the SEN, most of the economic benefits derived from fisheries and tourism leave the MPA and there is no re-investment in maintaining the delivery of these services. Less than 1% of the total gross benefit obtained from tourism and fisheries flowing through the SEN is taxed by local authorities (SATIM, 2015). Further increasing trade-offs among fisheries and tourism, the MPA's entrance fee paid by tourists is collected by the TIFM and not the park's management body. INPARQUES' total budget for operation in 2015, excluding salaries, was 0.0001% the amount collected by entrance fees alone. Appropriately reallocating monies derived from entrance fees to the park's management body could increase the MPA's management capacity significantly and help reduce trade-offs between fisheries and tourism, even if internalization through taxation is not pursued (Ansink and Bouma, 2015) which has proved effective in other Caribbean MPAs (Hawkins et al., 2005). To realize the high potential that user fees have to generate revenue to increase and maintain management capacity of MPAs, profound institutional change at the executive level of government would be needed to stop centralization of monies taxed for ecosystem services (Kushner et al., 2012). this is widely recognized as a barrier to financial sustainability of protected areas (Depondt and Green, 2006; Emerton, 2006).

Priority should be given to rescuing, strengthening and fostering social capital. Improving stakeholder's engagement through participatory management of resources can improve compliance and reduce the need for enforcement capacity (Cinner et al., 2016; Giakoumi et al., 2018; Halik et al., 2018), helping fisher's escape the socio-ecological trap caused by restricted and unequal access to ecosystem services benefits (Hicks et al., 2009). Fish processors and dive shop staff, as highly connected nodes could be leverage points to increase the transfer of information among fishers, lodges and boaters (Barnes et al., 2019b).

Ecosystem service valuation can help increase sustainable approaches to coral reef tourism (Spalding et al., 2017; Wongthong and Harvey, 2014) to reduce its impacts on natural systems and wildlife (Trave et al., 2017). However, inequalities in the access to those benefits can exacerbate indirect drivers of biodiversity loss (Hicks and Cinner, 2014; Daw et al., 2016), something that is often overlooked (Mastrángelo et al., 2019). Network's local metrics of SENs such as those used in this case-study, could improve our understanding on the dynamics between ecosystem services availability, benefits and access mechanisms. Network theory applied in modeling socio-ecological systems can also help in identifying interdependencies between the social and ecological components of MPAs, improving the implementation of both, ecosystem and resilience-based management frameworks (Bellwood et al., 2019; Mcleod et al., 2019). SENs can also be used to test the incorporation of ecosystem service valuation into management interventions, helping in lowering some of the barriers for realizing the potential of market-based strategies to protect coastal ecosystems (Balvanera et al., 2012; Vanderklift et al., 2019).

The SEN's topology and structure concomitantly with information about the management and governance context in Los Roques and the perception of stakeholders on these, show how rapid changes in governance, political allocation of resources, and inequalities can quickly decrease the conservation value accrued by an MPA for more than forty years; also reducing the capacity of its socio-ecological system to adapt to environmental change in a way that increases its resilience (Cretney, 2014; Sterk et al., 2017; Johnson et al., 2020). The SEN allowed the identification of critical interactions among components that are driving the MPA towards a socio-ecological trap and potential leverage points to escape such trap. Furthermore, being able to incorporate measures of benefits from ecosystem services within the SEN using data mostly recorded already by stakeholders, makes this approach useful even in MPAs with reduced management capacity. Although this is a case-specific study, its findings illustrate how site-level factors should be accounted for when setting international agreed targets for biodiversity conservation when actions to achieve such targets depend on national-level implementation.

With increased coverage of area-based protection being put in the fore of the post-Aichi biodiversity framework (Locke, 2015; Waldron et al., 2020), the site and context-specific nature of factors determining the effectiveness of management interventions in MPAs (Basurto, 2005; Ostrom, 2009; Daw et al., 2012; Cinner et al., 2016) should be considered for when setting targets. In Latin America, where centrally managed budgets cater to national priorities (Kushner et al., 2012), political allocation of resources is common (Leon, 2014) and strong government management can decrease the ability of socio-ecological systems to cope with change (Hicks et al., 2009; Brown and Mumby, 2014; Johnson et al., 2020). Adoption of appropriate management and governance indicators that incorporate interdependencies within socio-ecological systems, and provides accountability for their reporting, will be crucial to avoid area-based protection targets from driving positive feedbacks through increased inequality and poverty (Schleicher et al., 2019; IPBES, 2019).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FC-B conceived the study. FC-B and AC were in charge of overall planning. FC-B wrote the manuscript with support from AC, JR, and EY. JR and EY verified the results and contributed to the design of the research. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.671024/full#supplementary-material

REFERENCES

Agudo-Adriani, E. A., Cappelletto, J., Cavada-Blanco, F., and Cróquer, A. (2019). Structural complexity and benthic cover explain reef-scale variability of fish assemblages in Los Roques National Park, Venezuela. *Front. Mar. Sci.* 6:690. doi: 10.3389/fmars.2019.00690

Alonso Roldán, V., Villasante, S., and Outeiro, L. (2015). Linking marine and terrestrial ecosystem services through governance social networks analysis in Central Patagonia (Argentina). *Ecosyst. Serv.* 16, 390–402. doi: 10.1016/j.ecoser.2015.02.010

Ansink, E., and Bouma, J. A. (2015). "Payments for ecosystem services," in *Ecosystem Services: From Concept to Practice*, eds J. A. Bouma and P. J. H. E. van Beukering (Cambridge, MA: Cambridge University Press), 183–198.

Balvanera, P., Uriarte, M., Almeida-Leñero, L., Altesor, A., DeClerck, F., Gardner, T., et al. (2012). *Ecosystem Services Research in Latin America: The State of the Art*. Amsterdam: Elsevier.

Barbier, E. B., Koch, E. W., Silliman, B. R., Hacker, S. D., Wolanski, E., Primavera, J., et al. (2008). Coastal ecosystem-based management with nonlinear ecological functions and values. *Science* 319, 321–323. doi: 10.1126/science.1150349

Barnes, M. L., Bodin, Ö, Guerrero, A. M., McAllister, R. R. J., Alexander, S. M., and Robins, G. (2017). The social structural foundations of adaptation and transformation in social–ecological systems. *Ecol. Soc.* 22:16. doi: 10.5751/ES-09769-220416

Barnes, M. L., Bodin, Ö, McClanahan, T. R., Kittinger, J. N., Hoey, A. S., Gaoue, O. G., et al. (2019a). Social-ecological alignment and ecological conditions in coral reefs. *Nat. Commun.* 10, 1–10. doi: 10.1038/s41467-019-09994-1

Barnes, M. L., Mbaru, E., and Muthiga, N. (2019b). Information access and knowledge exchange in co-managed coral reef fisheries. *Biol. Conserv.* 238:108198. doi: 10.1016/j.biocon.2019.108198

Bastidas, C., Bone, D., Croquer, A., Debrot, D., Garcia, E., Humanes, A., et al. (2012). Massive hard coral loss after a severe bleaching event in 2010 at Los Roques, Venezuela. *Rev. Biol. Trop.* 60, 29–37.

Basurto, X. (2005). How locally designed access and use controls can prevent the tragedy of the commons in a Mexican small-scale fishing community. *Soc. Nat. Resour.* 18, 643–659. doi: 10.1080/08941920590959631

Basurto, X., Cinti, A., Bourillón, L., Rojo, M., Torre, J., and Weaver, H. H. (2012). The emergence of access controls in small-scale fishing commons: a comparative analysis of individual licenses and common property-rights in two mexican communities. *Hum. Ecol.* 40, 597–609. doi: 10.1007/s10745-012-9508-1

Bellwood, D. R., Hoey, A. S., and Hughes, T. P. (2012). Human activity selectively impacts the ecosystem roles of parrotfishes on coral reefs. *Proc. R. Soc. B Biol. Sci.* 279, 1621–1629. doi: 10.1098/rspb.2011.1906

Bellwood, D. R., Pratchett, M. S., Morrison, T. H., Gurney, G. G., Hughes, T. P., Álvarez-Romero, J. G., et al. (2019). Coral reef conservation in the Anthropocene: confronting spatial mismatches and prioritizing functions. *Biol. Conserv.* 236, 604–615. doi: 10.1016/j.biocon.2019.05.056

Bennett, N. J., and Dearden, P. (2014). Why local people do not support conservation: community perceptions of marine protected area livelihood impacts, governance and management in Thailand. *Mar. Policy* 44, 107–116. doi: 10.1016/j.marpol.2013.08.017

Bergsten, A., Galafassi, D., and Bodin, Ö (2014). The problem of spatial fit in social-ecological systems: detecting mismatches between ecological connectivity and land management in an urban region. *Ecol. Soc.* 19:6. doi: 10.5751/ES-06931-190406

Bisbal, F. (2008). The terrestrial vertebrates of the Federal Dependences of Venezuela. *Interciencia* 33, 103–111.

Boccaletti, S., Bianconi, G., Criado, R., del Genio, C. I., Gómez-Gardeñes, J., Romance, M., et al. (2014). *The Structure and Dynamics of Multilayer Networks*. Amsterdam: Elsevier.

Bodin, Ö, Crona, B., Thyresson, M., Golz, A.-L., and Tengö, M. (2014). Conservation success as a function of good alignment of social and ecological structures and processes. *Conserv. Biol.* 28, 1371–1379. doi: 10.1111/cobi.12306

Bohan, D. A., Landuyt, D., Ma, A., Macfadyen, S., Martinet, V., Massol, F., et al. (2016). *Networking Our Way to Better Ecosystem Service Provision*. Amsterdam: Elsevier Ltd.

Bonacich, P., and Lloyd, P. (2001). Eigenvector-like measures of centrality for asymmetric relations. *Soc. Netw.* 23, 191–201. doi: 10.1016/S0378-8733(01)00038-7

Boomhower, J., Romero, M., Posada, J., Kobara, S., and Heyman, W. (2010). Prediction and verification of possible reef-fish spawning aggregation sites in Los Roques Archipelago National Park, Venezuela. *J. Fish Biol.* 77, 822–840. doi: 10.1111/j.1095-8649.2010.02704.x

Bouma, J. A. (2015). "Local governance of ecosystems and community co-management," in *Ecosystem Services: From Concept to Practice*, eds J. A. Bouma and P. J. H. E. van Beukering (Cambridge, MA: Cambridge University Press), 250–263. doi: 10.1017/cbo9781107477612.017

Brown, C. J., and Mumby, P. J. (2014). Trade-offs between fisheries and the conservation of ecosystem function are defined by management strategy. *Front. Ecol. Environ.* 12, 324–329. doi: 10.1890/130296

Bruno, J. F., and Selig, E. R. (2010). A global analysis of the effectiveness of marine protected areas in preventing coral loss. *PLoS One* 5:e9278. doi: 10.1371/journal.pone.0009278

Burke, L., Greenhalgh, S., Prager, D., and Cooper, E. (2008). *Coastal Capital: Economic Valuation of Coral Reefs in Tobago and St. Lucia. 66*. Available online at: http://www.wri.org/publication/coastal-capital (accessed May 12, 2018).

Cavada-Blanco, F. (2018). *Linea Base Socioecologica para la conservacion de corales amenazados en el PN Archipelago Los Roques*. Caracas: Universidad Simon Bolivar. [dissertation/doctoral thesis].

CBD (2010). The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets. Available online at: https://www.cbd.int/sp/ (accessed October 21, 2020).

Choat, J., Robertson, D., Ackerman, J., and Posada, J. (2003). An age-based demographic analysis of the Caribbean stoplight parrotfish Sparisoma viride. *Mar. Ecol. Prog. Ser.* 246, 265–277. doi: 10.3354/meps246265

Cinner, J. E. (2011). Social-ecological traps in reef fisheries. *Glob. Environ. Change* 21, 835–839. doi: 10.1016/j.gloenvcha.2011.04.012

Cinner, J. E., Adger, W. N., Allison, E. H., Barnes, M. L., Brown, K., Cohen, P. J., et al. (2018). *Building Adaptive Capacity to Climate Change in Tropical Coastal Communities*. London: Nature Publishing Group.

Cinner, J. E., Folke, C., Daw, T., and Hicks, C. C. (2011). Responding to change: using scenarios to understand how socioeconomic factors may influence amplifying or dampening exploitation feedbacks among Tanzanian fishers. *Glob. Environ. Change* 21, 7–12. doi: 10.1016/j.gloenvcha.2010.09.001

Cinner, J. E., Huchery, C., MacNeil, M. A., Graham, N. A. J., McClanahan, T. R., Maina, J., et al. (2016). Bright spots among the world's coral reefs. *Nature* 535, 416–419. doi: 10.1038/nature18607

Claudet, J., Osenberg, C. W., Benedetti-Cecchi, L., Domenici, P., and García-Charton, S. (2008). Marine reserves: size and age do matter. *Ecol. Lett.* 11, 481–489. doi: 10.1111/j.1461-0248.2008.01166.x

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., et al. (2014). Changes in the global value of ecosystem services. *Glob. Environ. Change* 26, 152–158. doi: 10.1016/j.gloenvcha.2014.04.002

Coulthard, S. (2012). Can we be both resilient and well, and what choices do people have? incorporating agency into the resilience debate from a fisheries perspective. *Ecol. Soc.* 17:4. doi: 10.5751/ES-04483-170104

Cretney, R. (2014). Resilience for whom? Emerging critical geographies of socio-ecological resilience. *Geogr. Compass* 8, 627–640. doi: 10.1111/gec3.12154

Crona, B. I., Ernstson, H., Prell, C., Reed, M., and Hubacek, K. (2011). "Combining social network approaches with social theories to improve understanding of natural resource governance," in *Social Networks and Natural Resource Management: Uncovering the Social Fabric of Environmental Governance*, eds Ö Bodin and C. Prell (New York, NY: Cambridge University Press), 44–72. doi: 10.1017/cbo9780511894985.004

Cróquer, A., Pauls, S., and Zubillaga, A. L. (2003). White plague disease outbreak in a coral reefs at Los Roques National Park, Venezuela. *Rev. Biol. Trop.* 51, 39–45.

Cróquer, A., Weil, E., Zubillaga, A. L., and Pauls, S. M. (2005). Impact of a white plague-II outbreak on a coral reef in the archipelago Los Roques National Park, Venezuela. *Caribbean J. Sci.* 41, 815–823.

Croquer, A., Cavada-Blanco, F., Zubillaga, A. L., Agudo-Adriani, E. A., and Sweet, M. (2016). Is *Acropora palmata* recovering? A case study in Los Roques national Park, Venezuela. *PeerJ* 4:e1539. doi: 10.7717/peerj.1539

Dalege, J., Borsboom, D., van Harreveld, F., and van der Maas, H. L. J. (2017). Network analysis on attitudes: a brief tutorial. *Soc. Psychol. Pers. Sci.* 8, 528–537. doi: 10.1177/1948550617709827

Darling, E. S., Graham, N. A., Januchowski-Hartley, F. A., Nash, K. L., Pratchett, M. S., and Wilson, S. K. (2017). Relationships between structural complexity, coral traits, and reef fish assemblages. *Coral Reefs* 36, 561–575.

Darling, E. S., McClanahan, T. R., Maina, J., Gurney, G. G., and Graham, N. A. J. (2019). Social–environmental drivers inform strategic management of coral reefs in the Anthropocene. *Nat. Ecol. Evol.* 3, 1341–1350. doi: 10.1038/s41559-019-0953-8

Daw, T. M., Cinner, J. E., McClanahan, T. R., Brown, K., Stead, S. M., Graham, N. A. J. J., et al. (2012). To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery. *PLoS One* 7:e31460. doi: 10.1371/journal.pone.0031460

Daw, T. M., Hicks, C. C., Brown, K., Chaigneau, T., Januchowski-Hartley, F. A., Cheung, W. W. L., et al. (2016). Elasticity in ecosystem services: exploring the variable relationship between ecosystems and human well-being. *Ecol. Soc.* 21:11. doi: 10.5751/ES-08173-210211

Depondt, F., and Green, E. (2006). Diving user fees and the financial sustainability of marine protected areas: opportunities and impediments. *Ocean Coast. Manag.* 49, 188–202. doi: 10.1016/j.ocecoaman.2006.02.003

Dietz, T., Ostrom, E., and Stern, P. C. (2003). *The Struggle to Govern the Commons*. Washington, DC: American Association for the Advancement of Science.

Dominguez, S., and Hollstein, B. (2014). *Mixed Methods Social Networks Research. Design and Applications*. New York, NY: Cambridge University Press.

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506, 216–220. doi: 10.1038/nature13022

Emerton, L. (2006). *Sustainable Financing of Protected Areas: A Global Review of Challenges and Options*. Gland: IUCN.

Folke, C., Jansson, A., Rockström, J., Olsson, P., Carpenter, S. R., Stuart Chapin, F., et al. (2011). Reconnecting to the biosphere. *Ambio* 40, 719–738. doi: 10.1007/s13280-011-0184-y

Fox, H. E., Mascia, M. B., Basurto, X., Costa, A., Glew, L., Heinemann, D., et al. (2012). Reexamining the science of marine protected areas: linking knowledge to action. *Conserv. Lett.* 5, 1–10. doi: 10.1111/j.1755-263X.2011.00207.x

Gabor Csardi (2019). *Igraph*. Available online at: https://igraph.org/r/doc/ (accessed August 8, 2019).

Gaceta Oficial (1991). *Decreto 1213 Plan de Ordenamiento y Reglamento de Uso del Parque Nacional Archipielago Los Roques*. Gaceta Oficial 4.250. Spain: Gaceta Oficial.

Gaceta Oficial (2011). *Decreto 8549 Mediante el cual se crea el territorio Insular Francisco de Miranda*. Gaceta Oficial 39.797. Spain: Gaceta Oficial.

Giakoumi, S., McGowan, J., Mills, M., Beger, M., Bustamante, R. H., Charles, A., et al. (2018). Revisiting "success" and "failure" of marine protected areas: a conservation scientist perspective. *Front. Mar. Sci.* 5:223. doi: 10.3389/fmars.2018.00223

Guidetti, P., Milazzo, M., Bussotti, S., Molinari, A., Murenu, V., Pais, A., et al. (2008). Italian marine reserve effectiveness: does enforcement matter?. *Biol. Conserv.* 141, 699–709. doi: 10.1016/j.biocon.2007.12.013

Halik, A., Verweij, M., and Schlüter, A. (2018). How marine protected areas are governed: a cultural theory perspective. *Sustainability* 10:252. doi: 10.3390/su10010252

Hawkins, J. P., Roberts, C. M., Kooistra, D., Buchan, K., and White, S. (2005). Sustainability of scuba diving tourism on coral reefs of Saba. *Coast. Manag.* 33, 373–387. doi: 10.1080/08920750500217518

Hicks, C. C., and Cinner, J. E. (2014). Social, institutional, and knowledge mechanisms mediate diverse Ecosystem service benefits from coral reefs. *Proc. Natl. Acad. Sci. U.S.A.* 111, 17791–17796. doi: 10.1073/pnas.1413473111

Hicks, C. C., McClanahan, T. R., Cinner, J. E., and Hills, J. M. (2009). Trade-offs in values assigned to ecological goods and services associated with different coral reef management strategies. *Ecol. Soc.* 14:10. doi: 10.5751/ES-02712-140110

INE (2014). *Censos de Población Y Vivienda*. Available online at: http://www.ine.gov.ve/index.php?option=com_content&view=category&id=95&Itemid=26 (accessed June 19, 2014).

IPBES (2019). "Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services," in *IPBES Secretariat*, eds E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (Bonn, Germany).

Jackson, J. B. C., Donovan, M. K., Cramer, K. L., and Lam, V. V. (2014). *Status and Trends of Caribbean Coral Reefs*. Gland: Global Coral Reef Monitoring Network, IUCN, 1970–2012.

Janssen, M. A., Schoon, M. L., Ke, W., and Börner, K. (2006). Scholarly networks on resilience, vulnerability and adaptation within the human dimensions of global environmental change. *Glob. Environ. Change* 16, 240–252. doi: 10.1016/j.gloenvcha.2006.04.001

Johnson, L. R., Johnson, M. L., Aronson, M. F. J., Campbell, L. K., Carr, M. E., Clarke, M., et al. (2020). Conceptualizing social-ecological drivers of change in urban forest patches. *Urban Ecosyst.* [Epub ahead of print]. doi: 10.1007/s11252-020-00977-5

Koetse, M. J., Brouwer, R., and Van Beukering, P. J. H. (2015). "Economic valuation methods for ecosystem services," in *Ecosystem Services: From Concept to Practice*, eds P. J. H. van Beukering and J. A. Bouma (Cambridge: Cambridge University Press), 108–131. doi: 10.1017/cbo9781107477612.009

Kuffner, I. B., Toth, L. T., Hudson, J. H., Goodwin, W. B., Stathakopoulos, A., Bartlett, L. A., et al. (2019). Improving estimates of coral reef construction and erosion with in situ measurements. *Limnol. Oceanogr.* 64, 2283–2294. doi: 10.1002/lno.11184

Kushner, B., Waite, R., Jungwiwattanaporn, M., and Burke, L. (2012). *Influence of Coastal Economic Valuations in the Caribbean: Enabling Conditions and Lessons Learned*. Washington, DC: World Resource Institute.

Leon, G. (2014). Strategic redistribution: the political economy of populism in Latin America. *Eur. J. Polit. Econ.* 34, 39–51. doi: 10.1016/j.ejpoleco.2013.12.005

Levin, S. A., and Lubchenco, J. (2008). Resilience, robustness, and marine ecosystem-based management. *BioScience* 58, 27–32. doi: 10.1641/B580107

Locke, H. (2015). "Nature needs (At least) half: a necessary new agenda for protected areas," in *Protecting the Wild: Parks and Wilderness the Foundation for Conservation*, eds E. Crist, G. Wuerthner, and T. Butler (Washington, DC: Island Press-Center for Resource Economics), 5–15.

Maciejewski, K., and Cumming, G. S. (2015). The relevance of socioeconomic interactions for the resilience of protected area networks. *Ecosphere* 6:art145. doi: 10.1890/ES15-00022.1

Maestro, M., Pérez-Cayeiro, M. L., Chica-Ruiz, J. A., and Reyes, H. (2019). Marine protected areas in the 21st century: current situation and trends. *Ocean Coast. Manag.* 171, 28–36. doi: 10.1016/j.ocecoaman.2019.01.008

Mastrángelo, M. E., Pérez-Harguindeguy, N., Enrico, L., Bennett, E., Lavorel, S., Cumming, G. S., et al. (2019). Key knowledge gaps to achieve global sustainability goals. *Nat. Sustain.* 2, 1115–1121.

McLaughlin, P., and Dietz, T. (2008). Structure, agency and environment: toward an integrated perspective on vulnerability. *Glob. Environ. Change* 18, 99–111. doi: 10.1016/j.gloenvcha.2007.05.003

Mcleod, E., Anthony, K. R. N., Mumby, P. J., Maynard, J., Beeden, R., Graham, N. A. J., et al. (2019). *The Future of Resilience-Based Management in Coral Reef Ecosystems*. Cambridge, MA: Academic Press.

Molberg, F., and Folke, C. (1999). Ecological goods and services of coral reef ecosystem. *Ecol. Econ.* 29, 215–233. doi: 10.1016/s0921-8009(99)00009-9

Mora, C., Andréfouët, S., Costello, M. J., Kranenburg, C., Rollo, A., Veron, J., et al. (2006). Coral reef and global network of MPA. *Science* 312, 1750–1751.

Mumby, P. J., Flower, J., Chollett, I., Box, S. J., Bozec, Y. M., Fitzsimmons, C., et al. (2014). *Towards Reef Resilience and Sustainable Livelihoods: A handbook for Caribbean coral reef managers*. Exeter: University of Exeter.

Mumby, P. J., and Steneck, R. S. (2008). *Coral Reef Management and Conservation in Light of Rapidly Evolving Ecological Paradigms*. Amsterdam: Elsevier.

Newman, M., Barabási, A.-L., and Watts, D. J. (2006). *The Structure and Dynamics of Networks*. Princeton, NJ: Princeton University Press.

Newman, M. E. J. (2001). Scientific collaboration networks. II. Shortest paths, weighted networks, and centrality. *Phys. Rev. E Stat. Phys. Plasmas Fluids Relat. Interdiscip. Top.* 64:e016132. doi: 10.1103/PhysRevE.64.016132

Noldus, R., and Van Mieghem, P. (2015). Assortativity in complex networks. *J. Complex Netw.* 3, 507–542. doi: 10.1093/comnet/cnv005

Norberg, J., and Cumming, G. (2008). *Complexity Theory for a Sustainable Future*. Columbia University Press.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science* 325, 419–422. doi: 10.1126/science.1172133

Parnell, J. A., and Parnell, J. A. (eds) (2019). "Nonmarket strategy in venezuela," in *Nonmarket Strategy in Business Organizations* (Berlin: Springer International Publishing), 87–97. doi: 10.1007/978-3-319-93242-2_8

Pelenc, J., Lompo, M. K., Ballet, J., and Dubois, J. L. (2013). Sustainable human development and the capability approach: integrating environment, responsibility and collective agency. *J. Hum. Dev. Capabilit.* 14, 77–94. doi: 10.1080/19452829.2012.747491

Peterson St-Laurent, G., Oakes, L. E., Cross, M., and Hagerman, S. (2021). R–R–T (resistance–resilience–transformation) typology reveals differential conservation approaches across ecosystems and time. *Commun. Biol.* 4, 1–9. doi: 10.1038/s42003-020-01556-2

Posada, J. M., Villamizar, E., and Alvarado, D. (2003). *Rapid Assessment of Coral Reefs in the Archipelago de Los Roques national park, Venezuela (PART 2 : FISHES)*. Agra: AGRRA.

Pulver, S., Ulibarri, N., Sobocinski, K. L., Alexander, S. M., Johnson, M. L., and Mccord, P. F. (2018). Frontiers in socio-environmental research: components, connections, scale and context. *Ecol. Soc.* 23:23.

R Core Team (2018). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

Rodríguez, J. P. (2000). Impact of the Venezuelan economic crisis on wild populations of animals and plants. *Biol. Conserv.* 96, 151–159. doi: 10.1016/S0006-3207(00)00061-6

Rodríguez, J. P., Beard, T. D., Bennett, E. M. Jr., Cumming, G. S., Cork, S. J., Agard, J., et al. (2006). Trade-offs across space, time, and ecosystem services. *Ecol. Soc.* 11:28.

Roff, G., Zhao, J., and Mumby, P. J. (2015). Decadal-scale rates of reef erosion following El Niño-related mass coral mortality. *Glob. Change Biol.* 21, 4415–4424. doi: 10.1111/gcb.13006

Rogers, A., Blanchard, J. L., and Mumby, P. J. (2014). Vulnerability of coral reef fisheries to a loss of structural complexity. *Curr. Biol.* 24, 1000–1005. doi: 10.1016/j.cub.2014.03.026

Romero, M., Judson, B., Posada, J. M., and William, D. (2011). Identificacion de sitios de agregaciones de desove de peces a traves del conocimiento ecologico local de pescadores en el Parque Nacional Los Roques, Venezuela. *Interciencia* 36, 88–95.

SATIM (2015). *Rendicion de Cuentas 2015*. Caracas: Servicio de Administracion Tributaria Territorio Insular Miranda.

Sayles, J. S., Mancilla Garcia, M., Hamilton, M., Alexander, S. M., Baggio, J. A., Fischer, A. P., et al. (2019). *Social-Ecological Network Analysis for Sustainability Sciences: A Systematic Review and Innovative Research Agenda for the Future*. Bristol: Institute of Physics Publishing.

Schleicher, J., Zaehringer, J. G., Fastré, C., Vira, B., Visconti, P., and Sandbrook, C. (2019). Protecting half of the planet could directly affect over one billion people. *Nat. Sustain.* 2, 1094–1096. doi: 10.1038/s41893-019-0423-y

SDG (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. London: United Nations.

Spalding, M., Burke, L., Wood, S. A., Ashpole, J., Hutchison, J., and zu Ermgassen, P. (2017). Mapping the global value and distribution of coral reef tourism. *Mar. Policy* 82, 104–113. doi: 10.1016/j.marpol.2017.05.014

Sterk, M., van de Leemput, I. A., and Peeters, E. T. (2017). *How to Conceptualize and Operationalize Resilience in Socio-Ecological Systems?*. Amsterdam: Elsevier.

Strain, E. M. A., Edgar, G. J., Ceccarelli, D., Stuart-Smith, R. D., Hosack, G. R., and Thomson, R. J. (2019). A global assessment of the direct and indirect benefits of marine protected areas for coral reef conservation. *Divers. Distrib.* 25, 9–20. doi: 10.1111/ddi.12838

Tavares, R. (2009). *Análisis de Abundancia, Distribución y Tallas de Tiburones Capturados Por Pesca Artesanal en el Parque Nacional Archipiélago los Roques, Venezuela. Interciencia 34*. Available online at: http://ve.scielo.org/scielo.php?pid=S0378-18442009000700005&script=sci_arttext&tlng=en (accessed November 19, 2019).

Toonen, R. J., Wilhelm, T. A., Maxwell, S. M., Wagner, D., Bowen, B. W., Sheppard, C. R. C., et al. (2013). One size does not fit all: the emerging frontier in large-scale marine conservation. *Mar. Pollut. Bull.* 77, 7–10. doi: 10.1016/j.marpolbul.2013.10.039

Trave, C., Brunnschweiler, J., Sheaves, M., Diedrich, A., and Barnett, A. (2017). *Are We Killing Them With Kindness? Evaluation of Sustainable Marine Wildlife Tourism*. Amsterdam: Elsevier.

Trujillo, W., and Posada, J. M. (2007). *La Pesquería de Langosta (Panulirus argus) en el Parque Nacional Archipiélago los Roques: Temporadas 2004-2005 y 2005-2006*. London: Gulf and Caribbean Fisheries Institute, 182–187.

Van Beukering, P. J. H., Brouwer, R., and Koetse, M. J. (2015). "Economic values of ecosystem services," in *Ecosystem Services: From Concept to Practice*, eds P. J. H. van Beukering, and J. A. Bouma (Cambridge, MA: Cambridge University Press), 89–107. doi: 10.1017/cbo9781107477612.008

Vanderklift, M. A., Marcos-Martinez, R., Butler, J. R. A., Coleman, M., Lawrence, A., Prislan, H., et al. (2019). Constraints and opportunities for market-based finance for the restoration and protection of blue carbon ecosystems. *Mar. Policy* 107:103429. doi: 10.1016/j.marpol.2019.02.001

Waldron, A., Adams, M., Allan, J., Arnell, A., Asner, G., Atkinson, S., et al. (2020). *Protecting 30% of the Planet for Nature: Costs. Benefits and Economic Implications (Campaign for Nature)*. Available online at: https://www.conservation.cam.ac.uk/files/waldron_report_30_by_30_publish (accessed January 21, 2021).

Williams, G. J., Graham, N. A. J., Jouffray, J. B., Norström, A. V., Nyström, M., Gove, J. M., et al. (2019). Coral reef ecology in the Anthropocene. *Funct. Ecol.* 33, 1014–1022. doi: 10.1111/1365-2435.13290

Wongthong, P., and Harvey, N. (2014). Integrated coastal management and sustainable tourism: a case study of the reef-based SCUBA dive industry from

Thailand. *Ocean Coast. Manag.* 95, 138–146. doi: 10.1016/j.ocecoaman.2014.04.004

Woodhead, A. J., Hicks, C. C., Norström, A. V., Williams, G. J., and Graham, N. A. J. (2019). Coral reef ecosystem services in the Anthropocene. *Funct. Ecol.* 33, 1023–1034. doi: 10.1111/1365-2435.13331

Zamarro (2002). *Guía del parque Nacional Archipiélago Los Roques*. Spain: Agencia de Cooperacion Espanola-MARNNR.

Zhao, Q., Stephenson, F., Lundquist, C., Kaschner, K., Jayathilake, D., and Costello, M. J. (2020). Where marine protected areas would best represent 30% of ocean biodiversity. *Biol. Conserv.* 244:108536. doi: 10.1016/j.biocon.2020.108536

Zubillaga, A. L., Márquez, L. M., Cróquer, A., and Bastidas, C. (2008). Ecological and genetic data indicate recovery of the endangered coral Acropora palmata in Los Roques, Southern Caribbean. *Coral Reefs* 27, 63–72. doi: 10.1007/s00338-007-0291-1

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It's Just Conservation: To What Extent Are Marine Protected Areas in the Irish Sea Equitably Governed and Managed?

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It is not enough to simply designate a protected area. According to the Convention on Biological Diversity's Aichi Target 11, these sites should be governed and managed effectively and equitably. Equitable (i.e., fair and inclusive) conservation is vital to ensuring effective protection of natural resources while maintaining human well-being. Yet, equity tends to be overlooked in protected area assessments. Three marine protected areas (MPAs) in Great Britain, Northern Ireland, and the Republic of Ireland were selected to assess equitable governance and management in the Irish Sea. This is one of the first studies to assess equity across multiple stakeholder groups in MPAs. The Site-level Assessment for Governance and Equity (SAGE) toolkit, developed by the International Institute for Environment and Development (IIED) to address the gap in equity assessments, was used to evaluate equitable governance and management in these MPAs. Based on the three dimensions of equity (recognition, distribution, and procedure), SAGE contains Likert-scale questions to assess good governance by evaluating how different stakeholder groups perceive their protected area's management and how included they feel in decision-making. Quantitative data from SAGE is complemented by qualitative data from semi-structured interviews with stakeholders to understand the impact MPA management has on local communities and MPA users. The results of this study reveal a lack of communication between MPA authorities and local stakeholders. They highlight the need for co-management in the form of inclusive partnerships as an alternative to the current top-down governance approach favoed in the United Kingdom and Ireland.

Keywords: marine protected area, equity, governance, environmental management, Irish Sea, marine conservation, stakeholder inclusion, assessment tool

INTRODUCTION

Anthropogenic threats to the marine environment, such as overfishing and pollution, are making effective conservation a necessity to ensure the continued flow of ecosystem services that are vital to the Earth and its inhabitants (Halpern et al., 2008; Claudet, 2011; Fraschetti et al., 2011; Long et al., 2015). Marine protected areas (MPAs) are a popular ecosystem management tool, but their success depends on several considerations, influenced by both biological and socioeconomic factors (Pomeroy et al., 2005). An MPA is a clearly defined area for the effective protection and conservation of species, habitats, and natural and cultural resources within the marine environment. While initially created solely for biological conservation purposes, MPAs are now additionally designated to promote the sustainable use of natural resources and the protection of ecosystem services (Hill et al., 2016). Marine and terrestrial protected areas (PAs) have been advocated by the United Nations as a conservation tool and there has been a push to designate and establish more PAs worldwide (United Nations Environment Programme [UNEP], 2018). At the Tenth Meeting of the Conference of the Parties (COP10) in Nagoya, Japan (2010), the Strategic Plan for Biodiversity 2011–2020 was laid out. It includes the Aichi Targets, a set of conservation objectives supporting biodiversity and human well-being. Aichi Target 11 focusses on PAs and states:

> By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape (Convention on Biological Diversity [CBD], 2011).

Aichi Target 11 clearly establishes the need for equitable management of PAs, yet equity issues may be considered issues of governance rather than management (Franks et al., 2018). Equity issues in a management context are generally rooted in governance and should be approached as such (Franks et al., 2018). Governance – the decision-making processes of managing natural resources – is a strong predictor of whether PAs reach their goals (Dearden et al., 2005). An MPA's overall effectiveness is determined by how well it addresses both biophysical and socioeconomic issues: 'a particular MPA may be both an ecological "success"—resulting in increased fish abundance and diversity and improved habitat, for example—and a social "failure"—lacking broad participation in management, the sharing of economic benefits, and conflict resolution mechanisms' (Christie et al., 2003; p. 22). If socioeconomic issues, including inequity, are not addressed, it is likely that any successful biological conservation efforts will be short-lived (Christie et al., 2003; Halpern et al., 2013; Batista and Cabral, 2016) and if stakeholders are not involved in the decision-making and resulting management of a PA, conservation efforts could be met with conflict and resistance (Jentoft et al., 2007; Pita et al., 2013; Soma and Haggett, 2015; Hopkins et al., 2018; Bennett et al., 2020).

Equity is the principle that people should be treated as equals, in a fair and just manner (McDermott et al., 2013). In nature conservation, equity means that all people share the costs and benefits that come from the management and use of natural resources and ecosystem services (McDermott et al., 2013). It plays an important role in MPA governance because it refers to fairness and inclusion of stakeholders. Equity is argued by some experts to be an indicator of good governance (Dearden et al., 2005; Jones et al., 2013; McDermott et al., 2013; Soma et al., 2015) because 'perceived inequity undermines resource users' willingness to comply with conservation rules or participate in MPA processes' (Jones et al., 2013; p. 12). MPAs can have a significant socioeconomic impact on surrounding communities, which can lead to negative opinions of PAs and make stakeholders less likely to respect the MPA's legitimacy and follow the rules that have been imposed to meet conservation objectives (Jones et al., 2013; Klein et al., 2015; Dawson et al., 2018).

Equity tends to be overlooked in PA assessments, both terrestrial and marine (Klein et al., 2015; Hill et al., 2016; Schreckenberg et al., 2016), and emphasis on expanded area coverage to meet Aichi Target 11 may result in the inequitable distribution of benefits (and burdens) and overshadow the need for effective management (Campbell and Gray, 2019; Johnson et al., 2019; Brander et al., 2020). Equitable (i.e., fair and inclusive) conservation is vital to ensuring effective protection of natural resources while maintaining human well-being (Hill et al., 2016). Research shows that equity plays an important role in the success of PAs (Halpern et al., 2013; Jones et al., 2013; Batista and Cabral, 2016; Dawson et al., 2018), although the extent to which equity has a positive impact on conservation may vary (Halpern et al., 2013; Young et al., 2013). PAs can in turn have an impact on equity if their establishment disproportionately affects some stakeholders over others (Pita et al., 2013; Friedman et al., 2018; Bennett et al., 2020). Equity as it pertains to governance of PAs is poorly understood and requires further research (Franks et al., 2018; Campbell and Gray, 2019). Much of the literature on equity in PAs focusses on low or middle-income countries and on terrestrial ecosystems (Hill et al., 2016; Schreckenberg et al., 2016; Dawson et al., 2018; Friedman et al., 2018).

Equity has not been formally defined with respect to Aichi Target 11 (Campbell and Gray, 2019) and there is only limited evidence on the relationship between equity and effective conservation (Klein et al., 2015; Schreckenberg et al., 2016; Bennett et al., 2020). It can be challenging to measure because 'equity is associated with concepts of social justice and fairness, respecting that diverse people could have different perceptions and views about what is fair' (Zafra-Calvo et al., 2019; p. 1). While social equity has been assessed as part of greater management effectiveness tracking tools, these tools do not take into consideration the different dimensions of equity (Leverington et al., 2010; Zafra-Calvo et al., 2019). A further shortcoming of the research on social equity in conservation is its focus on PAs in the global South and in forest ecosystems (Friedman et al., 2018). A review of studies on social equity in conservation (n = 138) by Friedman et al. (2018) shows that few (7%, n = 11) of the studies surveyed took place in Europe. The purpose of this study is to examine the state of equitable governance and management in MPAs through a case study approach of three sites in the northern Irish Sea. Using a newly-developed site-level assessment tool for governance and equity (known as SAGE), this study identifies equity challenges and best practices to improve MPA governance and management in global North MPAs, provides suggestions for better stakeholder engagement, and promotes equitable conservation.

Governance and Equity of Marine Protected Areas

Much of the literature on the social dimensions of PAs focusses on the terrestrial environment, with MPAs receiving much less attention (Sowman and Sunde, 2018). This is surprising, as one of the main failures of MPAs in achieving their biological conservation objectives is the lack of involvement from stakeholders in the planning and decision-making process (Agardy et al., 2011; Sowman and Sunde, 2018). However, equity issues may appear less pressing or obvious in a marine context because MPAs generally do not displace people from their homes, but rather from the marine space itself and from access to and use of resources (Campbell and Gray, 2019). Nevertheless, for those whose livelihoods depend on fishing and protein derived from seafood consumption, MPAs can be seen to have a detrimental effect on food security, particularly in the global South (Campbell and Hanich, 2015; Campbell and Gray, 2019). This may be why much of the literature on the socioeconomic impacts of MPAs focusses on the global South and/or exclusively on fishers (Salayo et al., 2006; Gustavsson et al., 2014; Bakker et al., 2019; Gill et al., 2019; Bennett et al., 2020).

Good governance can be described as the interactions that lead to collective decision-making amongst various stakeholders (Dearden et al., 2005; van Tatenhove, 2013). Management is instrumental and tool-oriented, whereas governance addresses ethics and good practices (Jentoft et al., 2007). Governance 'involves a process of negotiation between, on the one hand, nested general institutions operating at several levels, and on the other hand, state actors, market parties and civil society organizations' (van Tatenhove, 2013; p. 298). PA governance is typically described as top-down, bottom-up, or co-management (somewhere between these approaches). In bottom-up governance, communities govern MPAs without state involvement, whereas in top-down governance, decisions are made by the state and imposed on community members of the MPA (Jones et al., 2013; Ban and Frid, 2018). Co-management, in between these two governance approaches, is the equitable sharing of decision-making power (Ban and Frid, 2018). However, co-management can be difficult to establish in practice and needs to be integrated into a formal government-supported management plan to truly be considered effective (Ban and Frid, 2018; Vucetich et al., 2018; Voorberg and Van der Veer, 2020).

The governability of a PA depends on several principles (Soma et al., 2015; Bennett, 2016), including accountability; legitimacy; representation; and transparency. These principles of governance can be found in the three dimensions of equity: recognition, procedure, and distribution (McDermott et al., 2013; Pascual et al., 2014). Recognition is the acknowledgment and acceptance of the legitimacy of rights, values, interests, and priorities of a PA's stakeholders (McDermott et al., 2013; Schreckenberg et al., 2016; Dawson et al., 2018; Vucetich et al., 2018). Recognizing a person's rights should also involve the respect of these rights, the lack of which is a concern for many stakeholders, particularly local, marginalized groups who feel their voices aren't being heard (Schreckenberg et al., 2016).

The main feature of procedural equity is the inclusion and effective participation of all relevant stakeholders in PA designation, implementation, and management (McDermott et al., 2013; Sterling et al., 2017; Di Franco et al., 2020). However, *who* participates is key, as not all participation is created equal (Arnstein, 1969). A study by Gustavsson et al. (2014) highlights the manipulation and passiveness of the participation process in a community-based managed MPA in Zanzibar, Tanzania, where stakeholder representatives are unelected and local people are not involved in development and conservation decision-making. This approach creates an illusion of participation and allows MPA authorities to claim that community participation did indeed take place. Procedure also involves accountability, transparency, and access to justice for dispute resolution (Hill et al., 2016; Schreckenberg et al., 2016; Vucetich et al., 2018). The MPA governing authority and managers as well as local stakeholders should all be held accountable for their actions (or inactions) with regards to equitable conservation management through adequate enforcement (Batista and Cabral, 2016; Schreckenberg et al., 2016). Communication between stakeholders and transparency, coupled with trust and social cohesion within and amongst stakeholder groups, can also lead to effective conservation (Young et al., 2013; Hill et al., 2016). Bottom-up governance, such as community-based management, may be seen as a solution to the often-alienating top-down governance approach favored by governments in the global North (Govan et al., 2008; Ban and Frid, 2018).

The third equity dimension, distribution, refers to the costs and benefits of a PA and how they are distributed between stakeholders (McDermott et al., 2013; Schreckenberg et al., 2016). Much of the policy work and socioeconomic assessments that take equity into account generally focus on the distribution dimension, as loss of income or revenue gains may be easily quantifiable and serve as readily measured indicators (Schreckenberg et al., 2016; Friedman et al., 2018). Dawson et al. (2018) argue that this reliance on material distribution and standardized indicators may be inadequate to properly assess local perceptions of equity, thereby making effective conservation more difficult. Distribution of costs and benefits can be a sensitive topic, as some stakeholders may feel that they have sacrificed more than others and/or did not receive their fair share of the benefits (Schreckenberg et al., 2016; Dawson et al., 2018; Friedman et al., 2018). Distribution is often a series of trade-offs, between resources and their uses and between stakeholder groups (Schreckenberg et al., 2016; Gill et al., 2019). There is no such thing as perfect equity in conservation because these trade-offs are necessary (e.g., which groups should be prioritized over others when resources are limited and why?); indeed, optimal marine conservation outcomes are often achieved without perfect equity (Halpern et al., 2013; Klein et al., 2015). Equity may be considered a matter of perception (what is *fair* and why?) and thus cannot be guaranteed for all (Halpern et al., 2013; Klein et al., 2015). Nevertheless, research shows that equity plays a role in conservation and cannot be excluded from natural resource governance and management if conservation objectives are to be met (Young et al., 2013; Hill et al., 2016; Dawson et al., 2018; Friedman et al., 2018).

Study Sites

The three MPAs selected for this study are located on the Irish Sea coastline (**Figure 1**). The Irish Sea separates the islands of Great Britain and Ireland; its coastline extends through England, Scotland, Wales, Northern Ireland (NI), the Republic of Ireland (ROI), and the Isle of Man. The MPAs included in this study cross county, national, and international boundaries and were specifically chosen for this reason, to look at equity across different administrative and spatial scales. These sites were selected based on six criteria linked to MPA effectiveness and chosen to ensure that enough data was available for assessment and analysis: A site was selected if it had multiple conservation designations (1), had an implemented management plan (2) and active monitoring (3), was larger than 100 km^2 (4), older than 10 years (5), and managed by an authority willing to work on the issue of equity in MPAs (6) (Edgar et al., 2014; Schéré et al., 2020).

Strangford Lough

Strangford Lough is a sea inlet located in County Down, on the eastern coast of Northern Ireland. The lough is known for its biodiversity – containing 72% of marine biodiversity in Northern Ireland waters – and is home to over 2,000 recorded marine species, while 60,000 people live around its shores and one million within an hour's drive (Christie et al., 2011; Yates et al., 2013; Department of Agriculture Environment and Rural Affairs [DAERA], 2017). The lough provides ecosystem services not only to the local community, but also to day visitors from Belfast, who flock to Strangford Lough on the weekends and especially during the summer. Commercial activities around the lough include agriculture, small fishing operations (about 20 pot fishing licenses), aquaculture, tourism, and recreation.

Strangford Lough is part of the EU networks Natura 2000 and European Marine Sites, as well as the OSPAR Network of MPAs. Strangford Lough is a multiple-designation site (World Database on Protected Areas [WDPA], 2020), boasting seven designation types (i.e., national, European, and international) and 12 individual designations. Arguably one of the most protected MPAs in Europe (and the only MPA in Northern Ireland to have a management plan as recently as 2013), the lough's *Modiolus modiolus* (horse mussel) biogenic reefs – protected under the Habitats Directive – were destroyed due to fishing activities, in particular trawling and dredging, despite being a designated MPA at the time (Johnson et al., 2008; Christie et al., 2011; Jones, 2012; Yates et al., 2013; Fariñas-Franco et al., 2018). Several authors criticize Northern Ireland for not adequately addressing environmental issues until the situation becomes

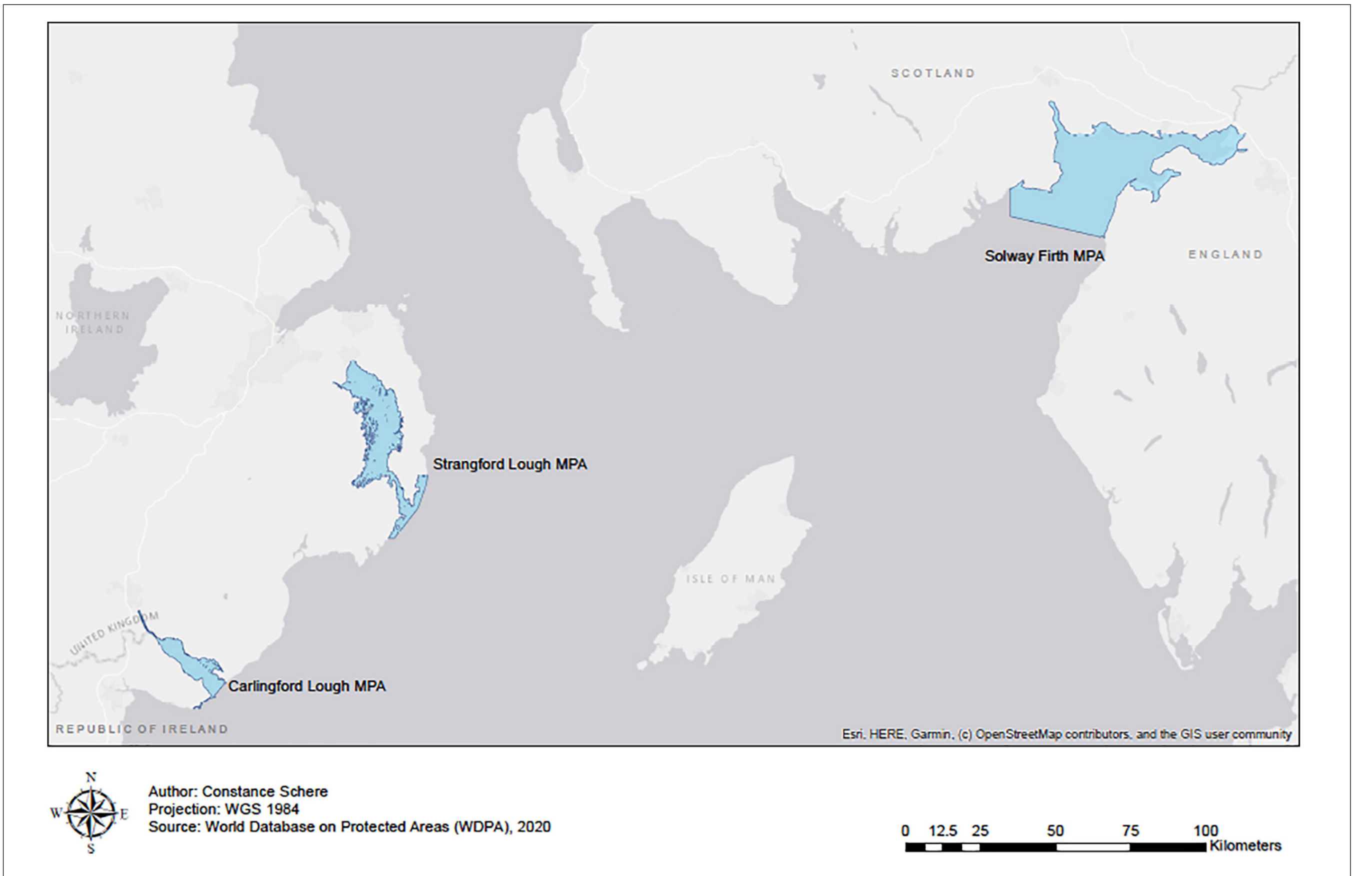

FIGURE 1 | Case study MPAs in the Irish Sea.

critical (Johnson et al., 2008; Smyth et al., 2009; Cooper, 2011; Jones, 2012; Yates et al., 2013). The fate of *M. modiolus* highlights how multiple departments overseeing marine management can be a problem (Cooper, 2011; Yates et al., 2013) and led to calls for an increase in coordination and collaboration between the different authorities overseeing Strangford Lough (Johnson et al., 2008; Smyth et al., 2009; Cooper, 2011; Jones, 2012; Yates et al., 2013). There are currently six management authorities working with the Department for Agriculture, Environment and Rural Affairs (DAERA) on the conservation of Strangford Lough. A new management plan is currently being developed for the lough by DAERA, in collaboration with other management authorities. These authorities include the Northern Ireland Environment Agency (an executive agency of DAERA), Newry Mourne and Down Council, Ards and North Down Council, the National Trust, the Crown Estate, and the Wildlife and Wetland Trust. The Strangford Lough and Lecale Partnership (SLLP) was originally created to handle the management of the lough, but this responsibility is now shared between the various authorities.

The Solway Firth

The Solway Firth is an inlet in the Irish Sea that forms the border between Scotland on the north shore and England in the south. The Solway Firth extends from St. Bees Head, south of Whitehaven in Cumbria (England), to the Mull of Galloway, in the western part of Dumfries and Galloway (Scotland) and spans an area of approximately 3,000 km^2 (Scottish Natural Heritage [SNH], 2016; World Database on Protected Areas [WDPA], 2020). Much of the firth is surrounded by coastal lowlands and small mountains, with saltmarshes and sandbanks present on both the north and south shores (Lloyd et al., 1999). The surrounding area is mainly rural, with fishing and farming dominating the local economy, as well as tourism (Solway Firth Partnership [SFP], 2020). Seafood is a major industry in the Solway, dominated by scallop fisheries, aquaculture, and seafood processing – which employs over 1,500 people (Solway Firth Partnership [SFP], 2015). The Solway Firth is home to Robin Rigg Wind Farm, which currently boasts 58 operational turbines in Scotland and is serviced from England (Solway Firth Partnership [SFP], 2020). The firth is a popular tourist destination, offering beaches and hiking trails along its coastline and opportunities for water sports, sailing, sea angling, and other recreation (Solway Firth Partnership [SFP], 2020).

The Solway Firth's large area boasts several conservation designations, such as Luce Bay and Sands SAC in Scotland and Allonby Bay MCZ in England (World Database on Protected Areas [WDPA], 2020). The inner estuary, however, is a transboundary site. This area, known as the Solway Firth and Upper Solway Flats and Marshes, spans approximately 436 km^2 and has six designations (Department for Environment Food and Rural Affairs [DEFRA], 2019; World Database on Protected Areas [WDPA], 2020). Part of this area is an Area of Outstanding Natural Beauty (1964) on the English coast (World Database on Protected Areas [WDPA], 2020). Governance and management of the Solway Firth MPA falls under the responsibility of the United Kingdom Marine Management Organisation (MMO), the Inshore Fisheries and Conservation Authority (IFCA), Natural England, NatureScot (formerly known as Scottish Natural Heritage), and Marine Scotland (Department for Environment Food and Rural Affairs [DEFRA], 2019). The Solway Firth Partnership (SFP), an independent charitable body, was created to support the local economy while respecting and protecting the area's heritage and natural features (Solway Firth Partnership [SFP], 2015). The SFP brings together stakeholders from both coasts of the firth to improve the sustainable management of the Solway (O'Higgins et al., 2019). In its own words, the SFP's objective is 'to provide a framework for marine planning and management that enables engagement by everyone with an interest in our marine and coastal area' (Solway Firth Partnership [SFP], 2015).

Carlingford Lough

Carlingford Lough is located some 60 km south of Strangford Lough. It is also a sea inlet and forms part of the border between Northern Ireland (County Down, United Kingdom) and the Republic of Ireland (County Louth). Inflowing catchments drain an area of 470 km^2, the majority of which are located in Northern Ireland: surface water quality from the Camlough, Clanrye, Kilbroney, Newry, and Whitewater rivers is poor due to agricultural runoff, urban pollution, and sediment loads (ALICE Project, 2016). Newry, located on the banks of the Clanrye river that flows into Carlingford Lough, is the largest settlement in the lough's catchment area (population: approximately 26,000 in 2011) but industrial activity is minimal (ALICE Project, 2016; Department of Agriculture Environment and Rural Affairs [DAERA], 2016). Warrenpoint and Greenore, located on the northern shore of the lough, are significant commercial ports and shipping traffic is considerable (Department of Agriculture Environment and Rural Affairs [DAERA], 2016). Other activities around and within Carlingford Lough include agriculture, fishing (commercial and recreational), aquaculture, forestry, tourism, recreational boating and sailing, water sports, and other forms of recreation (e.g., birdwatching, hiking, mountain biking, etc.). The lough is located about an hour to an hour and a half drive from both Dublin and Belfast and the Dublin-Belfast railway line stops at Newry station, making Carlingford Lough an accessible and popular weekend destination.

Like Strangford Lough, Carlingford Lough has several national, European, and international designations. The lough has been designated an MPA because of its species richness, particularly its avian biodiversity. Demersal fishing activities – such as trawling, dredging, or pot fishing – and organic pollution from sewage present major threats to benthic species (Greathead et al., 2014; Bastari et al., 2018). Carlingford Lough's MPA status is under the authority of the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland and the National Parks and Wildlife Service (NPWS), part of the Department of the Arts, Heritage and the Gaeltacht in the Republic of Ireland. Fisheries and aquaculture are managed by the Lough Agency, which was set up as one of the cross-border bodies under the 1998 Good Friday Agreement to 'provide sustainable social, economic and environmental benefits [. . .] through the effective conservation, management, promotion and development of the fisheries and marine resources of the Foyle and Carlingford areas' (Loughs Agency, 2021). Formal maritime boundaries for Carlingford Lough have never been agreed upon, so appropriate management of the lough may require an all-Ireland approach in the form of a single, cross-border institution, similar to the Solway Firth Partnership model between Scotland and England (Campbell and Hanich, 2015; O'Higgins et al., 2019).

MATERIALS AND METHODS

A limitation of many assessment tools of effectiveness and equity of PAs is that they are based solely on the views of PA authorities and management and thus yield biased results, with managers perceiving higher levels of effectiveness than other stakeholders (Campbell and Gray, 2019; Giglio et al., 2019). The need for an adequate equity assessment tool that considers the views of various stakeholder groups of PAs has resulted in the development of a new, separate equity toolkit, developed by the International Institute for Environment and Development (IIED), in collaboration with conservation professionals from various global institutions in government, NGOs, and academia. Named the Site-level Assessment for Governance and Equity (SAGE), this toolkit directly addresses the lack of understanding of equity and aims to further promote the implementation of equitable management of PAs (International Institute for Environment and Development [IIED], 2021). SAGE is designed as a score card, wherein participants answer Likert-scale questions to the best of their ability on the topics of governance and equity. Scores range from 1 (very negative – no measures are in place) to 4 (very positive – effective measures exist), with the possibility of selecting 'I don't know' (coded as a missing value).

Originally designed as a 1-day workshop, a revised version[1] of the toolkit was transformed into a 20-question online questionnaire (**Table 1**) to reach a wider audience during the COVID-19 pandemic. All 10 principles of equity and governance are represented, with at least one question covering each principle. The anonymous online questionnaire, created using Qualtrics XM (Qualtrics, 2020), was distributed to potential participants via gatekeepers such as the SLLP, the SFP, and various recreational clubs and businesses located in proximity to the MPAs. Flyers detailing the study and containing a QR code to access the online questionnaire were also handed out at random to passersby at each site, to promote participation beyond the scope of gatekeeper-recruited participants. Participants selected the type of stakeholder they identify with and answered the toolkit questions based on this position. The main stakeholder groups were: MPA management; marine recreational users (recreational fishers, yachters, coastal rowers, sailors, divers, etc.); coastal recreational users (birdwatchers, wildfowlers, dog-walkers, hikers, etc.); local business operators (e.g., commercial fishers, aquaculturists, shop owners, restauranteurs, sports rentals, etc.); local community members (i.e., people residing along the coast of the MPA); and tourists (i.e., day visitors or holidaymakers). The opportunity to enter in a prize draw for three Amazon gift cards (one gift card valued at £100/€100 and

TABLE 1 | SAGE questions by equity and governance principle.

Principle	Q#	Question
Respect for rights	Q1	What proportion of community members do you think are aware of the right to use (MPA) for commercial and recreational purposes?
	Q2	Do you think that community members who have the right to use (MPA) for commercial and recreational purposes are able to exercise this right?
Respect for actors	Q3	How do you feel people who work for (MPA) (e.g., site wardens/rangers) regard community members and their interests in (MPA)?
	Q4	How do you feel community members regard people who work for (MPA)?
	Q5	Do you perceive there to be any discrimination (e.g., favoritism of one stakeholder group over another) against any groups of stakeholders?
Participation	Q6	Do you think there are any opportunities (e.g., a committee or meeting) for relevant stakeholders to participate in decision-making on MPA-related issues?
	Q7	How much influence do you believe your stakeholder group has on MPA-related decision-making?
Transparency and accountability	Q8	Do you think MPA managers receive information from stakeholders on threats (e.g., illegal or detrimental activity) to the MPA?
Dispute resolution	Q9	What type of processes do you think exist for resolving disputes that relate to the MPA?
	Q10	Do you think these dispute resolution processes succeed in resolving MPA-related disputes?
Law enforcement	Q11	How do you think the people responsible for enforcing MPA laws (e.g., site rangers/police) behave when interacting with community members?
	Q12	In your opinion, how effective are enforcement activities in reducing law-breaking?
Impact mitigation	Q13	Do you think the organizations responsible for dealing with conflicts between stakeholder groups have the skills and resources to do the job properly?
Benefits sharing	Q14	How and by whom do you think decisions are made on the allocation of benefits [e.g., permits or other means to access/utilize (MPA) for recreational or commercial purposes] to communities?
	Q15	Do you feel the quality and quantity of the benefits received by communities is in line with what was agreed?
Achieving objectives	Q16	Do you think the process for developing and reviewing MPA strategies and plans involve key stakeholders?
	Q17	Do you think some aspects of MPA management have been changed in response to learning from experience?
	Q18	Do you think the objectives of protecting marine species and habitats [e.g., (key species)] are being achieved?
Coordination and collaboration	Q19	How good do you think coordination and collaboration is between different stakeholders at site level?
	Q20	How good do you think coordination and collaboration is between stakeholders at lower and higher (i.e., administrative) levels?

[1]The revised version of SAGE used in this study is based on the original version of the toolkit. The findings from this study and its application at other sites worldwide have contributed to the development of a second version, which is currently being piloted by IIED (for more information, see: https://www.iied.org/site-level-assessment-governance-equity-sage).

two valued at £50/€50 at each site) was used as an incentive to recruit participants. This study received ethical approval from King's College London (ethical clearance reference number: LRS-18/19-13395).

This study used a mixed methods design in order to better understand the state of governance and equity at each MPA site (Creswell and Plano Clark, 2011). The quantitative data drawn from the toolkit responses was used to represent the general views of various stakeholder groups. The results of the online questionnaire helped guide the types of questions that were asked in the semi-structured interviews. Participants for semi-structured interviews were recruited through the online questionnaire, wherein interested parties could choose to be interviewed after submitting their questionnaire responses. The qualitative data derived from the semi-structured interviews was used to better understand the personal views of stakeholders (Sterling et al., 2017) and to provide evidence to justify the scores attributed to each question in the toolkit.

Quantitative data were coded, analyzed, and visualized in SPSS 26 (IBM Corporation, 2019) and RStudio (RStudio PBC, 2020). The semi-structured interviews were held via videoconference software or over the phone due to distancing restrictions caused by the COVID-19 pandemic. These interviews were recorded and transcribed. They were then uploaded into NVivo 12 (QSR International, 2019) and coded into nodes (**Table 2**) that represented the different themes that arose during the semi-structured interviews (e.g., access, awareness, communication, etc.). The qualitative data was compared with the quantitative data to understand stakeholders' views of equity in their MPAs.

The three online questionnaires garnered a combined total of 131 responses: Strangford Lough (n = 55), the Solway Firth (n = 47), and Carlingford Lough (n = 29). A combined score for Strangford Lough's management that had been tallied during a pilot SAGE workshop was added to the analysis, bringing Strangford Lough's responses to a total of 56. The participants of the online questionnaire were evenly represented: 51% male and 49% female; however, more males were interviewed than females (62 and 38%, respectively). All participants who wanted to be interviewed had the chance to be interviewed. In total, 16 stakeholders were interviewed (Strangford Lough, n = 8; the Solway Firth, n = 5; Carlingford Lough, n = 3), which represents approximately 10% of total participants for each site. The relatively low response rate may be attributed to the difficulties posed by COVID-19 restrictions to interact more closely with stakeholders and potential participants: People were wary of close contact with strangers, despite taking the necessary precautions (masked, gloved, and maintaining a 2-m distance), and the lockdowns meant the majority of businesses were closed and most people did not leave their homes. Although approximately 100 flyers were distributed at each site, this study therefore relied most heavily on gatekeepers such as the SLLP to recruit participants.

TABLE 2 | Nodes used to code qualitative data in NVivo 12.

Node	Description
SLLP	Comments about the Strangford Lough and Lecale Partnership.
SFP	Comments about the Solway Firth Partnership.
Loughs Agency	Comments about the Loughs Agency.
Access to the MPA	Access to the MPA for commercial or recreational use.
Awareness of MPA status	Awareness of the existence of the MPA.
Communication with the public	Communication between MPA authorities and local stakeholders regarding the MPA, its purpose, ongoing conservation efforts, opportunities to participate, education materials and resources.
Environmental management	Successes and failures of environmental conservation in the MPA.
Law enforcement	Relating to law enforcement.
Resource constraints	Relating to staff and budget allowances and constraints.

RESULTS

Quantitative Results

The SAGE toolkit responses show that scores (1–4 scale) from non-management stakeholders tended to be lower compared to management scores. A mean score was attributed for principles with multiple questions to visualize trends in participant responses.

Strangford Lough

Strangford Lough's stakeholders were divided into six groups: MPA management, marine recreational users, coastal recreational users, business operators, community members, and others. Stakeholders in the 'Others' group did not feel they belonged to any of the proposed groups (e.g., scientists conducting research on Strangford Lough). Reponses to the online questionnaire show that MPA management at Strangford Lough perceived that *participation* (Q6 and Q7) and *transparency and accountability* (Q8) efforts were successful, while other stakeholder groups disagreed (**Figure 2**). All stakeholder groups agreed that efforts to *achieving objectives* (Q16, Q17, and Q18) were lacking and that there is a need for improved *coordination and collaboration* (Q19 and Q20). Missing scores exist where stakeholder groups did not know how to respond to questions, such as for *impact mitigation* (Q13). Missing values made up 37% of total responses to all questions. For a complete description of the data for Strangford Lough, please see Appendix 1 in **Supplementary Materials**.

The Solway Firth

The Solway Firth's stakeholders were made up of: MPA management, coastal recreational users, business operators, community members, and tourists. There were no marine recreational users, which may be attributed to the inner Solway's strong tidal action and turbidity. Reponses to the online questionnaire show that MPA management at the Solway Firth assessed its efforts rather critically compared to other sites (**Figure 3**). Missing responses for the Solway Firth made up 54% of all responses. All stakeholder groups tended to agree

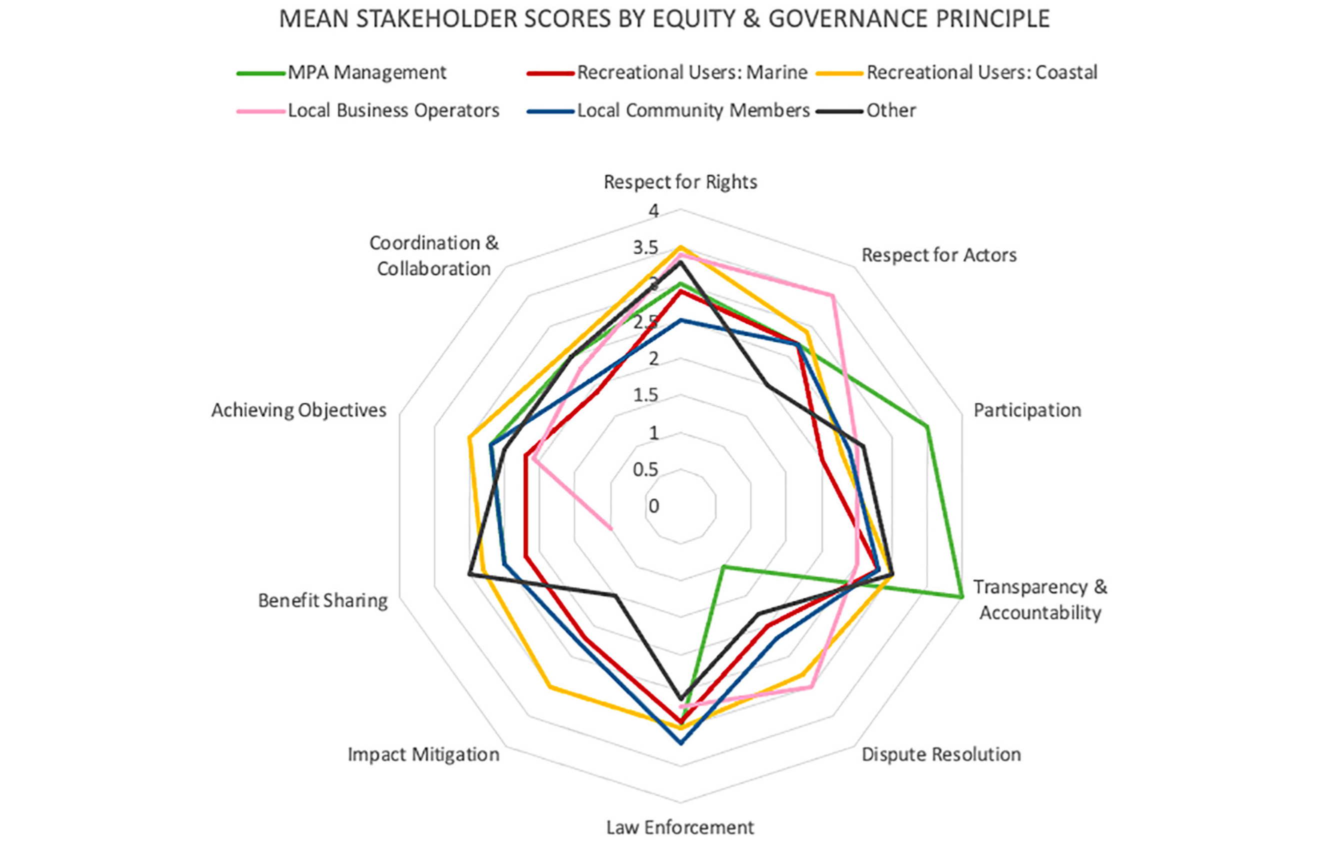

FIGURE 2 | Mean stakeholder scores by equity and governance principle for Strangford Lough.

(similar scores) on the state of *respect for actors* (Q3, Q4, and Q5). *Coordination and collaboration* (Q19 and Q20) was given high scores by MPA management and tourists, but *in situ* stakeholders (recreational users, community, and businesses) were more critical (lower scores). For a complete description of the data for the Solway Firth, please see Appendix 2 in **Supplementary Materials**.

Carlingford Lough

Stakeholder groups at Carlingford Lough were made up of: MPA management, marine recreational users, coastal recreational users, business operators, community members, and tourists. Carlingford Lough had the lowest response rate of all three sites, despite it being an international cross-boundary site and arguably the most affected by related issues such as Brexit and different national regulations. Results from the online questionnaire show that MPA management gave high scores (scores of 3 and 4) for almost all principles, while community members and marine recreational users viewed equity in more conservative terms (see **Figure 4**). *Transparency and accountability* (Q8) scores were high for businesses and community members, but on this principle MPA management's views were slightly more critical. Missing responses made up 44% of all responses to questions and exist where stakeholders did not know how to answer the question due to lack of knowledge regarding the lough's governance and management, such as in *benefit sharing* (Q14 and Q15) for the businesses group. For a complete description of the data for Carlingford Lough, please see Appendix 3 in **Supplementary Materials**.

Case Study Site Comparison

In order to compare perceptions of different stakeholders across all sites the following groups were compared: management, recreational users, business, and community members. A new stakeholder group was created, consolidating marine and coastal users into one category: recreational users. This was due to the lack of marine users in Solway Firth. Tourists were also removed from the analysis, as this group was absent at Strangford Lough, while the group named 'Other' was also excluded due to its absence at the Solway and Carlingford Lough. Differences between stakeholder groups and between MPAs for each of the twenty questions are also visualized in **Figure 5**, where one can see how management perceptions differ compared with other stakeholder groups. For example, management scores across all sites were generally higher than for other stakeholder groups, particularly at Carlingford Lough. *Coordination and collaboration* (Q19 and Q20) are viewed as weak in all three sites, particularly by non-management stakeholders. For a complete description of the data for stakeholders and MPAs, please see Appendices 4, 5, respectively, in **Supplementary Materials**.

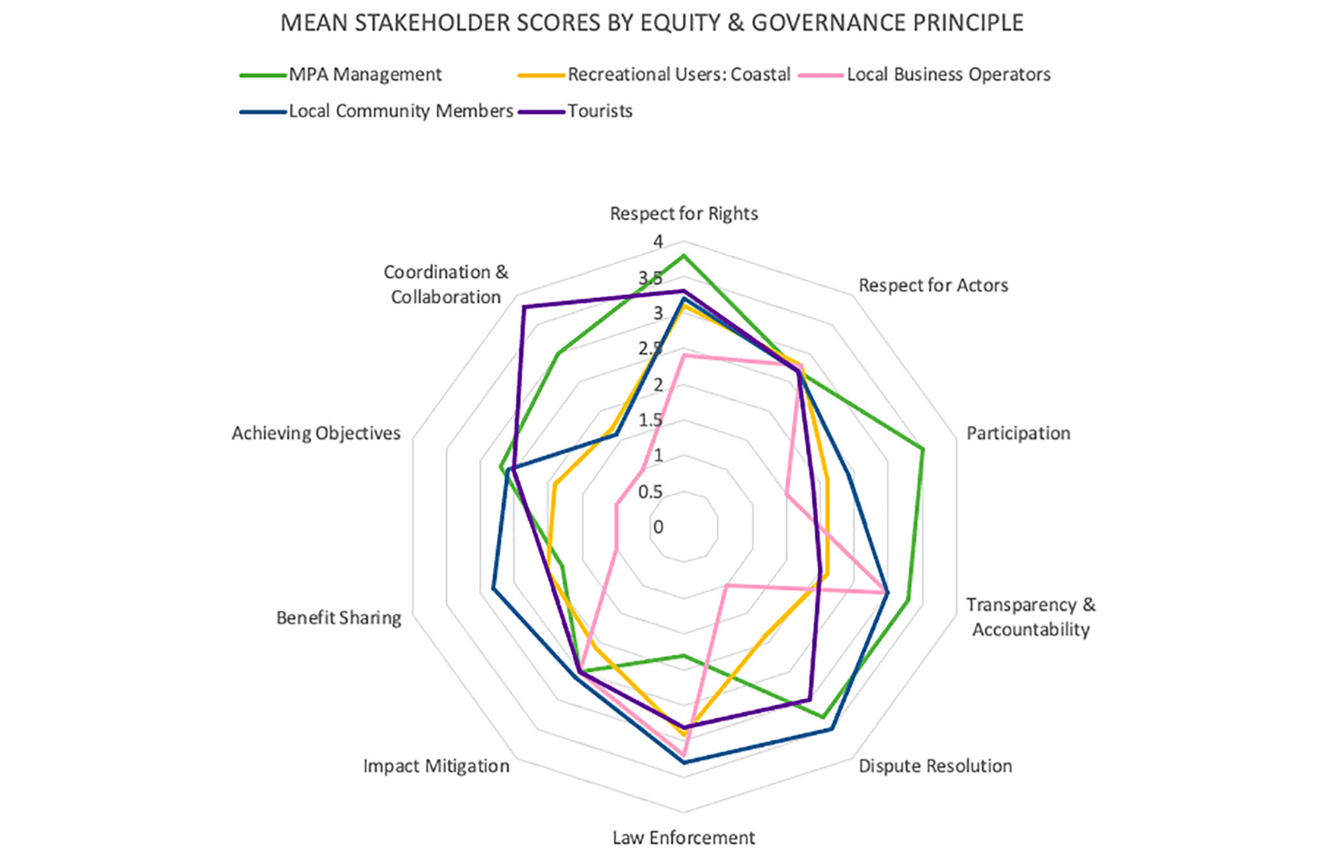

FIGURE 3 | Mean stakeholder scores by equity and governance principle for the Solway Firth.

Qualitative Results

SAGE revealed a number of disconnects between how MPA management views its efforts and performance in terms of governance and equity and the perceptions of different stakeholder groups across all sites, but particularly at Carlingford Lough. SAGE also identified issues specific to each MPA, such as access at Strangford Lough and litter on the Solway Firth. The comments written by participants to the online questionnaire and the semi-structured interviews reinforced much of the quantitative data provided by the SAGE questionnaire.

Governance Structures

SLLP

The Strangford Lough and Lecale Partnership (SLLP), originally the Strangford Management Committee and then the Strangford Lough Advisory Committee, serving as a liaison between stakeholders and government, has seen its role diminish over the years. Its offices were once located in Portaferry, making the SLLP accessible to local stakeholders and having its presence felt on the lough. A more bottom-up approach to the governance of Strangford Lough, wherein issues were discussed within the SLLP and brought to government to collaborate on decision-making, has shifted to an exclusively top-down approach – where management decisions are made and imposed on stakeholders without taking their views into account.

'The Strangford Lough Advisory Committee (now SLLP) has been a very valuable sounding ground – however, in more recent times its influence and the level of engagement between the MPA and the committee is much more limited. Decisions are made and then informed to the committee. In the past proposals were presented, discussed and revisions taken on board before decisions were made.' – *Strangford Lough marine user.*

'[SLLP] had premises in Portaferry. So they were in the center of things. Now, they're in Downpatrick. And it's sort of remote. [. . .] I would see none of them now, whereas you used to see them regularly going across the ferry and that sort of thing. And you could chat about related things when you did meet them. [Now] they don't give the impression of being taken seriously.' – *Strangford Lough community member.*

The SLLP office is now located within the Newry Mourne and Down Council offices, in Downpatrick, about 10 km away from Strangford Lough, and while it is viewed positively by stakeholders, according to a marine user, it is now 'just fragmenting constantly. It's quite sad, actually, because it was quite joined up.'

SFP

The governance structure of the Solway Firth means that a number of different actors (both public and private) are responsible for its management. The Solway Firth Partnership

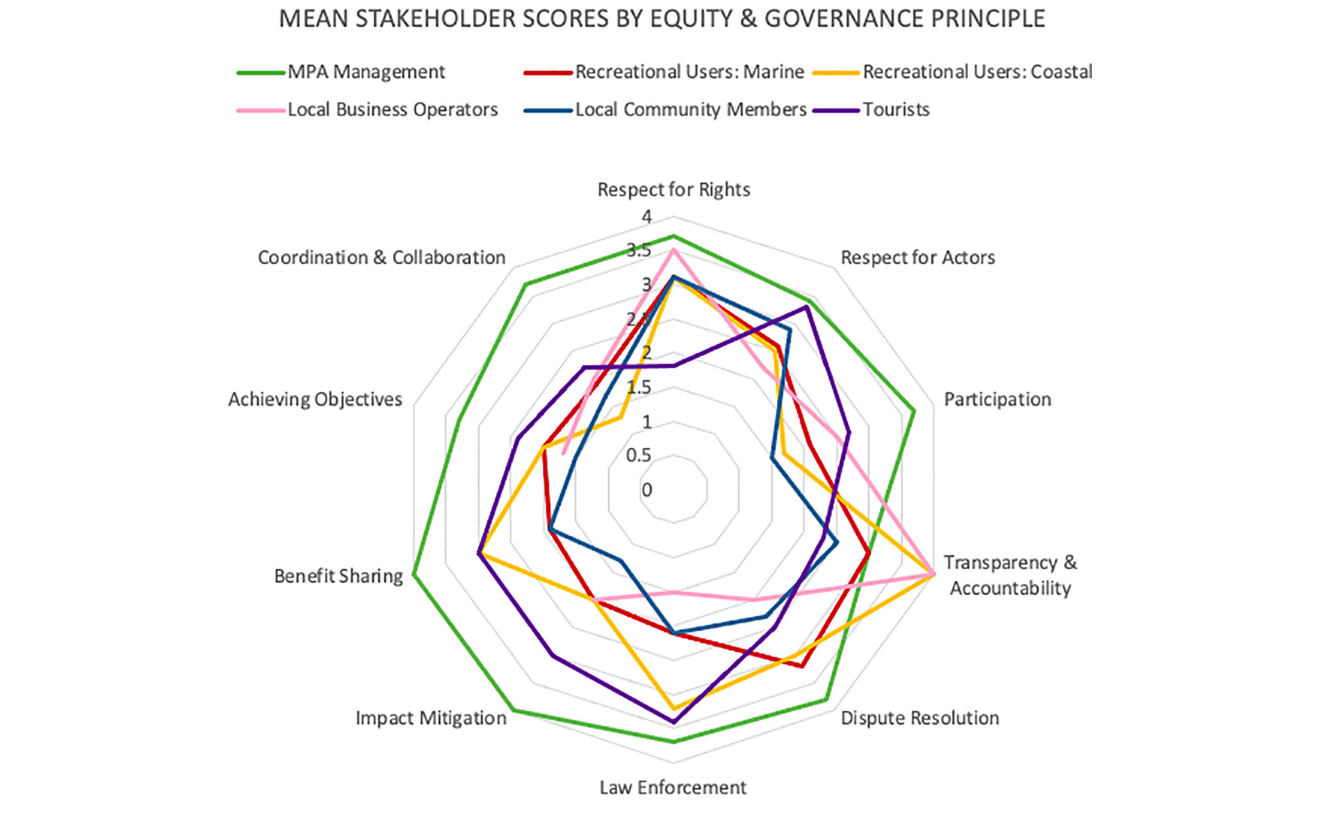

FIGURE 4 | Mean stakeholder scores by equity and governance principle for Carlingford Lough.

(SFP) brings together these different actors with stakeholders to discuss issues on the Solway as they arise and communicates Solway-related news to the local communities through its quarterly magazine, *Tidelines*. Its team is actively involved in the promotion and conservation of the Solway Firth, but a criticism of the SFP is that there is a perceived bias toward the Scottish side of the Solway by the SFP: 'Because [the SFP office is] based on the Scottish side [in Dumfries], and also the way it's funded through Marine Scotland, [. . .] there is very much a bias toward the Scottish side. But that's not the intention of the organization. It's always attempting to do more on the other side, often by working with the Solway Area of Outstanding Natural Beauty,' explains a Solway Firth coastal user. The SFP collaborates with the Solway Firth Area of Outstanding National Beauty (AONB) whose offices are located across the Solway in Silloth, England.

Loughs Agency

Unlike the other two sites, Carlingford Lough has no active partnership involved in its conservation and management. It does have the Loughs Agency, which is described as being well situated to work with stakeholders, the county councils, and the governments of Northern Ireland and the Republic of Ireland on transboundary issues related to the lough (House of Commons and Northern Ireland Affairs Committee, 2018; O'Higgins et al., 2019). However, its work focusses on fisheries and aquaculture and its presence is not felt on Carlingford Lough, despite having an office in Carlingford village. Participants describe the Loughs Agency as 'toothless' and 'having no face' at Carlingford Lough. According to one coastal user, 'We just don't see them. I don't know why they can deliver fantastic work up in Foyle and ignore Carlingford. [. . .] [W]hat history is there that's meant that there's this inequality?'

Access to the MPA

Stakeholders should be able to exercise their *rights* when it comes to the use of an MPA. While stakeholders have the right to use the water, they are limited in their ability to freely access it at Strangford Lough (Outdoor Recreation Northern Ireland, 2018). According to one member of MPA management, '[I]t's access for the general public [that] is limited. For those of us who know and [are] members of your [yacht or sailing] clubs or something like that, or members of the National Trust, it's a lot easier, but a lot of people can't afford that.' As many interview participants pointed out, there are only two public slipways at Strangford Lough: at Portaferry and Strangford village, both of which are located in the southern part of the lough – the Narrows, a channel linking the lough to the Irish Sea. The other main points of access to the water are located on privately-owned land or require paid membership to a yacht or sailing club to utilize, making access both geographically and financially prohibitive. Some participants, particularly marine users, reported conflicts over use of Strangford Lough for recreational or commercial

FIGURE 5 | Responses by stakeholder group (consolidated) and MPA across all case study sites.

purposes. These conflicts occurred within stakeholder groups, as well as with the MPA authorities.

> 'From the fisheries point of view, [. . .] we're basically barred out with a large section of the lough, the midsection, pretty much the amount of fishermen are allowed into the lough is severely restricted, and [. . .] diminishing. [. . .] They put a restricted licensing scheme. [. . .] [The MPA authority]'re wanting [to] make a fishery in Strangford Lough extinct and this is their way of doing it.' – *Strangford Lough marine user.*

> 'Some sailing club members seem to think they own the lough.' – *Strangford Lough marine user.*

The Solway Firth does not have an access issue in the way its Irish (NI and ROI) counterparts do because of the Land Reform (Scotland) Act 2003, known as 'freedom (or right) to roam' (Scottish Parliament, 2003). This means that, save for a handful of exceptions, people have the right to walk through privately-owned land and access inland water as long as they do so responsibly, making accessing the Solway Firth relatively simple. As one coastal user explains, 'The right to roam, I just kind of take it for granted because it's always been such a part of how in Scotland, [. . .] how we, you know, access the natural environment. There are obviously areas of the Solway coast that are inaccessible in terms of the Ministry of Defense area. But they're really limited.' The Solway Firth also differs from the other two MPAs in this study because of its lack of marine users as a stakeholder group. This can partially be attributed to the inner Solway's geology and its aging population. Its large tidal range and quicksand can make it dangerous for water sports and, despite current preservation efforts, the Solway's ancient fishing tradition of haaf netting is dying out (Solway Firth Partnership [SFP], 1996; Peters, 2020).

Awareness of MPA Status

A recurring theme flagged in both the quantitative and qualitative data is a lack of awareness by all stakeholder groups about marine conservation at Strangford Lough and the Solway Firth and, in particular, about their management. Many lifelong residents of the Strangford Lough area claimed they were unaware that Strangford Lough is an MPA and those who did know about its conservation importance did not know who was responsible for its management and monitoring, nor whom to contact regarding lough-related issues.

> 'I am not sure a significant number of the residents know or fully understand about [the] MPA. I have lived here for my entire life and I am unaware as to who the [MPA management] are and how

I would go about contacting them.' – *Strangford Lough community member.*

'I have lived beside Strangford Lough all my life but was unaware of these MPAs and their roles. I feel that the community requires more awareness on this issue.' – *Strangford Lough community member.*

At the Solway Firth, low scores for *respect for actors* may be attributed to the fact that awareness of the firth's management is largely unknown as, when prompted, many participants explained that they were unaware of who was responsible for the Solway or that it was even protected.

'I've lived and walked on the Solway for 15 years and have no clue who MPA [management] are. They aren't visible to me.' – *Solway Firth coastal user.*

'I live on the Solway coast but have never heard of the MPA. I walk the coast daily and have never seen a warden or ranger in my life.' – *Solway Firth coastal user.*

'There [are] a lot of different protections coming from different places, different legislation, protecting different things, but also protecting overlapping things. Everyone knows it's an important area. [. . .] But I would say that therein lies confusion of how its protected, what different designations they are, why they're there, and who manages them as well.' – *Solway Firth coastal user*.

Communication With the Public

This lack of awareness persists at the Solway Firth, as despite the presence of an active partnership (SFP) promoting the firth's environmental and cultural importance, stakeholders across all groups highlighted a need for more improved *coordination and collaboration* and more opportunities for *participation* for the local population. Those with an established interest in the Solway know where to find information, but someone new to the area may not.

'This is a sparsely populated [area] with an aging and declining population – very few of whom access the MPA. Annual public forums occur as well as stakeholder meetings – but attendance is poor.' – *Solway Firth coastal user.*

'[The] timing of events and meetings can leave those with no transport unable to contribute. [We] need more specific public engagement at large and local events.' – *Solway Firth coastal user.*

'There's no signposting [. . .] in terms of sort of public engagement, you know, articles in local papers or [. . .] anything like that really.' – *Solway Firth community member.*

'I think there's a lot of people who are very active, and the organizations do make an effort to try and involve people from all different sectors and different strata of society. And if people choose not to be involved, it's not because they don't have the opportunity.' – *Solway Firth community member.*

While means for *coordination and collaboration* and *participation* exist at Strangford Lough, participants across all stakeholder groups reported being unaware of when public forums were held. Many stakeholders have become wary of public consultations from MPA authorities because they feel that their voices are not being heard and that these consultations are merely a formality.

'If anybody appears in [a stakeholder's] yard, wearing yellow jacket and carrying a clipboard, their past experience has not been good. [. . .] I think the people who are involved in getting the opinion of the various stakeholders need to bear in mind the sensitivities and I think they don't, at least [. . .] the stories I hear suggest that they don't.' – *Strangford Lough community member.*

'I don't feel at all empowered with my local community. I would get involved, but I never hear of anything.' – *Strangford Lough marine user.*

Participation and *coordination and collaboration* remain poor at Carlingford Lough as well. One local business owner claims, 'Public consultations are manipulated to minimize participation,' as consultations are not advertised in local newspapers. A coastal user explains, 'There's nobody out there telling us that [forums are] happening. [. . .] Maybe there [are] formal communications between organizations, but there doesn't seem to be any communication at all [. . .] to the general public.'

At all sites, some participants found the authorities responsible for the management of the MPAs inaccessible and unresponsive to issues brought forth by stakeholders:

'We've ended up with [. . .] a political class that don't see the sea as part of their constituency [. . .] unless they represent a large commercial port [or] fishing port.' – *Solway Firth community member.*

'[We wanted to] get rid of the *Spartina* [*anglica,* an invasive species]. [. . .] But you need permission. And that's not easy to get, and [NPWS] ignore you and your emails go into the ether and never get answered.' – *Carlingford Lough coastal user.*

Respondents expressed frustration at the lack of communication about conservation work:

'People don't want [to be] engaged with to then have the results not turn into anything or [. . .] put in a report that gathers dust on a shelf somewhere, they want to see the actual impact that their feedback has.' – *Solway Firth a coastal user*.

[DAERA need to] 'publish and publicize the results [of ecological surveys] in ways that are actually user-friendly. Because sometimes you get to the data produced, and you just go, like, no one's gonna read this. You've got to produce some sort of factsheet that's user- friendly and is easy to read in plain English.' – *Strangford Lough marine user*.

Environmental Management

Stakeholders across all groups at the Solway Firth (including management) recognized that more efforts could be made in *achieving objectives* (Q16, Q17, and Q18). Litter was the most important issue brought up by participants, as the Solway's tides and weathering events bring in litter from all around and wash them up on shore. Beachgoers and fishers are also accused of littering on the Solway, and agricultural practices contribute to the problem: According to one coastal user, 'On busy days the Sandhills [Beach] bin is always overfull. It needs [to be] emptied more so rubbish doesn't blow into the sea. [There's] slurry from flooded farm land. Nothing is getting done about this.' Litter is the responsibility of private landowners as well as the county councils, and a large-scale project to tackle litter on the Scottish coast, known as SCRAPbook, has just come to a close due to lack of funding (SCRAPbook, 2020). At Strangford Lough, the destruction and subsequent restoration of the *Modiolus* reefs became a matter for the European Union, as DAERA failed to protect these fragile biogenic habitats: One manager explained, 'If it wasn't for the European Commission and for the NGOs in Northern Ireland, none of the work to restore the reefs in Strangford Lough would have ever taken place.'

Law Enforcement

Stakeholders noted a distinct absence of MPA authorities – DAERA in particular – at Strangford Lough and Carlingford Lough and some participants felt that conservation of the loughs was low on the Northern Ireland government's list of priorities. A similar sentiment was expressed with regards to *law enforcement* (Q11 and Q12) at Strangford Lough, which generally falls under the remit of the Police Service of Northern Ireland's Wildlife Crimes Unit. However, participants who tried to get in touch with law enforcement at Strangford Lough reported being met with disinterest:

> 'So [I] called the PSNI [about jet skis on Strangford Lough], who were also mystified and [didn't] really think it was something that they should have been [called about] and [they had] more important things to do.' – *Strangford Lough marine user.*

At Carlingford Lough, efforts to report environmentally-damaging activities also appear to have gone unheeded:

> '[DAERA] have an obligation under this law, that law, [they]'ll tick a box about how [they] do site surveys, but we've reported multiple issues of damage, environmental damage, animal by-product dumping and everything. And [DAERA's] answer is "We don't have the resources to do that."' – *Carlingford Lough business owner*.

Resource Constraints

The perceived lack of involvement on the part of MPA management in lough-related issues at both Strangford Lough and Carlingford Lough has been attributed by some participants to a lack of resources. Budget cuts and redistribution of personnel (Department of Finance, 2018; National Trust, 2020; O'Sullivan, 2021) within the organizations and agencies responsible for the loughs have made monitoring and communication between stakeholders and MPA management increasingly difficult.

> 'DAERA have appointed people and wardens to check on the fisheries. However, it has stumbled a bit because of staff changes. [. . .] There were enormous budgetary pressures. [. . .] I do believe that they have the intention, not always the resource, but the intention to monitor [. . .] very effectively.' – *Strangford Lough management*.

> 'There was a girl who was employed as the ranger [. . .] a few years ago, but that post has now gone. [S]he was actually very good at engaging with people as well.' – *Strangford Lough marine user.*

> 'I feel like they were doing the best they can with what they have.' – *Carlingford Lough coastal user.*

DISCUSSION

This study is the first to assess equity and governance in MPAs using the recently-developed SAGE tool and one of the first to look at equity across multiple stakeholder groups in PAs – both marine and terrestrial (Zafra-Calvo et al., 2019). Across all case study sites, similar issues arise. Awareness is a major obstacle to equitable conservation, as many stakeholders didn't know they had the right to participate in MPA decision-making. Lack of awareness can make *participation* (Q6 and Q7) and *coordination and collaboration* (Q19 and Q20) between stakeholder groups more difficult, and this study highlights a need for more public awareness and engagement opportunities at all three sites (Agardy et al., 2011; Soma and Haggett, 2015; Johnson et al., 2019; Morf et al., 2019). Confusion over designations and their objectives also means that participants are uncertain about their MPA's conservation importance and what restrictions exist and why.

Adding to the confusion are the complex governance structures of these MPAs, with various actors responsible for different aspects of the MPAs (Jones et al., 2013). This makes it difficult for stakeholders to know to whom to turn to with issues such as restrictions or to report lawbreaking and it can be discouraging when stakeholders are met with disinterest when they finally contact the appropriate person or organization. Stakeholders also criticized the lack of *coordination and collaboration,* particularly surrounding environmental reporting and stakeholder engagement. The questionnaire results show low scores from all stakeholder groups (excluding management). Stakeholders feel that their views are not taken into account during consultations or forums, echoing findings of other studies on MPA governance (Gustavsson et al., 2014; Soma and Haggett, 2015; Rush and Solandt, 2017; Sowman and Sunde, 2018; Morf et al., 2019).

As both the quantitative and qualitative data show, the top-down and centralized approach to governance favored in the United Kingdom and Ireland results in greater disparity between management and local stakeholders and lower perceived levels of equity by the latter (Jones, 2012; Jones et al., 2013; Ban and Frid, 2018; Sowman and Sunde, 2018). Participants at all sites reported a disinterest from government agencies, with some citing times when local knowledge was disregarded by MPA authorities and expressing frustration at lack of public engagement around conservation issues. This approach to governance may also be linked to reactive management due to centralization: by not incorporating local ecological knowledge and stakeholder experiences in management and – to an extent – monitoring, MPA authorities may miss key issues and introduce conservation measures too late (McKenna et al., 2008; Jones et al., 2013; Morf et al., 2019). Such a reactive rather than proactive approach to management is illustrated in the aforementioned *M. modiolus* case at Strangford Lough (Johnson et al., 2008; Smyth et al., 2009; Cooper, 2011; Jones, 2012; Yates et al., 2013; Fariñas-Franco et al., 2018). In 2003 and then again in 2011, the Ulster Wildlife Trust lodged a complaint to the European Commission over the NI government's failure to protect horse mussel beds, resulting in the government facing a fine of over £8 m (McKimm, 2011, 2012).

Partnerships such as the SFP – and, to a certain extent, the SLLP – may help bridge the gap between government and local communities, and perhaps provide an alternative approach to governance, somewhere between the bottom-up approach of community-based management and the current top-down approach (Govan et al., 2008; Jones, 2012; Rush and Solandt, 2017; Ban and Frid, 2018; Johnson et al., 2019; O'Higgins et al., 2019). A type of co-management, partnerships should be integrated into MPA management plans in order to be given the chance to be successful (Rush and Solandt, 2017; Ban and Frid, 2018; Voorberg and Van der Veer, 2020). At the time of publication, new management plans are being developed for Strangford Lough and Carlingford Lough, and this would be an ideal opportunity to integrate stakeholders and an active and representative partnership or committee into these plans. This is particularly topical at Carlingford Lough, where new infrastructure is being designed to accommodate the post-Brexit customs checks at Warrenpoint (Campbell, 2020), which will undoubtedly impact the lough's conservation and its local communities. Bringing lough-related issues to light is Love Your Lough, a volunteer-led grassroots environmental group of local stakeholders at Carlingford Lough (on both sides of the border) – but no formal statutory body currently exists to manage these issues and provide stakeholders with an official platform from which to meet with government agencies. The Loughs Agency has been proposed as a potential partnership and cross-boundary institution for local management to serve Carlingford Lough (and Lough Foyle) in a similar vein as the SFP, but there are currently no plans to expand the Loughs Agency's role (House of Commons and Northern Ireland Affairs Committee, 2018;O'Higgins et al., 2019).

A lack of financial resources is often cited by participants in the two Irish sites as being part of the problem. Indeed, financial resources are a major obstacle to effective conservation (Rush and Solandt, 2017; Singer and Jones, 2018). Budget cuts mean Strangford Lough no longer has a site-specific officer. The Irish National Parks and Wildlife Service's funding has decreased by 70% since 2008 (O'Sullivan, 2021): County Louth (Carlingford Lough) has one ranger to cover the entire county. Formal volunteer action (such as a partnership or committee) and an investment in technology to improve monitoring may help alleviate financial pressures (Rush and Solandt, 2017; Singer and Jones, 2018). This study shows that stakeholders care about their marine environment and the presence of advocacy groups such as Love Your Lough, community membership of the SFP, and stakeholder participation in citizen science projects such as Coastwatch and Seasearch demonstrate that there are volunteers willing to work toward more effective conservation of their MPAs and they should be given the chance to be included in decision-making through partnerships or co-management (Rush and Solandt, 2017; Singer and Jones, 2018; Johnson et al., 2019; Voorberg and Van der Veer, 2020).

Despite low response rates and sampling limitations in this pilot study, the data show that SAGE can nevertheless help identify major issues surrounding equity and governance in PAs, allowing PA management and governing bodies to make more informed decisions that take into account the views of local stakeholders. The online version of SAGE used in this study has its limitations, as participants have to navigate the assessment tool on their own. In-person workshops have the added benefit of facilitators to assist stakeholders in SAGE reporting, but may be time or cost-prohibitive for stakeholders to attend. A 1-day online workshop, or one that is spread out across multiple sessions, may be one possible solution.

Marine protected areas management may need to regain the trust of certain stakeholder groups to ensure equitable governance (Bennett et al., 2020). The considerable number of 'I don't know' responses (missing values) to the questionnaire data demonstrates the need for more communication from MPA authorities to stakeholders about their role in the conservation of these marine areas and how it can impact them. It also suggests that the principles concerned may be less relevant in the context of a particular MPA, although this may also indicate a lack of understanding from stakeholders as to processes available to them. For example, the questions for *dispute resolution* (Q9 and 10), *impact mitigation* (Q13), and *benefits sharing* (Q14 and Q15) had the highest missing values across all sites and stakeholder groups (76, 58, and 62%, respectively). While questions were reworded with input from stakeholders at the pilot workshop at Strangford Lough to make them more widely understandable, these aforementioned principles were not raised by stakeholders in semi-structured interviews as issues of concern, even when prompted. Understanding the issues that are important to stakeholders and fostering collaboration between these groups and MPA management to tackle these issues can lead to more equitable and effective conservation (Christie et al., 2003; Jentoft et al., 2007; Halpern et al., 2013; Soma and Haggett, 2015; Schreckenberg et al., 2016).

CONCLUSION

The relationship between equity and MPAs has been little studied (Bennett et al., 2020), making this study one of few published on the subject. It is also one of the first studies to assess the perceived equity and governance of multiple stakeholder groups in MPAs (Bennett et al., 2020). The results of this study in the Irish Sea show that the top-down approach to governance favored by the United Kingdom and the Republic of Ireland complicates communication and collaboration between stakeholders and management authorities, due to the perceived inaccessibility of the MPA agencies. The shift in the SLLP's role from management group to advisory board and its move from the shores of Strangford Lough to the offices of the county council 10 km away illustrates the centralization of governance away from the communities it is meant to support. It is worth noting that the SLLP remains positively viewed by Strangford Lough stakeholders and therefore could potentially take on a larger role once again following the SFP model. To improve stakeholder engagement and participation at Carlingford Lough, the Loughs Agency could also be redesigned to represent local stakeholders beyond fishing and aquaculture. The results of this study show that a lack of communication and inclusion are the biggest threats to equity in these Irish Sea MPAs, but that many stakeholders are willing to get more involved if given the chance. The literature suggests that equitably managed PAs have a greater chance of being ecologically successful (Christie et al., 2003; Halpern et al., 2013; Batista and Cabral, 2016), although more case study-based research may be needed to explore this socio-ecological relationship. Incorporating inclusive partnerships into management is one step in the right direction to achieving objectives while ensuring equitable conservation. As one marine user at Strangford Lough put it, 'While there's lots of things that need to be done, how much worse would it be if there was nothing [done] at all?'.

DATA AVAILABILITY STATEMENT

The original contributions generated for this study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by King's College London Research Ethics Office (Ethical clearance reference number: LRS-18/19-13395). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CS and KS contributed to the conceptualization, design, and methodology of this study. Fieldwork was conducted by CS, with KS also participating in the pilot workshop at Strangford Lough. Data analysis (quantitative and qualitative) was done by CS, with NJ contributing to statistical analysis. CS visualized the data. The first draft of the manuscript was written by CS. All authors contributed to manuscript revision, read, and approved the submitted version. CS is supervised by KS and TD.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.668919/full#supplementary-material

REFERENCES

Agardy, T., di Sciara, G. N., and Christie, P. (2011). Mind the gap: addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Mar. Policy* 35, 226–232. doi: 10.1016/j.marpol.2010.10.006

ALICE Project (2016). *ALICE in Northern Ireland: Carlingford Lough*. Available online at: https://project-alice.com/fr/alice-in-ireland/ (Accessed March 12, 2020).

Arnstein, S. R. (1969). A ladder of citizen participation. *J. Am. Plan. Assoc.* 35, 216–224. doi: 10.1080/01944366908977225

Bakker, Y. W., de Koning, J., and van Tatenhove, J. (2019). Resilience and social capital: the engagement of fisheries communities in marine spatial planning. *Mar. Policy* 99, 132–139. doi: 10.1016/j.marpol.2018.09.032

Ban, N. C., and Frid, A. (2018). Indigenous peoples' rights and marine protected areas. *Mar. Policy* 87, 180–185. doi: 10.1016/j.marpol.2017.10.020

Bastari, A., Pica, D., Ferretti, F., Micheli, F., and Cerrano, C. (2018). Sea pens in the Mediterranean Sea: habitat suitability and opportunities for ecosystem recovery. *ICES J. Mar. Sci.* 75, 1722–1732. doi: 10.1093/icesjms/fsy010

Batista, M. I., and Cabral, H. N. (2016). An overview of marine protected areas in SW Europe: factors contributing to their management effectiveness. *Ocean Coast. Manag.* 132, 15–23. doi: 10.1016/j.ocecoaman.2016.07.005

Bennett, N. J. (2016). Using perceptions as evidence to improve conservation and environmental management. *Conserv. Biol.* 30, 582–592. doi: 10.1111/cobi.12681

Bennett, N. J., Calò, A., Di Franco, A., Niccolini, F., Marzo, D., Domina, I., et al. (2020). Social equity and marine protected areas: perceptions of small-scale fishermen in the Mediterranean Sea. *Biol. Conserv.* 244:108531. doi: 10.1016/j.biocon.2020.108531

Brander, L. M., van Beukering, P., Nijsten, L., McVittie, A., Baulcomb, C., Eppink, F. V., et al. (2020). The global costs and benefits of expanding Marine Protected Areas. *Mar. Policy* 116:103953. doi: 10.1016/j.marpol.2020.103953

Campbell, B., and Hanich, Q. (2015). Principles and practice for the equitable governance of transboundary natural resources: cross-cutting lessons for marine fisheries management. *Marit. Stud.* 14:8. doi: 10.1186/s40152-015-0028-7

Campbell, J. (2020). *Brexit: 'Warrenpoint Harbour "Needs 40,000sq ft Facility for Goods Checks."' BBC News*. 30 June 2020. Available online at: https://www.bbc.co.uk/news/uk-northern-ireland-53233184 (Accessed January 14, 2021)

Campbell, L. M., and Gray, N. J. (2019). Area expansion versus effective and equitable management in international marine protected areas goals and targets. *Mar. Policy* 100, 192–199. doi: 10.1016/j.marpol.2018.11.030

Christie, P., McCay, B. J., Miller, M. L., Lowe, C., White, A. T., Stoffle, R., et al. (2003). Toward developing a complete understanding: a social science research agenda for marine protected areas. *Fisheries* 28, 22–26.

Christie, S. J., McCann, D., Annett, J., Bankhead, J., Burgess, D., Casement, P., et al. (2011). "Chapter 18: status and changes in the UK ecosystems and their services to society: Northern Ireland," in *UK National Ecosystem Assessment: Technical Report*, eds R. Watson and S. Albon (Cambridge: UNEP-WCMC), 775–894. Available online at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=MCZWs8Rz3fg%3D&tabid=82

Claudet, J. (2011). "Introduction," in *Marine Protected Areas: A Multidisciplinary Approach*, ed. J. Claudet (Cambridge: Cambridge University Press), 1–8. doi: 10.1017/CBO9781139049382.001

Convention on Biological Diversity [CBD] (2011). *COP 10 Decision X/2.Strategic Plan for Biodiversity 2011-2020*. Available online at: https://www.cbd.int/decision/cop/?id=12268 (Accessed July 15, 2020)

Cooper, J. A. G. (2011). Progress in Integrated Coastal Zone Management (ICZM) in Northern Ireland. *Mar. Policy* 35, 794–799. doi: 10.1016/j.marpol.2011.01.002

Creswell, J. W., and Plano Clark, V. L. (2011). *Designing and Conducting Mixed Methods Research*, 2nd Edn. Los Angeles, CA: SAGE Publications.

Dawson, N., Martin, A., and Danielsen, F. (2018). Assessing Equity in protected area governance: approaches to promote just and effective conservation. *Conserv. Lett.* 11:e12388. doi: 10.1111/conl.12388

Dearden, P., Bennett, M., and Johnston, J. (2005). Trends in global protected area governance, 1992-2002. *Environ. Manage.* 36, 89–100. doi: 10.1007/s00267-004-0131-9

Department for Environment Food and Rural Affairs [DEFRA] (2019). *Solway Firth Marine Conservation Zone*. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/805546/mcz-solway-firth-2019.pdf (Accessed May 10, 2020).

Department of Agriculture Environment and Rural Affairs [DAERA] (2016). *Conservation Actions and Potential Management Options: Carlingford Lough Marine Conservation Zone (MCZ)*. Available online at: https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Conservaton%20Objectives%20and%20Potential%20Management%20Options%20-%20Carlingford%20Lough%20MCZ_0.pdf (Accessed March 12, 2020)

Department of Agriculture Environment and Rural Affairs [DAERA] (2017). *Strangford Lough SAC Conservation Objectives*. Available online at: https://www.daera-ni.gov.uk/sites/default/files/publications/doe/Strangford%20Lough%20SAC%20Conservation%20Objectives%202018_.pdf (Accessed November 20, 2019)

Department of Finance (2018). *Briefing on Northern Ireland Budgetary Outlook 2018-20*. Available online at: https://www.finance-ni.gov.uk/sites/default/files/publications/dfp/Briefing%20on%20Northern%20Ireland%20Budgetary%20Outlook%202018-20v2.pdf (Accessed January 21, 2021)

Di Franco, A., Hogg, K. E., Calò, A., Bennett, N. J., Sévin-Allouet, M. A., Esparza Alaminos, O., et al. (2020). Improving marine protected area governance through collaboration and co-production. *J. Environ. Manage.* 269:110757. doi: 10.1016/j.jenvman.2020.110757

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506, 216–220. doi: 10.1038/nature13022

Fariñas-Franco, J. M., Allcock, A. L., and Roberts, D. (2018). Protection alone may not promote natural recovery of biogenic habitats of high biodiversity damaged by mobile fishing gears. *Mar. Environ. Res.* 135, 18–28. doi: 10.1016/j.marenvres.2018.01.009

Franks, P., Booker, F., and Roe, D. (2018). *Understanding and Assessing Equity in Protected Area Conservation: A Matter of Governance, Rights, Social Impacts and Human Wellbeing*. Available online at: https://pubs.iied.org/sites/default/files/pdfs/migrate/14671IIED.pdf (Accessed July 15, 2020).

Fraschetti, S., Claudet, J., and Grorud-Colvert, K. (2011). "MANAGEMENT – transitioning from single-sector management to ecosystem-based management: what can marine protected areas offer?," in *Marine Protected Areas: A Multidisciplinary Approach*, ed. J. Claudet (Cambridge: Cambridge University Press), 11–34. doi: 10.1017/cbo9781139049382.003

Friedman, R. S., Law, E. A., Bennett, N. J., Ives, C. D., Thorn, J. P. R., and Wilson, K. A. (2018). How just and just how? A systematic review of social equity in conservation research. *Environ. Res. Lett.* 13:053001. doi: 10.1088/1748-9326/aabcde

Giglio, V. J., Moura, R. L., Gibran, F. Z., Rossi, L. C., Banzato, B. M., Corsso, J. T., et al. (2019). Do managers and stakeholders have congruent perceptions on marine protected area management effectiveness? *Ocean Coast. Manag.* 179:104865. doi: 10.1016/j.ocecoaman.2019.104865

Gill, D. A., Cheng, S. H., Glew, L., Aigner, E., Bennett, N. J., and Mascia, M. B. (2019). Social synergies, tradeoffs, and equity in marine conservation impacts. *Annu. Rev. Environ. Resour.* 44, 347–372. doi: 10.1146/annurev-environ-110718-032344

Govan, H., Aalbersberg, W., Tawake, A., and Parks, J. E. (2008). *Locally-Managed Marine Areas: A guide to supporting Community-Based Adaptive Management*. Available online at: https://www.sprep.org/att/IRC/eCOPIES/Pacific_Region/210.pdf (accessed January 14, 2021).

Greathead, C., Gonzáles-Irusta, J. M., Clarke, J., Boulcott, P., Blackadder, L., Weetman, A., et al. (2014). Environmental requirements for three sea pen species: relevance to distribution and conservation. *ICES J. Mar. Sci.* 72, 576–586. doi: 10.1093/icesjms/fsu129

Gustavsson, M., Lindström, L., Jiddawi, N. S., and de la Torre-Castro, M. (2014). Procedural and distributive justice in a community-based managed marine protected area in Zanzibar, Tanzania. *Mar. Policy* 46, 91–100. doi: 10.1016/j.marpol.2014.01.005

Halpern, B. S., Klein, C. J., Brown, C. J., Beger, M., Grantham, H. S., Mangubhai, S., et al. (2013). Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. *Proc. Natl. Acad. Sci. U.S.A.* 110, 6229–6234. doi: 10.1073/pnas.1217689110

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V., Micheli, F., D'Agrosa, C., et al. (2008). A global map of human impact on marine ecosystems. *Science* 319, 948–952. doi: 10.1126/science.1149345

Hill, L. S., Johnson, J. A., and Adamowski, J. (2016). Meeting Aichi target 11: equity considerations in marine protected areas design. *Ocean Coast. Manag.* 134, 112–119. doi: 10.1016/j.ocecoaman.2016.09.017

Hopkins, C. R., Bailey, D. M., and Potts, T. (2018). Navigating future uncertainty in marine protected area governance: lessons from the Scottish MPA network. *Estuar. Coast. Shelf Sci.* 207, 303–311. doi: 10.1016/j.ecss.2018.04.020

House of Commons and Northern Ireland Affairs Committee (2018). *Brexit and Northern Ireland: Fisheries: Government Response to the Committee's Fourth Report*. Available online at: https://publications.parliament.uk/pa/cm201719/cmselect/cmniaf/1812/1812.pdf (Accessed February 11, 2021).

IBM Corporation (2019). *IBM SPSS Statistics for macOS, Version 26.0*. Armonk, NY: IBM Corporation.

International Institute for Environment and Development [IIED] (2021). *Site-Level Assessment of Governance and Equity (SAGE)*. Available online at: https://www.iied.org/site-level-assessment-governance-equity-sage (Accessed February 1, 2021)

Jentoft, S., van Son, T. C., and Bjørkan, M. (2007). Marine protected areas: a governance system analysis. *Hum. Ecol.* 35, 611–622. doi: 10.1007/s10745-007-9125-6

Johnson, D. E., Rees, S. E., Diz, D., Jones, P. J. S., Roberts, C., and Barrio Froján, C. (2019). Securing effective and equitable coverage of marine protected areas: the UK's progress towards achieving convention on biological diversity commitments and lessons learned for the way forward. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 29, 181–194. doi: 10.1002/aqc.3065

Johnson, M. P., Jessopp, M., Mulholland, O. R., McInerney, C., McAllen, R., Allcock, A. L., et al. (2008). What is the future for marine protected areas in Irish waters? *Biol. Environ.* 108, 9–14. doi: 10.3318/BIOE.2008.108.1.9

Jones, P. J. S. (2012). Marine protected areas in the UK: challenges in combining top-down and bottom-up approaches. *Environ. Conserv.* 39, 248–258. doi: 10.1017/S0376892912000136

Jones, P. J. S., Qiu, W., and De Santo, E. M. (2013). Governing marine protected areas: social-ecological resilience through institutional diversity. *Mar. Policy* 41, 5–13. doi: 10.1016/j.marpol.2012.12.026

Klein, C. J., Brown, C. J., Halpern, B. S., Segan, D. B., McGowan, J., and Watson, J. E. M. (2015). Shortfalls in the global protected area network at representing marine biodiversity. *Sci. Rep.* 5:17539. doi: 10.1038/srep17539

Leverington, F., Costa, K. L., Pavese, H., Lisle, A., and Hockings, M. (2010). A global analysis of protected area management effectiveness. *Environ. Manage.* 46, 685–698. doi: 10.1007/s00267-010-9564-5

Lloyd, J. M., Shennan, I., Kirby, J. R., and Rutherford, M. M. (1999). Holocene relative sea-level changes in the inner Solway Firth. *Quat. Int.* 60, 83–105. doi: 10.1016/S1040-6182(99)00009-9

Long, R. D., Charles, A., and Stephenson, R. L. (2015). Key principles of marine ecosystem-based management. *Mar. Policy* 57, 53–60. doi: 10.1016/j.marpol.2015.01.013

Loughs Agency (2021). *About Us*. Available online at: https://www.loughs-agency.org/about-us/ (Accessed January 14, 2021)

McDermott, M., Mahanty, S., and Schreckenberg, K. (2013). Examining equity: a multidimensional framework for assessing equity in payments for ecosystem services. *Environ. Sci. Policy* 33, 416–427. doi: 10.1016/j.envsci.2012.10.006

McKenna, J., Quinn, R. J., Donnelly, D. J., and Cooper, J. A. G. (2008). Accurate mental maps as an aspect of Local Ecological Knowledge (LEK): a case study from lough neagh, Northern Ireland. *Ecol. Soc.* 13:13. doi: 10.5751/ES-02393-130113

McKimm, M. (2011). *NI faces Huge EU fines over Strangford Lough Horse Mussels. BBC News. 19 November 2011*. Available online at: https://www.bbc.co.uk/news/uk-northern-ireland-15793436 (Accessed February 1, 2021)

McKimm, M. (2012). *Horse Mussels Fine from Europe could be £8m. BBC News. 15 March 2012*. Available online at: https://www.bbc.co.uk/news/uk-northern-ireland-17389346 (Accessed January 20, 2021)

Morf, A., Moodie, J., Gee, K., Giacometti, A., Kull, M., Piwowarczyk, J., et al. (2019). Towards sustainability of marine governance: challenges and enablers for stakeholder integration in transboundary marine spatial planning in the Baltic Sea. *Ocean Coast. Manag.* 177, 200–212. doi: 10.1016/j.ocecoaman.2019.04.009

National Trust (2020). *Our Spending Cut Plans in Response to Coronavirus Losses*. Available online at: https://www.nationaltrust.org.uk/news/our-spending-cut-plans-in-response-to-coronavirus-losses (Accessed January 21. 2021)

O'Higgins, T., O'Higgins, L., O'Hagan, A. M., and Ansong, J. O. (2019). "Challenges and opportunities for ecosystem-based management and marine spatial planning in the Irish Sea," in *Maritime Spatial Planning: Past, Present, Future*, eds J. Zaucha and K. Gee (Cham: Palgrave Macmillan), 47–69. doi: 10.1007/978-3-319-98696-8_3

O'Sullivan, K. (2021). *Government Announces Major Review of National Parks & Wildlife Service.' The Irish Times. 4 February 2021*. Available online at: https://www.irishtimes.com/news/environment/government-announces-major-review-of-national-parks-wildlife-service-1.4476077 (Accessed February 4, 2021)

Outdoor Recreation Northern Ireland (2018). *An Audit of Access to Strangford Lough for Water-based Recreation*. Available online at: https://www.strangfordlough.org/images/publications/STRANGFORD_LOUGH_WATER_ACCESS_REPORT_-_Final_Version.compressed.pdf (Accessed January 21, 2021)

Pascual, U., Phelps, J., Garmendia, E., and Corbera, E. (2014). Social equity matters in payments for ecosystem services. *BioScience* 64, 1027–1036. doi: 10.1093/biosci/biu146

Peters, J. (2020). *The Solway Firth Haaf Netters Fighting to Save a Fishing Tradition.' BBC News. 21 January 2021*. Available online at: https://www.bbc.co.uk/news/uk-scotland-south-scotland-51124288 (Accessed January 27, 2021)

Pita, C., Theodossiou, I., and Pierce, G. J. (2013). The perceptions of Scottish inshore fishers about marine protected areas. *Mar. Policy* 37, 254–263. doi: 10.1016/j.marpol.2012.05.007

Pomeroy, R. S., Watson, L. M., Parks, J. E., and Cid, G. A. (2005). How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas. *Ocean Coast. Manag.* 48, 485–502. doi: 10.1016/j.ocecoaman.2005.05.004

QSR International (2019). *NVivo for macOS, Version 12.6*. Melbourne: QSR International.

Qualtrics (2020). *Qualtrics XM, Version 5.2020*. Provo, UT: Qualtrics.

RStudio PBC (2020). *RStudio for macOS, Version 1.3.1073*. Boston, MA: RStudio.

Rush, S., and Solandt, J. L. (2017). Challenges on providing conservation advice for a growing network of English marine protected areas. *Mar. Policy* 83, 75–82. doi: 10.1016/j.marpol.2017.05.026

Salayo, N. D., Ahmed, M., Garces, L., and Viswanathan, K. (2006). An overview of fisheries conflicts in South and Southeast Asia: recommendations, challenges and directions. *Naga WorldFish Cent. Q.* 29, 11–20.

Schéré, C. M., Dawson, T. P., and Schreckenberg, K. (2020). Multiple conservation designations: what impact on the effectiveness of marine protected areas in the Irish Sea? *Int. J. Sustain. Dev. World Ecol.*, 596–610. doi: 10.1080/13504509.2019.1706058

Schreckenberg, K., Franks, P., Martin, A., and Lang, B. (2016). Unpacking equity for protected area conservation. *Parks* 22, 11–26. doi: 10.2305/iucn.ch.2016.parks-22-2ks.en

Scottish Natural Heritage [SNH] (2016). *Solway Firth Proposed Special Proteciton Area (pSPA) NO. UK9005012*. Available online at: https://www.nature.scot/sites/default/files/2017-12/Marine%20Protected%20Area%20%28Proposed%29%20-%20Site%20selection%20document%20-%20Solway%20Firth.pdf (Accessed March 12, 2020)

Scottish Parliament (2003). *Land Reform (Scotland) Act 2003*. Available online at: https://www.legislation.gov.uk/asp/2003/2/contents (Accessed January 14, 2021)

SCRAPbook (2020). *SCRAPbook: Targeting Scotland's Coastal Litter*. Available online at: https://scrapbook-scotland.org.uk/ (Accessed January 14, 2021).

Singer, R., and Jones, P. (2018). Lyme bay marine protected area: a governance analysis. *Mar. Policy* 127, 1–8. doi: 10.1016/j.marpol.2018.07.004

Smyth, D., Roberts, D., and Browne, L. (2009). Impacts of unregulated harvesting on a recovering stock of native oysters (Ostrea edulis). *Mar. Pollut. Bull.* 58, 916–922. doi: 10.1016/j.marpolbul.2008.12.021

Solway Firth Partnership [SFP] (1996). *Solway Firth Review*. Available online at: http://solwayfirthpartnership.co.uk/wp-content/uploads/2018/09/Solway-Firth-Review.docx (Accessed January 13, 2021)

Solway Firth Partnership [SFP] (2015). *Solway Firth Partnership Business Plan 2015-2018*. Available online at: https://solwayfirthpartnership.co.uk/wp-content/uploads/2018/09/SFP_Business_Plan_2015-2018.pdf (Accessed March 12, 2020.

Solway Firth Partnership [SFP] (2020). *Socio-Economic Assessment of the Scottish Solway: Summary*. Available online at: https://www.solwayfirthpartnership.co.uk/wp-content/uploads/2020/04/SEASS-Report-One-Page-Summary.pdf (Accessed May 11, 2020)

Soma, K., and Haggett, C. (2015). Enhancing social acceptance in marine governance in Europe. *Ocean Coast. Manag.* 117, 61–69. doi: 10.1016/j.ocecoaman.2015.11.001

Soma, K., van Tatenhove, J., and van Leeuwen, J. (2015). Marine governance in a European context: regionalization, integration and cooperation for ecosystem-based management. *Ocean Coast. Manag.* 117, 4–13. doi: 10.1016/j.ocecoaman.2015.03.010

Sowman, M., and Sunde, J. (2018). Social impacts of marine protected areas in South Africa on coastal fishing communities. *Ocean Coast. Manag.* 157, 168–179. doi: 10.1016/j.ocecoaman.2018.02.013

Sterling, E. J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., et al. (2017). Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biol. Conserv.* 209, 159–171. doi: 10.1016/j.biocon.2017.02.008

United Nations Environment Programme [UNEP] (2018). *Protected Planet Report 2018*. Available online at: https://livereport.protectedplanet.net/pdf/Protected_Planet_Report_2018.pdf (Accessed July 15, 2020).

van Tatenhove, J. P. M. (2013). How to turn the tide: developing legitimate marine governance arrangements at the level of the regional seas. *Ocean Coast. Manag.* 71, 296–304. doi: 10.1016/j.ocecoaman.2012.11.004

Voorberg, W., and Van der Veer, R. (2020). Co-management as a successful strategy for marine conservation. *J. Mar. Sci. Eng.* 8:491. doi: 10.3390/JMSE8070491

Vucetich, J. A., Burnham, D., Macdonald, E. A., Bruskotter, J. T., Marchini, S., Zimmermann, A., et al. (2018). Just conservation: what is it and should we pursue it? *Biol. Conserv.* 221, 23–33. doi: 10.1016/j.biocon.2018.02.022

World Database on Protected Areas [WDPA] (2020). *Marine Protected Areas*. Available online at: https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas (Accessed March 12, 2020)

Yates, K. L., Payo Payo, A., and Schoeman, D. S. (2013). International, regional and national commitments meet local implementation: a case study of marine conservation in Northern Ireland. *Mar. Policy* 38, 140–150. doi: 10.1016/j.marpol.2012.05.030

Young, J. C., Jordan, A., Searle, K. R., Butler, A., Chapman, D., Simmons, P., et al. (2013). Does stakeholder involvement really benefit biodiversity conservation? *Biol. Conserv.* 158, 359–370. doi: 10.1016/j.biocon.2012.08.018

Zafra-Calvo, N., Garmendia, E., Pascual, U., Palomo, I., Gross-Camp, N., Brockington, D., et al. (2019). Progress toward equitably managed protected areas in aichi target 11: a global survey. *Bioscience* 69, 191–197. doi: 10.1093/biosci/biy143

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Trash or Treasure? Considerations for Future Ecological Research to Inform Oil and Gas Decommissioning

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Numerous oil and gas (O&G) installations worldwide will need to be decommissioned in the near future. Complete removal of subsea structures is often the default approach although some regions retain structures under rigs-to-reefs programs. Here, we reviewed the published literature to understand the status of global research on decommissioning, and specifically identify gaps in ecological knowledge. We estimated the frequency of different research categories (i.e., themes, and spatial/temporal scales), and tested the assumption that the number of papers across the categories of each research aspect was even in distribution. However, the frequency of studies focusing on biodiversity at a local ($\leq$100 km^2) scale (relative to regional and oceanic and pan-oceanic scales) were significantly higher; while other theme categories (e.g., eco-toxicology, connectivity, structural-integrity, restoration and other) were significantly lower than expected. Temporally, $\leq$1-year studies were more frequent than multi-year studies, but these frequencies did not significantly deviate from the assumed distribution of equal frequencies. We propose that further research be carried out to evaluate the benefits of both retention and removal of structures. Ecological research on decommissioning should extend its focus beyond biodiversity, to include eco-toxicology, structural-integrity, connectivity at larger spatial and temporal scales. This would provide a more holistic assessment of ecological impacts to inform sustainable and equitable development choices in multiple Blue Economy sectors, as we transition from offshore O&G to marine renewables.

Keywords: subsea structures, decommissioning, offshore wind, marine renewables, rigs-to-reefs, oil and gas (O&G) industry, offshore & marine structures

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DECOMMISSIONING OF OIL AND GAS SUBSEA STRUCTURES: A GROWING ISSUE

Worldwide, oil and gas (O&G) companies are facing the challenge of managing unproductive subsea infrastructure that cannot be re-purposed (Cullinane and Gourvenec, 2017). Retiring infrastructure and returning a title to regulators is known as decommissioning. This process can encompass anything from complete removal to leaving subsea structures in place (*in situ* decommissioning), with numerous options in between (Techera and Chandler, 2015; Fam et al., 2018; Sommer et al., 2019). Full removal is the default regulatory position in the United Kingdom and in Australia. In the North Sea, the OSPAR convention specifies that a derogation could be obtained for steel foundations weighing over 10,000 t (OSPAR, 1998). Australia has a mechanism to assess decommissioning on a case-by-case basis, where the risk needs to be "as low as reasonably possible" (ALARP) (NOPSEMA, 2020). In the United States, policies vary from full removal to decommissioning *in situ* (Kaiser and Pulsipher, 2005). The Gulf of Mexico's is often cited for its rigs-to-reef program (Fam et al., 2018). However, policies are set to evolve based on experience in given countries, and shared knowledge worldwide.

There are several presumed drivers for leaving retired subsea structures *in situ*. These include cost savings, logistics, including avoiding potentially unsafe operations at sea, and creating artificial reefs. In addition to ecological considerations, the social (including public perception) and economic dimensions are an important part of multi-criteria assessments and approaches, that consider these varied criteria (e.g., Fowler et al., 2014). Net environmental benefits analysis offers a way to compare and rank net environmental benefits associated with management alternatives and can be used in assessing decommissioning options but research on its merit for *in situ* decommissioning is needed. Stakeholders have concerns regarding the social, economic, and environmental aspects of decommissioning and a comprehensive list of questions on the risks and benefits are given in Shaw et al., 2018. In this article, we focus solely on research questions and research pertaining to the potential ecological value of biological assemblages on and around O&G infrastructure. This is generating considerable interest among regulators, industry, and scientific communities, who seek to understand the environmental implications of *in situ* decommissioning.

As decommissioning is of increasing international relevance (International Energy Agency, 2019), it is important to review existing research and identify gaps in knowledge, to direct future research and facilitate evidence-based decisions by policy makers. To this effect, we evaluated the peer-reviewed ecological research on *in situ* decommissioning and assessed research questions formulated by experts (Fowler et al., 2019) and stakeholders (Shaw et al., 2018). While we recognize that decisions regarding decommissioning will necessarily be multi-faceted and include engineering, social, economic considerations, as well as environmental ones, we focus here specifically on environmental inputs to decommissioning decisions. This review highlights where future research efforts can be targeted to gain a more holistic view of *in situ* decommissioning of subsea O&G infrastructure, and thus better inform government policy and industry decisions worldwide.

ANALYZING GLOBAL ECOLOGICAL RESEARCH ON DECOMMISSIONING THROUGH PUBLISHED RESEARCH AND RESEARCH QUESTIONS

We found global research articles on *in situ* decommissioning through an electronic search using Web of Science and Google Scholar. We used several combinations of the following keywords to search both databases: "decommissioning," "offshore," "infrastructure," "platform," "pipeline," "oil," "gas," "rigs-to-reefs," "subsea," "marine," "environment," "ecosystem," "future," and "impact."

The literature search was limited to terms that related directly to decommissioning. This gave results that regulators are likely to find when carrying out a similar search. In total, the literature searches yielded 182 records pertaining to ecological aspects of decommissioning (**Supplementary Material**). Those records came predominantly from North America (35.2%), Europe (26.4%), and Australia (9.9%), and 61.5% were published in the last 5 years. Few contributions came from the Middle East (0.5%), Africa (1.1%), South America (3.3%) and Asia (3.8%). Peer-reviewed publications accounted for 59.3% (108) of the search results and the rest was "gray literature," composed of conference contributions, seminars, workshops (11%), reports (8.8%), theses (3.8%), and other (17%) (**Supplementary Material**). In the peer-reviewed literature, 44.4% were studies with primary data obtained through biological/ecological field work, experiments and/or modeling; while the remaining were papers on methods (4.6%), frameworks (5.6%), concepts (29.6%), and other (15.7%).

Ecological research on decommissioning of O&G infrastructure was analyzed by identifying the (1) main theme, (2) temporal scale, and (3) spatial scale specific to each paper. This was carried out via content analysis (Krippendorff, 2004) and chi-squared goodness-of-fit tests. Content analysis was used to identify the frequency of research themes as well as the spatial and temporal scale of studies. Each paper was classified into one of five common research themes, stemming from the research questions developed by experts (Fowler et al., 2019) and stakeholders (Shaw et al., 2018). Publications were assigned to one theme only, as their focus fell clearly in one category. The research themes were: biodiversity, connectivity, ecotoxicology, structural integrity (i.e., how a collapsing or crumbling structure affects the biological assemblages on and around it), restoration (of historical assemblages at the site that were present prior to the structure being commissioned) and "other." The literature was classified into two temporal scales of data collection – i.e., ≤1 year or multi-year – and four spatial scales of data collection – i.e., local (≤100 km^2), regional (1,000 km^2), ocean and pan-ocean.

We tested the assumption that studies in research themes, spatial and temporal scales categories would occur with an equal probability using chi-squared goodness-of-fit tests. Statistical analyses were conducted in the R language for statistical computing (R Core Team, 2021). The observed frequencies of each of these research categories were tested independently, but we represented the frequency of interactions between theme, spatial and temporal scale categories using a mosaic plot with the "ggplot2" package in R (Wickham, 2016).

Biodiversity was the focus of 91.7% of all peer-reviewed studies with primary data and the main research question (60.3%) (**Figure 1**). Thirteen of the 44 biodiversity studies used video footage derived from routine engineering inspections with remotely operated vehicles (ROVs), rather than footage from specially designed scientific field campaigns. Of the biodiversity studies, 43.2% were on fish and other species of commercial interest. The presence of such species on structures was typically

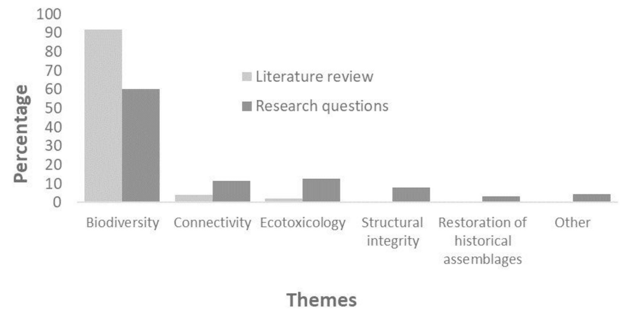

FIGURE 1 | Prevalence of common ecological research themes in global peer-reviewed publications and priority research questions formulated by experts (Fowler et al., 2019) and Australian stakeholders (Shaw et al., 2018).

used to demonstrate the ecological value of the infrastructure as a habitat, in that it increases local biodiversity. Another cited value of infrastructure was its presumed protective role against trawling and a negative value was its possible role in spreading marine invasive species (Fowler et al., 2018, 2019). Only 9.1% of biodiversity studies were focused on non-native or invasive species, the presence of which was typically used to support removal of subsea infrastructure. Published research was most frequently conducted at a local scale (i.e., $\leq$100 km^2; 98%), and over short periods of time ($\leq$1 year) (**Figure 2**).

We found that developed nations that have started the decommissioning process (United States, United Kingdom, Australia) produce more peer-reviewed publications than other regions of the world, such as Asia, where decommissioning has also begun. We also found that the literature is dominated by studies on biodiversity (mostly fish species of commercial value) rather than being spread across themes selected by stakeholders

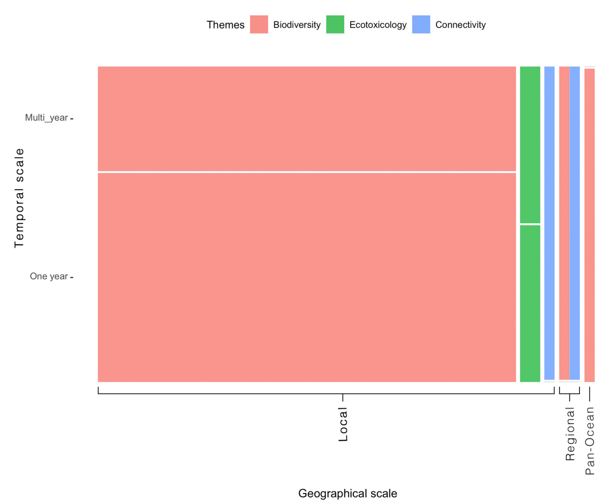

FIGURE 2 | The proportion of published peer-reviewed literature on oil and gas decommissioning (n = 48) that were classified into different themes, and into spatial and temporal categories. Note categories with zero counts (i.e., "restoration" and "other" in the Themes variable are not displayed).

(derived from Shaw et al., 2018). The most frequent spatial scale was local ($\leq$100 km^2) and studies were often carried out once (i.e., $\leq$1 year). Chi-square goodness-of-fit tests showed that the themes, and geographical spread were significantly different to an even distribution across categories (Themes: p = 1.13E-39, Geographical scale: p = 2.24E-17, α = 0.05). Modeling studies were classified as multi-year, and this resulted in the observed frequencies between single and multi-year studies being not significantly different from each other (p = 0.249794, α = 0.05) (**Supplementary Material**).

We recognize that there are challenges involved with acquiring information about biological communities on/around O&G structures. Carrying out field work at these locations is challenging (depth, safety training requirements, company buy-in etc.). Analyzing ROV footage acquired for industry purposes is a first step but does not always guarantee the quality necessary for scientific studies (lack of replication), especially when quantifying marine sessile invertebrates [e.g., 6 months of viewing 5746.2 GB of industrial video at 7.5 h a day took 6 months and yielded only 428 usable photos (Schläppy pers. com)]. Archival footage is better suited to quantify fish biodiversity (Bond et al., 2018a; McLean et al., 2021). Although, research questions formulated by experts (Fowler et al., 2019) and other stakeholders (Shaw et al., 2018) encompass many themes that are important to make informed decisions (**Figure 1**), those themes, do not get reflected in the research that has been carried out to date, aside from biodiversity assessments.

When regulators need to make decisions and cannot wait for additional information, they have two options: (1) make decisions that are based on the available literature or (2) take into account other themes that have not been researched extensively and apply the precautionary principle. However, unlike in situations where it is clear what precautionary (in)action would be, it is more difficult to ascertain in the case of decommissioning because we do not know yet whether removing or retaining those structures is the more benign option for the environment. This is the reason why there is a pressing need for a wider variety of studies to be carried out. In a context of paucity of studies on alternative perspectives of value and risk of *in situ* decommissioning, it is understandable that nations with a "removal base-case" (e.g., United Kingdom, Australia, parts of the United States) are not yet prepared to consider *in situ* decommissioning as a valid option. Improving temporal and spatial scales of sampling could help, by generally increasing the gradients of environmental conditions and ecological responses observed (Hewitt et al., 2007). Collecting data at larger scales would increase the robustness of models predicting future ecological impacts in changing climate and environmental conditions. Of course, some degree of extrapolation will always be required, as novel climate and ecological responses will emerge in time (Williams et al., 2007; Moritz and Agudo, 2013).

To support decision-making that considers both the advantages of retaining and removing O&G subsea infrastructure in the context of a global increase in ocean sprawl (Firth et al., 2016), future efforts should address ecological questions beyond just biodiversity. This includes connectivity, ecotoxicology, restoration of historical assemblages and finding out whether collapsing or altered structures will harbor similar biodiversity. This would enhance the transparency, accountability and legitimacy of current decommissioning policies and regulations. Below, we highlight ecological knowledge gaps that should be addressed and considerations for assessing the advantages/disadvantages of *in situ* decommissioning, to reduce uncertainty in decision-making.

CONSIDERATIONS FOR INTERPRETATION OF RESEARCH RESULTS AND KNOWLEDGE GAPS IN DECOMMISSIONING RESEARCH

Themes

Biodiversity

This review revealed that most studies focused on biodiversity and more specifically on fish, with an emphasis on those of commercial value. Much less attention to date has been given to sessile invertebrates or how marine megafauna use and inhabit subsea structures (but see Robinson et al., 2013 and Russell et al., 2014). Although fish studies offer a valuable first step in our knowledge of assemblages on and around subsea structures, it would be highly valuable to broaden the scope and include other organisms, and thus be able to assess diverse trophic levels present on a given structure. The attraction of focusing on fish reflects the perceived social benefits that structures could bring to recreational and commercial fishers. In future, when discussing the value of subsea structures as a habitat for marine organisms, we suggest paying attention to the following points:

The section of a subsea structure that remains in the water does matter

We know that biodiversity on vertical subsea structures is largely dependent on depth (McLean et al., 2018; Thomson et al., 2018). On pipelines, biodiversity is higher at spans, and where structural complexity is enhanced due to sessile invertebrates (McLean et al., 2017). Therefore, not all parts of a subsea structure will have the same habitat value depending on where it is located. The value of biological assemblages on subsea structures should be formulated according to different scenarios: (a) retaining the whole structure; (b) retaining most of the structure except for the portion closest to the sea surface (e.g., platform jacket cut 50 m below the surface, or a pipeline cut 1–10 km from the shore); (c) removing most of the structure (cut 1–10 m above sediment). Thought should also be given to how the structural integrity of the structure will affect biodiversity in the future.

The presence of pelagic fish around a subsea structure is not automatically positive

Subsea structures may not be nurturing habitats for pelagic fish species even if these are attracted to them. Although artificial structures can attract pelagic fish, they could also become ecological traps (Schlaepfer et al., 2002) rather than ecological havens for two reasons: (1) fish at these locations will be easier to catch by fishers, and (2) pelagic fish species attracted to subsea structures may be physiologically disadvantaged by residing there. For instance, pelagic fish like Skipjack tuna *Katsuwonus pelamis*, and yellowfin tuna *Thunnus albacares* that are attracted to artificial structures i.e., fish aggregation devices (Fonteneau et al., 2000) for long periods of time have been shown to have emptier stomachs and be in poorer condition than conspecifics caught away from the structure (Hallier and Gaertner, 2008; Jaquemet et al., 2011). Future studies on the condition of organisms on and around subsea structures will enable us to test whether the structures offer an optimal habitat for pelagic and/or migratory species or whether their presence may only benefit fishers.

Connectivity

Research on the effect of offshore infrastructure on the metapopulations of different marine organisms already exists (Thorpe, 2012; Simons et al., 2016; van der Molen et al., 2018); however, with the increase of artificial offshore structures (e.g., offshore wind, tidal and wave energy devices), assessing the (cumulative) effect of those structures on marine communities is critical (Bailey et al., 2014; Goodale and Milman, 2016).

The value of biological assemblages on subsea structures is likely to be related to whether they are a source of larvae that spreads to natural communities and therefore will be a function of the extent of their connection with other structures and analogous natural assemblages. Sources and sinks of larvae could be modeled by including the main oceanic currents in a region, coupled with population genetic research. Even if a subsea O&G structure produces larvae of "desirable" species, it might still not be of high ecological interest if the propagules are dispersed by ocean currents to unsuitable locations for their survival. Genetic information about connectivity could be obtained well before decommissioning is necessary, by comparing the genetic structure of organisms on structures to those in analogous natural habitats in the region. If the connectedness of the structures translates into the facilitated spread of invasive species, then connectivity is not conservation-enhancing. When considering the potential for any subsea structures to harbor and spread invasive species by functioning as stepping-stones (Rivas et al., 2010; De Mesel et al., 2015), larger spatial scales than those researched to date are also important. O&G infrastructure has already initiated several species range extensions. Some of these species have gained pest status at their new location (Page et al., 2006; Sammarco et al., 2014; Tanasovici et al., 2020). Noting that current research on invasive species represents only 9% of biodiversity studies for *in situ* decommissioning research, a priority would be to investigate the propensity of invasive species to colonize subsea O&G structures.

Ecotoxicology

Only two studies on decommissioning relate to the theme of ecotoxicology (i.e., Henry et al., 2017 and Lourenço et al., 2015). Ecotoxicology studies are necessary to uncover whether local pollution poses a health risk to organisms on and around subsea structures. This may have repercussions on whether polluted subsea structures constitute a nurturing environment that is conducive to them acting as a source or sink of larvae. We know that bioaccumulation occurs in some organisms such as mussels (Lourenço et al., 2015) but further ecotoxicological tests of contaminants, and organisms' tolerance are necessary. This is especially true for naturally occurring radioactive materials (NORMs) and plastics, to determine with increased certainty their effect on the growth, reproduction and survival of those organisms and the impact on humans through ingestion of fish caught at these locations. Knowledge gaps exist around species' tolerance to contaminants and which level of pollution exposure in water or sediment is deleterious. Laboratory experiments of sediment resuspension and the effect of NORMs would help to ascertain the rate of uptake by organisms and help predict their level across the food chain.

One of the arguments put forward in favor of *in situ* decommissioning of O&G infrastructures is that the sediment plume and pollution associated with their removal will be deleterious to the biological assemblages on and around the subsea structures. There are three scenarios under which the sediment plume due to decommissioning could be more deleterious than the plume created while installing the infrastructure if: (1) the sediment suspension created by the decommissioning activity is higher than levels deemed acceptable during the development of the O&G field (noting environmental standards may have changed in the intervening period); (2) new scientific evidence shows that lower sediment loads (than previously thought) are deleterious to nearby organisms; (3) the concentrations of pollutants released during the removal operations are above those currently leaching out from the sediments (Gray et al., 1990) and drill cuttings (Henry et al., 2017). Ecotoxicological studies are needed to fill those knowledge gaps and ascertain with more confidence the benefits of retaining or removing O&G structures.

Structural Integrity

No study addressed the theme of structural integrity, but stakeholders are concerned with this issue and have formulated questions on this subject (Shaw et al., 2018 and **Figure 1**). During operations, O&G companies fight to retain the structural integrity of infrastructure by carrying out maintenance and treatments, such a cathodic protection (to prevent oxidation of metals). Therefore, there is a poor understanding about how, when left in the water without care, these structures will lose their current structural integrity. Although this could be viewed as an engineering matter only, it is likely to have an effect on biodiversity and on the ecological significance of the assemblages present on and around the structure, especially if degradation of products are toxic or result in the loss of habitat. The current value given to those biological assemblages may differ in the future as a structure degrades.

Restoration of Historical Assemblages

On land, industries that create environmental disturbances, such as mining, are usually required to remediate the disturbed site when exploitation is finished. To our knowledge, this is not common practice for offshore O&G operations. It is unclear whether restoration is possible, or whether these sites are in fact novel ecosystems whose value lies in a state, different to the historical and current state (van Elden et al., 2019). No studies were found on restoration of historical assemblages and stakeholders asked whether this is even possible, and with what success (Shaw et al., 2018). The first step to investigate this would be to carry out surveys at sites where subsea structures were removed. Access to those places is likely to be unrestricted, unlike access to active subsea structures. The biodiversity on subsea structures often appears to be much higher than adjacent communities (Bond et al., 2018b). However, many subsea structures with a hard surface cannot be meaningfully compared to the flat areas surrounding the structure that are often dominated by mobile sediments. Before *in situ* decommissioning can be considered a better environmental option than removal, the role of natural or restored historical assemblages should also be studied. For example, vast expanses of sediment with a mix of filter-feeders provide valuable ecosystem services, such as carbon sequestration.

Spatial Scale

The biodiversity of species found at a local scale was the focus of most published studies. How well the subsea structure is connected to analogous natural habitats (i.e., hard substratum, at the same depth) and the role of populations on structures in the context of the metapopulation are two aspects that will drive the value of biological assemblages on a subsea structure. Although local ($\leq$100 km^2) studies constitute a good start that makes the most of available industrial ROV footage, regional ($\leq$1000 km^2) studies are necessary when investigating connectivity.

Status of an Organism's Metapopulation

Subsea structures can influence larval recruitment, and therefore species conservation, by intercepting larvae that would normally recruit to natural habitats, thus depleting larval supply to natural habitats (no conservation gain). If the metapopulation is of a species that requires conservation, subsea structures could provide a habitat for recruitment and contribute recruits to natural habitats (conservation gain). If the metapopulation is healthy elsewhere, no additional gain is obtained from a species present on/around artificial structures especially if those function as ecological traps (see above). Considering these complexities, a precautionary approach would be to consider each species present on the subsea structures as ecologically neutral, until it is shown to be either deleterious or beneficial to its corresponding metapopulation, rather than implying that their presence is beneficial.

Temporal Scale

Biological Assemblages Are Likely to Change Over Time

Our review showed that 30 out of the 48 past studies collected data at one point in time ($\leq$1 year), and that multi-year studies were less frequent (18/48, due to several multi-year modeling studies). Characterizing the biological assemblages found on and around O&G subsea structures over less than 1 year is a good preliminary step. However, whether those assemblages are stable through time is uncertain. Studies should ideally consider temporal trends, using appropriate experimental designs to ensure multi-year comparisons that enhance the predictive power of the ecological value of those assemblages.

Assemblages may change seasonally, before/after natural events (e.g., heatwaves and storms). They may also change as a result of sloughing, may be influenced by the sewage and macerated food that is routinely discarded from crewed platforms (at levels allowed in permits) or by the heat produced during operations, which may favor or disfavor the settlement and survival of certain organisms. Given the difficulty of predicting future assemblages, their future ecological value is equally uncertain. To understand temporal dynamics of organisms on/around O&G infrastructure, surveys should be repeated over several years, well before *in situ* decommissioning becomes considered, using consistent methods to ensure that comparable data can be used for future predictions.

CONCLUSION: A WAY FORWARD

Ultimately, deciding on whether *in situ* decommissioning yields positive, negative, or neutral environmental outcomes requires a body of research on a range of themes. To achieve evidence-based management, science that spans multiple facets of ecology, and across larger spatial and temporal scales than the studies to date, will be required. The questions elicited from stakeholders and experts (Shaw et al., 2018; Fowler et al., 2019) and the studies published to date (**Supplementary Material**) mostly focus on the presence of biodiversity, especially of commercially important fish species. This is not surprising as this is one of the simplest question to address with existing industrial ROV footage, but this perspective unduly emphasizes the advantage of retaining subsea structures. So, while studies conducted to date constitute a valuable start, they partially reflect the availability of archival data, rather than what is required for a holistic approach to research on this topic.

Our identification of knowledge gaps suggests future research projects should also investigate the environmental effects of removing subsea infrastructures and cover ecologically meaningful spatial and temporal scales[1]. As decommissioning is becoming an increasingly global societal issue, partnerships between industry, government and philanthropists are necessary to effectively address the full suite of research questions. There is no doubt that considerable investment is required to adequately answer the full range of questions needed to inform a complete environmental assessment of *in situ* decommissioning. Prioritization of research questions could occur through a triage framework (Bottrill et al., 2008) or consultative processes (Wallace et al., 2016).

Ultimately, subsea O&G structures are not the only artificial structures in the marine environment, and their ecological role needs to be considered in synergy with other types of structures (e.g., shipwrecks, offshore wind turbines, wave and tide renewable energy infrastructure). How regulators decide to approach decommissioning of subsea O&G structures is likely to pave the way for how the decommissioning of future marine renewable installations will be handled. Therefore, best practices must be adopted now, using evidence at the appropriate spatial and temporal scales, as this will contribute to equitable decision-making procedures, which is an investment towards present and future ocean health.

[1]For example, projects funded by programmes such as the INfluence of man-made Structures In The Ecosystem (INSITE) in Europe and the National Decommissioning Research Initiative (NDRI) in Australia.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

M-LS designed the study. M-LS, LR, and VC-A acquired and analyzed the data. M-LS, LR, VC-A, and KM interpreted the data, drafted the work, and revised it critically for important intellectual content, approved the final version to be published and agreed to be held accountable for all aspect of the work. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.642539/full#supplementary-material

REFERENCES

Bailey, H., Brookes, K. L., and Thompson, P. M. (2014). Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. *Aquat. Biosyst.* 10:8. doi: 10.1186/2046-9063-10-8

Bond, T., Langlois, T. J., Partridge, J. C., Birt, M. J., Malseed, B. E., Smith, L., et al. (2018a). Diel shifts and habitat associations of fish assemblages on a subsea pipeline. *Fish. Res.* 206, 220–234. doi: 10.1016/j.fishres.2018.05.011

Bond, T., Partridge, J. C., Taylor, M. D., Langlois, T. J., Malseed, B. E., Smith, L. D., et al. (2018b). Fish associated with a subsea pipeline and adjacent seafloor of the north west shelf of western Australia. *Mar. Environ. Res.* 141, 53–65. doi: 10.1016/j.marenvres.2018.08.003

Bottrill, M. C., Joseph, L. N., Carwardine, J., Bode, M., Cook, C., Game, E. T., et al. (2008). Is conservation triage just smart decision making? *Trends Ecol. Evol.* 23, 649–654. doi: 10.1016/j.tree.2008.07.007

Cullinane, B., and Gourvenec, S. (2017). Decommissioning–the next Australian oil and gas boom? *APPEA J.* 57, 421–425. doi: 10.1071/aj16203

De Mesel, I., Kerckhof, F., Norro, A., Rumes, B., and Degraer, S. (2015). Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. *Hydrobiologia* 756, 37–50. doi: 10.1007/s10750-014-2157-1

Fam, M. L., Konovessis, D., Ong, L. S., and Tan, H. K. (2018). A review of offshore decommissioning regulations in five countries–strengths and weaknesses. *Ocean Eng.* 160, 244–263. doi: 10.1016/j.oceaneng.2018.04.001

Firth, L. B., Knights, A. M., Bridger, D., Evans, A. J., Mieszkowska, N., Moore, P. J., et al. (2016). Ocean sprawl: challenges and opportunities for biodiversity management in a changing world. *Oceanogr. Mar. Biol. Annu. Rev.* 54, 193–269. doi: 10.1201/9781315368597

Fonteneau, A., Pallarés, P., and Pianet, R. (2000). "A worldwide review of purse seine fisheries on FADs," *in Proceedings of the Conference Pêche Thonière et Dispositifs de Concentration de Poissons, 15–19 October*, eds Y Le Gall, P Cayré and M Taquet (Martinique: IFREMER), 15–35.

Fowler, A. M., Jørgensen, A.-M., Coolen, J. W. P., Jones, D. O. B., Svendsen, J. C., Brabant, R., et al. (2019). The ecology of infrastructure decommissioning in the North Sea: what we need to know and how to achieve it. *ICES J. Mar. Sci*. 77, 1109–1126. doi: 10.1093/icesjms/fsz143

Fowler, A. M., Macreadie, P. I., Jones, D. O. B., and Booth, D. J. (2014). A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure. *Ocean Coast. Manag.* 87, 20–29. doi: 10.1016/j.ocecoaman.2013.10.019

Fowler A. M., Jørgensen, A. M., Svendsen, J. C., Macreadie, P. I., Jones, D. O. B., Boon, A. R., et al. (2018). Environmental benefits of leaving offshore infrastructure in the ocean. *Front. Ecol. Environ.* 16, 571–578. doi: 10.1002/fee.1827

Goodale, M. W., and Milman, A. (2016). Cumulative adverse effects of offshore wind energy development on wildlife. *J. Environ. Plan. Manag.* 59, 1–21. doi: 10.1080/09640568.2014.973483

Gray, J., Clarke, K., Warwick, R., and Hobbs, G. (1990). Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Mar. Ecol. Prog. Ser.* 66, 285–299. doi: 10.3354/meps066285

Hallier, J. P., and Gaertner, D. (2008). Drifting fish aggregation devices could act as an ecological trap for tropical tuna species. *Mar. Ecol. Prog. Ser.* 353, 255–264. doi: 10.3354/meps07180

Henry, L. A., Harries, D., Kingston, P., and Roberts, J. M. (2017). Historic scale and persistence of drill cuttings impacts on North Sea benthos. *Mar. Environ. Res.* 129, 219–228. doi: 10.1016/j.marenvres.2017.05.008

Hewitt, J. E., Thrush, S. F., Dayton, P. K., and Bonsdorff, E. (2007). The effect of spatial and temporal heterogeneity on the design and analysis of empirical studies of scale-dependent systems. *Am. Nat.* 169, 398–408. doi: 10.1086/510925

International Energy Agency (2019). *Annual Average Decommissioning Need for Offshore Oil and Gas Assets by Region, 2000–2040*. Available online at: https://www.iea.org/data-and-statistics/charts/annual-average-decommissioning-need-for-offshore-oil-and-gas-assets-by-region-2000-2040 (accessed April 17, 2020).

Jaquemet, S., Potier, M., and Ménard, F. (2011). Do drifting and anchored Fish Aggregating Devices (FADs) similarly influence tuna feeding habits? A case study from the western Indian Ocean. *Fish. Res.* 107, 283–290. doi: 10.1016/j.fishres.2010.11.011

Kaiser, M. J., and Pulsipher, A. G. (2005). Rigs-to-reef programs in the Gulf of Mexico. *Ocean Dev. Int. Law* 36, 119–134. doi: 10.1080/00908320590943990

Krippendorff, K. (2004). Reliability in content analysis. *Hum. Commun. Res.* 30, 411–433.

Lourenço, A. R., Francisco de Oliveira, F., Haddad Nudi, A., Rebello Wagener, Â. de L, Guadalupe Meniconi, M. de F, and Francioni, E. (2015). PAH assessment in the main Brazilian offshore oil and gas production area using semi-permeable membrane devices (SPMD) and transplanted bivalves. *Cont. Shelf Res.* 101, 109–116. doi: 10.1016/j.csr.2015.04.010

McLean, D., Cure, K., Abdul Wahab, M. A., Galaiduk, R., Birt, M., Vaughan, B., et al. (2021). A comparison of marine communities along a subsea pipeline with those in surrounding seabed areas. *Cont. Shelf Res.* 219:104394. doi: 10.1016/j.csr.2021.104394

McLean, D. L., Partridge, J. C., Bond, T., Birt, M. J., Bornt, K. R., and Langlois, T. J. (2017). Using industry ROV videos to assess fish associations with subsea pipelines. *Cont. Shelf Res.* 141, 76–97. doi: 10.1016/j.csr.2017.05.006

McLean, D. L., Taylor, M. D., Partridge, J. C., Gibbons, B., Langlois, T. J., Malseed, B. E., et al. (2018). Fish and habitats on wellhead infrastructure on the north west shelf of Western Australia. *Cont. Shelf Res.* 164, 10–27. doi: 10.1016/j.csr.2018.05.007

Moritz, C., and Agudo, R. (2013). The future of species under climate change: resilience or decline? *Science* 341, 504–508. doi: 10.1126/science.1237190

NOPSEMA (2020). *Core Concepts*. 1–25. Available online at: https://www.nopsema.gov.au/assets/Guidance-notes/A138249.pdf (accessed December 12, 2020).

OSPAR (1998). *Sintra Statement (Vol. 45)*. Available online at: https://www.ospar.org/site/assets/files/36552/98_sintra_statement_english.pdf (accessed April 17, 2020).

Page, H. M., Dugan, J. E., Culver, C. S., and Hoesterey, J. C. (2006). Exotic invertebrate species on offshore oil platforms. *Mar. Ecol. Prog. Ser.* 325, 101–107. doi: 10.3354/meps325101

R Core Team (2021). A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Available online at: https://www.r-project.org/ (accessed February 3, 2021).

Rivas, G., Moore, A., Dholoo, E., and Mitchell, P. (2010). Alien invasive species: risk and management perspectives for the oil and gas industry. Society of Petroleum Engineers. *Paper Presented at the SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production*, Rio de Janeiro, 2482–2497.

Robinson, D. P., Jaidah, M. Y., Jabado, R. W., Lee-Brooks, K., Nour El-Din, N. M., Malki, A. A. A., et al. (2013). Whale sharks, rhincodon typus, aggregate around offshore platforms in Qatari waters of the Arabian Gulf to feed on fish spawn. *PLoS One* 8:e58255. doi: 10.1371/journal.pone.0058255

Russell, D. J. F., Brasseur, S. M. J. M., Thompson, D., Hastie, G. D., Janik, V. M., Aarts, G., et al. (2014). *Marine Mammals Trace Anthropogenic Structures at Sea.in Current Biology*, Vol. 24. Amsterdam: Elsevier Ltd, 638–639.

Sammarco, P. W., Porter, S. A., Sinclair, J., and Genazzio, M. (2014). Population expansion of a new invasive coral species, tubastraea micranthus, in the northern gulf of mexico. *Mar. Ecol. Prog. Ser.* 495, 161–173. doi: 10.3354/meps10576

Schlaepfer, M. A., Runge, M. C., and Sherman, P. W. (2002). Ecological and evolutionary traps. *Trends Ecol. Evol.* 17, 474–480. doi: 10.1016/S0169-5347(02)02580-6

Shaw, J., Seares, P., and Newman, S. (2018). *Decommissioning Offshore Infrastructure: A Review of Stakeholder Views and Science Priorities*. Available online at: www.wamsi.org.au/decommissioning-offshore-infrastructure-review-stakeholder-views-and-science-priorities (accessed June 19, 2020).

Simons, R. D., Page, H. M., Zaleski, S., Miller, R., Dugan, J. E., Schroeder, D. M., et al. (2016). The effects of anthropogenic structures on habitat connectivity and the potential spread of non-native invertebrate species in the offshore environment. *PLoS One* 11:e0152261. doi: 10.1371/journal.pone.0152261

Sommer, B., Fowler, A. M., Macreadie, P. I., Palandro, D. A., Aziz, A. C., and Booth, D. J. (2019). Decommissioning of offshore oil and gas structures–environmental opportunities and challenges. *Sci. Total Environ.* 658, 973–981. doi: 10.1016/j.scitotenv.2018.12.193

Tanasovici, R. M., Kitahara, M. V., and Dias, G. M. (2020). Invasive coral *Tubastraea* spp. population growth in artificial habitats and its consequences to the diversity of benthic organisms. *Mar. Biol.* 167:119. doi: 10.1007/s00227-020-03734-6

Techera, E. J., and Chandler, J. (2015). Offshore installations, decommissioning and artificial reefs: do current legal frameworks best serve the marine environment? *Mar. Policy* 59, 53–60. doi: 10.1016/j.marpol.2015.04.021

Thomson, P. G., Fowler, A. M., Davis, A. R., Pattiaratchi, C. B., and Booth, D. J. (2018). Some old movies become classics–a case study determining the scientific value of ROV inspection footage on a platform on Australia's North West Shelf. *Front. Mar. Sci.* 5:471. doi: 10.3389/fmars.2018.00471

Thorpe, S. A. (2012). On the biological connectivity of oil and gas platforms in the North Sea. *Mar. Pollut. Bull.* 64, 2770–2781. doi: 10.1016/j.marpolbul.2012.09.011

van der Molen, J., García-García, L. M., Whomersley, P., Callaway, A., Posen, P. E., and Hyder, K. (2018). Connectivity of larval stages of sedentary marine communities between hard substrates and offshore structures in the North Sea. *Sci. Rep.* 8:14772. doi: 10.1038/s41598-018-32912-2

van Elden, S., Meeuwig, J. J., Hobbs, R. J., and Hemmi, J. M. (2019). Offshore oil and gas platforms as novel ecosystems: a global perspective. *Front. Mar. Sci.* 6:548. doi: 10.3389/fmars.2019.00548

Wallace, K. J., Wagner, C., and Smith, M. J. (2016). Eliciting human values for conservation planning and decisions: a global issue. *J. Environ. Manag.* 170, 160–168. doi: 10.1016/j.jenvman.2015.12.036

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York, NY: Springer Verlag.

Williams, J. W., Jackson, S. T., and Kutzbach, J. E. (2007). Projected distributions of novel and disappearing climates by 2100 AD. *Proc. Natl. Acad. Sci. U.S.A.* 104, 5738–5742. doi: 10.1073/pnas.0606292104

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frontiers in Marine Science

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Effect of a Seasonal Fishery Closure on Sardine and Mackerel Catch in the Visayan Sea, Philippines

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The implementation of seasonal fishery closures (SFC) can be controversial due to the frequent lack of clear objectives, monitoring and empirical evidence of management success. In the Philippines, an SFC implemented for the conservation of important fishery commodities in the Visayan Sea has been ruled a success after stricter implementation of this fishery policy in 2012. However, a comprehensive, detailed, and robust analysis of this fishery policy is lacking. Using a difference-in-differences (DID) framework, we estimated the effect of SFC on the interannual and seasonal catch for sardine and mackerel. We expanded our analysis to other species not regulated under the SFC policy. We also conducted semi-structured interviews (N = 235), focus group discussions (N = 9) and key informant interviews (N = 37) involving municipal fisheries stakeholders in the surrounding municipalities around the Visayan Sea, and representatives from the government and non-government agencies, to complement our analyses. Seasonal analyses of catch data show a significant increase in sardine catch at the end of the seasonal closure among SFC-participating provinces. However, overall, the SFC had no significant effect on sardine interannual catch among the provinces participating in the SFC. We also found no significant effect of the SFC on interannual and seasonal catch for mackerel. Furthermore, our findings show no significant changes in fishing pressure to other aquatic species. Interview results corroborate our DID findings for mackerel, but not for sardine. The varying perceptions on the outcomes of the SFC policy can be attributed to several challenges such as lack of implementing guidelines, lack of alternative livelihoods for the affected stakeholders, persistence of illegal fishing, and uneven implementation of the SFC. Since the management objective of this SFC was to conserve the regulated species, alternative management measures may be needed to achieve this goal. This could entail more consistent enforcement, improved cooperation and communication between fisheries managers and stakeholders, fish size or gear restrictions, and identification and conservation of key habitats needed to restore overexploited species.

Keywords: seasonal fishery closure, fishery policy evaluation, fisheries management, Visayan Sea, sardine, mackerel

INTRODUCTION

Seasonal fishery closures (SFCs) are areas temporarily closed to fishing for one or more species or to specific fishing gears (Gell and Roberts, 2002). Various justifications have been offered for closing fisheries for limited or longer periods. For example, SFCs have been widely used in fisheries management to prevent overfishing and collapse of a fishery, rebuild depleted stocks, reduce gear conflicts, and reduce bycatch of protected species (National Oceanic and Atmospheric Administration (NOAA), 1985; Gell and Roberts, 2002; Farmer et al., 2016; Agar et al., 2019). In some cases, SFCs are imposed during the breeding or spawning period of species with the aim to reduce fishing mortality directly, thus, achieving greater annual reproductive output (Murawski et al., 2000; Arendse et al., 2007). According to Beets and Manuel (2007), SFCs are management strategies that are easily enforced and often accepted by fishers due to their simplicity. In most instances, there are few theoretical justifications for seasonal closures (Gulland, as cited by Beets and Manuel, 2007). Despite potential benefits from SFCs, there are varying reviews about this management strategy in places where it has been implemented (Arendse et al., 2007; Jiang et al., 2009; Mendoça and Sobrinho, 2013; Wang et al., 2015). For example, SFCs implemented in the Gulf of Mexico shrimp fishery and Florida lobster fishery [National Oceanic and Atmospheric Administration (NOAA), 1985; Beets and Manuel, 2007], United States Virgin Islands grouper fishery (Beets and Friedlander, 1999) and coral reefs in Kenya (McClanahan, 2010) showed positive results. In contrast, seasonal closure enacted for the groundfish fishery in New England had little impact on reviving the groundfish stocks (Sinclair and Valdimarsson, 2003; Brodziak et al., 2004). In the case of the Pacific halibut fishery, while initial attempts for a closed season provided the base for subsequent regulatory measures, it failed to curb fishing effort and was thought to have limited conservation value (Babcock et al., 1931; Bell, 1969; Skud, 1985). In a paper that reviewed the temporal and seasonal closures used in fisheries management in tropical and subtropical regions, and important species for Hawaii, Beets and Manuel (2007) noted that, although quantitative analyses of the specific value of this fishery management strategy have not been conducted, managers who evaluated SFCs concluded that they have been useful and beneficial based on perceived benefits and stock effects (Beets and Manuel, 2007).

The implementation of spawning area closures in particular, can be controversial among some communities due to the frequent lack of clear objectives, monitoring and empirical evidence of management success (Sadovy and Domeier, 2005; Beets and Manuel, 2007; Grüss et al., 2014b; Clarke et al., 2015; Rola et al., 2018). For a spawning closure to have a net benefit to population growth, there should be a reduction in the annual fishing mortality at the scale of the stock (Clarke et al., 2015). However, a spawning closure may have no effect if the spawning fishes are not particularly susceptible to capture during spawning or there is a change in the fishing effort during other seasons (Beets and Manuel, 2007; Grüss et al., 2014a; Grüss and Robinson, 2015). For example, fishers may respond with greater fishing effort during open season to compensate for their inactivity during the closed season. Further, Everson (1986) argues that fishing bans during spawning seasons may not have an effect on future stocks because even if the enormous number of eggs that are produced by an individual fish can help in building up a stock, additional catching capacity will likely be introduced in the fishery, and unless the open season is shortened, fishing mortality may ultimately tend to return to its original level. There is also a high rate of natural mortality among early life history stages of fish as small fishes are normally exposed to more potential predation than bigger fishes and escape ability typically increases with body size (Bailey and Houde, 1989; Stige et al., 2019). Furthermore, fishing effort may be diverted to other resources that may be overfished or nearing an overfished condition (Beets and Manuel, 2007) or, to other areas (Horwood, 2000).

Seasonal fishery closures are particularly common in data poor fisheries because they can be implemented in areas where stock assessments have not been conducted to assess allowable catch. For example, the winter closure for Pacific Halibut was introduced before the existence of the International Pacific Halibut Commission (IPHC) and conservation was only a minor consideration in its implementation [Thompson and Freeman, 1930; International Fisheries Commission (IFC), 1948; Skud, 1985]. Biological justifications for the closed season were noted only in later years, but the IPHC retained it based on economic considerations (Babcock et al., 1931; Skud, 1985). Agar et al. (2019) note that seasonal closures have been advanced for protecting aggregating fisheries for which managers have limited information on the location and timing of their reproductive events. In the case of the Philippines, the introduction of the SFC in its fisheries was anchored on precautionary principle in response to observed decline in fish catch. The Philippines first implemented a SFC in 1939 to conserve sardines, herrings, and mackerels in the Visayan Sea, as per Fish and Game Administrative Order (FGAO) No. 13, s. 1939 [Department of Agriculture-Bureau of Fisheries and Aquatic Resources (DA-BFAR), 1939]. However, there is no information whether this regulation considered the species biology and its corresponding socioeconomic impact in decision making. The declaration of the SFC in 1939 was one of the first initiatives of the Philippine government to conserve the country's aquatic resources by regulating fishing activities in its critical fishing grounds (Ronquillo and Llana, 1987). It has undergone several revisions. The most recent issuance related to the SFC is the Fisheries Administrative Order No. 167-3, s. 2013, which shortens the SFC period to 3 months (November 15 to February 15; DA-BFAR, 2013a). This change was prompted by the realization on the part of the Bureau of Fisheries and Aquatic Resources (BFAR), the lead agency in the management of the fisheries and aquatic resources in the Philippines, that poor compliance of fishers with the SFC was caused by the longer period (Bagsit, 2020).

Studies that assessed the fisheries in the Visayan Sea have indicated heavy exploitation of stocks, particularly the pelagic species (Dalzell and Ganaden, 1987; Dalzell et al., 1990; Armada, 1999; Guanco et al., 2009; Bayate and Mesa, 2012). This was confirmed by Armada (1999) who noted that the maximum sustainable yield for most of the small pelagic species in the Visayan Sea was already reached in the mid-1970s. Sardine and mackerel are among the commercially important small pelagic fishes that historically dominated the Philippine fishery (Dalzell and Ganaden, 1987; Dalzell et al., 1990). Analysis of fish catch composition of different gears designed to catch pelagic and demersal species in the Visayan Sea shows that sardine (*Sardinella fimbriata and S. lemuru*) and mackerel (*Rastrelliger kanagurta* and *R. brachysoma*) were the most frequently caught fishes (Armada, 1999). Guanco et al. (2009) also observed that 67% of the catch from commercial fishing vessels (e.g., Danish seine, purse seine, trawl, and ring net) were predominantly pelagic fishes, with sardine and mackerel dominating the catch. These species are among the highest biomass of catches in terms of volume (DA-BFAR, 2014). They rank first in catch among marine municipal fisheries and third in commercial fisheries production (Subong, 2017). Municipal fisheries in the Philippines involve small-scale, labor-intensive fishing operations using motorized or non-motorized boats of three gross tons (GT) or less, within municipal waters (from the coastline to 15 km seaward). In contrast, the commercial fisheries sector is composed of capital-intensive corporate enterprises with more centralized fishing operations that take place beyond the 15 km boundary of the municipal waters up to the seaward edge of the 200-nautical mile Exclusive Economic Zone (EEZ) [Republic Act (RA) 8550, 1998]. These boats are classified into small-scale (3.1 GT up to 20 GT); medium-scale (20.1 GT up to 150 GT); and large-scale (>150 GT). Overall, fish catch from the Visayan Sea comprises approximately 10–13% of the total production of sardine and mackerel in the country (DA-BFAR, 2012).

Despite the SFC being in effect for eight decades, it was not strictly enforced until 2012. This coincided with the change in the BFAR's leadership which revitalized the Bureau's efforts in addressing destructive fishing methods, the continuous intrusion of commercial fishers in the municipal waters, and conservation efforts in fisheries (DA-BFAR, 2011). This resulted in the review, amendment, and active implementation of the SFCs. Since the start of a reinvigorated enforcement, there had been claims that the SFC was a success, noting an increase in fish catch each year at the end of the seasonal closure period (DA-BFAR, 2013b; Mesa, 2014; Ramos, 2014). However, in a recent study which examined whether the implementation of the SFC in the Visayan Sea has achieved its conservation goals, results showed a decrease in the catch-per-unit-effort (CPUE) of municipal fishers whose target species are sardine (Napata et al., 2020). Nonetheless, their analyses were limited to sardine only and not mackerel, hence, did not include all the species covered by the SFC. Further, the CPUE data presented were based on perceptions of municipal fishers using encircling gillnets only. As a result, there are contradicting indicators regarding management success of the Visayan Sea SFC and a comprehensive, detailed, and robust analysis inclusive of multiple species is yet to be performed. To address this issue, we applied a difference-in-differences (DID) approach to examine the effect of the SFC policy on the (1) municipal and commercial interannual catch for sardine and mackerel among provinces participating in the SFC in the Visayan Sea; (2) municipal and commercial seasonal catch for sardine and mackerel (i.e., catch during closed vs open seasons) among SFC-participating provinces; (3) interannual catch for the non-target species not regulated under the SFC; and (4) we conducted semi-structured interviews (SSI), focus group discussions (FGDs) and key informant interviews (KIIs) to complement our DID results. The interannual and seasonal analyses are complementary because they addressed different hypotheses. The interannual analysis addressed whether the strict implementation of the SFC led to increased catches of the protected species in recent years. In contrast, the seasonal analysis evaluated the claim of the BFAR that the SFC is effective because catches rebound seasonally after the end of the SFC. The third analysis examined whether there was a shift in fishing pressure to other species that are not regulated under the SFC. The SSIs, FGDs, and KIIs provided in-depth insights on the results of our DID analyses which helped us better understand the SFC in the context of the stakeholders involved in its implementation. Different insights into fisheries can be provided by fisheries dependent catch data versus qualitative interviews, as these datasets can sometimes illustrate differences between perceptions versus reality. Understanding stakeholder's perceptions of the SFC policy is vital in the sustainable management of the Visayan Sea.

The findings in this paper are important at multiple scales. At the local scale, people's livelihoods are at stake due to the disruption in their livelihoods during the SFC. At the national scale, the government has scarce resources to implement fishery policy, thus it is important to understand which policies are likely to be the most effective and which require review and revision. Our approach might also be useful to replicate in other regions with data poor fisheries and no stock assessments. At the global scale, global maxima of marine biodiversity is noted in the Indo-Malay-Philippines archipelago and data shows peak marine biodiversity in the central Philippines where the Visayan Sea lies (Carpenter and Springer, 2005). Philippine sardine biodiversity, for example, is among the highest in the world (Willette et al., 2011). Hence, appropriate management of the Visayan Sea is critical for maintaining biodiversity. Proper management of key biodiversity areas is integral in achieving the United Nation's Sustainable Development Goal 14 on conservation and sustainable use of the oceans and marine resources for sustainable development. This is especially true given that recent data show that the sustainability of global fishery resources continues to decline and current efforts to protect key marine environments and small scale fishers, among others, fell short of addressing the urgent need to protect these vast and fragile resources (United Nations, 2020). Finally, the Philippines is one of the major fish producing countries in the world in terms of marine capture production, hence, the sustainability of its fishing grounds is critical to local and global food security and protection of livelihood of coastal dwellers (FAO, 2020).

MATERIALS AND METHODS

Study Area and Data

The Visayan Sea is a traditional and major fishing ground in the Philippines (Food and Agriculture Organization (FAO), 2000; Ferrer, 2009). It is in the central Philippines and covers an area of about 10,000 km^2 (**Figure 1**). It is surrounded by three regions

(V-Bicol region, VI-Western Visayas and VII-Central Visayas) and 31 coastal municipalities in five provinces: Capiz, Iloilo, Negros Occidental, Cebu, and Masbate. This body of water is relatively shallow, with water depths of approximately 40 meters (Armada, 1999).

Provincial-level longitudinal fish catch data were obtained from the Philippine Statistics Authority [PSA] (2018)[1] to inform our analysis. The provincial-level data were aggregates of the municipal-level data, which are not publicly available. The data were comprised of sardine and mackerel catch from municipal and commercial fishers of the Visayan Sea. The PSA collected fish catch data on a quarterly basis using a Quarterly Municipal Fisheries Survey (QMFS) from traditional landing centers in 67 provinces. Five key informants in each center provided information on the average daily volume (in metric tons or MT) of unloading and price per kilogram (PhP/kg) of the top 31 species and other fishes combined in an "others" category. Additional data were gathered by the PSA from non-traditional landing centers that are managed by the Philippine Fisheries Development Authority (PFDA) and local government units (LGUs) [Philippine Statistics Authority (PSA), 2016].

Specifically, we considered Bali sardine (*S. lemuru*), Fimbriated sardine (*S. fimbriata*), Indian mackerel (*R. kanagurta*), and Indo-Pacific mackerel (*R. brachysoma*) spanning the period 2007–2018. Strict enforcement of the SFC happened in 2012. Hence, we analyzed fish catch data 6 years before and 6 years after 2012. Herrings were not included in the analysis because present landings of this species in the Visayan Sea are considered negligible. For example, in 2019 data from the PSA indicated that herring landings in the study sites comprised only 0.6% among the 33 fish species reported. Similarly, Guanco et al. (2009) and Armada (1999) showed that herring landings in the Visayan Sea were not substantial.

We analyzed data from provinces enforcing the SFC (participating group) and those not enforcing the SFC (non-participating group) (**Supplementary Table 1**). Since the enclosed area around the SFC in the Visayan Sea is surrounded by the provinces of Capiz, Iloilo, Negros Occidental, Cebu and Masbate, these areas were assigned as the participating group. We included all other provinces in the Philippines that have reported catch for sardine and mackerel for at least 7 years of the inclusive period (2007–2018) as the non-participating group. All other provinces wherein an SFC for similar species has been implemented were excluded from the non-participating group. Overall, 61 provinces were analyzed for municipal sardine catch, 46 provinces for commercial sardine catch, 61 provinces for municipal mackerel catch and 47 provinces for commercial mackerel catch. A summary of the sample size in each category of this analysis for sardine and mackerel is provided in **Supplementary Tables 2, 3**.

Data were aggregated at the provincial level but not all municipalities in these provinces observed the SFC. We argue, however, that province-level data should not have confounding effects on our results as previous studies show high concentration of fish catch for sardine and mackerel in the Visayan Sea and the enclosed area during SFC is composed largely of municipal waters of the SFC-participating municipalities in the surrounding provinces around Visayan Sea. Hence, we assumed that immediate provinces surrounding the Visayan Sea form our participating group. Further, we assumed that sardine and mackerel fisheries are homogeneous throughout the Philippines.

[1] http://openstat.psa.gov.ph/

Empirical Framework and Estimation

We adopted a DID framework to examine the effect of the SFC policy on sardine and mackerel catch. The DID framework is a variation of the before-after-control-impact (BACI) design analysis (Smith, 2002). The framework is one of the most popular tools used in applied research to evaluate the effect of policy interventions on independent variables. DID and BACI analyses have been widely used in ecology to evaluate natural- and human-induced perturbations on ecological systems when treatment sites cannot be randomly chosen (Conner et al., 2016). More specifically, it has been used to assess the effects of fishing area closures (Claudet and Guidetti, 2010; Ojeda-Martinez et al., 2011; Osenberg et al., 2011; Fenberg et al., 2012; Cheung et al., 2015; Clarke et al., 2015). To use DID, we needed observed outcomes of the group that received the intervention, in this case, the SFC (i.e., the treatment or the participating group) and a group that is not exposed to the intervention (i.e., the control or the non-participating group). Information on both groups is required before and after the intervention. This allowed for the comparison of the potential outcomes of the intervention to outcomes without the intervention. The conventional DID framework assumes that, in the absence of the intervention, the average effect on the participating and non-participating groups would have followed a similar path over time, implying similar characteristics. However, this strict assumption may not be plausible if attributes that are thought to be associated with the dynamics of the independent variable are unbalanced between the participating and non-participating group (Abadie, 2005), which is typical for quasi-experiments like ours.

The first DID model examined the effect of the SFC policy on interannual catch for sardine and mackerel. That is,

$$Y_{it} = \alpha + \beta_1 P_{it} + \beta_2 G_{it} + \beta_3 (P \times G)_{it} + \varepsilon_{it}, \quad (1)$$

where Y is the observed catch, P is a dummy variable representing the policy-year, and is equal to one if year is after 2012 and zero otherwise); G is a dummy variable that is equal to one if the SFC is enforced in the province and zero otherwise; i is province; and t is year; α and β are parameters; and ε_{it} is the random error term which is assumed to be normally distributed. The parameter of greatest interest is β_3, which estimates the average effect of the SFC on observed catch among participating provinces.

The second specification (equation 2) examined the effect of the SFC policy on seasonal catch for sardine and mackerel:

$$\begin{aligned} Y_{it} = {} & \gamma + \delta_1 P_{it} + \delta_2 S_{it} + \delta_3 G_{it} + \delta_4 (P \times S)_{it} \\ & + \delta_5 (P \times G)_{it} + \delta_6 (S \times G)_{it} + \delta_7 (P \times S \times G)_{it} + \varepsilon_{it}. \end{aligned} \quad (2)$$

Except for δ and S, the terms in equation 2 are as defined in equation 1. S is a dummy variable which is equal to one if SFC is

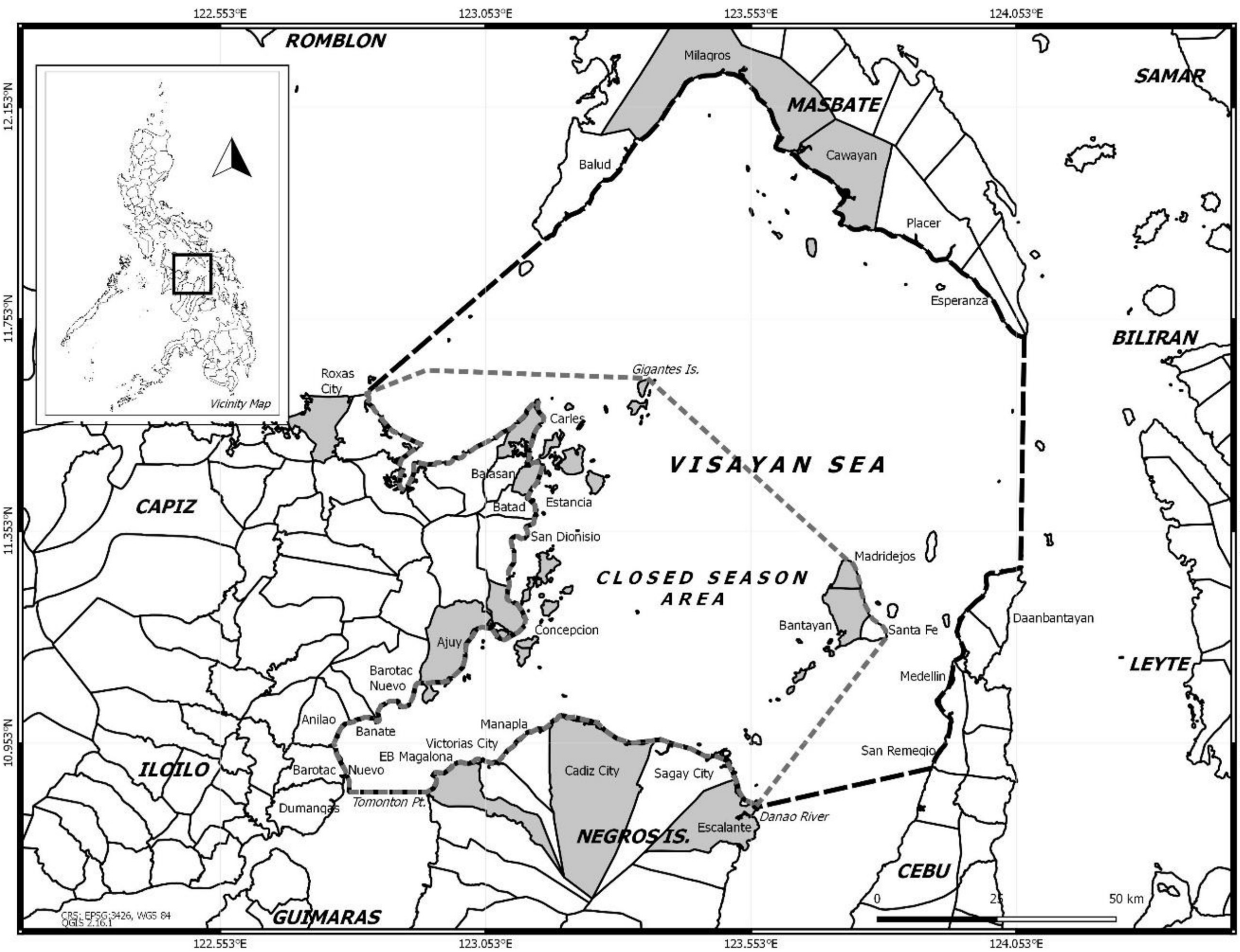

FIGURE 1 | Map showing the study sites (gray shade) and the seasonal fishery closure area (gray broken lines) in the Visayan Sea, Philippines. The black dash lines indicate the boundary of the Visayan Sea.

not enforced in a season and zero otherwise, and δ are parameters. The parameter δ_7 indicates the average effect of the SFC on the observed seasonal catch. Since this is a three-way interaction term, this effect would vary as a function of P (policy-year).

Equations 1 and 2 were estimated using Generalized Estimating Equations (GEE) (Liang and Zeger, 1986). GEE estimated the population average effects, took into account the covariance structure of the errors, and used a robust sandwich estimator for the standard errors. The GEE was also robust to the misspecification of the correlation structure (Rokicki et al., 2018). That is, it allowed for obtaining coefficient estimates when analyzing correlated data without relying on a joint distribution of the responses, which is usually unknown (Wilson and Lorenz, 2015). Further, it used quasi-likelihood estimation rather than maximum likelihood estimation (MLE) or ordinary least squares (OLS), which are more sensitive to variance structure specification [Pennsylvania State University (PSU), 2018]. We specified the link function as identity and the covariance matrix as exchangeable. The GEE estimation routine in Stata version 13.1 was used in this study. As a robustness check, we also estimated the models using panel fixed-effects and presented the results side-by-side with that of the GEE (**Supplementary Tables 5, 6**). While the panel fixed-effects allowed for the unobserved province effects to correlate with the independent variables, it did not allow for the estimation of time-invariant variables. In all models, standard errors were clustered at the province level to allow for arbitrary serial correlation of observations within provinces. Results from the GEE and panel fixed effects, as they relate to the parameter of greatest interests, were similar, thus, we chose to discuss the GEE results.

A third set of DID analyses were performed using GEE to examine whether SFC implementation might affect non-target species not regulated under the SFC. This effect could occur if fishers more heavily targeted alternative species during the SFC. This analysis was conducted at the interannual scale and used the same set of participating and non-participating provinces as described above. Provincial-level longitudinal fish catch data available at the PSA portal was used for the analysis of the other 27 fishes. A list of these species is provided in the **Supplementary**

Materials (**Supplementary Table 4**). PSA provides fish catch data for 31 species; four of these are the regulated species analyzed as previously described (sardine and mackerel). We expanded our analysis to include the other 27 species.

Semi-Structured Interviews, Focus Group Discussions, and Key Informant Interviews

To investigate whether fisher perceptions of the SFC strict implementation match or diverge from the picture painted by analysis of catch statistics, we conducted a face-to-face SSI among 235 municipal fisheries stakeholders of the Visayan Sea to complement our DID results. Nine of the 18 municipalities that were initially included in the Visayan Sea SFC were randomly selected to represent study sites. These included four municipalities in the province of Iloilo (Carles, Estancia, Concepcion, and Ajuy), three municipalities in the province of Negros Occidental (Cadiz City, E.B. Magalona, and Escalante City), and two municipalities in the province of Cebu (Bantayan and Madridejos). Two municipalities in the province of Masbate (Milagros and Cawayan) and one city in the province of Capiz (Roxas City) were added to ensure representativeness of the municipalities in the five provinces surrounding the Visayan Sea considering that previous studies on Visayan Sea were limited in geographical scope. For example, the study by Ferrer (2009) focused on municipalities in Northern Iloilo only, while the study by Napata et al. (2020) included municipalities in the provinces of Iloilo, Negros Occidental, Cebu and Capiz, but failed to include municipalities in Masbate. The additional municipalities were selected based on geographical location, accessibility, and safety considerations.

A non-probability, purposive sampling strategy was used to select the interview respondents (Bernard, 2017), which included municipal fishers, fish dryers, fish vendors/fish traders/fish brokers, LGU representatives, fish wardens, and members of the Philippine National Police-Maritime Group and Philippine Coast Guard (PNP-MG/PCG). We focused on municipal fisheries stakeholders in the fishing communities surrounding the Visayan Sea primarily because the enclosed area during the SFC is largely comprised of municipal waters (~75%). **Table 1** shows the number of respondents interviewed per group.

A SSI questionnaire was prepared initially in English, then translated to the local dialects since the populations in the study sites speak different dialects. In the provinces of Iloilo and Negros Occidental, the primary spoken language is *Hiligaynon*, while in the province of Cebu, people speak *Cebuano/Bisaya*. In contrast, populations in the province of Masbate predominantly speak *Minasbate* that has mutual intelligibility with *Hiligaynon. Cebuano/Bisaya* is also spoken in the southeastern part of Masbate. The SSI questionnaire was pre-tested in one of the study sites, municipality of Ajuy, Iloilo, to ensure that the instrument was comprehensive and that questions were clear and easy to understand. Field interviews were conducted from February to April 2019.

Results of these interviews are described in depth in Bagsit (2020). We present here only the questions and results that are relevant to the objective to understand how the SFC has affected fishery catch for sardine and mackerel. Specifically, we asked the respondents to specify their level of agreement with the following statements: (1) There is an observed increase in the sardine catch in the last 5 years; and (2) There is an observed increase in the mackerel catch in the last 5 years. Responses were measured using a Likert scale (e.g., a score of 5 means the respondent strongly agrees with the statement, while a score 1 indicates strong disagreement with the statement). Respondents' motivations in following the SFC and their coping mechanisms during the time the SFC is in effect were also explored and are documented in Bagsit (2020).

In addition, nine FGDs that were participated in by 77 municipal fisheries stakeholders and KIIs with representatives from government and non-government organizations (N = 12) and members of the City or Municipal Fisheries and Aquatic Resource Management Councils (C/MFARMCs) in the study sites (N = 25) were conducted to complement results from the SSI (**Table 1**). FGD and KII participants were asked about their opinions whether the SFC is achieving its purpose and about issues and challenges in the implementation of the SFC in the Visayan Sea. This complemented the SSI and catch data analysis by providing local insights from managers and non-government agencies involved in fisheries management and conservation in the country, about underlying issues related to documented catch trends and stakeholder's perception of those trends.

TABLE 1 | Summary of respondents for the SSIs, FGDs, and KIIs conducted.

Respondents	SSI (N = 235)	FGD* (N = 9)	KII (N = 37)
Municipal fisher	117		
Fish dryer	35		
Fish vendor/Fish trader/Fish broker	35		
Local government unit	27		
Fish warden	10		
Philippine National Police-Maritime Group/ Philippine Coast Guard	11		
Government agency	–	–	7
Non-government agency	–	–	5
City/Municipal Fisheries and Aquatic Resource Management Council	–	–	25
Total	235	9	37

**The FGDs were participated in by different set of municipal fishery stakeholders (N = 77) from the study sites.*

RESULTS

Interannual DID Analysis of Sardine and Mackerel Catch

Results from the interannual DID model showed a significantly greater volume of sardine catch throughout all years among SFC-participating provinces as indicated by the estimated

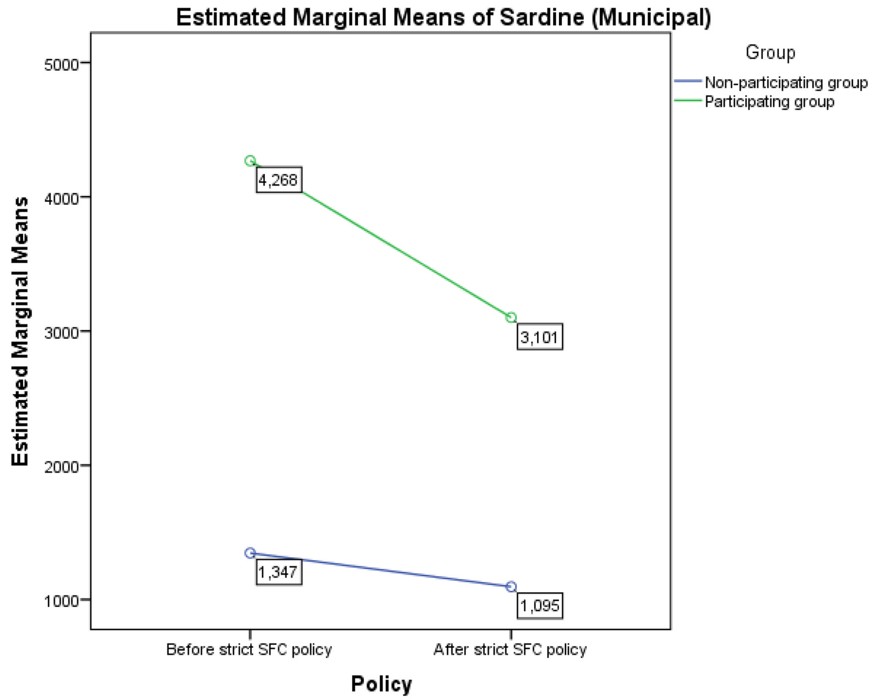

FIGURE 2 | Estimated marginal means of municipal catch for sardine (in MT) between the non-participating and participating groups, before and after the strict implementation of the SFC policy in the Visayan Sea.

coefficient on the participating group (G). Specifically, we found that sardine catch is 2,922 MT higher in municipal sector and 2,993 MT higher in commercial sector, among provinces observing the SFC compared to their counterparts. The estimated parameter on policy-year (P) indicated that sardine catch had declined by 251 MT in the municipal sector and 178 MT in the commercial sector since the strict implementation of the SFC. This decline was common to both participating and non-participating groups. More importantly, the coefficient of the interaction term G × P indicated that compared to non-SFC-participating provinces, sardine catch for municipal and commercial sectors among SFC-participating provinces declined by 917 MT and 1,133 MT, respectively, since the strict implementation of SFC in 2012 (**Supplementary Table 5**). This suggested a much greater decline in annual catches among participating groups compared to non-participating groups, even though both groups experienced declining sardine catch (**Figures 2**, **3**).

Difference-in-differences results on interannual changes in catch showed a significantly higher municipal and commercial mackerel catch among SFC-participating provinces (G) compared to the non-participating provinces both before and after the strict enforcement (**Figures 4**, **5**). Further, the estimated parameter on policy-year (P) indicated that mackerel catch had significantly decreased by 273 MT in the municipal sector and 316 MT in the commercial sector, following the strict enforcement of the SFC. The estimated coefficients on the interaction term G × P indicated an increase in municipal mackerel catch by 561 MT and a decline in commercial mackerel catch by 99 MT, but they were not significant (**Supplementary Table 5**). This suggests that there was no significant change in mackerel catch among participating group in both sectors following the strict implementation of the SFC.

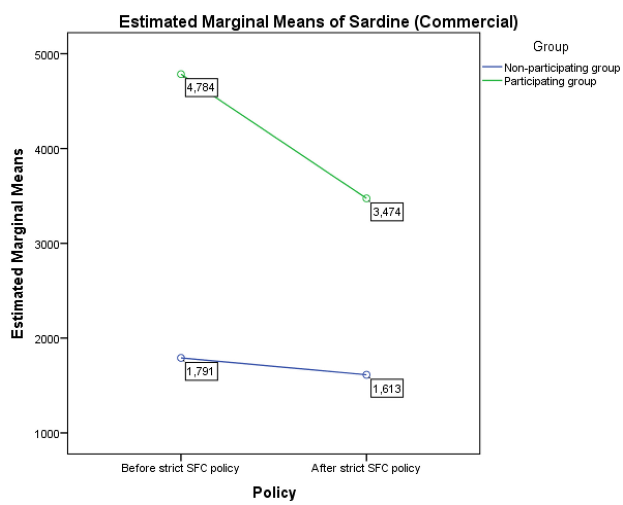

FIGURE 3 | Estimated marginal means of commercial catch for sardine (in MT) between the non-participating and participating groups, before and after the strict implementation of the SFC policy in the Visayan Sea.

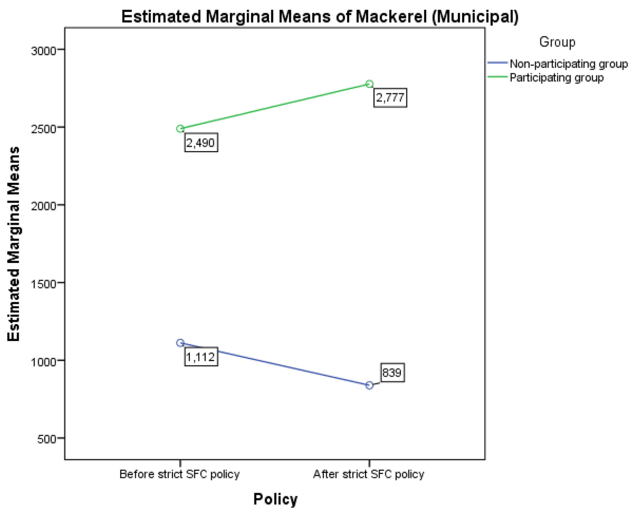

FIGURE 4 | Estimated marginal means of municipal catch for mackerel (in MT) between the non-participating and participating groups, before and after the strict implementation of the SFC policy in the Visayan Sea.

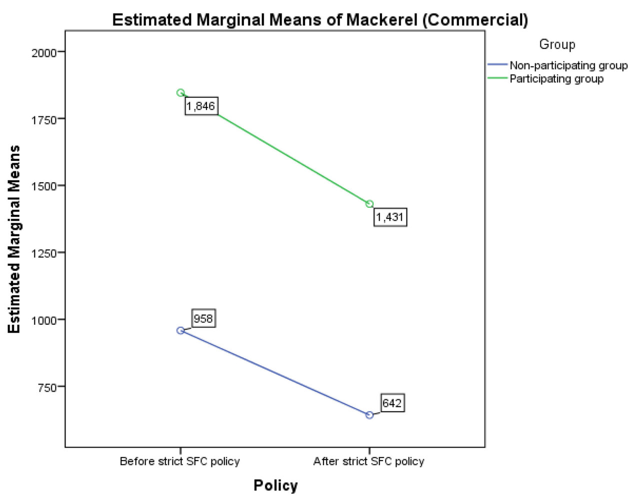

FIGURE 5 | Estimated marginal means of commercial catch for mackerel (in MT) between the non-participating and participating groups, before and after the strict implementation of the SFC policy in the Visayan Sea.

Seasonal DID Analysis of Sardine and Mackerel Catch

We also tested if there was an increase or decrease in the catch for the regulated species in the season when the SFC was not enforced. This analysis was done to check for consistency with a BFAR report that the SFC has successfully met management goals since there was a seasonal increase in small pelagic fish catch at the end of the seasonal closure (DA-BFAR, 2013b; Mesa, 2014). Results from the estimated DID model showed that the estimated coefficient on the variable of utmost interest, $G \times S \times P$ was positive and significant, indicating that sardine catch in SFC-participating provinces increased by at least 200 MT in both sectors during the open season, compared to the non-participating provinces (**Figures 6**, **7**; **Supplementary Table 6**). Specifically, seasonal sardine catch increased by 286 MT in the municipal sector and 232 MT in the commercial sector, of the SFC-participating provinces.

In contrast, we found no significant season-to-season effect of the SFC on mackerel catch among the SFC-participating provinces (**Figures 8**, **9**; **Supplementary Table 6**). A slight increase in the mackerel catch was observed in the municipal sector (16 MT), while mackerel catch decreased by 66 MT in the commercial sector, of the SFC-participating provinces following the closed season.

Fishing Pressure on Other Species

Regarding fishing pressure to other unregulated species, as shown in **Supplementary Table 4**, generally, among the SFC-participating provinces, catch for the 27 species had declined. However, we cannot attribute this to the implementation of the SFC. Only the effect on Threadfin bream is significant, but weak. Given the large number of repeated tests among the 27 species, this effect may very well be spurious. That is, overall, we found no significant effect of the SFC enforcement on fishing pressure to the unregulated species in the participating provinces.

Semi-Structured Interviews, Focus Group Discussion, and Key Informant Interview

The municipal fishers that were interviewed largely target sardines and mackerels, using seine nets, gill nets, ring nets, small trawl, and other fishing gear. Most municipal fishers used motorized boats (87%).

The interviewed fish dryers earn at least 80% of their income from fish drying. The fishes they dry were either caught by their household members or bought or loaned from fishers within their communities or neighboring municipalities. The fish vendors/fish traders/fish brokers buy and sell a variety of fishes, including sardine and mackerel.

The LGU representatives interviewed were directly involved in the fisheries management in their respective municipalities, while the fish wardens were deputized individuals, locally known as Bantay-dagat, who were tasked to help in the monitoring, control, and surveillance (MCS) of fishing activities in their respective municipal waters. They conduct seaborne patrol to deter illegal fishing activities; they also aid in rescue operations at sea.

We also interviewed members of the PNP-MG/PCG stationed in the study sites. These are members of the composite team (together with the LGU representatives, fish wardens, BFAR personnel) that conduct MCS activities and enforce laws at sea. Except for the PNP-MG/PCG respondents, all other respondents have been living in the study sites for at least 39 years, hence, they are knowledgeable about the SFC.

SSI

Majority of the municipal fishers (N = 75) and LGU representatives (N = 17) agreed that there was an observed increase in the catch for sardine in their respective municipalities

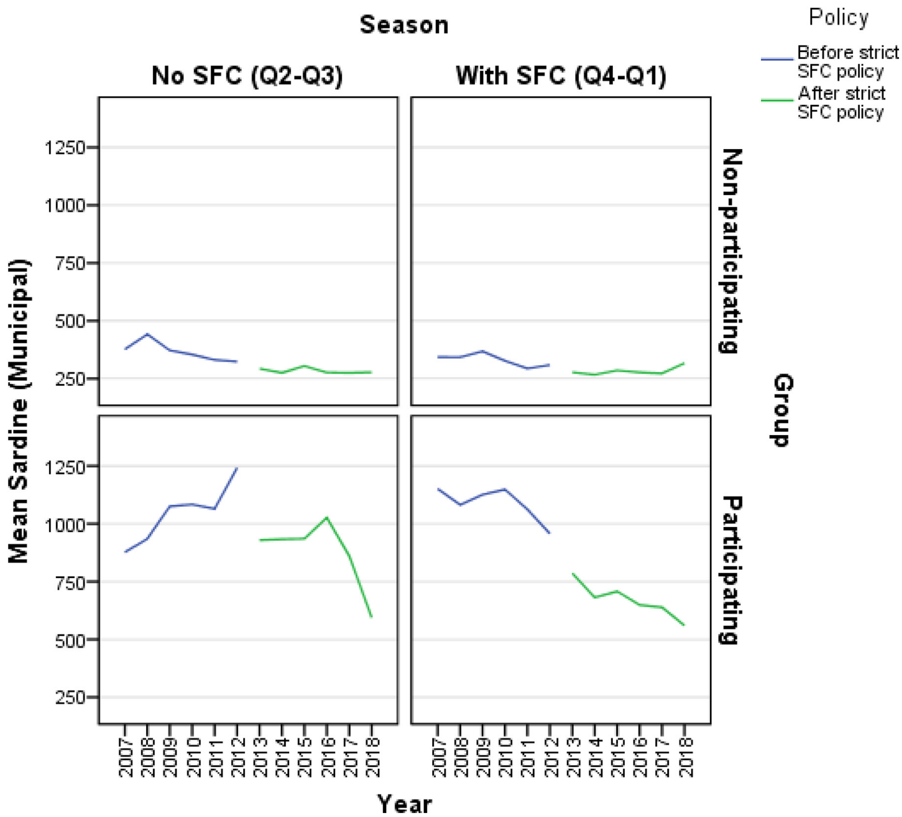

FIGURE 6 | Mean municipal catch for sardine in the participating and non-participating groups during the quarters with and without SFC, before and after the strict implementation of the SFC in 2012.

in the last 5 years (**Figure 10**). However, fish dryers were divided on their responses on whether there was an increase in the catch for sardines in their municipalities in recent years. Similarly, the PNP-MG/PCG had split responses: 15 of them agreed that there was an increase in the catch for sardine in their locality for the past 5 years, while the other 15 were not sure about this. Further, while 16 of the fish vendor/fish trader/fish broker respondents agreed that there was an increase in the sardine population in their areas in recent years, 11 were not sure about this and eight disagreed (**Figure 10**). One interesting observation noted by some of the respondents was the increase in the catch for *S. lemuru* (locally called *tuloy*), but not *S. gibbosa* (locally called *tabagak*).

Apart from the LGU representatives, municipal fisheries stakeholders interviewed were also divided on their responses when asked if there was an observed increase in the catch for mackerel in their respective municipalities in the last 5 years. For example, there were more fishers (N = 48), fish dryers (N = 19), fish wardens (N = 4), and PNP-MG/PCG (N = 5) who were neutral on their responses. In the case of the fish vendors, fish traders, and fish brokers, 14 of them agreed that catch for mackerel has increased in recent years, but 13 of them were not sure and eight of them disagreed (**Figure 11**). Another interesting finding was some respondents from the municipalities of Milagros (Masbate), E.B. Magalona (Negros Occidental), and Roxas City (Capiz) said they do not catch mackerel in their areas.

FGD

Focus group discussions results revealed varying opinions from participants regarding the SFC in the Visayan Sea. For example, FGD participants in the municipality of Estancia, Iloilo did not think that the SFC is achieving its purpose because illegal fishing activities persist. They also found the SFC policy difficult to understand because its provisions were not clear, that is, it did not specify which areas and fishing gears are included in the fishing ban. The FGD participants have expressed their agreement with the fishery management goals of the SFC because according to them, the SFC gives the fishes a chance to spawn during this period. However, they also emphasized that the SFC should be implemented fairly because they had observed other fishers that continued fishing operations even when the fishing ban was in effect. When they get caught, the violators just paid the fines. These observations were echoed during the FGD in Bantayan, Cebu, wherein participants noted that some fishers continue to fish covertly and fishers using illegal fishing gears like Danish seines continue their operations. FGD participants in Carles, Iloilo also noted that fishing activities in their municipality remained the same whether the SFC was in effect or not. While FGD participants in Ajuy, Iloilo noted that fishes caught were

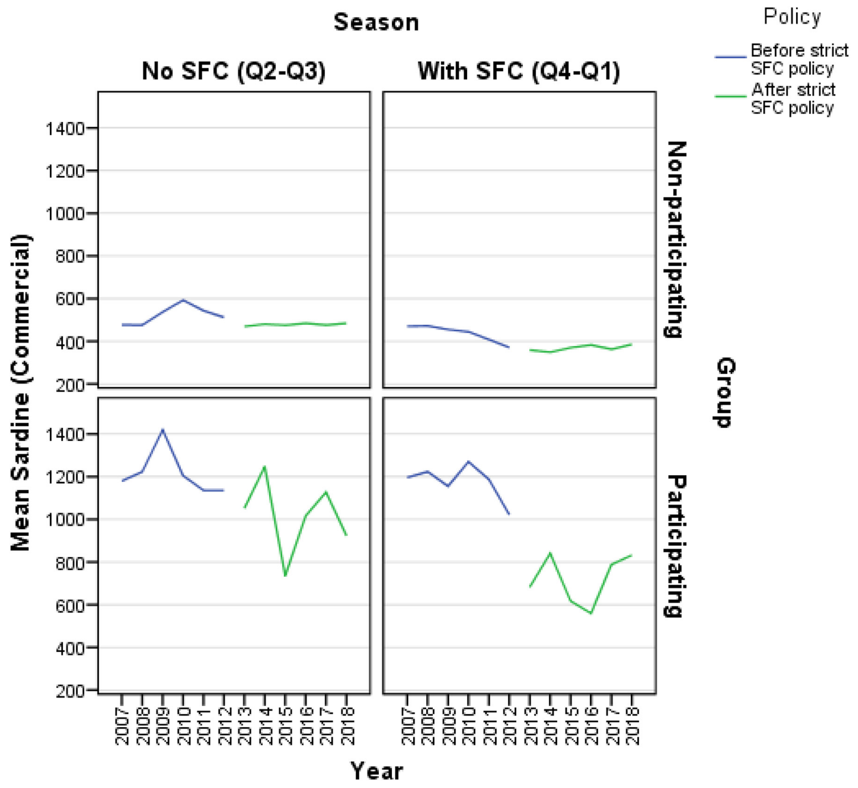

FIGURE 7 | Mean commercial catch for sardine in the participating and non-participating groups during the quarters with and without SFC, before and after the strict implementation of the SFC in 2012.

mature and bigger after the SFC was lifted, they also said that the SFC will achieve its purpose only if illegal fishers do not catch the protected species.

In contrast, FGD participants in the municipalities of Concepcion, Iloilo and Madridejos, Cebu believed that the SFC is achieving its objectives because they observed that they have bountiful fish catch during the open season. According to one participant, they did not have to fish very far from the shore since there were already fishes nearshore; they also observed many juvenile fishes.

In the case of Cadiz City, Negros Occidental, FGD participants observed a difference in their fish catch. For example, in the past, catch was plenty, but catch has dwindled in recent years. Apparently, sardine juveniles (locally called as *lupoy*) are caught as soon as the sardines had spawned. According to them, fishes were depleted easily due to overfishing; there were just too many fishers competing over a very scarce resource. Heavy fishing pressure often leads to capture of fishes before they reach maturation (Guanco et al., 2009). FGD participants also noted that the SFC no longer coincides with the actual breeding period of sardines because they observed presence of juvenile sardines even before the SFC is enforced. Furthermore, they said they have different fishing seasons for sardine and mackerel; that is, they catch sardines during southwest monsoon (Habagat, June-October) and mackerels during northeast monsoon (Amihan, November-May).

KII

The SFC policy was established to conserve sardines, herrings and mackerels in the Visayan Sea. According to a BFAR respondent, the SFC is achieving its objectives because there was very good compliance among fishers during the 2013–2015 SFC cycles and they observed a sudden increase in fish catch based on monitoring in markets and fish landing sites. This was corroborated by a CFARMC respondent from Negros Occidental province who observed sudden rush-in (locally called as *dagsa*) of sardines nearshore (normally from May-June). But according to her, this was not consistent across the years. She noted that the volume of fish catch increased, but not the fish size. For example, they used to have large sardines (classified as TL, meaning *Tabagak* Large) when they sort fishes during drying process, but nowadays, they cannot even get TM (*Tabagak* Medium). The majority of their catch consisted of TS (*Tabagak* Small).

Respondents from the Iloilo Provincial office also confirmed that there was an oversupply of sardines in the fishing ports at the end of the SFC. People tend to overfish the resources again after the closed season because there is an abundant supply of fish. According to respondents, even though they see an increase in the catch as per the BFAR data, the BFAR would probably say that the fisheries is still overfished. Respondents also emphasized that the government, specifically the LGUs, need to strengthen efforts on sales ban because they observed that *bañeras* (buckets made of plastic or steel used to haul fish catch; one *bañera* can

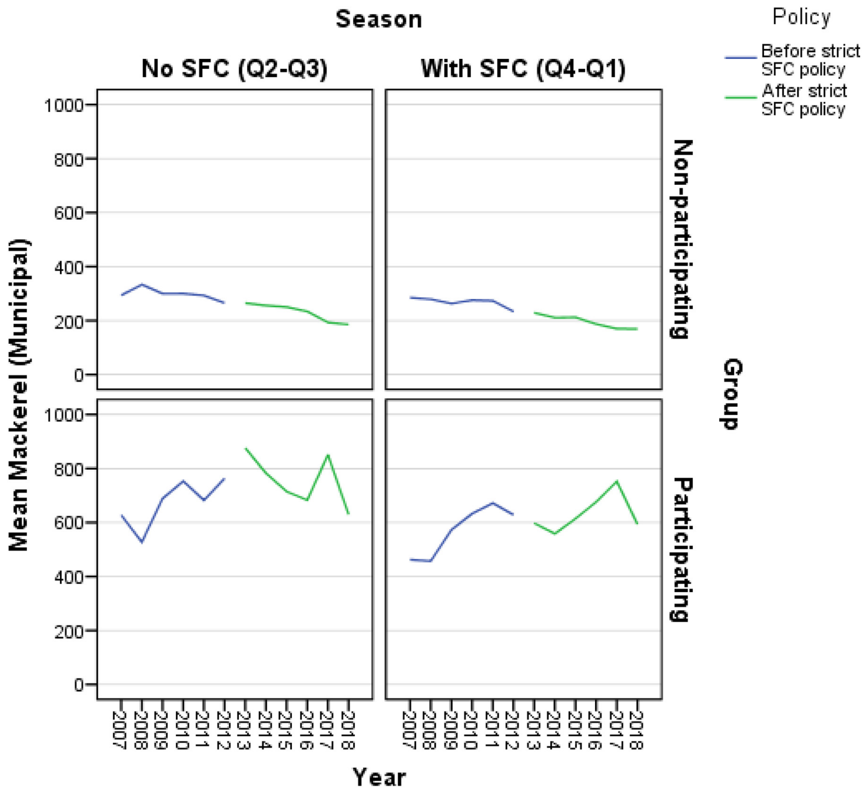

FIGURE 8 | Mean municipal catch for mackerel in the participating and non-participating groups during the quarters with and without SFC, before and after the strict implementation of the SFC in 2012.

carry ∼40 kgs of fish) of sardines still flood the market during closed season. According to them, the LGUs should be on top of this because it is under their jurisdiction.

Although the BFAR cited success of the SFC in 2013–2015, they encountered problems in the succeeding years because they noticed that fishers "race to fish" before and after the SFC was declared. They also observed that species protected during the SFC were still caught and exploited at the end of the closure period and the impact on the fish stocks was much worse. Although the BFAR is strictly implementing the SFC among commercial fishers, the Bureau is lenient on the municipal level because the LGUs have jurisdiction in this area. The BFAR respondents recognized that this should not be the case since 50% of the fisheries production in the Visayan Sea is from the municipal sector. The BFAR is now actively campaigning among the LGUs in the SFC-participating municipalities to create an ordinance that will regulate the use of fine mesh nets and the catching of *lupoy* (sardine juveniles), which are the supposed gains from the SFC. As per a NGA respondent, "the issue right now is what happens after the SFC. If they keep on catching juveniles after the closure period, then the SFC is not making any sense."

Illegal fishing activities were identified as a perennial issue in the Visayan Sea. For example, the C/MFARMC respondents noted that while they implement the SFC in their respective municipalities, there are too many violators from within (i.e., in addition to non-compliance with the SFC, fishers use fine mesh nets) and outside their municipalities (i.e., commercial fishers encroaching in the municipal waters). Poachers have faster boats making it difficult for fish wardens and small-scale fishers to catch them. Respondents also noted lapses in the monitoring of the SFC because they cannot police all the coastal barangays. For example, fish wardens in certain SFC-participating municipalities cannot fully implement the SFC because they do not have the capacity and resources. Unlike other members of the MCS team who receive salary for their services, some fish wardens only receive allowances, while fish wardens in other areas serve as volunteers. Thus, the LGUs cannot oblige them to police the municipal waters.

On the part of the LGUs, respondents found the SFC policy difficult to implement because it is vague and has too many loopholes. The LGU respondents said they do not know how to fully implement the SFC policy because of the lack of specific implementing rules and regulations on the SFC policy. They cited a case wherein they apprehended a fisher selling banned fishes in a fishing port while the SFC in effect, but the fisher argued that he caught the fishes from another municipality (with a certification from that municipality). They expressed their concern over getting into a sticky situation with the violators because of this. They further said that even the BFAR personnel assigned in the fishing ports are not sure how to

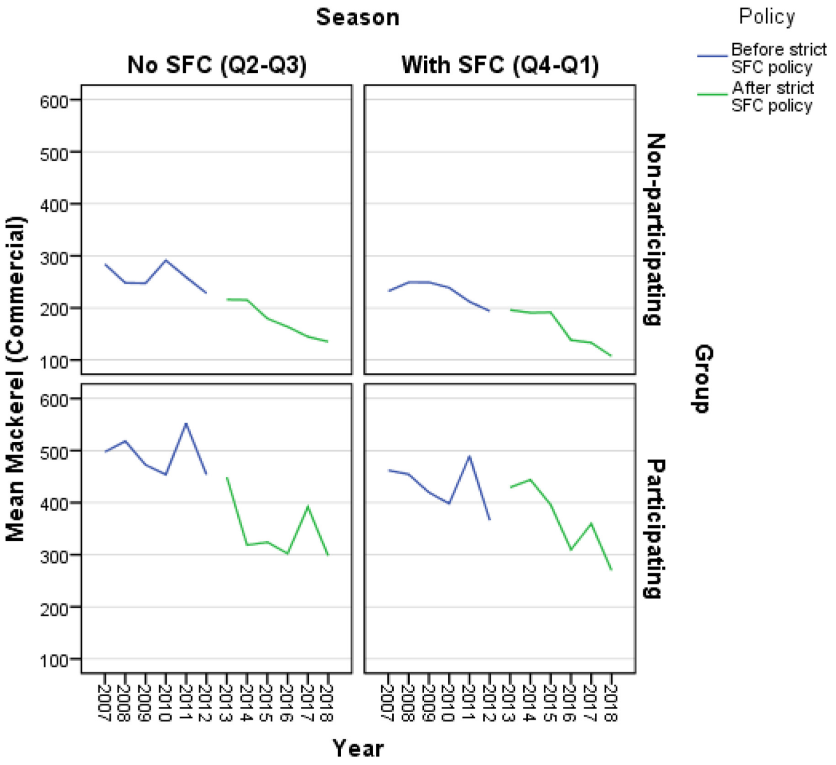

FIGURE 9 | Mean commercial catch for mackerel in the participating and non-participating groups during the quarters with and without SFC, before and after the strict implementation of the SFC in 2012.

handle SFC violations. For example, they have encountered a fisher in possession of the banned species, but the BFAR personnel present during that time said they should allow it because the catch was not that much. However, they do not have any basis for what qualifies for a small catch. The BFAR respondents admitted that the objectives of the SFC are not very clearly stated and the SFC policy did not mention municipal and commercial fishers, nor specific fishing gears banned. It broadly stated that it is prohibited, under the law, to catch the regulated species. Thus, there is a varying interpretation of the SFC policy.

Another critical issue raised by a C/MFARMC respondent is that some small-scale fishers are heavily dependent on the fishery resources. While the big fishing operators have other sources of income and can fish further out to sea during the closed season, this is not the case for the small-scale fishers. Several respondents said violations of the SFC policy are inevitable because those who depend on fishing for their day-to-day survival continue to fish. And unless alternative livelihoods for the affected stakeholders are put into place, non-compliance with the SFC will continue. For example, some LGU respondents admitted that they are not implementing the SFC in their municipality because of the lack of alternative livelihood for the affected fishers. The BFAR respondents acknowledged their agency's shortfall in providing alternative livelihoods to affected stakeholders.

DISCUSSION

The BFAR claims success of the SFC, particularly in improving the catch for the regulated species. For example, the BFAR reported that sardine catch has increased seasonally in 2013 following the SFC (DA-BFAR, 2013b, 2018; Mesa, 2014). This increase is attributed by the BFAR to its intensive information, education, and communication (IEC) campaign and stricter MCS activities (Mesa, 2014). However, our study argues that the mere comparison of fish catches before and after the implementation of the SFC program in a normal seasonal cycle is misleading because fishers "race to fish" as soon as the open season begins, thus, causing the seasonal catch increase reported by the BFAR. This has been confirmed by the BFAR representatives during an interview; key informants reported that fishers indeed tend to "race to fish" as soon as the SFC is declared and immediately after the fishing ban is lifted. Further, the claimed success of the SFC according to the BFAR is not convincing because fishing effort is indeed expected to decline during the SFC and spike immediately after the SFC is lifted. If no such decline followed by an increase were reported, this would likely indicate that the SFC was not adequately enforced. Furthermore, the reported increase in the catch for sardine is based on only 2 years of observations following stricter enforcement of the SFC. This may not be conclusive for evaluating SFC success because 2 years of implementation is a very short period to observe a meaningful impact of the policy since previous studies on sardine populations

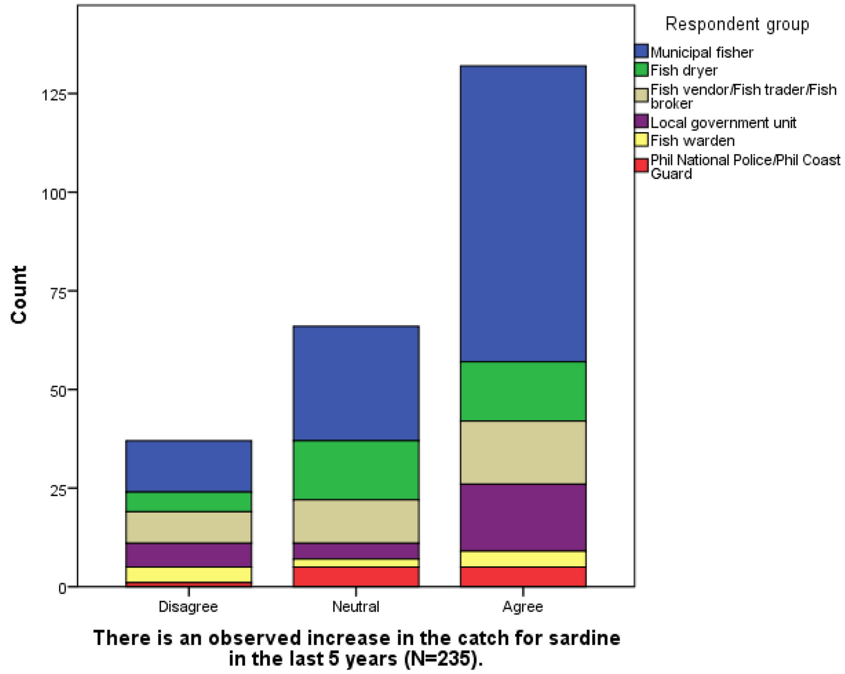

FIGURE 10 | Municipal stakeholders' level of agreement with the statement "*There is an observed increase in the catch for sardine in the last 5 years*."

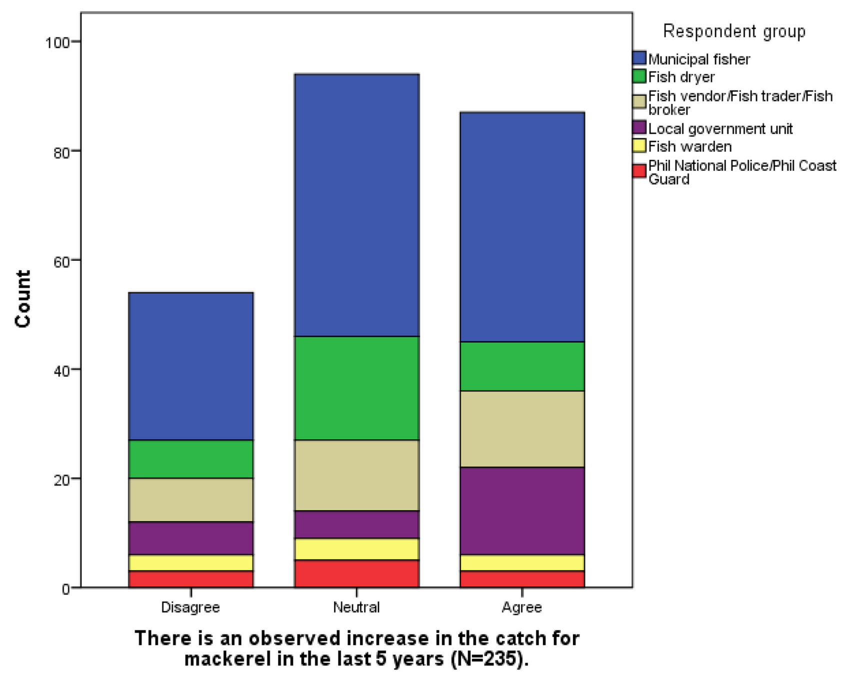

FIGURE 11 | Municipal stakeholders' level of agreement with the statement "*There is an observed increase in the catch for mackerel in the last 5 years*."

in the Philippines indicate that these species take about 2–3 years to reach sexual maturity (Willette et al., 2011). In a study of seasonal closure effects in the Gulf of Mexico shrimp fishery, increases in overall yield and values were documented in the first year, although no benefits were observed in the second year (Beets and Manuel, 2007). These findings suggest that evaluation of success of SFCs should be based on analysis of data from several years.

We expanded upon BFAR's data by reporting results over a longer time frame. Results of our seasonal analysis showed a significant increase in the municipal and commercial catch for sardine in the participating group during the quarters in a year when the SFC is not implemented. These results corroborated the BFAR's claims of an increasing catch for sardine in the months following the SFC in 2011–2012 and 2012–2013 (Mesa, 2014). These findings might also be what the municipal fisheries stakeholders cited as the observed increase in the catch for sardine in their respective municipalities in the last 5 years (**Figure 10**). However, our analysis showed that catch for sardine has decreased overall when examining interannual rather than seasonal trends. The decrease was not significant.

Interview results corroborate our DID findings for mackerel since the majority of the municipal fisheries stakeholders interviewed were not sure as to whether there was an increase in the catch for mackerel in the last 5 years (**Figure 11**). This is not surprising since some respondents in Milagros (Masbate province), E.B. Magalona (Negros Occidental province), and Roxas City (Capiz province) said they do not have mackerel catch in their area. Respondents from Cadiz City (Negros Occidental province) claimed they catch mackerel during the northeast monsoon (*Amihan*; November-May), which implies that their fishing season for mackerel in Cadiz City overlaps with the SFC in the Visayan Sea.

In general, the majority of the respondents claimed that the SFC is strictly implemented in their own municipalities, but they doubt if this is the case in other municipalities. Compliance with the SFC among municipal and commercial fishers appears to remain a challenge because of the lack of alternative livelihoods for the affected fishers. Apparently, the implementation of the SFC has become a secondary concern to the surrounding fishing communities around the Visayan Sea because illegal fishing activities remain rampant in these areas. The illegal fishing activities can be partly attributed to the relatively low fines for violations and lenient implementation of fishery laws at the municipal level. The respondents recognize that the objectives of the SFC will be met only if illegal fishing activities are addressed. Further, the lack of implementing guidelines for the SFC inhibits proper enforcement of this policy. In spite of these management gaps, municipal fisheries stakeholders said the SFC helps slow down illegal fishing because of the MCS activities during the SFC. These findings reflect on the quality of management in the Visayan Sea, and the uneven implementation of, and support for, the SFC. In a study that examined six seasonal closures in the Commonwealth of Puerto Rico, small-scale fishers similarly perceived seasonal closures as effective fishery management measures although these measures did not always improve the fisher's livelihoods nor result in their support for these measures (Agar et al., 2019).

Since the goal of this policy is to conserve the regulated stocks, the decline in interannual sardine catch after strict SFC implementation suggests that this goal has not yet been fully achieved. In general, an SFC management strategy is primarily based on effort control; it aims to reduce fishing mortality by limiting the fishing activity to an appropriate level thereby increasing the stock size. However, Beets and Manuel (2007) argue that predicting fishing mortality based on effort control may be difficult because that would depend on how fishers respond to set regulations. For example, fishers affected by the SFC in the Visayan Sea "race to fish" before and after the SFC is lifted to compensate for their low catches during the SFC period, while other fishers continue to fish covertly to survive. It is important to note that small pelagic fishes, such as sardine and mackerel, serve as a main source of inexpensive animal protein, especially for the poor and lower-income populations in the country. Food security is a critical consideration when introducing more traditional fishing controls, such as closed seasons and no-take areas, and alternative livelihoods that can provide immediate food or cash needs are to be preferred above those that require longer-term investments to realize benefits (Muallil et al., 2012, 2013). The lack of alternative livelihood opportunities for the SFC-affected fishers is not unique to the Visayan Sea because government funding for livelihoods is limited and opportunities outside the fishery are generally lacking in the Philippines (Muallil et al., 2013).

The noted prevalence of illegal fishing in the Visayan Sea and commercial fishing in the municipal waters are some of the factors that hinder the success of the SFC policy because whatever gains accrued during the 3-month SFC are readily lost to illegal and commercial fishing operations, especially given that some LGUs allow commercial fishing within municipal waters. For example, some coastal towns in the Philippines allow commercial fishing operations from 10.1 km seaward through municipal ordinances. This has serious implications to the small-scale fishers because of increased competition with commercial fishers in reduced ranges due to the permitting of commercial fishing in municipal waters and the enclosure from the SFC. These findings imply that the SFC policy should be properly enforced and complied with, and an alternative source of livelihood should be provided to the affected stakeholders before positive results can be expected.

Studies have shown that the design of SFCs presents a challenge because the net benefits to the fishery or other resources are often unknown (Sanchirico and Wilen, 2001; Sanchirico, 2005). Clearly, the implementation of the SFC alone is not enough to effect positive results in the management of sardine and mackerel in the Visayan Sea, particularly with regard to the goal of increasing fish catch. Although there might be positive effects on the overall population size of these species, this remains unknown, especially since CPUE data for this fishery are unavailable.

Fishers also reported shifting to catching other species during the 3-month fishing ban (Bagsit, 2020). DID estimates for the other 27 species we analyzed showed no significant shift in fishing pressure to these species, suggesting that increased fishing pressure on these species did not compensate for lost income or sources of protein during the SFC.

Despite being in effect for eight decades now, the science behind the SFC in the Visayan Sea continues to be challenged because of the lack of supporting evidence on the causes of the decline in the regulated species. This is particularly important for sardine and mackerel because studies in other areas indicate that their populations are sensitive to ocean climate and productivity (Checkley et al., 2017; Spijkers and Boonstra, 2017; Das et al., 2020). Therefore, a careful study of the SFC and the spawning habitat used by sardine and mackerel in this area is crucial to ensure that management efforts, and thus government expenditure, translate to measurable outcomes toward sustainable fisheries in the Visayan Sea. Understanding the spatial and temporal constraints on spawning habitat and if this habitat is associated with specific oceanic conditions for sardine and mackerel in the Visayan Sea is imperative because, if these species are shown to use a subset of habitats in the Visayan Sea or spawn over a more contracted season, then it may be possible to protect the spawning stock in a more targeted manner.

Previous studies have shown that fish abundance fluctuates as a result of fishing activity, and productivity can shift between high and low regimes unrelated to abundance (Gilbert, 1997; Mantua and Hare, 2002; Axenrot and Sture, 2003; MacKenzie et al., 2007; Vert-pre et al., 2013). For example, the collapse of stocks of Peruvian anchoveta (*Engraulis ringens*), the Alaskan pollock (*Theragra chalcogramma*), and the Atlantic cod stock off eastern Canada (*Gadus morhua*) have been attributed to the combined effects of changing ecosystems and overfishing (Alheit and Niquen, 2004; Bailey, 2011; Lilly et al., 2013; Skern-Mauritzen et al., 2015). In addition to variations between productivity regimes, climate change is affecting many living marine resources. In a review paper that looks at the relationship between climate and populations of anchovy and sardine, Checkley et al. (2017) conclude that anchovy and sardine populations vary in response to climate. While fishing may change the fluctuations in anchovy and sardine stocks, it neither causes nor prevents these fluctuations. Several studies have also pointed out the wide changes in the production levels of sardine and anchovy fisheries, which has sustained periods of high and low catch occurring almost in synchrony in different systems, suggesting a large-scale, interdecadal phenomenon that links these events rather than just the effect of independent fishing pressure (Kawasaki and Omori, 1988; Lluch-Belda et al., 1989; Kawasaki et al., 1991; Lluch-Cota et al., 1997). Kawasaki and Omori (1988) observe that the fluctuations in sardine and anchovy abundances in Japan, California, and Peru-Chile Systems are associated with globally sustained warm periods, while the high anchovy high and low sardine abundances are associated with sustained cold periods. On the contrary, Crawford et al. (1987) report an opposite pattern for sardine-anchovy abundances in the Benguela System.

Similar findings have been reported for mackerel (Overholtz et al., 2011; Kanamori et al., 2019). Overholtz et al. (2011) observed that changes in the spatial and bathymetry distribution of the Northwest Atlantic stock of Atlantic mackerel (*Scomber scombrus*) are related to interannual temperature variability and gradual warming. Examination of the long-term changes in spawning patterns and spawning ground of the chub mackerel (*Scomber japonicus*) in the western North Pacific reveals extension of the spawning period and movement of the geographic location of the spawning ground northward in relation to changes in sea surface temperature (Kanamori et al., 2019).

Notwithstanding the current debate on the causes of these variabilities in the environment, fisheries management agencies need to acknowledge that irregular changes in productivity are common, and that harvest regulation and management targets need to be flexible and robust to productivity changes (Vert-pre et al., 2013). In the case of the SFC in the Visayan Sea, in addition to monitoring fish catch landings, it will be valuable for resource managers to understand the ecosystem drivers of fish stock productivity in the area because fish stock production is dependent on the physical and biological conditions of the ecosystem (Skern-Mauritzen et al., 2015; Fowler et al., 2018; Kurota et al., 2020). This is fundamental for the BFAR management especially since the agency has recently adopted the ecosystem approach to fisheries management in the Visayan Sea (DA-BFAR, 2018). One of the main pillars of this approach is the inclusion and consideration in management of the ecosystem processes that impact fish stock production (Skern-Mauritzen et al., 2015).

We recommend that the BFAR should consider adopting a more direct and effective method of controlling fishing mortality other than SFCs, such as controlling for catch levels or landings, or controlling access to the resource (Caddy, 1984). However, we recognize that, although these strategies may also have associated challenges, such as funding requirements and sufficient staffing available to monitor catch levels in real-time throughout the region. Given the limited resources of the BFAR and the LGUs, strict monitoring of fish landings in the market and landing sites might be a more feasible strategy, rather than the more costly and risky MCS activities at sea. Similar recommendations might help improve management of data poor fisheries in other regions in lieu of using seasonal closures.

It would also be helpful if the BFAR and National Fisheries Research and Development Institute (NFRDI) allow public access to the National Stock Assessment Program data they have collected to facilitate a more robust analysis of their programs, which can be beneficial to the stakeholders and policymakers. Homologous datasets, such as fish catch, landings, fish stock size, fish quotas, and coastal habitat maps, are publicly available in a number of organizations and countries (e.g., National Oceanic and Atmospheric Administration, United States; Department of Environment, Food and Rural Affairs, United Kingdom; Australian Fisheries Management Authority, Australia; National Parks Board, Singapore). Making such datasets available allows independent researchers to use them to study questions relevant to fisheries management and accelerates scientific progress.

The BFAR must also develop clear metrics for evaluating the success or failure of the SFC policy. This will ultimately aid informed decision-making and lead to an improved fisheries management framework, appropriate programs for fisheries stakeholders, and efficient and responsible spending of government funds. Finally, there should be an independent body that will audit the performance of the BFAR in the management of the fisheries not only in the Visayan Sea, but throughout the country, to identify the gaps and help strengthen the role of the BFAR in the conservation, protection, and monitoring of the fisheries in the country. There are several academic institutions in the country that can help in this aspect.

CONCLUSION

Based on a BACI design analysis with a DID estimation strategy, the effect of the SFC policy on sardine and mackerel was evaluated. Although seasonal analysis of the catch for sardine showed a significant increase in the municipal and commercial catch for sardine in the participating group during the open season (Q2-Q3), overall, the SFC policy has no significant effect on the sardine interannual catch among SFC-participating provinces after the strict enforcement of the SFC in 2012. Further, there was no significant effect of the SFC policy on the catch for mackerel even during the open season. There was an increase in the interannual municipal catch for mackerel after 2012; however, the increase was not significant. These findings do not support the claims by the BFAR on the increasing catch of sardine in the Visayan Sea. These results are also contrary to the perceptions of the municipal fisheries stakeholders in the participating municipalities of the SFC who have indicated increasing catch for sardine catch in the Visayan Sea in the last 5 years. Further, while fishers reported a shift to catching other aquatic species during the 3-month fishing ban (Bagsit, 2020), the effect on other species was negligible based on our analysis of their catch. Some of these differences between catch statistics and stakeholders' perception may reflect the integration of catch data over a larger spatial area which includes regions of the Visayan Sea where there have been variations in the extent of SFC enforcement and the amount of illegal fishing reported by locals.

The fluctuation in the abundance of the regulated species in the Visayan Sea may be a result of the combined effects of fishing activity and productivity shifts driven by changes in the environment. Understanding the underlying mechanisms that govern the fluctuations in the abundance of fish stocks is critical to the appropriate management of the fisheries. In addition to monitoring fish catch landings, it will be valuable for the BFAR management, through the NFRDI, to collect biophysical data (e.g., sea temperature, chlorophyll-a, dissolved oxygen, salinity) to aid in understanding the ecosystem drivers of fish stock productivity in the Visayan Sea. Several studies have shown that physical and biological conditions of the ecosystems in other areas greatly influence fish migration, mortality rates, and recruitment (Kawasaki and Omori, 1988; Lluch-Belda et al., 1989; Kawasaki et al., 1991; Lluch-Cota et al., 1997; Overholtz et al., 2011; Kanamori et al., 2019). Many of these variables can be remotely sensed and data from remote sensing are publicly available, allowing managers and scientists to obtain information on environmental variables associated with fish habitat inexpensively. However, some expertise, training, and potentially fishery-independent survey data would need to effectively connect these variables with fish habitat use patterns.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s. The secondary datasets analyzed are publicly available. This data can be found here: https://openstat.psa.gov.ph/.

ETHICS STATEMENT

This study was reviewed and approved by the University and Medical Center Institutional Review Board (UMCIRB) at East Carolina University (ECU). The respondents provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FB contributed to conception and experimental design, investigation, data collection and analysis, research administration, and writing of original draft of the study. EF contributed to experimental design and data analysis of the study. RA and HM contributed to conception and experimental design of the study. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.640772/full#supplementary-material

Supplementary Table 1 | List of provinces in the participating and non-participating groups in the BACI analysis.

Supplementary Table 2 | Categorical variable information for sardine.

Supplementary Table 3 | Categorical variable information for mackerel.

Supplementary Table 4 | DID estimates for the 27 species not regulated under the SFC in the Visayan Sea.

Supplementary Table 5 | DID estimates for municipal and commercial interannual catch for sardine and mackerel.

Supplementary Table 6 | DID estimates for municipal and commercial seasonal catch for sardine and mackerel.

REFERENCES

Abadie, A. (2005). Semiparametric difference-in-differences estimators. *Rev. Econ. Stud.* 72, 1–19. doi: 10.1111/0034-6527.00321

Agar, J., Shivlani, M., Fleming, C., and Solís, D. (2019). Small-scale fishers' perceptions about the performance of seasonal closures in the commonwealth of Puerto Rico. *Ocean Coast. Manag.* 175, 33–42. doi: 10.1016/j.ocecoaman.2019.03.025

Alheit, J., and Niquen, M. (2004). Regime shifts in the Humboldt Current ecosystem. *Proüess Oceanogr.* 60, 201–222. doi: 10.1016/j.pocean.2004.02.006

Arendse, C. J., Govender, A., and Branch, G. M. (2007). Are closed seasons an affective mean of increasing reproductive output? A per-recruit simulation using the limpet *Cymbula granatina* as a case history. *Fish. Res.* 85, 93–100.

Armada, N. B. (1999). *Assessment and Management of Small Pelagic Fisheries in the Visayan Sea*. Iloilo. 44. doi: 10.1515/9783110808384-003

Axenrot, T., and Sture, H. (2003). Predicting herring recruitment from young-of-the-year densities, spawning stock biomass, and climate. *Limnol. Oceanogr.* 48, 1716–1720. doi: 10.4319/lo.2003.48.4.1716

Babcock, J. P., Found, W. A., Freeman, M., and O'Malley, H. (1931). *Report of the International Fisheries Commission Appointed under the Northern Pacific Halibut Treaty. IFC Report 1*. Seattle, WA: International Pacific Halibut Commission, 31.

Bagsit, F. U. (2020). *The political ecology of the seasonal fishery closure in the Visayan Sea, Philippines. A Ph D. Submitted to the Faculty of the Department of Coastal Studies*. Greenville, NC: East Carolina University, 240.

Bailey, K. M. (2011). An empty donut hole: the great collapse of a North American fishery. *Ecol. Soc.* 16:2.

Bailey, K. M., and Houde, E. D. (1989). Predation on eggs and larvae of marine fishes and the recruitment problem. *Adv. Mar. Biol.* 25, 1–83. doi: 10.1016/s0065-2881(08)60187-x

Bayate, D. E., and Mesa, S. V. (2012). *Visayan Sea Sardine Stock and its Fishery Conservation Initiatives in Western Visayas, Philippines: A Review. Bureau of Fisheries and Aquatic Resources, National Stock Assessment Program, Regional Office 6*. Iloilo City: Bureau of Fisheries and Aquatic Resources, 26.

Beets, J., and Friedlander, A. (1999). Evaluation of a conservation strategy: a spawning aggregation closure for red hind, *Epinephelus guttatus*, in the U.S. Virgin Islands. *Environ. Biol. Fish.* 43, 217–241.

Beets, J., and Manuel, M. (2007). *Temporal and Closed seasons Used in Fisheries Management: A Review with Application to Hawai'i*. Available online at: http://dlnr.hawaii.gov/coralreefs/files/2015/02/BeetsTempClosuresRpt08.pdf (accessed March 9, 2017).

Bell, F. H. (1969). *Agreements, Conventions, and Treaties Between Canada and the United States of America with respect to the Pacific Halibut Fishery*, 1st Edn. Seattle, WA: Canada and the United States of America with respect to the Pacific Halibut Fishery.

Bernard, R. (2017). *Research Methods in Anthropology, Qualitative and Quantitative Approaches*, 6th Edn. Lanham MD: Rowman & Littlefield.

Brodziak, J. K. T., Mace, P. M., Overholtz, W. J., and Rago, P. J. (2004). Ecosystem trade-offs in managing new england fisheries. *Bull. Mar. Sci.* 52:2004.

Caddy, J. F. (1984). "Indirect approaches to regulation of fishing effort," in *FAO (1984) Papers Presented at the Expert Consultation on the Regulation of Fishing Effort (Fishing Mortality). Rome, 17–26 January 1983. A Preparatory Meeting for the FAO World Conference on Fisheries Management and Development*, Vol. Suppl.2, (Rome: FAO), 214.

Carpenter, K. E., and Springer, V. G. (2005). The center of the center of marine shore fish biodiversity: the Philippine Islands. *Environ. Biol. Fish.* 72, 467–480. doi: 10.1007/s10641-004-3154-4

Checkley, D. M. Jr., Asch, R. G., and Rykaczewski, R. R. (2017). Climate, anchovy, and sardine. *Annu. Rev. Mar. Sci.* 9, 469–493. doi: 10.1146/annurev-marine-122414-033819

Cheung, W. W. L., de Mitchelson, Y. S., Braynen, M. T., and Gittens, L. G. (2015). Are the last remaining Nassau grouper *Epinephelus striatus* fisheries sustainable? Status quo in the Bahamas. *Endangered Species Res.* 20, 2013.

Clarke, J., Bailey, D. M., and Wright, P. J. (2015). Evaluating the effectiveness of a seasonal spawning area closure. *ICES J. Mar. Sci.* 72, 2627–2637. doi: 10.1093/icesjms/fsv144

Claudet, J., and Guidetti, P. (2010). Improving assessments of marine protected areas. *Aquat. Conserv. Mar. Freshwater Ecosyst.* 20, 239–242. doi: 10.1002/aqc.1087

Conner, M. M., Saunders, W. C., Bouwes, N., and Jordan, C. (2016). Evaluating impacts using a BACI design, rations, and a Bayesian approach with focus on restoration. *Environ. Monit. Assess.* 188:555.

Crawford, R. J. M., Shannon, L. V., and Pollock, D. E. (1987). The Benguela ecosystem. IV: the major fish and invertebrate resources. *Oceanogr. Mar. Biol. A. Rev.* 25, 353–505.

DA-BFAR (2011). *BFAR Chief Bats for Resource Conservation*. Available online at: https://www.bfar.da.gov.ph/newsarchives.jsp?id=202 (accessed February 20, 2018).

DA-BFAR (2012). *Commercial Fishers Support Government Sardine Closed Season for the Visayan Sea*. Available online at: https://www.bfar.da.gov.ph/newsarchives.jsp?id=183 (accessed June 17, 2016).

DA-BFAR (2013a). *Fisheries Administrative Order No. 167-3, s. 2013. Amending Fisheries Order No. 167 series of 1989*. Available online at: https://www.bfar.da.gov.ph/LAW?fi=468#post (accessed May 28, 2018).

DA-BFAR (2013b). *Success of Sardine Closure, Not Impossible for Galunggong*. Available online at: https://www.bfar.da.gov.ph/newsarchives.jsp?id=140 (accessed October 16, 2016).

DA-BFAR (2014). *Philippine Fisheries Profile 2014*. Ghaziabad: DA-BFAR, 36.

DA-BFAR (2018). *Management Framework for the Conservation, Protection and Restoration of the Visayan Sea*. Ghaziabad: DA-BFAR, 30.

Dalzell, P., Corpuz, P., Arce, F., and Ganaden, R. (1990). Philippine small pelagic fisheries and their management. *Aquacult. Fish. Manag.* 21, 77–94. doi: 10.1111/j.1365-2109.1990.tb00384.x

Dalzell, P., and Ganaden, R. (1987). *The Overfishing of Small Pelagic Fish Stocks in the Philippines*. Available online at: http://www.fao.org/3/a-bm734e.pdf (accessed May 27, 2018).

Das, I., Lauria, V., Kay, S., Cazcarro, I., Arto, I., Fernandes, J. A., et al. (2020). Effects of climate change and management policies on marine fisheries productivity in the north-east coast of India. *Sci. Total Environ.* 724:138082. doi: 10.1016/j.scitotenv.2020.138082

Department of Agriculture-Bureau of Fisheries and Aquatic Resources (DA-BFAR) (1939). Fish and Game Administrative Order No. 13, s. 1939. Regulations Establishing Closed Season for the Conservation of Sardines and Herrings. Available online at: https://www.bfar.da.gov.ph/LAW?fi=56#post (accessed February 24, 2020).

Everson, A. (1986). *Closed Season as a Management Policy in Lobster Fisheries. NOAA. Southwest Fisheries Center, Administrative Report H-86-7*. Washington, DC: NOAA.

FAO (2020). *State of the World Fisheries and Aquaculture: Sustainability in Action*. Rome: FAO, 224.

Farmer, N. A., Gowan, T. A., Powell, J. R., and Zoodsma, B. J. (2016). Evaluation of alternatives to winter closure of black sea bass pot gear: projected impacts on catch and risk of entanglement with north right whales *Eubalaena glacialis*. *Mar. Coast. Fish.* 8, 202–221. doi: 10.1080/19425120.2016.1146181

Fenberg, P. B., Caselle, J. E., Claudet, J., Clemence, M., Gaines, S. D., Antonio Garci'a-Charton, J., et al. (2012). The science of European marine reserves: status, efficacy, and future needs. *Mar. Policy* 36, 1012–1021. doi: 10.1016/j.marpol.2012.02.021

Ferrer, A. J. (2009). *Evaluation of Fisheries Management Options for the Visayan Sea, Philippines: The Case of Northern Iloilo. Research Report No. 2009-RR5. Published by the Economy and Environment Program for Southeast Asia (EEPSEA)*. Port Aransas, TX: EEPSEA.

Food and Agriculture Organization (FAO) (2000). *Information on Fisheries Management in the Republic of the Philippines*. Available online at: http://www.fao.org/fi/oldsite/FCP/en/PHL/body.htm (accessed March 9, 2017)

Fowler, A. E., Leffler, J. W., Johnson, S. P., Lawrence, B. D., and Sanger, D. M. (2018). Relationships between meteorological and water quality variables and fisheries-independent white shrimp (*Litopenaeus setiferus*) Catch in the ACE Basin NERR, South Carolina. *Estuar. Coasts.* 41:79. doi: 10.1007/s12237-016-0171-4

Gell, F. R., and Roberts, C. M. (2002). *The Fishery Effects of Marine Reserves and Fishery Closures*. Washington, DC: WWF.

Gilbert, D. J. (1997). Towards a new recruitment paradigm for fish stocks. *Can. J. Fish. Aquat. Sci.* 54, 969–977. doi: 10.1139/f96-272

Grüss, A., Kaplan, D. M. M., and Robinson, J. (2014a). Evaluation of the effectiveness of marine reserves for transient spawning aggregations in data-limited situations. *ICES J. Mar. Sci.* 71, 435–449. doi: 10.1093/icesjms/fst028

Grüss, A., and Robinson, J. (2015). Fish populations forming transient spawning aggregations: should spawners always be the targets of spatial protection efforts? *ICES J. Mar. Sci.* 69, 1205–1217.

Grüss, A., Robinson, J., Heppell, S. S., Heppell, S. A., and Semmens, B. X. (2014b). Conservation and fisheries effects of spawning aggregation marine protected areas: what we know, where we should go, and what we need to get there. *ICES J. Mar. Sci.* 71, 1515–1534. doi: 10.1093/icesjms/fsu038

Guanco, M. R., Mesa, S. V., Belga, P. B., and Nuñal, D. P. M. (2009). *Assessment of the Commercial Fisheries of Western and Central Visayan Sea*. Iloilo City: National Stock Assessment Project Bureau of Fisheries and Aquatic Resources, 45.

Horwood, J. W. (2000). "No-take zones: a management context," in *Effects of Fishing on Non-Target Species and Habitats: Biological, Conservation and Socio-Economic Issues*, eds M. J. Kaiser and S. J. De Groot (Oxford: Blackwell Science), 302–312.

International Fisheries Commission (IFC) (1948). *Regulation and Investigation of the Pacific Halibut Fishery in 1947. Rep.Int.Fish.Comm*. Washington, D.C: IFC, 35.

Jiang, Y.-Z., Cheng, J.-H., and Li, S.-F. (2009). Temporal changes in the fish community resulting from a summer fishing moratorium in the northern East China Sea. *Mar. Ecol. Prog. Ser.* 387, 256–273. doi: 10.3354/meps08078

Kanamori, Y., Takasuka, A., Nishijima, S., and Okamura, H. (2019). Climate change shifts the spawning ground northward and extends the spawning period of chub mackerel in the western North Pacific. *Mar. Ecol. Prog. Ser.* 624, 155–166. doi: 10.3354/meps13037

Kawasaki, T., and Omori, M. (1988). "Fluctuations in the three major sardine stocks in the Pacific and the global trend in temperature," in *Long-Term Changes in Marine Fish Populations*, eds T. Wyatt and M. G. Larrañeta (Vigo, Spain: Instituto de Investigaciones Marinas de Vigo), 37–53.

Kawasaki, T., Tanaka, S., Toba, Y., and Taniguchi, A Eds (1991). *Long-Term Variability of Pelagic Fish Population and Their Environmental*. Tokyo: Pergamon Press, 402.

Kurota, H., Szuwalski, C. S., and Ichinokawa, M. (2020). Drivers of recruitment dynamics in Japanese major fisheries resources: effects of environmental conditions and spawner abundance. *Fish. Res.* 221:105353. doi: 10.1016/j.fishres.2019.105353

Liang, K.-Y., and Zeger, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika* 73, 13–22. doi: 10.1093/biomet/73.1.13

Lilly, G. R., Nakken, O., and Brattey, J. (2013). A review of the contributions of fisheries and climate variability to contrasting dynamics in two Arcto-boreal Atlantic cod (*Gadus morhua*) stocks: persistent high productivity in the Barents Sea and collapse on the Newfoundland and Labrador Shelf. *Prog. Oceanogr.* 114, 106–125. doi: 10.1016/j.pocean.2013.05.008

Lluch-Belda, D., Crawford, R. M. J., Kawasaki, T., MacCall, A. D., Parrish, R. H., Schwartzlose, R. A., et al. (1989). World-wide fluctuations of sardine and anchovy stocks: the regime problem. *S. Afr. J. Mar. Sci.* 8, 195–205. doi: 10.2989/02577618909504561

Lluch-Cota, D. B., Hernández-Vázquez, S., and Lluch-Cota, S. E. (1997). *Empirical Investigation on the Relationship Between Climate and Small Pelagic Global Regimes and El Niño-Southern Oscillation (ENSO). FAO Fisheries Circular. No: 934 1997*. Rome: FAO, 48.

MacKenzie, B. R., Bager, M., Ojaveer, H., Awebro, K., Heino, U., Holm, P., et al. (2007). Multi-decadal scale variability in the eastern Baltic cod fishery 1550–1860—Evidence and causes. *Fish. Res.* 87, 106–119. doi: 10.1016/j.fishres.2007.07.003

Mantua, J. M., and Hare, S. R. (2002). The pacific decadal oscillation. *J. Oceanogr.* 58, 35–44.

McClanahan, T. (2010). Effects of fisheries closures and gear restrictions on fishing income in a Kenyan Coral Reef. *Conserv. Biol.* 24, 1519–1528. doi: 10.1111/j.1523-1739.2010.01530.x

Mendoça, J. T., and Sobrinho, R. P. (2013). Management of fishing of the Broadband Anchovy (*Anchoviella lepidenstole*) (Fowler, 1911), in south São Paulo State. *Braz. Braz. J. Biol* 73, 691–697. doi: 10.1590/s1519-69842013000400003

Mesa, S. V. (2014). *The Fisheries Resource Status of Visayan Sea*. Available online at: http://fscluster.org/sites/default/files/documents/BFAR%20VI_Visayan%20Sea%20Assessment%20Report_050314.pdf (accessed January 16, 2018).

Muallil, R. N., Cabral, R., Mamauag, S., and Aliño, P. (2012). "Status, trend and sustainability of small-scale fisheries in the Philippines," in *Proceedings of the 12th International Coral Reef Symposium*, (Cairns, Aus).

Muallil, R. N., Cleland, D., and Aliño, P. M. (2013). Socio-economic factors associated with fishing pressure in small-scale fisheries along the West Philippine Sea biogeographic region. *Ocean Coast. Manag.* 82, 27–33. doi: 10.1016/j.ocecoaman.2013.04.013

Murawski, S. A., Brown, R., Lai, H.-L., Rago, P. J., and Hedrickson, L. (2000). Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. *Bull. Mar. Sci.* 66, 775–798.

Napata, R. N., Espectato, L. N., and Serofia, G. D. (2020). Closed season policy in Visayan Sea, Philippines: a second look. *Ocean Coast. Manag.* 187:105115. doi: 10.1016/j.ocecoaman.2020.105115

National Oceanic and Atmospheric Administration (NOAA) (1985). *Management of the shrimp fishery of the gulf of Mexico. In: FAO, Papers Presented at the Expert Consultation on the regulation of fishing effort (fishing mortality). Rome, 17–26 January 1983. A preparatory meeting for the FAO World Conference on fisheries management and development. FAO Fish. Rep*, Vol. Suppl. 3. Washington, D.C: NOAA, 215–470.

Ojeda-Martinez, C., Bayle-Sempere, J. T., Sanchez-Jerez, P., Salas, F., Stobart, B., Goni, R., et al. (2011). Review of the effects of protection in marine protected areas: current knowledge and gaps. *Animal Biodiversity and Conservation* 34, 191–203.

Osenberg, C. W., Shima, J. S., Miller, S. L., and Stier, A. C. (2011). "Assessing effects of marine protected areas: confounding in space and possible solutions," in *Marine Protected Areas. A Multidisciplinary Approach*, ed. J. Claudet (Cambridge MA: Cambridge University Press), 143–167. doi: 10.1017/cbo9781139049382.010

Overholtz, W. J., Hare, J. A., and Keith, C. M. (2011). Impacts of interannual environmental forcing and climate change on the distribution of Atlantic mackerel on the US Northeast continental shelf. *Mar. Coast. Fish.* 3, 219–232. doi: 10.1080/19425120.2011.578485

Pennsylvania State University (PSU) (2018). *Introduction to Generalized Estimating Equations*. Available online at: https://newonlinecourses.science.psu.edu/stat504/node/180/ (accessed December 15, 2019).

Philippine Statistics Authority (PSA) (2016). *Highlights of the Philippine Population 2015 Census of Population*. Available online at: https://psa.gov.ph/content/highlights-philippine-population-2015-census-population (accessed March 19, 2021).

Philippine Statistics Authority (PSA) (2018). *Fisheries Production Data From 2007-2018*. Available online at: http://openstat.psa.gov.ph/ (accessed August 1, 2018).

Ramos, G. (2014). *Oceana Philippines supports closed fishing season in Visayan Sea*. Available online at: http://ph.oceana.org/press-releases/oceana-philippines-supports-closed-fishing-season-visayan-sea (accessed February 1, 2018).

Republic Act (RA) 8550 (1998). *The Philippine Fisheries Code of 1998*. Available online at: http://www.lawphil.net/statutes/repacts/ra1998/ra_8550_1998.html (accessed September 12, 2016).

Rokicki, S., Cohen, J., Fink, G., Salomon, J. A., and Landrum, M. B. (2018). Inference with difference-in-differences with a small number of groups. *Med. Care* 56, 97–105. doi: 10.1097/mlr.0000000000000830

Rola, A. C., Narvaez, T. A., Naguit, M. R. A., Elazeguia, D. D., Brillo, B. B. C., Paunlaguia, M. M., et al. (2018). Impact of the closed fishing season policy for sardines in Zamboanga Peninsula. Philippines. *Mar. Policy* 87, 40–50. doi: 10.1016/j.marpol.2017.09.029

Ronquillo, I. A., and Llana, M. E. G. (1987). "Biological effects of fishery management measures in the Philippines," in *A Paper Presented during the Symposium on the Exploitation and Management of Marine Fishery Resources in Southeast Asia, 16-19 Feb 1987*, (Australia), 244–248.

Sadovy, Y., and Domeier, M. (2005). Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. *Coral Reefs* 24, 254–262. doi: 10.1007/s00338-005-0474-6

Sanchirico, J. N. (2005). Additivity properties in metapopulation models: implications for the assessment of marine reserves. *J. Environ. Econ. Manag.* 49, 1–25. doi: 10.1016/j.jeem.2004.03.007

Sanchirico, J. N., and Wilen, J. E. (2001). A bioeconomic model of marine reserve creation. *J. Environ. Econ. Manag.* 42, 257–276. doi: 10.1006/jeem.2000.1162

Sinclair, M., and Valdimarsson, G. (2003). *Responsible Fisheries in the Marine Ecosystem*. Rome: FAO, 426.

Skern-Mauritzen, M., Ottersen, G., Handegard, N. O., Huse, G., Dingsør, G. E., Stenseth, N. C., et al. (2015). Ecosystem processes are rarely included in tactical fisheries management. *Fish Fish.* 17, 165–175. doi: 10.1111/faf.12111

Skud, B. E. (1985). "The history and evaluation of closure regulations in the pacific halibut fishery," in *FAO, 1985 Papers Presented at the Expert Consultation on the Regulation of Fishing Effort (Fishing Mortality). Rome, 17–26 January 1983. A Preparatory Meeting for the FAO World Conference on Fisheries Management and Development. FAO Fish.Rep*, Vol. Suppl.3, (Rome: FAO), 215–470.

Smith, E. P. (2002). "BACI design," in *Encyclopedia of Environmetrics*, Vol. 1, eds A. H. ElShaarawi and W. W. Piegorsch (Chichester: John Wiley & Sons, Ltd), 141–148.

Spijkers, J., and Boonstra, W. J. (2017). Environmental change and social conflict: the northeast Atlantic mackerel dispute. *Regional Environ. Chang.* 17, 1835–1851. doi: 10.1007/s10113-017-1150-4

Subong, E. S. (2017). *Visayan Sea 'Closed Season' for Herrings, Sardines, Mackerels.* Available online at: https://pia.gov.ph/news/articles/1001808 (accessed February 10, 2020).

Stige, L. C., Rogers, L. A., Neuheimer, A. B., Hunsicker, M. E., Yaragina, N. A., Ottersen, G., et al. (2019). Density- and size-dependent mortality in fish early life stages. *Fish Fish.* 20, 962–976. doi: 10.1111/faf.12391

Thompson, E. F., and Freeman, N. L. (1930). *History of the Pacific Halibut Fishery. Report Of The International Fisheriescommission, 5*. Vancouver, BC. 61.

United Nations (2020). *Progress Towards the Sustainable Development Goals, Report of the Secretary-General*. New York NY: United Nations.

Vert-pre, K. A., Amoroso, R. O., Jensen, O. P., and Hilborn, R. (2013). Frequency and intensity of productivity regime shifts in marine fish stocks. *Proc. Natl. Acad. Sci.U.S.A.* 110, 1779–1784. doi: 10.1073/pnas.1214879110

Wang, Y., Duan, L., Li, S., Zeng, Z., and Failler, P. (2015). Modeling the effect of the seasonal fishing moratorium on the Pearl Estuary using ecosystem simulation. *Ecol. Modell.* 312, 406–416. doi: 10.1016/j.ecolmodel.2015.06.011

Willette, D. A., Bognot, E. D. C., Mutia, M. T. M., and Santos, M. D. (2011). *Biology and Ecology of Sardines in the Philippines: A Review. Bureau of Fisheries and Aquatic Resources-National Fisheries Research and Development Institute, Technical Paper Series, August 2011*, Vol. 13. Iloilo City: Bureau of Fisheries and Aquatic Resources-National Fisheries Research and Development Institute, 1.

Wilson, J. R., and Lorenz, K. A. (2015). "Generalized estimating equations logistic regression," in *Modeling Binary Correlated Responses using SAS, SPSS and R. ICSA Book Series in Statistics*, Vol. 9, (Cham: Springer).

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Co-governance, Transregional Maritime Conventions, and Indigenous Customary Practices Among Subsistence Fishermen in Ende, Indonesia

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This article presents a case study of a fishery in the port-town community of Ende, Flores, a former littoral hub located at the periphery of major commercial systems in the Indo-Pacific region. The article argues that more attention be paid to the role of transregional maritime networks, nautical conventions, and navigational practices embedded within local tenure systems to understand the apparent absence of formal control of marine and coastal resources. Through ethnographic and archival research, this study identifies the presence of indigenous institutions for fishing grounds regulation and documents the existence of broader transregional norms dictating proper fishing and navigation. Exploring the interactions between more pluralistic customary systems that exist in port-towns such as Ende and recent fishery development policies, the article discusses some of the obstacles to implementing sustainable co-management strategies. While the Indonesian central government is strongly promoting co-governance approaches for resource management, these institutional models are based on geographically narrow definitions of tradition and customary law which can lead to management failures, such as elite capture and local fishers' disenfranchisement. In this case, policies emphasize the formation of cooperative groups without considering transregional beliefs about independence and pre-established systems of obligations. As a result, disputes among the fishermen, conflicts with local fishery officers, and the use of non-sustainable practices continue. For example, embodying predominant Southeast Asian beliefs, Endenese are known for their entrepreneurial nature and strong self-sufficiency ethos. Yet, these notions are ignored by local government agencies that view the fishermen as selfish and disorganized. In order to formulate true participatory solutions, a careful assessment of the role played by transregional perspectives that go beyond geographically localized understandings of customary practices is needed. The article concludes with a consideration of the role played by decentralization processes, subsidies, and aid programs in entrenching poverty and inequality among local communities.

Keywords: customary law, adat, co-management, transregional, non-sustainable practices

INTRODUCTION

Small-scale fisheries are undergoing rapid socioeconomic and environmental changes due to overfishing, declining fishing stocks, and the degradation of marine and coastal landscapes. To match the high levels of uncertainty associated with the new scenarios, fishing communities have revised their local ecological knowledge and practices, diversified their livelihoods, and developed novel institutional arrangements (FAO, 2019; Aswani, 2020; Green et al., 2021). As part of these innovations to regulate the use of natural resources, a wide range of sectors and academic disciplines has renewed the call for co-management and user-rights frameworks (von Benda-Beckmann et al., 2016; Tilley et al., 2019; Villaseñor-Derbez et al., 2019). Such efforts are not new, but build upon several decades of research on institutions, collective action, and fishery management policies (Bubandt, 2004; Henley and Davidson, 2008; van Ast et al., 2014). Legal developments reflect a broader pluralistic tendency in international law that seeks to revitalize customary and faith-based systems and the value of cultural heritages (von Benda-Beckman and von Benda-Beckman, 2011; Adhuri, 2018, 2019; von Benda-Beckmann, 2019). An exclusive emphasis on indigenous tenure arrangements runs counter to the many interconnections, linkages, and transregional mobility that have dominated maritime activities in Southeast Asia for the past two millennia (Lockard, 2010; Henley and Schulte Norholdt, 2015; Manguin, 2017; Hoogervorst, 2018). The renewed focus on customary and user-rights approaches has dire implications for some of the most cosmopolitan yet impoverished fishing communities in this part of the world. Originating in old port towns or entrepots, marine tenure institutions may be difficult to recognize in these highly dynamic and pluralistic societies. Managers' failure to detect customary structures, pre-established usages, and maritime regulations may lead to a community's disenfranchisement, the exclusion of stakeholders in key decision-making processes, and the loss of opportunities to sustainably manage resources (Adhuri, 2013; Steenbergen, 2016). The goal of this article is to advance the understanding of how co-management frameworks may benefit from adopting a transregional perspective in the identification of local systems of coastal and marine tenure.

Over the past 35 years, Southeast Asian countries such as Indonesia have introduced legal instruments that seek to devolve authoritative power to local governments (Satria and Matsuda, 2004; Satria, 2009; Rauf et al., 2019). Institutional developments, such as the decentralization laws of 1999 and early 2000s (U.U. 22/199, P.P. 25/2000, Presidential Decree No. 177/2000), have met with limited success (Ostwald et al., 2016; Bedner and Arizona, 2019; Subekti et al., 2020). In 2014, the arrival of Joko Widodo to the presidency inaugurated an unprecedented program of reforms in fishery management systems to curb illegal practices and overfishing. At the cornerstone of changes is the revitalization of customary laws known as *hak-hak masyarakat* or *hukum adat* (shortened to *adat*; Village Law 8/2014) to increase local stewardship and accountability. The amendment of Indonesia's coastal and small island legislation (U.U. No.27/2007) has allowed a more explicit consideration of traditional communities' interests in the extraction of marine resources. Other significant changes have introduced controversial modifications in the small-scale fisheries sector's definition, broadening its scope to incorporate vessels below 10 tons (Halim et al., 2019). In practice, the new impetus on *adat* has translated into the mapping of all existing coastal communities that still maintain traditional management practices. In short, the intention behind legal changes is to assist communities in obtaining formal recognition from the provincial and national governments that may grant spatial jurisdiction and resource management autonomy (Halim et al., 2020).

Identifying local tenure systems can be especially difficult among maritime societies that actively participate in transregional networks regulating resource exchange and use (Gorris, 2016). In this context, transregional refers to the political and economic connections established between a littoral society and the distant trade centers located across other regions of Southeast Asia. At a broader Indo-Pacific scale, transregional meant the existence of sustained interactions between commercial settlements of the Malay Peninsula, the South China Sea, of kingdoms in Sumatra, Java, Sulawesi, and Kalimantan, and along many localities in Eastern Indonesia including Flores, Timor, and the Maluku and Banda Islands (Tagliacozzo, 2010). Owing to the wide geographical span of trade relations, port towns, entrepots, and coastal cities that are part of transregional systems can be highly dynamic cosmopolitan centers. The inter-island commerce that dominates the economic life of these settlements may give rise to largely diverse societies populated by culturally distinct co-resident groups (Widodo, 2012). In Southeast Asia, exchanges were built upon a set of common institutions such as nautical conventions or trade practices found in the Islamic world which later became embedded into indigenous juridical systems (Khalilieh, 1998; Sutherland, 2015a,b). Because of the plurality of resource uses found within these communities, norms fluidly shifted and adapted to specific situations (Zerner, 1994; Knudsen, 2008; Fabinyi et al., 2010). Challenging the notion of a static or geographically circumscribed tradition, the identification of a standard juridical framework in these littoral societies becomes an arduous process (Macknight, 1973; Pearson, 2006). Furthermore, broader naturalized conventions, practices ingrained in symbolic representations, or emerging behaviors, may also remain implicit and hard to discern from everyday habits, leading to the idea that no rules exist (McCay, 2002; Quimby, 2015).

This article presents a case study of a fishery in the port-town community of Ende, Flores, a former littoral hub positioned at the periphery of major commercial systems in the Indo-Pacific region. Although this settlement is in a relatively remote location when compared to other islands such as Java and Sumatra, it represents a vital center within the larger Nusa Tenggara Timur and Maluku provinces. Ende is second in importance to other towns like Kupang in Timor, Waingapu in Sumba, and Ambon in Maluku, and constitutes a significant step in the movement of commodities, supplies, and raw materials toward the eastern parts of the archipelago. The case study argues that more attention be paid to the role of transregional maritime networks, nautical usages, and navigational practices that are embedded within local tenure systems to understand the apparent absence of formal control of marine and coastal resources. Through ethnographic and archival research, the objectives are to identify the presence of indigenous institutions that regulate access, control, and use of fishing territories and specific stocks and to document the existence of broader transregional norms, rules, and conventions dictating proper fishing and navigation. By exploring the interactions between nested systems of local and transregional regulations and more recent fishery development policies, the goal is to discuss some of the obstacles to implementing sustainable co-management strategies in port-towns such as Ende. The article concludes with a consideration of the role played by decentralization processes, subsidies, and aid programs in increasing inequality among local communities.

Customary Marine Tenure, Community Driven Development, and Co-Governance Frameworks in Eastern Indonesia.

At the crossroads of global trade maritime routes, Eastern Indonesia has seen the emergence of numerous coastal ports, entrepots, and seasonal trading centers in the past two millennia (Reid, 1988; Hall, 2011; Sutherland, 2015a; Webster et al., 2015). Coastal settlements are an amalgam of different cultures with local communities, depicting the adoption, accommodation, and integration of co-resident groups of varied ethnic backgrounds (Macknight, 1973; Knaap and Sutherland, 2012; Sutherland, 2015b). Affiliations and alliances among different ethnicities through kinship ties and economic activities can lead to rich interactions where exchanges are not just limited to commodities but also extend to beliefs, institutions, and practices (Pearson, 2006). As a result of the multi-ethnic fabric of coastal hubs, fishing communities residing in them can be highly heterogeneous in how they value and manage resources. The combination of local indigenous rules with exposure to broader transregional nautical usages and maritime conventions creates a constellation of diverse institutions regulating fishing activities, the access to stocks and potential commodities, or even preferences regarding the adoption of technology.

In Malacca and in the South Sulawesi kingdoms of Gowa-Tallo, Wajo, and Bone, which dominated maritime trade before the arrival of colonial forces, legal systems often constituted a mix of religious, territorial, and genealogical principles at different levels of consolidation and change (Raffles, 1879; Friedericy, 1932; Caron, 1937; Noorduyn, 1957; Liaw and Ahmad, 2003; Cummings, 2011). Formal nautical codices inspired by Islamic law intersected with indigenous customary institutions to organize all aspects of civil, criminal, and commercial life. Islamic precepts acted as a set of transparent rules that governed business transactions (Borschberg, 2019). While shared conventions and usages predominated in nautical and economic settings, practices and rules were deeply embedded at the local level in the social and cultural structures of indigenous *adat*. Consequently, the types of tenure rights and the ability of certain institutions to enact them were directly determined and subordinated to an individual's group membership (adscription to lineages), place of residence, and religious and ethnic affiliation. In this context, *adat* denoted pre-existing ancestral structures with a solid sphere of influence in arbitrating cases related to kinship or reciprocity obligations. Regarding the management and use of natural resources, customary laws assumed the form of taboos, prescriptions, and moral beliefs closely tied to origin narratives and cosmologies.

Although a core set of tenets related to kinship remained unchanged, within indigenous legal systems cultural and institutional boundaries were highly dynamic, reshaped and adjusted to fit particular circumstances (Macknight, 1973). As observed by colonial officers, variations and divergences from a common principle constituted the norm (Vollenhoven, 1918). In addition, common usages and rules became so naturalized in everyday decision processes that it became impossible to verbalize the rationale behind choices (Friedericy, 1932). Thus, in most descriptions of *adat*, emphasis was placed on the more fixed aspects of customary systems that can be easily discerned, such as marriage practices or ceremonial wealth distribution. Even in present days, the focus on some institutions at the exclusion of others in the characterization of indigenous legal systems distorts and obscures interpretations of the role played by customary structures in the control of natural resources (Knudsen, 2008; von Benda-Beckman and von Benda-Beckman, 2011; Ellen, 2016). In addition, the discernment of how broader regional maritime principles articulate with customary practices remains largely unexplored within current legal and institutional governance studies (Khalilieh, 1998, 2019; Borschberg, 2019). This creates a gap in the understanding of resource use practices within littoral hubs, former entrepots, and port-towns, that can shape and affect the development of sustainable policies in marine and coastal management (Gorris, 2016; Steenbergen, 2016).

Since the late 1980s and early 1990s, models of co-governance and participatory management, the sharing of responsibility and authority between a state government and indigenous institutions in natural resource management, have gained prominence in the field of marine policy (Berkes, 2006, 2009; Charles, 2012). The interest in co-governance represented a combination of both practical and theoretical concerns (Plummer and Fitzgibbon, 2004). On the one hand, as important declines were observed in fisheries, many countries such as Indonesia were undergoing important transitions in their political organization through decentralization processes that called for creative ways of resource governance across a multitude of ethnic communities (Shivakoti and Shivakoti, 2008; Ostwald et al., 2016). On the other hand, an important theoretical change took place among institutional design frameworks that challenged traditional views of the role of government control in decision-making and in the administration of common resources. The work of Elinor Ostrom along with the numerous contributions of anthropologists, biologists, and ecologists exploring indigenous tenure systems around the world offered key insights regarding the value of local rules and self-governance to solving collective action issues (Cordell, 1989; Ostrom, 1990, 2007; Johannes, 1993; Ruddle, 1998; McCay, 2002; Basurto et al., 2012; Lauer, 2017). Central to the approach was the identification of a collection of design principles that could foster long-term stewardship in the adaptive management of resources (Berkes, 2015; Trimble and Berkes, 2015). User characteristics, their needs and conditions, along with the type of resources (stationary vs. mobile), and the existing governance structures regulating exchanges between users and resources, were three crucial dimensions to consider according to the theory. Because the new approach emphasized the need to involve local actors in the practice of formulating policies, regulating access, and overseeing the control of resource systems (Berkes, 2009; Ostrom, 2009), the existence of local rules and institutions, their documentation and the understanding of their use, became essential to the theory (Zerner, 1994; Adhuri, 2013).

While international institutions embraced many of the new recommendations, others expressed caution against the use of customary practices to manage natural resources (Pannell, 1997, 2007; Afiff and Lowe, 2007; Leach et al., 2012; Lauer, 2017). The quick adoption of cultural representations by government and non-government organizations was seen as problematic, leading to the rationalization of otherwise dynamic social processes and to the simplification of complex social institutions (Pannell, 1996; Ribot and Peluso, 2009; Fabinyi et al., 2010; Coulthard, 2011). Furthermore, scholars called attention to the fact that in locations where customary principles were hard to discern, were undergoing change, or had a strong emphasis on individuality, these systems were at risk of not being properly recognized (Knudsen, 2008; Gorris, 2016).

In Eastern Indonesia, where Ende is located, the movement toward co-governance began in the mid-1990s with the introduction of decentralization policies in the agricultural sector (Susilowati, 1996; Satria and Matsuda, 2004; Sugishima, 2006). Decentralization consisted in the devolvement of management functions to the lower government levels, including districts, sub-districts, and villages (Steenbergen, 2016). The district government jurisdiction was defined to extend up to 4 miles offshore. Provinces held management and administrative responsibilities between 4 and 12 miles offshore according to coastal management regulations (U.U. No. 27/2007, U.U. No. 1/2014). Other fishery instruments, including U.U. No. 45/2009, P.P. No. 60/2007, and Kep.06/MEN/2014, were introduced to support the implementation of integrated spatial planning, leading to the creation of a network of marine protected areas in the Savu sea (Mujiyanto et al., 2019). In the early 2010s, local offices participated in surveys and assessments to support zoning efforts. More recent policies have introduced additional amendments to licenses and permits (U.U. No. 1/2014, U.U. No. 7/2016), along with changes in the definition of fishing communities and the roles of customary law (Ministry of Internal Affairs Regulation No. 52/2014, Ministry of Marine Affairs and Fisheries Regulation No. 8/2018). Given the current mandates to incentivize effort (see for example, Goti, 2020; Suimam, 2021a) and the absence of consistent development policies for the fishery (Djata, 2018; Langga, 2020), the impact of the new regulations on customary management introduced by the central Indonesian government is yet to be determined. To this date, and to the author's best knowledge, coastal Endenese villages in the regency's southern areas have not gained proper legal recognition either as *adat* (*masyarakat adat*) or as traditional communities (*masyarakat tradisional*).

MATERIALS AND METHODS

Study Site

Coastal Endenese are a paradigmatic example of a littoral society, embodying a rich cultural and religious identity forged over centuries of interactions with other groups (Fernandez, 1990; Soenaryo, 2006; Nakagawa, 2007). Part of a regional inter-island trade network, the city of Ende and the smaller island of Pulau Ende maintained numerous ties with merchant communities in Malacca, Ternate, and Makassar (see **Figure 1**). As ships made their way to the sandalwood and spice centers, Chinese and Javanese merchants visited the entrepot since the early 1300s (Heuken, 2002; Abdurachman, 2008). After the arrival of Portuguese and Dutch forces, groups of Makassarese and Bugis merchants relocated in Ende in the early 1600s (Roos, 1872; de Roo van Alderwerelt, 1905; Van Suchtelen, 1921). A rajadom was created in 1638, and through its foundation, Coastal Endenese became a separate, self-identifying group. The polity subsisted on the commerce of slaves and other commodities. During the twentieth century, the economy transitioned to the production of agricultural staples such as coconuts (*kopra*) for exports (Needham, 1987; Parimartha, 2002).

Presently, there are close to 3,000 active fishermen distributed along villages in the southern coast of Ende regency (**Figure 2**, BPSKE, 2019). Fisheries are subsistence-based, with most captures including large and small pelagic stocks such as Scombridae, Clupeidae, Lutjanidae, Serranidae, and Carangidae families (Ramenzoni, 2013a). Most of the fishing occurs along the shorelines on canoes and small-motorized plank boats. Prevalent fishing gear includes small gillnets (mesh size of 2.5–12 cm), troll lines, and hand line fishing. With weekly incomes ranging anywhere between USD $15 to $70, poverty has become, next to socioeconomic and environmental uncertainty, a significant pressure preventing the eradication of non-sustainable practices. After the second world war, Endenese fishermen began using bombs and potassium cyanide when fishing in coral reefs (Ramenzoni, 2013b; Ramenzoni et al., 2017). As a consequence, they have had amassed a notoriously bad reputation throughout the region (de Rosary, 2020). The lack of resources to support enforcement has resulted in a game of cat-and-mouse between fishermen and authorities.

In tandem with coral blasting, over the past 40 years, the regency has experienced an irregular intensification of its fishing effort (Ramenzoni, 2017). Still, mechanization and industrial development are extremely limited. With no serious opportunities for professionalization and a lack of consistency in policies (Djata, 2018), Endenese fishermen are highly individualistic in their operations and share a robust ethos that ties each individual's fortune to their capacity for diligent work and courage. This explains why most fishermen choose not to affiliate or form any external organizations. Despite some past attempts at creating a local branch of the National

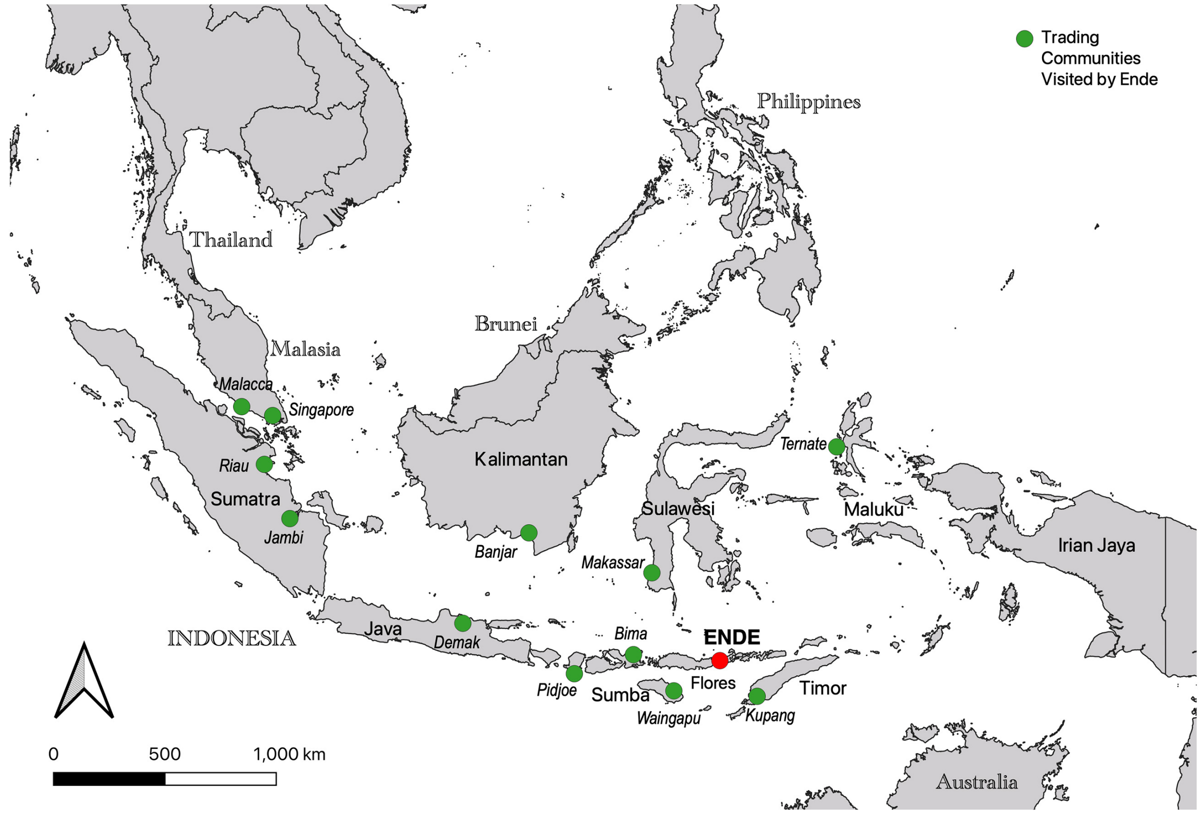

FIGURE 1 | Map of Ende Regency and trade towns of Eastern Indonesia.

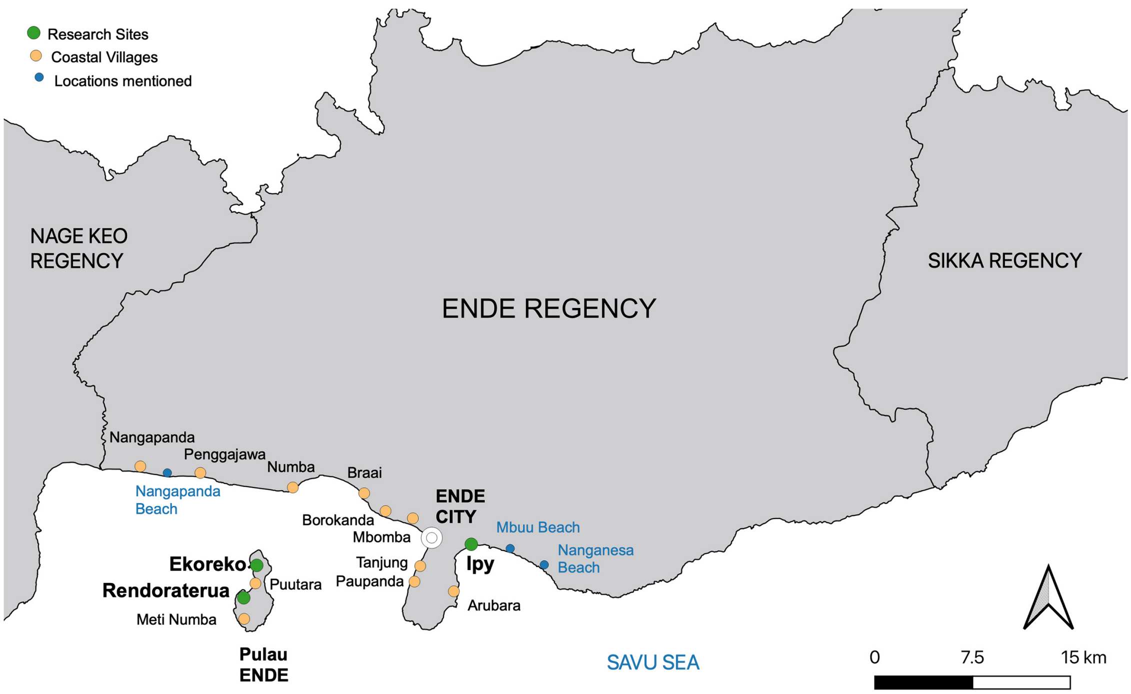

FIGURE 2 | Map of research sites along Ende Regency, Eastern Indonesia.

Fishermen Federation (*Federasi Serikat Nelayan Nusantara*), there are no active fishing associations in the regency. The degree of group aggregation is in most cases temporary and rests upon the choice of fishing techniques, boat size, gear ownership, and kinship ties. Self-sufficiency prevails among singly manned canoes and small out-board engine plank boats which dominate the fishery. For example, at the time of research, less than ten percent of all fishermen worked as a crew in the larger purse seine boats (known as *lampara*). In terms of organization, Endenese fishermen recognize no leaders beyond the boat captain. Through a well-established patronage system, middlemen (*papelele*) and financial partners influence activities by determining revenues from sales and advancing funds to cover operational costs. Support for local fishermen continues to be provided by the local government in the form of aid packages, funded through specific budgets, that are distributed to a few individuals each time (Suimam, 2021b). These parties usually include nets or fiber boats, and prioritize the formation of fishing clusters and cooperative arrangements rather than capacity development.

Data Collection Methods

Data were collected over 22 months of fieldwork in Ende with visits in 2009 and 2010, and residing in the villages of Eko Reko, Rendo Rate Rua, and Ipy from June 2011 to December 2012. Follow-up visits to Jakarta took place in 2013, 2019, and 2020. Interviews, along with responses to demographic surveys, field notes, and archival research, constitute the major sources of data for the thematic analysis.

Semi-Structured Interviews

A total of 140 semi-structured interviews and conversations with fishermen (*n*: 130), and officers and administrative personal from the local fishing commission, the environmental office, and the marine police (*n*: 10) were carried out from 2011 to 2013. Of these, a total of 60 interviews were tape-recorded with consent from participants. All interviews followed a common guide that included specific questions on local resource management practices such as customary usages and rules, fishing grounds and taboo areas, and fishing regulation (authorities responsible for controlling access at the village level); normal fishing activities and fishing clusters; reciprocity, sharing, and obligations; fishing behavior and responsibilities at sea; and fishery policies in relation to other types gear, non-sustainable practices, and government incentive programs. Additional information from informal conversations was also captured in field notes and diaries. Interviews and conversations were conducted in Bahasa Indonesia with the support of three Indonesian research assistants.

Surveys

Demographic and basic fishing information including earnings from fishing by month and season, estimates of calendar month fishing effort, and ownership of gear and normal fishery targets per season, was also obtained through a specific survey and included a total of 135 households in the villages of Ipy, Eko Reko, and Rendo Rate Rua in mid 2011. Results from the demographic questionnaire, in conjunction with official fishing surveys documenting fishing effort from the local fishing office and reports from the Indonesian statistical office in Ende from 2009 through 2019 (Badan Pusat Statistik Ende), are used to contextualize the fishery.

Participant Observation

In addition to ethnographic fieldwork in Eko Reko, Rendo Rate Rua, and Ipy villages starting with visits in 2009 and concluding at the end of 2012, the researcher participated in public meetings on the topics of environmental protection, zoning, and socialization carried out in April and September of 2012. During meetings in April of 2012, the researcher presented preliminary results on non-sustainable practices and fishing effort among local officers and fishermen representatives. In September of 2012, the researcher was present as part of the audience in a training session on management policies for environmental conservation.

Archival Research

The researcher also visited archives and consulted document collections in Maumere, Yogyakarta, and Jakarta, Indonesia, and Nijmegen and Amsterdam, The Netherlands. Archival research in the years of 2009, 2011, 2012, 2013, 2019, and 2020 complemented field data and focused on identifying management policies and their impacts on the local population. It included documents such as annual reports, policy briefs, copies of presentations, and newspaper articles. Finally, since 2009 the author has maintained regular contacts through internet and telephone with five key informants from Ende, including fishermen and residents of the villages of Ende City, Eko Reko, and Rendo Rate Rua. Consultations with informants as well as publications from local scholars in the area (Djata, 2018; Langga, 2020) are used to verify, comment, and actualize findings from fieldwork and archival research.

RESULTS: ADAT, MARITIME RESOURCES, AND SEAFARING PRACTICES

No written books of law, village ordinances or royal codes have been found to date among coastal Endenese. In the earlier work of legal scholars, Endenese belonged to the Timorese Circle (Vollenhoven, 1918). Similar to other *adat* systems, coastal Endenese recognized the institution of a *tuan tanah*, the lord of the land, called "mosalaki tana" or "mosalaki pu'u" (Roos, 1872). This office oversaw the distribution and management of communal clan land. Few coastal Endenese villages still maintain a tuan *tanah*, with the office reverting to family leaders. Other forms of resource control are related to the sanctioning of transgressions of private property, family-based prescriptions, and taboos (Weber, 1890; Van Suchtelen, 1921).

While indigenous prohibitions may be perceived as largely pertaining to agricultural or land-based resources rather than marine or coastal products, through interviews I was able to establish that Coastal Endenese see numerous connections between the ocean and the terrestrial worlds. With both dimensions linked in practice and traditions, the application of indigenous *adat* acknowledges this continuity and does not necessarily uphold a distinction in terms of jurisdiction (see Edjid, 1979, for rigidity of coastal adat in Ende). For example, like other Southeast Asian cultures, the violation of prescriptions in marine spaces carries serious consequences that follow the infractor to land or sea (Andaya, 2016, 2017). Therefore, if managers seek to identify specific principles that only apply to the marine world without considering land-ocean interdependences, they may conclude that few local rules, if any, are tailored to manage coastal or marine resources. With this in mind, I carefully discuss findings pertaining to the regulation of marine and coastal resources as well as fishing and navigation behavior.

Regulations of Marine Resources

Coastal Endenese possess several institutions seeking to manage or harvest specific fisheries and coastal organisms, which are deeply embedded in religious and cultural practices. For example, there are rules and prohibitions related to the fishing of red snapper (*ikan kakap merah*, or "iká asa," *Lutjanus campechanus*; "iká ziké," *Lutjanidae* spps.). When entering known habitats of red snapper, or areas of aggregation and reproduction, fishermen are to follow specific behavior rules. These areas are known as *pantangan* or *pemali* ("pire"), terms that indicate the existence of a taboo. As discussed by several interviewees, fishermen cannot talk or make noise, relieve themselves, spit, smoke, light a fire, or stand in their canoe at the risk of disturbing the fish underneath. Besides, if someone finds a spot where red snapper bite, that person has priority in accessing the fishing ground the following days. Others can only enter the area after the lucky fisherman chooses a place and drops a line (*tidak boleh masuk duluan*). If the order of precedence is not respected, offenders will not capture any fish for the duration of that lunar month.

Taboo areas are part of a larger set of spatial locations recognized by all yet owned by no one. Even when supposedly bountiful, some of these locations were referred to as *angker* (cursed) by the interviewees. Inhabited by spirits (*setan, djin*), visiting these spaces can lead to mystical encounters, hauntings, or strange events. Currents may not behave normally, with fishermen getting stuck or trapped, and nets being so heavy that several men cannot pull them. Some fishermen even described being deceived and or warned by spirits. According to respondents, rules about red snappers are directly inherited from their ancestors (*nenek moyang*). Their origin is in a legend that accounts for how Endenese were taught and granted permission to fish by a red snapper's spirit. Other Endenese traditional narratives mention sailfish, sharks, and dugongs as sharing a common ancestry with humans; and portray marlin, dolphins, and whales as helpers of human ancestors. Whereas some of these legends do not often prohibit species harvesting, they may limit the sale or use of the carcasses and parts. In addition to origin narratives, numerous individual and family level taboos restrict the consumption of marine products such as octopus, whales, sharks, marlin, rays, porcupine or blow fish, flying fish, and garfish. Additional prescriptions are associated with illness from collecting items (pearls and thorn or branch corals) without the custodian spirits' permission or when squandering valuable objects, even if their finding was unintentional.

Finally, a few respondents indicated that there were additional ritual traditions and special rules to follow to harvest "ika ipú" (*ikan bandeng*, milkfish, *Chanos chanos*) and "nale" (*nyale*, sea worms). These prescriptions are found in the regency of Ende and along coastal villages in the Sikka and Manggarai regencies in Flores, as well as in Sumba, Sumbawa, Lembata and Lombok. Fish fry are harvested during their upstream migration. Sea worms become more numerous in the annual low tide. Both species are associated with changes in seasons. In Ende, the flocks of small milkfish are seen in the beaches of Mbu'u and Nanganesa and in the coast of Nangapanda during April and May. To anticipate their arrival, *adat* chiefs or elders keep calculations based on prior occurrences. Prohibitions are in place surrounding the harvesting with people being forbidden from crowding the coast at the risk of scaring the organisms. Permissions are granted after envoys observe sufficient numbers of stocks.

Regulation of Fishing Areas and Tidal Lands

Access to nearby maritime and coastal resources is loosely regulated at the village level, with anyone residing within the village or neighboring areas being able to exploit associated fishing grounds at will. The local jurisdiction of fishing areas extends to approximately 3 miles offshore, a practical distance that encompasses what the eye can see. Areas may have expanded or contracted in the past depending on warfare, nautical traffic, and regulatory changes. Fishing grounds often include reef areas ("peró iká," coral fish places) where only small nets and lines can be deployed. Fishermen perceive local grounds as a commons: no one from the village owns, has priority, or exclusive rights over these spaces and outsiders are precluded from using them without appropriate permissions. Endenese beaches and tidal flats ("meti tu'u") positioned directly in front of the village are also communally owned.

Every year, the fishing grounds and nearshore habitats around Ende receive the visit of foreign Indonesian Bajau and Buginese fishermen seeking sea cucumbers (*Holothuria* spps., trepang) or lobster. Local village chiefs are responsible for granting permission to use local commons to outsiders after the payment of a small fee. The amount or kind of payment may include a percentage of gains, a fixed amount, or a proportion of landings. Yet, permission to operate in a village's fishing grounds is not always conceded. During my research I encountered a village head who refused access to Bajau fishermen to protect local yields (*jaga hasil laut nelayan*) and because they associated this group with coral blasting. In other cases, I found that village chiefs did not care to impose any restrictions or that when they did their enforcement was lax. No limitations existed on the amount of resources that foreigners could harvest since those products were not regularly extracted by the local fishermen. In principle, Endenese did not oppose the activities of the Bajau. However, they were upset by the complacent attitude shown by most village chiefs who regarded fishing grounds as open access rather than communally regulated commons and allowed the unrestricted exploitation of valuable products.

Previous examples may suggest that Endenese have ineffective mechanisms to control the harvesting of certain resources. Yet, on the other hand, there are very clearly delineated prescriptions regarding the types of gear that can be deployed within a village's fishing grounds. Large nets such as gill nets, any kind of trawling (*pukat harimau*), and purse seiners (*pukat cincin, pukat lampara*) are not allowed within nearshore habitats and tidal areas. While these norms are followed and adhered to by a large proportion of the local fishermen, changes in boat sizes and mechanization have created new challenges to their enforcement. When fieldwork was conducted, conflicts had been proliferating between canoe fishermen and larger boats in terms of the deployment of bigger nets and neon lights. The reason was the lack of a clear ordinance from the district fishing commission regulating larger *lampara* boats' activities in nearby grounds. While said regulation seems to have been in place and poorly respected, most large-scale fishermen were conveniently unaware of their existence or willingly chose to break the rules (see for example, the Agricultural Decree No. 607/1976). Furthermore, some village chiefs were complicit (*kepala desa tidak keras*, the village leader is not hard enough), allowing illegal or indiscriminate practices.

According to the prevailing fishing laws when research was conducted (U.U. No. 31/2004, U.U. No. 45/2009, PER.01/MEN/2011), local subsistence fishers who relied on non-intensive gear or used boats of small tonnage (<10 tons) were not required to possess any license. However, under the purview of local regency and provincial government offices, fishermen often needed to have the proper permits to operate in areas beyond their place of residence for business purposes (Government Regulations Act No. 54/2002). Among the local fishermen, provincial or regency permits, widely known as *surat mancing* (fishing license), were common sources of complaints. If caught without a license, fines were deemed hefty or may result in a stay in jail. As mentioned in interviews, other document requirements were also issued by the district's fishing commission and depended on the type of fishing equipment and activities performed. Larger *lampara* or purse seine nets needed to obtain a special license and identification papers (U.U. No. 27/2007). Some practices such as lime production from corals (*kapur*), cyanide poisoning, shark finning, and coral blasting were completely forbidden, although they continued to the dismay of fishery managers (de Rosary, 2020).

Finally, interviewees also reported the presence of larger Indonesian, Taiwanese, and Korean tankers in offshore areas (more than 12 miles). By definition, these fishing grounds were under provincial or central government level controls and required specific permits (*Izin Usaha Perikanan, Surat Penangkapan Ikan, Surat Ijin Kapal Pengangkut Ikan*). Since most Endenese fishermen did not venture into the open seas except for seafaring or traveling, they did not trouble themselves with the larger tankers. When encountered, local fishermen were invited on board to receive a gift of frozen fish, money, or even cigarettes.

Regulation of Fishing Behavior

When entering a common fishing ground, or when traveling together and choosing fishing spots, there is a proper set of navigational practices and courtesies that must be observed. These norms apply to either canoes, small motorboats, and *lampara*, whether in coastal fishing spots or more distant fishing grounds. If arriving at a common ground, customs dictate that the new party should ask politely for permission (*mintah sopan*) and offer a small gift of fish or cigarettes. In Ende, since departure times coincide with the low tide, it is common for local fishermen to travel the distance to fishing grounds as a group or convoy (*rombongan, jalan bersama*; we travel together). If along the way or when arriving at suitable spot one of the boats decides to stop, it must signal the others. The rest of the group must pass the boat and can only stop in locations that do not interfere with the fishing activities of the first vessel. It is expected that newcomers will keep a proper distance and will not deploy their gear in a way that may affect the captures of other boats.

Usually, when setting a long gill net in deeper waters, fishermen position their boat at the "top of the current." The boat navigator may use a line with a small weight to assess the direction of the current. Then, fishermen drop an anchor, and throw the net end overboard over the boat's side that faces the wind. Slowly, the fishermen continue to deploy the net by moving the boat at an angle to the current, allowing the net to drift without tangling. Net setting is a process that is done quickly but with a high level of skill and expertise. The operation is challenging given that Endenese gill nets can range in length, anywhere from 10 to 50 m long. Because currents change with the tide and conditions at sea may affect water layers, the nets can get tangled or even sink if not properly set early on. Thus, great care is taken among the fishermen to provide sufficient space in their maneuvers not to hamper others' performance. Most significantly, an order of precedence is respected that prevents latecomers from deploying their gear in a way that intercepts fishing stocks and prevents them from reaching other fishermen's nets. Interviewees explained this as *harus [lewat] arus di bawah, jangan lawan arus dari atas*, that is, arriving vessels and their nets must not cut or traverse the ocean current from the top (where other boats are standing). The newcomers should position themselves south of the flowing current to prevent the entanglement with pre-existing fishing nets and the luring of targeted stocks with their lamps. A similar more simplified principle of precedence applies to canoes, which rely on hook and line for their captures. However, because they relocate multiple times in a single trip to accommodate changes in currents, they are constantly aware of whether they may be intruding or impinging upon another fisherman's space. Other types of fishing gear such as fishing traps and aggregating devices (*rompong*), should be also clearly marked with floats and buoys to prevent accidents. Thefts were deemed unusual by respondents, though one interviewee indicated that in the past prohibition signs were also placed in fishing cages.

In conclusion, in what pertains to fishing behavior, Endenese have clear long-standing rules that must be followed. Orders of arrival and precedence are observed when entering fishing grounds. Placing the boat in the wrong location or too close to others (*terlalu dekat*), is considered both a breach of etiquette and a significant offense. When the violation of one of these conventions occurs, there is no standard or predetermined way to penalize infractors. Most frequently, if wrongdoers are local, they would suffer recriminations and disapproval from others; consequences would affect all daily life interactions in the village. In this way, the spirit of adat rules requires people to be respectful in all instances, a system that strictly sanctions when someone speaks out of turn, insults an elder, or disrespects important topics (*jangan omong sembarangan*, do not speak without care). According to the Endenese, circumspection must predominate in all social interactions, including fishing practices. Discretion and sobriety must also extend to implementing sanctions. However, in the cases where the gravity of offenses could not be ignored, local fishermen would directly tell infractors that they were not the first to arrive (*aku yang dulu*, I was here first), or that they were cheating (*kamu curi*, you are stealing). Conflicts between smaller sampan and *lampara* boats often played out in this context, with fishermen complaining about the larger vessels' neon lights making nets visible to the fish or drawing stocks away. In other cases, if infractors were outsiders, verbal confrontations may ensue, and Endenese fishermen may resort to damaging or stealing fishing gear such as lamps and flotation devices.

Transregional Conventions and Rules for Sailing and Navigation

The Endenese, like other Islamic societies, deem the open seas beyond fishing grounds as areas of free navigation. Numerous agreed-upon customs, usages, and seafaring conventions that originate from a legacy of navigational and trading activities are followed when sailing in these spaces. Similar to the rules discussed above when entering fishing grounds, many if not all of the navigational norms that the Endenese adhere to are perceived as a given. Regulations are not verbalized in conversation and remain implicit unless evoked through particular events. It would be a mistake to assume that these norms are incipient, emergent, or recent in nature. Endenese rules reflect a blend of local beliefs and ethics with more general conventions found in classic nautical codices (Nooteboom, 1936). Treatises include the *Undang Undang Laut Melaka* (Liaw and Ahmad, 2003), the Makassar Annals and Buginese or *Wajo Lontara* from *Ammanna Gappa* (Noorduyn, 1957; Sulistyo, 2020), local *adat* from South Sulawesi polities such as Bone (Friedericy, 1932), and the broader Islamic jurisprudence that dominated maritime commerce in the previous centuries (Anand, 1981; Khalilieh, 2019; Azeem, 2020). Examples of transregional principles include the determination of the right of way, anchorage and navigation mechanics, boat design and building, and sailing techniques and directions, with the latter being determined by the type of vessel and mostly following Buginese practices (Ammarell, 2002b). The duties and roles associated with different offices such as the captain and the crew, the distribution of profits and shares, the customs regarding accidents and their determination, mandatory aid for wreckages, and collisions, burial at sea, and salvage operations also follow larger Southeast Asian and Arabic canons (Anand, 1982; Khalilieh, 2019).

Most interestingly, works such as *Ammanna Gappa* also include what can be best described as a set of ethics or precepts regarding business in maritime navigation and trade (Sulistyo, 2020). Close to this moral philosophy that governs individual behavior is the belief in the observance of religious Islamic principles in conducting commercial activities such as distributing or buying goods, pecuniary transactions, and the hiring of people. The Buginese and Wajorese polities that adhered to different versions of this code all were unified in the notion that as Muslims their actions were accountable to Allah, the causa prima that governs and controls the universe (Khalilieh, 2019; Sulistyo, 2020). Essential values to guide conducts were to be found in verses of the Qur'an or the hadiths, and included notions such as fairness, accountability, and practicing good to others. Other tenets comprised the idea of embracing fate or pursuing one's destiny, a quest for awareness through pure means (*IKHLAS*). Perseverance, independence, and the capacity to deploy initiative even in the most challenging times are essential attributes of good character (Acciaioli, 2004).

A highly individualistic entrepreneurial ethos and the belief in the role of fortune are two key elements in the Endenese maritime culture that have a common origin in transregional values of independence and moral ethics. Underpinned in the Islamic notion of barakah (*berkat*, or blessing), the search for luck was described by Alfred Wallace in 1856 when discussing the inhabitants of Dobbo in the Aru Islands. It has been present throughout the Malay world in the vernacular term of *mencari rezeki*, also referring to the Arabic term rizqui indicating sustenance. The expression reflects the continuity of cultural motives across trading littoral societies (see Acciaioli, 2004), and it provides a larger moral background to explain endemic mobility, the significance of labor, and a sense of honor. Matching Bugis or Bajau cultural idiosyncrasies, the interpretation of economic activities and behavior in Ende requires that we consider them not simply as actions purely motivated in the pursuit of wealth (Ammarell, 2002b; Acciaioli, 2014). It is in the daily search of a livelihood according to the Quranic teachings that one encounters the blessings of God for one does not fortuitously run into good fortune unless one works for it (Acciaioli, 2004). The notion of searching for luck connects the success in both material and spiritual endeavors to an individual's capacity for diligent work and courage. Thus, a fisherman must make his own fortune (in Endenese "ngga'e ka," literally the noble search for food) by going out to sea, but also through praying and dedication (Ramenzoni, 2013a, 2015). As it was explained to me by an older fisherman the making of a living requires constant and persisting efforts, and also poses dangerous perils and threats to the unprepared. One needs to be receptive to God in order to receive his grace, but also be constantly guarded against the deceptions of djins and the devil.

While reflecting in spirit broader transregional conventions, Endenese rules and moral beliefs are deeply woven into indigenous customary institutions and Islamic syncretism. Dominated by kinship and reciprocity, *adat* governs all economic and civil transactions aboard a vessel, comprising fishing rights, the allocation of shares and responsibilities, and proper behavior. For example, interviewed fishermen mentioned that, according to *adat*, they were mandated to respect their captain and *papelele* (often part of the same family). They were also required to help in fixing the nets and fishing gear, take part in communal work ("kema lambo," work in boat), and participate in ceremonies and religious prayers (*Fatiha*). In other cases, customary obligations stipulated a remuneration system for those that helped fishermen haul their boat when onshore or transport and process captures, with the allocation of different parts of the fish according to rank and effort. Most significantly, *adat* dictated that a fisherman ought to share his fortune with family members (*bagi-bagi*), friends, and neighbors, without expecting a commensurate remuneration (*kamu punya rezeki, tidak makan sendiri*; you were lucky, you are not eating alone). Reciprocity is both tinted by local notions of kinship and Islamic values. It was referred to me as the "zekat" (*zakat*, an obligatory payment and one of the five mandatory pillars for Muslims). However, mandated reciprocity can also be a cause of complaint. Many fishermen indicate that *adat* kinship obligations kept them at subsistence levels (*adat rugi, adat paksa, adat setengah mati*; adat brings ruin, *adat* is heavy pressure, *adat* leaves you half-dead). Finally, interviewees described other *adat* practices in terms of safety, solidarity, and decency (*hati ikhlas*, pure heart). It is *adat* to rescue someone in distress, and when going fishing during the rainy and windy season, if one person has departed in rapidly deteriorating weather conditions others have to follow to ensure safe return. Thus, constant surveillance and awareness of who is at sea are normal among Endenese neighbors, with rescue efforts often bringing together several villages to procure aid.

It should be noted that, like other *adat* systems of Eastern Indonesia (Zerner, 1994; Pannell, 1997), some of the rules currently in place have suffered important changes over time due to the pressures imposed by colonization, the emergence of the Indonesian nation, and development projects. Interviewees attributed key changes in the system of shares and profit distribution as a result of the growing influence of the *papele* in the early decades of the 1980s and 1990s. The more recent introduction of fishing mechanization policies in the early 2000s and 2010s has led to the adoption of bigger *lampara* boats, more powerful engines, and purse seine nets. With changes in labor dynamics and wealth concentration, crew-patron relationships have been revitalized. These contracts, juxtaposed to kinship ties, are rapidly evolving into purely economic relations and leading to a more intensive exploitation of maritime and coastal resources.

Non-sustainable Practices and Rule Enforcement

During my interviews and conversations with local fishery officers and managers, I came across the same explanation of why most efforts to regulate coastal resources and develop the fishery had failed: *orang Ende tidak punya adat* (the Endenese people do not know customary law). However, Coastal Endenese do follow a series of norms and rules to control access to local fishing grounds, specific resources, and proper norms of behavior. Lack of awareness of customary principles and their application to all transactions concerning marine and coastal ecosystems could be explained by the absence of significant interactions between managers and fishermen. As many fishermen said: *orang perikanan tidak turun ke pantai* (the fishery managers do not come visit the coast).

Regarding non-sustainable practices, and despite reports to the contrary by fishery officers and media articles (de Rosary, 2020; Pius, 2020), I found that there is broad resistance to coral blasting and potassium use among the local communities (Ramenzoni, 2013b). Most fishermen saw a connection between the reduction in the size of the catch over the last 30 years and damaging fishing practices, directly blaming illegal fishing for the current situation. With some exceptions depending on the village, they would actively report anyone who uses bombs in local fishing grounds. The use of explosives was equated to non-halal ways of making money and described as *rezeki kotor* (dirty luck) and *barang panas* (hot items). Yet, dynamite use is still prevalent due to the existence of what were considered valid excuses. The majority of interviewed fishermen were disappointed by long-standing institutional promises to provide more powerful engines, bigger nets, buying partners, or contracts with processing plants to develop the fishery. Non-sustainable practices such as coral blasting provided a way of drawing attention to local plights and the inefficacy of current policies.

On the other hand, enforcement and management officers considered weak customary institutions, selfishness, and the lack of environmental awareness and education as the key factors explaining the prevalence of non-sustainable and illegal practices. Endenese fishermen were in managers' minds *perompak dan perampok*, pirates and bandits, who only cared about their individual profit. The solution to the problem was to teach fishermen to work collaboratively by creating cooperatives or clusters (*kelompok*). Thus, to qualify for a subsidy, the regency's fishing commission (*Dinas Kelautan dan Perikanan*, DKP) required fishermen to form fishing groups and to submit a formal application. In some cases, programs were composed of financial loans to be paid back within a period of 5–10 years. Other programs provided access to equipment (engines and boats), or productive inputs such as seaweed seeds. The assistance provided by the DPK had the objective of supporting the economic self-sufficiency of several household heads. Hence, priority was given to those fishermen who had formed groups in the past, irrespective of their success. Expectations were that fishermen within clusters would work in close solidarity, maintain cohesiveness, and be serious and fair in distributing benefits. Notably, in the cases of loans, it was expected that some revenue would revert back as a payment every month. The main rationale explained to me was that fishing clusters would allow for the introduction of more efficient fishing fleets over time, and fishermen would progressively transition from smaller boats to the larger *lampara* seiners, increasing captures in a region whose potential is deemed as largely unexploited (Djata, 2018; Langga, 2020; Suimam, 2021a).

Despite policies' intentions, conflict and dispute arose as a result of their implementation. First and foremost, subsidies were not granted regularly nor followed a clear timeline in their distribution. Second, assistance packages based on an egalitarian logic had to contest with long-standing social reciprocity institutions, power structures, and patronage systems. Within villages, pre-existing fishing clusters were dominated by kinship principles, so the distribution of the new benefits was scaled according to status. Invoking *adat* obligations, only powerful family heads and local leaders could directly mobilize labor that would allow them to apply for subsidies, a process known elsewhere as elite capture (McCarthy et al., 2016). For instance, it was said during conversations that only people in elevated positions, middlemen and patrons, religious figures, and those involved in the administration of the village received government support. The least privileged fishermen, which were sometimes called free-riders or parasites ("umpang") given that they only had their workforce to sell, continued to have no access to any kind of aid or welfare.

Apart from having connections and influence with local government officers, local elites also monopolized available programs by entering their family names even when the individuals forming the clusters were children. When neighbors created fishing groups *ad hoc*, aid distribution led to disputes about fishing effort and gains allocation. As an example, I witnessed litigation among three partners concerning a fiberglass high-power boat that unfolded over the span of 3 years. Due to a disagreement in profit shares the equipment was never used, and the engine was even sold by one of the parties without the consent of the others. This was not an unusual event. Fishermen complained about the fishing commission pushing a type of organization that brings conflict and corruption to the village (see, for example, Florespedia, 2019). They were angry that the DPK would not respect their preferences. For instance, a fisherman said: *orang di sini tidak bisa punya pikiran sendiri diri*, the people here are not allowed to think for themselves. In this way, any kind of policy originating from the government was seen as not transparent, and increasing inequality (*orang miskin tambah miskin*, poor people become poorer).

Most importantly, the rules for obtaining aid were in open conflict with longstanding principles of independence and luck that dominated the larger Southeast Asian maritime world. Endenese beliefs about merit and fortune, rooted in religious ideas about the relation between diligent work and God's blessings, dictated that success was an individual achievement. Boats, nets, and general wealth were fruits of hard labor and initiative reflecting the patient dedication (surrender) to Allah. Because it was only through an individual's effort that spiritual and material gains were obtained, local fishermen saw the sharing of ownership in their means of production (boats and nets) as subordinating their capacity for action to the willingness of others. It must be emphasized that fishermen were not against collaboration in general. However, they were skeptical of the notion that working with others would prove fruitful and felt that policy requirements were diminishing their agency. Overall, the high level of frustration with the DPK, and the onerous customary obligations that Endenese had to comply with in terms of reciprocity and patronage systems, their feelings of disempowerment, and the blatant corruption shown by the distribution of aid led many fishermen to dismiss subsidies altogether.

GENERAL DISCUSSION

The core issue discussed in this article concerns the identification of tenure systems within a highly cosmopolitan fishery in Ende, Eastern Indonesia. Challenging perceptions on their absence, findings underscore the complex set of arrangements devised by local fishermen to control access and use of resources. Institutions comprise a mix of customary principles based on kinship and genealogy nested within broader transregional maritime usages and conventions. This diverse evolving body of regulations continues to play a central role among Endenese coastal villages mostly through reciprocity obligations, prescriptions, and the regulation of behavior by religious and moral beliefs. Like other fisheries, Endenese maintain a strict etiquette concerning precedence and order within fishing grounds, and carefully regulate the use of spaces and the deployment of gear (Knudsen, 2008; Quimby, 2015). Proper behavior is followed in navigation, when fishing in taboo areas, and in the harvesting of particular species. Depending on descent and family lineages, strict prohibitions are observed. Furthermore, Endenese have a strong religious and moral belief on the role of fortune and diligence in their search for both material and spiritual wealth. Reminiscent of Buginese and Bajau cultures, this reflects a larger transregional motif that values independence, an entrepreneurial attitude, merit, and initiative in everyday life (Ammarell, 2002a,b; Acciaioli, 2004, 2014). In all, while formal legal instruments from the government reinforce some of these norms (i.e., gear regulation in inshore habitats), other widespread and deeply naturalized rules such as the sharing of captures and spatial usages are not contemplated within policies. There is a gap in the understanding of how Endenese communities regulate marine environments and of the cultural value of independence, leading to the idea among fishery managers that tenure institutions are weak or inexistent.

Since the introduction in the 1980s of community-based conservation programs, researchers have expressed caution against the use of customary practices as the basis for managing natural resources (Pannell, 1997, 2007; Afiff and Lowe, 2007; Leach et al., 2012; Lauer, 2017). Central to the approach has been the identification of local rules and institutions to support the sustainable governance of coastal and marine landscapes (Zerner, 1994; Tsing et al., 1999; Adhuri, 2013). Appropriation of cultural representations by government and non-government organizations has led to the rationalization of otherwise dynamic social processes into codices and compendia, and in some cases has contributed to the fictionalization or simplification of local institutions (Pannell, 1996; Ribot and Peluso, 2009; Fabinyi et al., 2010; Coulthard, 2011). More significantly, in locations where customary principles are hard to discern, undergoing change, or have a strong emphasis on individuality or independence, the assumption is wrongly made that no rules operate at all (Knudsen, 2008; Gorris, 2016). Such a conclusion results, as this study indicates, in the disenfranchisement of local communities, their lack of participation in decision-making, and their exclusion in the design and application of management solutions. Therefore, the implementation of co-management policies based purely on the existence of *adat* or categories such as *masyarakat tradisional* in port-towns and highly cosmopolitan coastal hubs like Ende cannot only be challenging, but also lead to policy failures and further environmental degradation.

Next to co-management instruments, the formation of fishing cooperatives and the promotion of collaborative enterprises have been adopted by governments and institutions as one of the most inclusive and sustainable strategies to achieve local development (Ostrom, 2007; McCay et al., 2011). Yet, as illustrated in this case, a cooperative model based on loans and parceled financial support is far from representing an institutional framework that guarantees stakeholder engagement. Because the distribution of assistance is not adequately targeted to equally ensure participation and ignores pre-existing customary obligations in terms of reciprocity and kinship as well as client-patronage systems, the provision of aid is often monopolized by those who can demonstrate the capacity to constitute working clusters (Florespedia, 2019). Current findings mirror what others have seen in other fishing communities in Eastern Indonesia (Afiff and Lowe, 2007; Gorris, 2016; Steenbergen, 2016; Tilley et al., 2019) and replicate evaluations of community driven development elsewhere in the archipelago (McCarthy et al., 2016). Indicated in many of these studies, although programs are designed to incorporate local stakeholders in their actions, they do not originate at the village scale or as a result of communal initiatives. A top-down approach to co-management and development initiatives, even when centered in the community's empowerment, means that the space of participation is defined by outsiders. Local populations interact with managers in prescribed ways through forms of engagement that are predetermined by extra-local actors (McCarthy et al., 2016). In the case of customary law, essentialist or incorrect expectations are formulated by fishery officers and policy makers regarding traditions and their continuity (Tsing et al., 1999; Zerner, 2003). Ignoring the high dynamism and levels of change that communities have experienced, local fisheries are expected to maintain cultural structures that may not provide adequate responses to current realities (Knudsen, 2008). From assertions about customary management and their apparent absence follow discourses about what is right and what is wrong, who is good, and who is bad, and how change can result in the dissolution of indigenous traditions and morals (Pannell, 2007; von Benda-Beckmann, 2019). This is what is noted by interviewees in Ende, where a blanket enforcement of cooperative policies derived from models of what co-management should entail contributes to the emergence of conflicts and fishermen's skepticism in the value of government programs. It is also seen in the different descriptions of Endenese as bandits who do not care for the environment, where entrepreneurialism is equated with selfishness, and attributed to their ignorance and need of education about the proper ways of fishing (Pius, 2020). Most critically, it is captured in the justifications voiced by officials that Endenese do not have an *adat* or strong institutions, or that they are not good Muslims, despite all evidence to the contrary.

Challenges in attaining sustainable management reflect misunderstandings between the local reality, moral values, and the ideal community as envisioned in central government development programs. Whereas a strong independence ethos embodies both local and transregional values, it also responds to the fishermen's need for flexibility to cope with socioecological uncertainties. In Ende, uncertainties are a product of economic and environmental change and of the fragmented sporadic attempts at industrialization of the fishery sector that critically alters labor conditions (Ramenzoni, 2015, 2017). Among fishermen, independence is not incompatible with equity and equitable distribution. In fact, and mentioned during interviews, fishermen are not against forming cooperatives *per se*. In the early 2012, brough together by a common rejection of changes in fuel subsidies and anger toward the DPK, a local movement tried to create an association that could help process and market captures. The efforts did not prosper due to the lack of institutional and administrative resources to support the organization. Fishermen indicated that there were no viable avenues that they could pursue to request the right type of aid they needed: not just funding for a few nets or an engine, but knowledge about institutional design that could help them create a new type of organization. Unfortunately, the framing of assistance programs by the DPK forces individuals to work with others to initially secure funds or equipment without providing the necessary incentives and resources to maintain collaboration over time. With policies failing to scope a long-term structure that can help fishermen cope with changing conditions, local fishermen are left to reconcile local realities with cultural and social obligations. As a consequence, fishermen choose to prioritize self-sufficiency over ventures that are perceived as risky, that go against their own principles of merit and entrepreneurism, and that can be highly unrewarding if all partners do not do their part. Ultimately, the absence of an effective co-management program signifies a loss of opportunities for Endenese to administer and develop their fishery. It keeps the living standards within the community at subsistence levels (Ramenzoni, 2013b; Ramenzoni et al., 2017).

Into the future, Endenese fishery managers should consider the engagement of a wider set of local actors along with an unbiased exploration of juridical indigenous and transregional instruments to develop participation and compliance policies. The key is to create programs that can improve household economic conditions not just by adopting micro-finance and cooperative loans, initiatives that in themselves rely on devolving control to groups embodying preconceived and westernized notions of *adat*, egalitarianism, and social capital (see McCarthy et al., 2016). To be successful, co-management models should consider a philosophy of legal pluralism that allows for the coexistence of diversity in resource management practices and welcomes alternative notions of fairness, equity, and moral systems in the design of institutional structures. This may require a careful documentation of viewpoints and perspectives locally defined yet tangled within larger transregional principles. It may also require the deciphering and decanting of rules that while perceived as obvious or promptly dismissed by local actors as known to everyone, they may be ignored by managers and juridical experts. Social scientists, particularly ethnographers and legal anthropologists, have a fundamental role to play by assisting in the elicitation of unwritten transregional conventions and local variations and their many expressions within civil, economic, and religious institutions. Looking at the broader interconnections, the bundle of relationships and rights that emerged in these littoral societies, with a keen legal and critical eye, becomes essential to envisioning truly inclusive co-governance structures. To that end, the collaboration of indigenous lawyers, practitioners, and fishery experts is crucial to attaining realistic and effective policies. Along with institutional theories of collective action, several decades of historical maritime and legal studies, political ecology, and economic anthropology can also provide key contributions (Brosius et al., 2005; Ribot and Peluso, 2009; Wolf and Eriksen, 2010; von Benda-Beckmann, 2019). In all, awareness of the biases and asymmetries in the application of co-governance programs, how such schemes may dismiss the influence of transregional and localized cosmologies, constitutes a much-needed step to finding representative solutions in an increasingly globalized world. In a country such as Indonesia, where unity in diversity (*bhinneka tunggal ika*) has become a national declaration of religious and cultural tolerance, legalistic pluralism is paramount to achieving a more equal future.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board from the University of Georgia at the Office of Research Ethics, the University of Georgia. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. The researcher obtained necessary research permits from the Indonesian office of research (RISTEK) for fieldwork between 2011 and 2013.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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REFERENCES

Abdurachman, P. R. (2008). *Bunga Angin Portugis di Nusantara: jejak-jejak Kebudayaan Portugis di Nusantara*. Indonesia: Yayasan Pustaka Obor Indonesia.

Acciaioli, G. (2004). From Economic Actor to Moral Agent: knowledge, Fate and Hierarchy among the Bugis of Sulawesi. *Indonesia* 78, 147–179.

Acciaioli, G. L. (2014). *Bugis Entrepreneurialism and Resource Use: structure and Practice*. Australia: The University of Western Australia. doi: 10.7454/ai.v0i57.3347

Adhuri, D. S. (2013). *Selling the Sea: a study of conflict over marine tenure in Kei Islands, Eastern Indonesia*. Australia: ANU Press. doi: 10.26530/OAPEN_459922

Adhuri, D. S. (2018). The State and Empowerment of Indonesian Maritime Culture: the Case of Traditional Marine Resource Management. *J. Ocean Cult.* 1, 18–34. doi: 10.33522/joc.2018.1.18

Adhuri, D. S. (2019). Socio-Ecological Diversities of the Sulawesi Islands. *J. Ocean Cult.* 2, 22–36. doi: 10.33522/joc.2019.2.22

Afiff, S., and Lowe, C. (2007). Claiming Indigenous Community: political Discourse and Natural Resource Rights in Indonesia. *Alternatives* 32, 73–97. doi: 10.1177/030437540703200104

Ammarell, G. (2002a). Bugis migration and modes of adaptation to local situations. Ethnology, 41, 51–68. doi: 10.2307/4153020

Ammarell, G. (2002b). Knowing when to set sail: practical knowledge and simple heuristics in Bugis navigational strategies. *Bijdr. Taal. Land. Volkenkd.* 2, 191–223. doi: 10.1163/22134379-90003779

Anand, R. P. (1981). Maritime Practice in South-East Asia until 1600 A. D. and the Modern Law of the Sea. *Int. Compar. Law Q.* 30, 440–454. doi: 10.1093/iclqaj/30.2.440

Anand, R. P. (1982). *Origin and Development of the Law of the Sea: history of International Law Revised*. New Delhi: Jawaharlal Nehru University.

Andaya, B. W. (2016). Rivers, Oceans, and Spirits: water Cosmologies, Gender, and Religious Change in Southeast Asia. *Trans. Reg. Natl. Stud. Southeast Asia* 4, 239–263. doi: 10.1017/trn.2016.2

Andaya, B. W. (2017). Seas, Oceans and Cosmologies in Southeast Asia. *J. Southeast Asian Stud.* 48:349. doi: 10.1017/s0022463417000534

Aswani, S. (2020). New Directions in Maritime and Fisheries Anthropology. *Am. Anthropol.* 122, 473–486. doi: 10.1111/aman.13380

Azeem, T. (2020). Muslims' Share of the Waves: law, War and Tradition. *Policy Perspect.* 17, 67–82. doi: 10.13169/polipers.17.2.0067

Basurto, X., Cinti, A., Bourillón, L., Rojo, M., Torre, J., Weaver, A. H. et al. (2012). The Emergence of Access Controls in Small-Scale Fishing Commons: a Comparative Analysis of Individual Licenses and Common Property-Rights in Two Mexican Communities. *Hum. Ecol.* 40, 597–609. doi: 10.1007/s10745-012-9508-1

Bedner, A., and Arizona, Y. (2019). Adat in Indonesian Land Law: a Promise for the Future or a Dead End? *Asia Pacif. J. Anthropol.* 20, 416–434. doi: 10.1080/14442213.2019.1670246

Berkes, F. (2006). From community-based resource management to complex systems: the scale issue and marine commons. *Ecol. Soc.* 11:45.

Berkes, F. (2009). Evolution of co-management: role of knowledge generation, bridging organizations and social learning. *J. Environ. Manag.* 90, 1692–1702. doi: 10.1016/j.jenvman.2008.12.001

Berkes, F. (2015). *Coasts for People: interdisciplinary Approaches to Coastal and Marine Resource Management* (1 edition). United Kingdom: Routledge.
Borschberg, P. (2019). "Empires of the Sea: maritime Power Networks in World History", in *Empires of the Sea*, eds R. Strootman, F. van den Eijnde, and R. van Wijk (Netherlands: Brill), 263–293. doi: 10.1163/9789004407671_012
BPSKE. (2019). *Kabupaten Ende Dalam Angka*. Indonesia: Badan Pusat Statistik Kabupaten Ende.
Brosius, P. J., Tsing, A. L., and Zerner, C. (2005). *Communities and Conservation: histories and Politics of Community-based Natural Resource Management*. Altamira: Rowman.
Bubandt, N. (2004). *Towards a New Politics of Tradition? Decentralisation, Conflict, and Adat in Eastern Indonesia*. Denmark: University of Aarhus. doi: 10.7454/ai.v0i74.3585
Caron, L. J. J. (1937). *Het handels-en Zeerecht in de Adatrechtsregelen van den Rechtskring ZuiSd-Celebes*. Bussum: Van Dishoeck.
Charles, A. (2012). People, oceans and scale: governance, livelihoods and climate change adaptation in marine social-ecological systems. *Curr. Opin. Environ. Sustain.* 4, 351–357. doi: 10.1016/j.cosust.2012.05.011
Cordell, J. (1989). *A Sea of Small Boats. Cultural Survival*. Massachusetts: Cultural Survival.
Coulthard, S. (2011). More than just access to fish: the pros and cons of fisher participation in a customary marine tenure (Padu) system under pressure. *Mar. Policy* 35, 405–412. doi: 10.1016/j.marpol.2010.11.006
Cummings, W. (2011). *The Makassar Annals*. Netherlands: Brill. doi: 10.1163/9789004253629
de Roo van Alderwerelt, J. (1905). *Historische Aanteekeningen Over Sumba (residentie Timor en Onderhoorigheden)*. Netherlands: Het Utrechts Archief.
de Rosary, O. E. (2020). *Destructive Fishing Masih Marak Terjadi di NTT, Kenapa? Mongabay Environmental News*. US: Mongabay.
Djata, B. (2018). Peran pendamping serta dampak anggaran di bidang kelautan dan perikanan terhadap kondisi kesejahteraan masyarakat nelayan di Kabupaten Ende. *J. Peril. Dan Strat. Bis.* 6:78. doi: 10.26486/jpsb.v6i1.422
Edjid, H. (1979). *Tiga Ratus Tahun Kerajaan Ende. 1638-1962*. Indonesia: Universitas Negeri Nusa Cendana.
Ellen, R. (2016). Nuaulu Ritual Regulation of Resources, Sasi and Forest Conservation in Eastern Indonesia. *South East Asia Res.* 24, 5–22. doi: 10.5367/sear.2016.0290
Fabinyi, M., Knudsen, M., and Segi, S. (2010). Social complexity, ethnography and coastal resource management in the Philippines. *Coast. Manag.* 38, 617–632. doi: 10.1080/08920753.2010.523412
FAO. (2019). "Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options" in *FAO Fisheries and Aquaculture Technical Paper 627* (United Nations: Food and Agriculture Organization).
Fernandez, S. O. (1990). Kebijakan manusia Nusa Tenggara Timur dulu dan kini. Indonesia:Sekolah Tinggi Filsafat Katolik.
Florespedia. (2019). *Warga Pulau Ende Keluhkan Bantuan Dinas Perikanan Tidak Tepat Sasaran*. Kumparan. Available online at: https://kumparan.com/florespedia/warga-pulau-ende-keluhkan-bantuan-dinas-perikanan-tidak-tepat-sasaran-1s3TDseikzb (accessed March 17, 2021).
Friedericy, H. J. (1932). PONRE. Bijdrage tot de kennis van adat en adatrecht van Zuid-Celebes. *Bijdr. Taal. Land. Volkenkd.* 89, 1–34.
Gorris, P. (2016). Deconstructing the Reality of Community-Based Management of Marine Resources in a Small Island Context in Indonesia. *Front. Mar. Sci.* 3:120. doi: 10.3389/fmars.2016.00120
Goti, O. (2020). *Produksi Ikan Turun Drastis, Ini Harapan Bupati Ende Djafar Achmad—Pos Kupang. Pos Kupang**. Available online at: https://kupang.tribunnews.com/2020/10/15/produksi-ikan-turun-drastis-ini-harapan-bupati-ende-djafar-achmad (accessed May 26, 2021).
Green, K. M., Selgrath, J. C., Frawley, T. H., Oestreich, W. K., Mansfield, E. J., Urteaga, J., et al. (2021). How adaptive capacity shapes the Adapt, React, Cope response to climate impacts: insights from small-scale fisheries. *Clim. Change* 164:15. doi: 10.1007/s10584-021-02965-w
Halim, A., Loneragan, N. R., Wiryawan, B., Fujita, R., Adhuri, D. S., Hordyk, A. R., et al. (2020). Transforming traditional management into contemporary territorial-based fisheries management rights for small-scale fisheries in Indonesia. *Mar. Policy* 116:103923. doi: 10.1016/j.marpol.2020.103923
Halim, A., Wiryawan, B., Loneragan, N. R., Hordyk, A., Sondita, M. F. A., White, A. T., et al. (2019). Developing a functional definition of small-scale fisheries in support of marine capture fisheries management in Indonesia. *Mar. Policy* 100, 238–248. doi: 10.1016/j.marpol.2018.11.044
Hall, K. R. (2011). *A History of Early Southeast Asia: Maritime Trade and Societal Development, 100–1500*. United States: Rowman & Littlefield Publishers.
Henley, D., and Davidson, J. S. (2008). In the Name of Adat: regional Perspectives on Reform, Tradition, and Democracy in Indonesia. *Mod. Asian Stud.* 42, 815–852. doi: 10.1017/S0026749X07003083
Henley, D., and Schulte Norholdt, H. (2015). "Environment, Trade and Society in Southeast Asia: a Longue Durée Perspective" in *Environment, Trade and Society in Southeast Asia*, eds D. Henley, and Schulte Norholdt (Netherlands: Brill). Available online at: https://brill.com/view/title/27139
Heuken, A. (2002). *Be My Witness to the Ends of the Earth!: the Catholic Church in Indonesia Before the 19th Century*. Indonesia: Cipta Loka Caraka.
Hoogervorst, T. (2018). Sailors, Tailors, Cooks, and Crooks: on Loanwords and Neglected Lives in Indian Ocean Ports. *Itinerario* 42, 516–548. doi: 10.1017/S0165115318000645
Johannes, R. E. (1993). "Integrating traditional ecological knowledge and management with environmental impact assessment" in *Traditional Ecological Knowledge: Concepts and Cases*, ed. J. Inglis (Canada: Canadian Museum of Nature), 33–39
Khalilieh, H. S. (1998). *Islamic Maritime Law: an Introduction*. Netherlands: Brill.
Khalilieh, H. S. (2019). *Islamic Law of the Sea: freedom of Navigation and Passage Rights in Islamic Thought*. United Kingdom: Cambridge University Press.
Knaap, G., and Sutherland, H. (2012). *Monsoon Traders: Ships, Skippers and Commodities in Eighteenth-Century Makassar*. Verhandelingen: KITLV Press.
Knudsen, S. (2008). Ethical Know-how and Traditional Ecological Knowledge in Small Scale Fisheries on the Eastern Black Sea Coast of Turkey. *Hum. Ecol.* 36, 29–41. doi: 10.1007/s10745-007-9134-5
Langga, L. (2020). Analisis Pengembangan Usaha Produksi Ikan Pada Nelayan Kecamatan Pulau Ende di Kabupaten Ende. *Analisis* 19, 65–75. doi: 10.37478/analisis.v19i1.324
Lauer, M. (2017). Changing understandings of local knowledge in island environments. *Environ. Conserv.* 44, 336–347. doi: 10.1017/s0376892917000303
Leach, M., Mearns, R., and Scoones, I. (2012). "Environmental Entitlements: dynamics and Institutions in Community-Based Natural Resource Management" in *Milestones and Turning Points in Development Thinking*, ed. R. Jolly (UK: Palgrave Macmillan), 218–233. doi: 10.1057/9781137271631_16
Liaw, Y. F. and Ahmad, H. (2003). *Undang-undang Melaka dan undang-undang laut*. Malaysia: Yayasan Karyawan.
Lockard, C. A. (2010). "The Sea Common to All": maritime Frontiers, Port Cities, and Chinese Traders in the Southeast Asian Age of Commerce, ca. 1400-1750. *J. World Hist.* 21, 219–247. doi: 10.1353/jwh.0.0127
Macknight, C. C. (1973). The nature of early maritime trade: some points of analogy from the eastern part of the Indonesian archipelago. *World Archaeol.* 5, 198–208. doi: 10.1080/00438243.1973.9979566
Manguin, P.-Y. (2017). *Ships and Shipping in Southeast Asia*. Oxford: Oxford Research Encyclopedia of Asian History. doi: 10.1093/acrefore/9780190277727.013.30
McCarthy, J., Steenbergen, D., Warren, C., Acciaioli, G., Baker, G., Lucas, A., et al. (2016). Community Driven Development and Structural Disadvantage: interrogating the Social Turn in Development Programming in Indonesia. *J. Dev. Stud.* 53, 1–17. doi: 10.1080/00220388.2016.1262024
McCay, B. J. (2002). "Emergence of institutions for the commons: contexts, situations, and events". in *Committee on the Human Dimensions of Global Change, Division of Behavioral and Social Sciences and Education, The Drama of the Commons*, eds E. Ostrom, T. Dietz, N. Dolšak, P. C. Stern, S. Stonich, and E. U. Weber (United States: National Academy Press) 360–402.
McCay, B. J., Weisman, W., and Creed, C. (2011). "Coping with Environmental Change: systemic Responses and the Roles of Property and Community in Three Fisheries" in *World Fisheries*, eds R. E. Ommer, R. I. Perry, K. Cochrane, and P. Cury (United States: Wiley-Blackwell). 381–400. doi: 10.1002/9781444392241.ch23
Mujiyanto, M., Sugianti, Y., and Riswanto. (2019). "The Important Seeing Back of Zoning for Cetacean Migration In Sabu Raijua District Waters, Savu Sea

National Marine Park" in *Singapore International Multidisciplinary Academic Conference (SIMAC 2019)* (Singapore: Suntec Convention Centre & National University of Singapore).

Nakagawa, S. (2007). From paddy to vanilla, elephant tusks to money. *アジア・アフリカ地域研究=. Asian African Area Stud.* 7, 92–108.

Needham, R. (1987). *Mamboru: history and Structure in a Domain in Northwestern Sumba*. (United Kingdom: Oxford University Press).

Noorduyn, J. (1957). C.H. Thomsen; The editor of "A code of Bugis Maritime Laws. *J. Hum. Soc. Sci. Southeast Asia* 113, 238–251. doi: 10.1163/22134379-90002285

Nooteboom, C. (1936). Vaartuigen van Ende. *Land. Volkenkunde* 76, 87–126.

Ostrom, E. (1990). *Governing the Commons: the Evolution of Institutions for Collective Action*. United Kingdom: Cambridge University Press.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proc. Natl. Acad. Sci.* 104, 15181–15187. doi: 10.1073/pnas.0702288104

Ostrom, E. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325, 419–422. doi: 10.1126/science.1172133

Ostwald, K., Tajima, Y., and Samphantharak, K. (2016). Indonesia's Decentralization Experiment: motivations, Successes, and Unintended Consequences. *J. Southeast Asian Econ.* 33, 139–156. doi: 10.1355/ae33-2b

Pannell, S. (1996). Homo Nullius or 'Where Have All the People Gone'? Refiguring Marine Management and Conservation Approaches. *Austral. J. Anthropol.* 7, 21–42. doi: 10.1111/j.1835-9310.1996.tb00335.x

Pannell, S. (1997). Managing the Discourse of Resource Management: the Case of Sasi from 'Southeast' Maluku, Indonesia. *Oceania* 67, 289–307. doi: 10.1002/j.1834-4461.1997.tb02622.x

Pannell, S. (2007). *Of Gods and Monsters: indigenous Sea Cosmologies, Promiscuous Geographies and the Depths of Local Sovereignty*. Netherlands: Brill. 71–102.

Parimartha, I. G. (2002). *Perdagangan Dan Politik di Nusa Tenggara, 1815-1915*. Indonesia: Djambatan.

Pearson, M. N. (2006). Littoral Society: the Concept and the Problems. *J. World Hist.* 17, 353–373. doi: 10.1353/jwh.2006.0059

Pius, R. (2020). *Dinas Perikanan Dan Kelautan Ende Akui Masih Terjadi Pemboman Ikan*. Pos Kupang. Available online at: https://kupang.tribunnews.com/2020/01/27/dinas-perikanan-dan-kelautan-ende-akui-masih-terjadi-pemboman-ikan (accessed March 17, 2021).

Plummer, R., and Fitzgibbon, J. (2004). Co-management of Natural Resources: a Proposed Framework. *Environ. Manag.* 33, 876–885. doi: 10.1007/s00267-003-3038-y

Quimby, B. (2015). Emerging customs: small-scale fishing practices in Aceh, Indonesia. *Appl. Geogr.* 59, 125–130. doi: 10.1016/j.apgeog.2014.11.026

Raffles, S. (1879). The Maritime Code of the Malays. *J. Straits Branch R. Asiatic Soc.* 3, 62–84.

Ramenzoni, V. C. (2013a). Endenese fisheries: exploratory findings on environmental perceptions, fish effort, and overfishing in eastern Indonesia. *Ethnobiol. Lett.* 4, 39–51. doi: 10.14237/ebl.4.2013.8

Ramenzoni, V. C. (2013b). *Destructive fishing practices in Ende, Flores, Indonesia: the Importance of Designing Co-governance Programs and Policy-making in Dealing With Climate Change*. Japan: Digital Library of the Commons.

Ramenzoni, V. C. (2015). "Is Environmental Uncertainty Redefining Fishing Strategies? The Use of the Traditional Lunar Calendar to Allocate Fishing Effort in Ende, Eastern Indonesia" in *Climate Change, Culture, and Economics: anthropological Investigations* (United Kingdom: Emerald Group Publishing Limited).

Ramenzoni, V. C. (2017). Reconstructing the History and the Effects of Mechanization in a Small-Scale Fishery of Flores, Eastern Indonesia (1917–2014). *Front. Mar. Sci.* 4:65. doi: 10.3389/fmars.2017.00065

Ramenzoni, V. C., Sari, J., and Putra, S. (2017). The roads to economic development in small scale fisheries in Ende, Flores, Indonesia: institutional and socio-cultural shortcomings in implementing sustainable strategies. Proceedings for IGSCI Jurnal Sekolah Pasca Sarjana (accessed October 20, 2017).

Rauf, R., Munaf, Y., Zarina, S. Z. S., Arifin, K., and Rizal Razman, M. (2019). Analysis of the Development on Deconcentration in Indonesia. *J. Eng. Appl. Sci.* 14, 7179–7186. doi: 10.36478/jeasci.2019.7179.7186

Reid, A. (1988). *Southeast Asia in the Age of Commerce, 1450-1680: Volume One: the Lands below the Winds (Reprint edition)*. United Kingdom: Yale University Press.

Ribot, J., and Peluso, N. (2009). A Theory of Access. *Rural Sociol.* 68, 153–181.

Roos, D. S. (1872). *Bijdrage Tot de kennis Van Taal, Land en Volk op Het Eiland Soemba*. Australia: National Library of Australia.

Ruddle, K. (1998). The context of policy design for existing community-based fisheries management systems in the Pacific Islands. *Ocean .Coas. Manag.* 40, 105–126. doi: 10.1016/s0964-5691(98)00040-4

Satria, A., and Matsuda, Y. (2004). Decentralization of fisheries management in Indonesia. *Mar. Policy* 28, 437–450. doi: 10.1016/j.marpol.2003.11.001

Satria, A. (2009). *Ekologi Politik Nelayan*. Indonesia: Penerbit Lkis Group.

Shivakoti, Y., and Shivakoti, G. P. (2008). Decentralization and Co-Management of Protected Areas in Indonesia. *J. Legal Plural. Unofficial Law* 40, 141–165. doi: 10.1080/07329113.2008.10756620

Soenaryo, F. X. (Ed.). (2006). *Sejarah kota Ende*. Indonesia: Dinas Pendidikan dan Kebudayaan, Kabupaten Ende.

Steenbergen, D. J. (2016). Strategic Customary Village Leadership in the Context of Marine Conservation and Development in Southeast Maluku, Indonesia. *Hum. Ecol.* 44, 311–327. doi: 10.1007/s10745-016-9829-6

Subekti, S., Sulistiyono, S. T., and Adhuri, D. S. (2020). Adat Movements for Environmental Justice: the Case of Benoa Bay Bali. *Soc. Cult. Environ.* 202:07035. doi: 10.1051/e3sconf/202020207035

Sugishima, T. (2006). *Where Have the "Entrepreneurs" Gone? A Historical Comment on Adat in Central Flores*. Japan: Kyoto University.

Suimam (2021a). *Produksi Perikanan Tangkap Ditargetkan Akan Meningkat di Tahun 2021—Daerah |RRI Ende|.Rri.Co.Id*. Available online at: https://rri.co.id/ende/daerah/992277/produksi-perikanan-tangkap-ditargetkan-akan-meningkat-di-tahun2021?utm_source=terbaru_widget&utm_medium=internal_link&utm_campaign=General%20Campaign (accessed May 26, 2021).

Suimam (2021b). *Kelompok Nelayan di Ende Terima Bantuan Program Pengelolaan Perikanan Tangkap—Daerah | RRI Ende. Rri.Co.Id*. Available online at: https://rri.co.id/ende/daerah/1058226/kelompok-nelayan-di-ende-terima-bantuan-program-pengelolaan-perikanan-tangkap?utm_source=terbaru_widget&utm_medium=internal_link&utm_campaign=General%20Campaign (accessed March 17, 2021).

Sulistyo, B. (2020). Trade and Ethnicity: business Ethics and the Glory of Maritime Trade of The Makassar's Wajorese in the 18th Century. *J. Maritime Stud. Natl. Integr.* 4, 108–114. doi: 10.14710/jmsni.v4i2.9610

Susilowati, I. (1996). *A Review of Natural Resource Laws and Policies in Indonesia and its Prospects for Fisheries Co-Management*. Malaysia: WorldFish.

Sutherland, H. (2015a). "On the Edge of Asia: maritime Trade in East Indonesia, Early Seventeenth to Mid-twentieth Century" in *Commodities, Ports and Asian Maritime Trade Since 1750*, eds U. Bosma and A. Webster (UK: Palgrave Macmillan), 59–78. doi: 10.1057/9781137463920_3

Sutherland, H. (2015b). "Pursuing the Invisible: makassar, City and Systems" in *Environment, Trade and Society in Southeast Asia*, eds D. Henley and H. Schulte Norholdt (Netherlands: Brill), 133–148. doi: 10.1163/9789004288058_010

Tagliacozzo, E. (2010). Trans-Regional Indonesia over One Thousand Years: the Art of the Long View. *Indonesia* 90, 1–13.

Tilley, A., Hunnam, K. J., Mills, D. J., Steenbergen, D. J., Govan, H., Alonso-Poblacion, E., et al. (2019). Evaluating the Fit of Co-management for Small-Scale Fisheries Governance in Timor-Leste. *Front. Mar. Sci.* 6:392. doi: 10.3389/fmars.2019.00392

Trimble, M., and Berkes, F. (2015). Towards adaptive co-management of small-scale fisheries in Uruguay and Brazil: lessons from using Ostrom's design principles. *Maritime Stud.* 14:14. doi: 10.1186/s40152-015-0032-y

Tsing, A. L., Brosius, J. P., and Zerner, C. (1999). Assessing Community-Based Natural-Resource Management. *Ambio* 28, 197–198.

van Ast, J. A., Widaryati, A., and Bal, M. (2014). The 'Adat' institution and the Management of Grand Forest 'Herman Yohannes' in Indonesian Timor: the Role of Design Principles for Sustainable Management of Common Pool Resources. *Conserv. Soc.* 12, 294–305. doi: 10.4103/0972-4923.145146

Van Suchtelen, B. C. C. M. M. (1921). Endeh (Flores). USA: Weltevreden.

Villaseñor-Derbez, J. C., Aceves-Bueno, E., Fulton, S., Suarez, A., Hernández-Velasco, A., Torre, J., et al. (2019). An interdisciplinary evaluation of community-based TURF-reserves. *PLoS One* 14:e0221660. doi: 10.1371/journal.pone.0221660

Vollenhoven, C. V (1918). *Het adatrecht van Nederlandsch-Indië*. Netherlands: Brill.

von Benda-Beckman, F., and von Benda-Beckman, K. (2011). Myths and stereotypes about adat law: a reassessment of Van Vollenhoven in the light of current struggles over adat law in Indonesia. *Bijdr. Taal. Land Volkenkd.* 167, 167–195. doi: 10.1163/22134379-90003588

von Benda-Beckmann, F., von Benda-Beckman, K., and Eckert, J. (2016). *Rules of Law and Laws of Ruling: on the Governance of Law*. UK: Routledge.

von Benda-Beckmann, K. V. (2019). Anachronism, Agency, and the Contextualisation of Adat: van Vollenhoven's Analyses in Light of Struggles Over Resources. *Asia Pacific J. Anthropol.* 20, 397–415. doi: 10.1080/14442213.2019.1670242

Weber, M. (1890). Ethnographische Notizen uber Flores und Celebes. Trap [etc.]. Supplement zu Band III von "Internationales Archiv für Ethnographie". P. W. M. Trap, Leiden.

Webster, A., Bosma, U., and Melo, J. D. (2015). *Commodities, Ports and Asian Maritime Trade Since 1750*. Germany: Springer.

Widodo, J. (2012). "Morphogenesis and Hybridity of Southeast Asian Coastal Cities" in *Southeast Asian Culture and Heritage in a Globalising World: diverging Identities in a Dynamic Region*, eds O. G. Ling, A. P. R. Ismail, and D. B. J. Shaw (United States: Ashgate Publishing, Ltd), 79–92.

Wolf, E. R., and Eriksen, T. H. (2010). *Europe and the People Without History*. United States: University of California Press.

Zerner, C. (1994). Through a Green Lens: the Construction of Customary Environmental Law and Community in Indonesia's Maluku Islands. *Law Soc. Rev.* 5:1079. doi: 10.2307/3054024

Zerner, C. (2003). *Culture and the Question of Rights: Forests, Coasts, and Seas in Southeast Asia*. United States: Duke University Press.

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Blue Carbon Ecosystem Services Through a Vulnerability Lens: Opportunities to Reduce Social Vulnerability in Fishing Communities

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Ecosystem services (ES) are benefits nature provides to humans; these services change in space and time and are largely dependent on context. Coastal habitat that provides key ES are blue carbon ecosystems, namely seagrass and mangroves. One important ES they provide is the provisioning of seafood, which benefits coastal populations with livelihoods and food security. We employed a social-ecological approach that draws from the vulnerability literature for social, ecological, and economic criteria to map ES provision in ten communities on Busuanga Island, Palawan Province, Philippines. We assess the spatial dynamics of ES provision for small-scale fisheries in seagrass and mangroves, in relation to local beneficiaries. Using a mixed-methods approach with ecological assessments of seagrass beds, spatial analysis, landing surveys, household and key informant interviews, we overlaid biophysical variables on social data, mapping sensitivities and adaptive capacities to compare communities' social vulnerabilities. Spatial analysis revealed healthy blue carbon ecosystems in ten local communities (barangays) as measured by proportion of coastline covered, low patchiness and high continuity along the coastline, and the presence of adjacent habitat. We found seagrass ecosystems were more vulnerable than mangroves. Rural barangays had less exposure and lower sensitivity to blue carbon ecosystem loss than urban barangays. Blue carbon ecosystem fisheries are highly sensitive fisheries, due to their catch composition and low catch per unit effort, with mangrove fisheries having a slightly lower sensitivity than seagrass fisheries due to greater catch per unit effort. Diversified livelihoods and the presence of NGOs and People's Organizations (POs) increased adaptive capacity and reduced overall vulnerability. We aim to highlight a coastal human community's relationship with blue carbon ecosystems using context-specific vulnerability criteria. Our site-specific social vulnerability assessment may be adapted for use in other coastal communities within the coral triangle. This work suggests opportunities for conservation interventions to manage local communities' sensitivities and adaptive capacity around the use of blue carbon ecosystems.

Keywords: blue carbon, ecosystem services, vulnerability, seagrass, mangroves, small scale fisheries

INTRODUCTION

Ecosystem services (ES) are benefits nature provides to humans; these services change in space and time and are largely dependent on context (Millennium Ecosystem Assessment, 2005). In coastal areas, seagrass meadows and mangroves provide key ecosystem services, including carbon sequestration and climate mitigation. The carbon sequestered in coastal and marine vegetated ecosystems is known as blue carbon, and the ecosystems are usually referred to as blue carbon ecosystems (Howard et al., 2014). Mangroves are coastal tropical forests that are regularly flooded by tidal water (Spalding et al., 2010). Seagrasses are marine flowering plants found in coastlines all over the world except Antarctica (Green and Short, 2003). Both ecosystems capture carbon from the atmosphere and store it at rates more effective than counterparts on land, such as boreal, temperate and tropical forests (Mcleod et al., 2011; Fourqurean et al., 2012). Most of the carbon stored in coastal blue carbon ecosystems remain in their soils (Donato et al., 2011). Interactions between mangroves and seagrasses show the supporting role that adjacent habitats' carbon storage plays within the seascape (Huxham et al., 2018).

Blue carbon has become a rallying call to mitigate climate change (Crooks et al., 2014; Wylie et al., 2016). Global calls to action for blue carbon ecosystem conservation use the ecosystem services framework. This framework helps to reach key sustainable development goals (SDGs) to balance environmental, social, and economic dimensions (Mironenko et al., 2015). Mangrove ecosystem services include provisioning services such as timber and fisheries, supporting services such as habitat for biodiversity and juvenile life stages, regulating services such as coastal protection, shoreline stabilization, climate regulation and water quality, and their recreational, spiritual and cultural values (UNEP, 2014). Seagrass ecosystem services include supporting functions like biodiversity maintenance, regulating functions like water filtration, climate regulation, buffering against ocean acidification, and coastal protection, provisioning functions such as seafood, and cultural services like tourism (United Nations Environment Programme (UNEP), 2020). The services cross scales, with carbon sequestration at the global scale, to tourism benefits and shoreline protection at national scales, then providing local ecosystem services such as provisioning seafood, improving water quality, and improving human well-being (Barbier et al., 2011).

Southeast Asia is a blue carbon hotspot, or area of concentrated carbon extraction and permanent burial (Thorhaug et al., 2020). Despite their value to society and the biosphere, blue carbon ecosystems are being lost - seagrass are being lost at a rate of 7% year^{-1} globally (Waycott et al., 2009), and mangroves are being lost at a rate of 1-3% year^{-1} globally (FAO, 2007) largely due to human stressors such as land use change (Goldberg et al., 2020). In Southeast Asia, seagrass loss is between 2.82% yr^{-1} (Stankovic et al., 2021) and 10.9% yr^{-1} (Sudo et al., 2021) due to coastal development, fisheries and storms. Philippine seagrasses have among the greatest extent in Southeast Asia at 2.7 million has (Fortes et al., 2018), but around 76,897 ha yr^{-1} is being lost (Stankovic et al., 2021), and in a single site, authors found a rate of decline of 1.7% year^{-1} (Blanco et al., 2014). Thirty five percent of original Philippine mangroves were lost by the end of the 20th century (Valiela et al., 2001), and Philippine mangroves decreased by half from 1918-2010, declining at a rate of 10.5% from 1990 to 2010 (Long et al., 2014).

In Southeast Asia mangroves sequester more organic carbon than seagrasses (Thorhaug et al., 2020), but these ecosystems can also be a major source of carbon emissions when they are converted or degraded, because carbon stored in the soils is released back into the atmosphere and the ocean, releasing as much as 0.15 to 1.02 billion tons of carbon into the atmosphere each year (Pendleton et al., 2012). Carbon stocks in seagrass beds are vulnerable to climate change and the increased frequency of extreme events such as marine heatwaves cause damage to seagrass sediments, releasing carbon into the atmosphere (Arias-Ortiz et al., 2018).

Blue carbon ecosystems are part of a complex social-ecological system that is particularly important to the food security of coastal human populations (McClanahan et al., 2009; Cullen-Unsworth et al., 2014; Unsworth et al., 2018). Small-scale fisheries rely heavily on nearshore marine habitat (de la Torre-Castro et al., 2014). Fishing in mangroves and seagrass is ubiquitous in the tropics due to these ecosystems' proximity to the shore and ease of access (De La Torre-Castro and Rönnbäck, 2004; Beitl, 2015; Nordlund et al., 2018; Quiros et al., 2018).

There are 200 million people in the world that engage in small-scale fisheries, which are commercial fisheries with limited technology and economic security (De La Torre-Castro and Rönnbäck, 2004; FAO and WFP, 2009). In developing countries, fishing is the main source of livelihood when there are limited alternatives (Béné et al., 2016). Small-scale fisheries employ 90% of people who work in capture fisheries and are particularly important in supporting rural livelihoods, which are characterized by part-time work in many sectors, including seasonal, occasional, and part-time labor (FAO, 2016). In the Philippines, small scale fishers make up 85% of the fisher population and are its poorest sector (Green et al., 2003).

Under this context, we examine the social vulnerability of fishing communities that rely on blue carbon ecosystems. We define social vulnerability as a community's ability to resist and recover from exposure events (Buckle et al., 2001; Cutter et al., 2008). The small-scale fishery system is "intimately connected with the economic, social and cultural life in local communities" (Jentoft, 2014). Data from fisheries and habitats are crucial when assessing vulnerability (Birkmann et al., 2014), especially when examining the relationship between social vulnerability and resource use (Berkes et al., 2001).

Vulnerability studies have been used to assess communities and fisheries' vulnerability to climate change (Mamauag et al., 2013; Licuanan et al., 2015; Ekstrom et al., 2015). Ekstrom et al. (2015) conducted a spatially explicit multidisciplinary vulnerability analysis of human coastal communities in the United States, integrating the natural and social sciences with biochemical, economic and social indicators. Tan et al. (2018) used vulnerability analyses combined with ecosystem service flows to prioritize conservation planning in Southeast Asian seagrass meadows with country-level single site-specific analysis, using threat criteria based on the literature. Quiros et al. (2018) assessed social vulnerability in two communities and their fisher sectors, comparing their sensitivity and adaptive capacity, using natural capital, socio-economic and demographic indicators. Siegel et al. (2019) compared social-ecological vulnerability across islands in the Caribbean using climatic threats, and ecological and socio-economic sensitivity and adaptive capacity.

Here, we use a place-based concept of vulnerability to see how fishing communities respond to the loss or degradation of blue carbon ecosystems, examining vulnerability of human communities due to social processes, and the vulnerability of natural ecosystems due to environmental processes (IPCC, 2012). Using a social vulnerability framework (Cutter et al., 2008; Ekstrom et al., 2015), we define exposure as loss or degradation of blue carbon ecosystems due to site-specific threats, and perturbations from the socio-economic context, including land conversion and degradation due to urban development and tourism. We define sensitivity in two parts: people's dependency on the blue carbon ecosystems, which is affected by the loss of habitat, or in other words, the "local societal importance" of seagrass and mangroves, and a community's present ability to respond to threats (Ekstrom et al., 2015). We define adaptive capacity as the "assets available" to help prepare for or avoid impacts of the loss or degradation of habitat, or in other words, their ability to change in the face of current and future threats (Ekstrom et al., 2015; **Figure 1**). All three contribute to overall risk, or social vulnerability (Cutter et al., 2008).

Vulnerability analyses can help evaluate coastal communities' reliance on blue carbon ecosystems while examining risk to those ecosystems (**Figure 1**). Looking at the social-ecological system with a vulnerability framework, we can address natural resource management concerns and human community risk. This is important because some international interventions for climate mitigation may not acknowledge the actual needs of local communities (Plan Vivo, 2015). Therefore, by acknowledging the importance of both human and natural systems, we can have more equitable solutions.

In this paper, we aim to highlight a coastal human community's relationship with blue carbon ecosystems, using context-specific vulnerability criteria. We create a site-specific vulnerability assessment that aims to assist policymakers in resource management in Busuanga Island, Philippines, which may be adapted for use in other coastal communities within the coral triangle.

MATERIALS AND METHODS

Site Description

Among the Calamianes Group of islands in Palawan, Philippines, Busuanga is the largest and is divided into two municipalities: "Busuanga" in the west and "Coron" in the east. In Busuanga, our study sites include barangays Concepcion, New Busuanga, Quezon, Salvacion, and Turda. In Coron, our sites include barangays Borac, Barangay 5, Decalachao, San Jose and

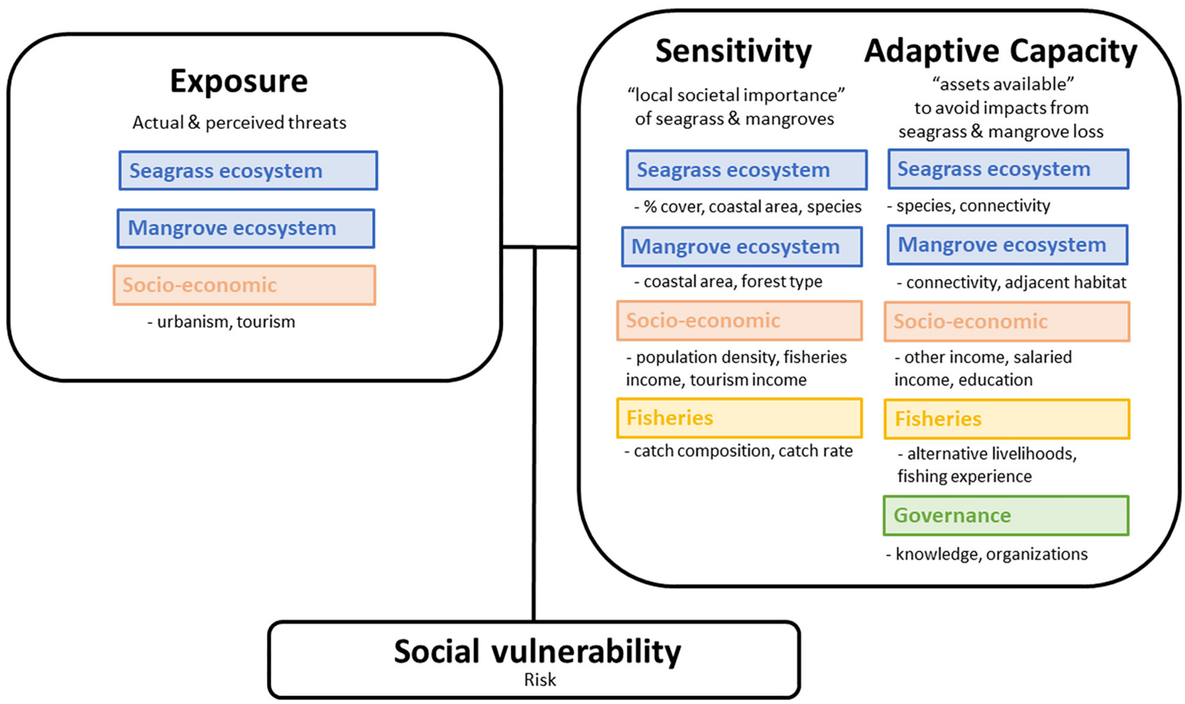

FIGURE 1 | Conceptual diagram of the vulnerability framework. Exposure are the actual and perceived threats to the seagrass and mangrove ecosystems and exposure due to socio-economic context. Sensitivity is the community's present ability to respond to the threat, or the "local societal importance" of seagrass and mangroves. Adaptive capacity is the ability of communities to change in the face of current and future threats, or the "assets available" to avoid impacts from threats. Adapted from Cutter et al. (2008) and Ekstrom et al. (2015). All three contribute to overall risk, or social vulnerability.

Tagumpay (**Figure 2**). Busuanga Island is diverse in natural resources. The pristine mangrove areas and existing MPAs are considered the strengths of Busuanga Island due to their diversity. However, the richness and vastness of its natural resources are slowly vanishing and exploited due to upland human-related activities which affects the coastal ecosystems. Unsustainable human activities occurring simultaneously in marine ecosystems of Busuanga are threatening the island's biodiversity (C3 Philippines personal communication, February 3, 2021).

Almost 70% of protected mangroves in the Philippines are found in Palawan (74,267 has). In Busuanga Island, there are 24 true and 28 associate mangrove species, with the most abundant mangroves *Rhizophora spp.* and *Xylocarpus granatum*. However, these mangroves have been heavily exploited, especially those within easy access to roads for charcoal, fuel and building materials. Busuanga Island seagrass beds are dense and speciose (up to 8 species of seagrass) and serve as feeding grounds for dugong (PCSD, 2006), but have been declining since the 1980s (Tamondong et al., 2021).

Vulnerability Assessment Framework for Fishing Communities

Our place-based social vulnerability assessment for fishing communities adapted several vulnerability assessment tools and approaches (Allison et al., 2009; Mamauag et al., 2013; Orencio and Fujii, 2013; Jacinto et al., 2015; Licuanan et al., 2015; Quiros et al., 2018).

We chose criteria based on availability of data, the literature, and the ease of explaining criteria to non-specialist stakeholders (Licuanan et al., 2015). We used four criteria: ecosystem, socio-economic, fisheries, and governance (**Figure 1**). Variables for these criteria were modified from tools to assess fisheries ecosystem vulnerabilities to climate change impacts, and we kept the number of criteria low, for ease of uptake by stakeholders (Mamauag et al., 2013; Jacinto et al., 2015; Licuanan et al., 2015). The scale of assessment is the coastal community or the barangay, the smallest political unit in the Philippines. We limited our study to 10 barangays from two municipalities (Busuanga and Coron) within Busuanga Island.

Scoring was based on a simple, semi-quantitative approach, where scores ranged from 1 to 5, with 1 or 2, categorized as low, 3 to 4 categorized as medium, and 5 as high (**Tables 1–3**; Mamauag et al., 2013; Licuanan et al., 2015). Threshold values were based on Philippines specific conditions from the literature (**Tables 1–3**; Licuanan et al., 2015). The numerical values for each criteria were summed, then converted to a rank system with point class intervals of low, medium, or high (**Table 4**; Jacinto et al., 2015).

We gathered field data and engaged in participant observation between February 2019 and October 2020 in 10 barangays in Busuanga Island, Palawan Province in the Philippines.

Exposure to Threats

We define Exposure as actual and perceived threats that result in the loss or degradation of blue carbon ecosystems (**Table 1**, **Figure 2**). We gathered qualitative data from fishers' perceptions

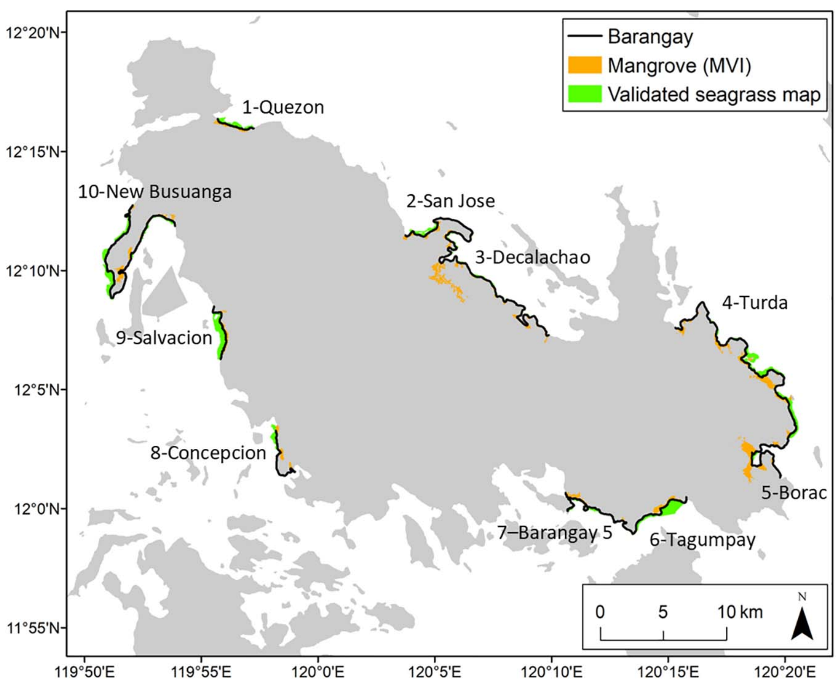

FIGURE 2 | Mangrove and seagrass coverage in Busuanga Island. Municipality of Busuanga: 1- Quezon, 10- New Busuanga, 9- Salvacion, 8- Concepcion; Municipality of Coron: 2- San Jose, 3- Decalachao, 4- Turda, 5- Borac, 6- Tagumpay, 7- Barangay 5.

TABLE 1 | Exposure criteria.

Exposure criteria	Low exposure (1–2)	Medium exposure (3–4)	High exposure (5)	Basis for reference and citation	Vulnerability Tool used/citation	Data source
(E1) Perception of changes to seagrass cover (E2) Perception of changes to mangrove cover	Widespread, dense	Patchy, decreasing	Sparse	Simplified estimate based on local expert knowledge of the natural remaining mangrove forest (Licuanan et al., 2015)	I-C-SEA Change – Licuanan et al., 2015	Household surveys
(E3) Urban gradient, measured by the weighted average distance to the town	Weighted distance > 40 km	Weighted distance 20–40 km	Weighted distance < 20 km	Urbanism is the cause of land use change and habitat loss (Birkmann et al., 2014), and distance to the nearest city is a proxy for urbanism (Quiros et al., 2018)	New vulnerability criteria added for this study	Spatial analysis
(E4) Tourism gradient	Low tourism	Medium tourism	High tourism	Tourism development has the potential to lead to environmental degradation and loss of access to natural resources (Shah et al., 2000)	New vulnerability criteria added for this study	Expert opinion and number of registered tourism businesses

to assess the exposure of environmental resources (i.e., coastal ecosystems and fishing grounds) to threats (i.e., land use changes due to development) (Jacinto et al., 2015) and context specific socio-economic criteria (Quiros et al., 2018). Threats to blue carbon ecosystems in Coron are due to illegal and unsustainable forest practices, illegal cutting of mangroves, changes in land use, and improper waste disposal (Abrenica et al., 2013). In Busaunga, the major threats are unsustainable agricultural and forest practices, timber poaching, and conflicting knowledge about marine protected areas (Bautista et al., 2017). Coastal development has a significant negative impact on seagrass condition (Quiros et al., 2017), while it is the biggest threat to mangroves (Spalding et al., 2010).

Socio-economic context influences a barangay's exposure (Quiros et al., 2018). For the first Exposure variable, a weighted distance to the towns (**Table 1** and **Supplementary Table 3**) is a proxy for urbanism (Birkmann et al., 2014; Quiros et al., 2018). We used the distance to Coron, the major town of Busuanga Island and the capital of the Coron municipality, and the distance to Salvacion, the capital of Busuanga municipality for this calculation.

The second Exposure variable is the presence of tourism defined by combining expert opinion and counting the number of registered establishments from the Coron Tourism Office (**Table 1** and **Supplementary Table 3**). Many development initiatives, road building and land conversion projects are due to tourism development, which in some cases leads to environmental degradation and loss of access to natural resources (Shah et al., 2000).

The third and fourth Exposure variables use qualitative data from household surveys about the perceived condition of blue carbon ecosystems, rating seagrass and mangroves separately on a 5-point scale (low, medium, high exposure). Low exposure of blue carbon ecosystems is defined as widespread, dense coverage, medium exposure is patchy and/or decreasing coverage, and high exposure is sparse coverage (**Table 1** and **Supplementary Table 3**).

We choose not to include physical variables like wave exposure, temperature, or sea level height as Exposure variables because these physical stressors operated at spatial scales larger than the barangay, and other studies found the same exposure level for adjacent barangays (Licuanan et al., 2015). Instead, we used local perceptions of mangrove and seagrass ecosystem condition as a basis to compare Exposure across different barangays, in addition to the socio-economic context of urbanism and tourism. The benefits of this type of analysis are to manage for the social vulnerabilities of individual barangays, while their Exposure to larger scale physical variables remains the same.

Sensitivity

Sensitivity variables fall under ecosystem, socio-economic and fisheries criteria (**Figure 1** and **Table 2**). We collected field data and conducted spatial analysis on seagrass and mangrove fisheries and habitats separately, and for socio-economic variables, we obtained household interview data and barangay statistics.

Blue Carbon Ecosystem Sensitivity

To assess ecosystem sensitivity, we collected data on the quality and extent of blue carbon ecosystems. We conducted spatial analysis to estimate the coverage of mangroves and

TABLE 2 | Sensitivity criteria.

Parameters	Sensitivity criteria	Low sensitivity score (1–2)	Medium sensitivity score (3–4)	High sensitivity score (5)	Basis for reference and citation	Vulnerability tool used/citation	Data source
Blue Carbon Ecosystem Sensitivity	(S1) Seagrass% cover	> 51% cover	21 – 50% cover	< 20% cover	Seagrass meadows with high percent cover can help stabilize sediments, filter runoff and provide habitat for marine organisms (Bjork et al., 2008)	VA-TURF – Mamauag et al., 2013	IPSN
	(S2) Coastal area covered by seagrass	Seagrasses cover more than half of the reef flat	Seagrass cover more than 1/8 to 1/2 of reef flat	Seagrasses cover less than 1/8 of the reef flat	Greater habitat extent has more species and habitat complexity (Mamauag et al., 2013)	I-C-SEA Change – Licuanan et al., 2015	Spatial analysis
	(S3) Maximum seagrass species no	> 5 species	2-4 species	Monoculture	More seagrass species, more resilient the bed is to disturbances (Bjork et al., 2008)	I-C-SEA Change – Licuanan et al., 2015	IPSN
	(S4) Coastal area covered by mangroves	Mangroves cover more than half of the coastline	Mangroves cover more than 1/8 to 1/2 of the coastline	Mangroves cover less than 1/8 of the coastline	Greater habitat extent has more species and habitat complexity (Mamauag et al., 2013).	I-C-SEA Change – Licuanan et al., 2015	Spatial analysis
	(S5) Kind of mangrove forest	Riverine-basin-fringing	Riverine-fringing	Scrub-fringing	Widest mangroves are riverine-basin-fringing types, with riverine mangroves as the most productive due to large amounts of sediment, trapping nutrients (Licuanan et al., 2015)	I-C-SEA Change – Licuanan et al., 2015	Key informant interviews
Socio-economic Sensitivity	(S6) Human Population density (person/ha)	< 200/km^2	200-400/km^2	> 500/km^2	Increased population determines sensitivity to pertubations (Mamauag et al., 2013)	VA-TURF – Mamauag et al., 2013; I-C-SEA Change – Licuanan et al., 2015	Barangay statistics
	(S7) Dependence on resource; Fisheries income % HH	< 25% full time fishers	25-50% full time fishers	> 50% full time fishers	Coastal communities in the tropics depend on fisheries resources for food and livelihood (Allison et al., 2009; Muallil et al., 2011)	Allison et al., 2009; VA-TURF – Mamauag et al., 2013; Fish Vool – Jacinto et al., 2015; Siegel et al., 2019	Household surveys
	(S8) Tourism income % HH	< 7% tourism workers	7-15% tourism workers	> 15% tourism workers	Tourism in Busuanga relies on high quality coastal resources (Fabinyi, 2010). Proportion of reef-based tourism had greater weighting for social-ecological vulnerability scores (Siegel et al., 2019).	Siegel et al., 2019	Household surveys
Fisheries Sensitivity	(S9) Dominant catch composition	pelagics	mix of pelagic, demersal	demersal, nearshore	Nearshore fisheries depend on mangrove & seagrass habitat (Mamauag et al., 2009; de la Torre-Castro et al., 2014)	VA-TURF – Mamauag et al., 2013; I-C-SEA Change – Licuanan et al., 2015	Landing surveys
	(S10) Seagrass catch rate (kg/hr CPUE)	> 8 kg/fisher/day	3 - 8 kg/fisher/day	< 3 kg/fisher/day	Higher catch rate means lower sensitivity (Mamauag et al., 2009; Muallil et al., 2011)	VA-TURF – Mamauag et al., 2013; I-C-SEA Change – Licuanan et al., 2015	Landing surveys
	(S11) Mangrove catch rate (kg/hr CPUE)						

TABLE 3 | Adaptive capacity criteria.

Parameters	Adaptive capacity criteria	Low adaptive capacity score (1–2)	Medium adaptive capacity score (3–4)	High adaptive capacity score (5)	Basis for reference and citation	Vulnerability tool used/citation	Data source
Blue Carbon Ecosystem Adaptive Capacity	(A1) Seagrass Species composition	*Enhalus acoroides* dominated meadow; or no seagrass	*Enhalus acoroides – Thalassia Hemprichii* dominated meadow (3); *Thalassia-Cymodocea-Halodule* dominated meadow (2)	*Halophila-Halodule* dominated meadow	Climax species like *Enhalus, Thalassia* need more time to anchor in the sediment (Bjork et al., 2008)	I-C-SEA Change – Licuanan et al., 2015	IPSN
	(A2) Seagrass habitat extent- along the coastline (connectivity ratio %)	Small, fragmented seagrass, or no seagrass	Patchy but relatively large seagrass habitat	Large contiguous seagrass habitats, relative to coastline	Contiguous habitat means greater species and more catch (Mamauag et al., 2013)	VA-TURF – Mamauag et al., 2013	Spatial analysis
	(A3) Presence of adjacent habitat	Absence of adjacent habitats or extreme degradation of adjacent habitats	Presence of 1 adjacent habitat in good condition	Presence of two adjacent habitats in good condition	Adjacent habitat enhances connectivity of life stages and enhances condition and recovery of habitat (Mamauag et al., 2013)	VA-TURF – Mamauag et al., 2013	Spatial analysis
	(A4) Mangrove habitat extent along the coastline (connectivity ratio %)	Small, fragmented mangroves, or no mangroves	Patchy but relatively large mangrove habitat	Large contiguous mangrove habitats, relative to coastline	Contiguous habitat means greater species and more catch (Mamauag et al., 2013)	VA-TURF – Mamauag et al., 2013	Spatial analysis
Socio-economic Adaptive Capacity	(A5) Proportion of fishers with other sources of income	Less than 40% of fishers have other sources of income	40-60% of fishers have other sources of income	Greater than 60% of fishers have other sources of income; coastal areas with no fishers	Alternative livelihoods are a key indicator of adaptive capacity (Allison et al., 2009; Muallil et al., 2011)	VA-TURF – Mamauag et al., 2013	Household surveys
	(A6) Salaried income % HH	< 10% salaried workers	10-15% salaried workers	> 15% salaried workers	Salaried employment shows low dependence on fishing (Cinner et al., 2009)		Household surveys
	(A7a) Education; Indicator- fisher's average years of schooling (A7b) % fishers with less than 10 years schooling	More than 60% of the population has less than 10 years schooling	Between 40-60% of the population has less than 10 years schooling (3); Between 20-40% of the population has less than 10 years of schooling (4)	Less than 10% of population has less than 10 years of schooling	Level of education positively influences fishers to exit the fisheries and provides opportunities for alternative livelihoods (Muallil et al., 2011). Literacy rate influenced social-ecological vulnerability scores (Siegel et al., 2019).	Allison et al., 2009; Fish Vool – Jacinto et al., 2015; I-C-SEA Change – Licuanan et al., 2015; Siegel et al., 2019	Fisher interviews
Fisheries Adaptive Capacity	(A8) Alternative livelihoods to Fishing	Only fishing	Fishers have two other sources of livelihood (3); Fishing plus one other source of livelihood (2)	Fishers have more than 3 other sources of livelihood	Alternative livelihoods is a key indicator of adaptive capacity (Allison et al., 2009; Muallil et al., 2011)	VA-TURF – Mamauag et al., 2013; I-C-SEA Change – Licuanan et al., 2015	Household surveys

(Continued)

TABLE 3 | Continued

Parameters	Adaptive capacity criteria	Low adaptive capacity score (1-2)	Medium adaptive capacity score (3-4)	High adaptive capacity score (5)	Basis for reference and citation	Vulnerability tool used/citation	Data source
	(A9) Average fishing experience per fisher	More than 20 years	10-20 years (3); 5-10 years (4)	Less than 5 years per fisher	Number of years a fisher spends fishing influences exit from the fishery (Muallil et al., 2011)	CCVI – Orencio and Fujii, 2013; I-C-SEA Change – Licuanan et al., 2015	Fisher interviews
Governance Adaptive Capacity	(A10) Access to scientific knowledge/information Indicator- number of NGOs with natural resource management or blue carbon ecosystem projects	No current or past presence of NGOs (1); Past presence of at least 1 NGO (2)	1 NGO with an active natural resource management project (3); 1 NGO with an active blue carbon ecosystem project and 1-2 NGOs with active natural resource management projects, but no future or past NGO presence (4)	At least 2 NGOs with active blue carbon ecosystem and/or natural resource management projects, and past or future presence of NGOs (5)	Access to knowledge/scientific information through government programs or universities (Ekstrom et al., 2015) and institutions with environmental initiatives (Orencio and Fujii, 2013) increases a community's adaptive capacity	CCVI – Orencio and Fujii, 2013; Ekstrom et al., 2015; Fish Vool – Jacinto et al., 2015; Siegel et al., 2019	Key informant interviews
	(A11) Action Indicator- number of People's Organizations (PO)	No presence of PO (1); 1 active PO (2)	2-3 active POs (3); 4-5 active POs (4)	> 5 active POs	Local organizations positively influence political action (Ekstrom et al., 2015). Participation of organized local communities contributes to policy & decreases institutional vulnerability (Orencio and Fujii, 2013).	CCVI – Orencio and Fujii, 2013; Ekstrom et al., 2015	Key informant interviews

TABLE 4 | Ranking classification for vulnerability parameters, adapted from Jacinto et al. (2015).

Parameters	Number of criteria	Minimum/maximum total score	Point class interval
Exposure	4	4/20	4 – 10 Low (L), 11 – 15 Medium (M), 16 – 20 High (H)
Sensitivity	11	11/55	11 – 27 Low (L), 28 – 42 Medium (M), 43 – 55 High (H)
Adaptive capacity	11	11/55	11 – 27 Low (L), 28 – 42 Medium (M), 43 – 55 High (H)
Overall vulnerability		−40/59	<10 Low (L), 10-20 Medium (M), >20 High (H)

seagrasses along the coastline. We conducted field surveys of seagrass habitat and due to fieldwork constraints, we held key informant interviews to determine mangrove habitat categories.

As part of the Indo Pacific Seagrass Network (IPSN), we collected complete IPSN data for one of the barangays (Concepcion), then we simplified the IPSN methodology for the 9 other barangays, collecting only a subset of data needed for the vulnerability analysis. The IPSN methodology was carried out using SeagrassWatch methods, wherein three 50 m transects were laid out parallel to each other and perpendicular to the shore, and 25 m apart on each site. Seagrass percent cover was estimated at 5-meter intervals within 0.25 m^2 quadrats along the transects (McKenzie and Campbell, 2002; Indo-Pacific Seagrass Network (IPSN), 2021). We collected seagrass species and percent cover data from within each quadrat.

Mangrove forest types have different ecosystem vulnerabilities with riverine mangroves, the least vulnerable and most productive due to high nutrient input and sediment trapping (McLeod and Salm, 2006). We categorized each mangrove forest using Licuanan et al. (2015) mangrove categories (**Table 2**). Seagrass meadows with high percent cover can help stabilize sediment, filter run-off and provide habitat for marine organisms. The more seagrass species a meadow has, the less sensitive and more resilient it is to disturbances due to a higher range of responses to change (Bjork et al., 2008).

Socio-Economic Sensitivity

We obtained barangay level population statistics for human population density (Abrenica et al., 2013; Bautista et al., 2017) and conducted household interviews (n = 30 per barangay) to assess dependence on blue carbon ecosystems (Pollnac and Crawford, 2000; Cinner et al., 2009; Quiros et al., 2018). We defined households by a group of people living in the same house and contributing income toward the household. We surveyed every fifth house along paved and unpaved roads and spoke to the head of the household present. If a house was empty, we skipped that house and moved to the next one.

Population density is an indicator of the pressure on natural resources evidenced by increases in fishing pressure (Licuanan et al., 2015) and tourism by increasing coastal development (Fabinyi, 2010). Since coastal communities in the tropics largely depend on fisheries resources for food and income (Allison et al., 2009; Muallil et al., 2011), we chose income sources from fisheries and tourism income as indicators of reliance on blue carbon ecosystems.

Fisheries Sensitivity

We used landing surveys to determine the dominant catch composition and the catch rate as measured by kilograms per fisher per day in seagrass and mangrove habitats, separately (**Supplementary Table 1**). For our classification, we used Licuanan et al. (2015) catch categories (**Table 2**). Catch associated with nearshore habitat is more sensitive to habitat degradation (i.e., habitat loss) than those found in the water column (Mamauag et al., 2009, 2013). Catch per unit effort is a proxy for standing biomass of fish stocks, with high standing biomass less sensitive (Mamauag et al., 2013).

We trained fisheries observers to collect seagrass and mangrove landing data at landing sites. We considered a single fisher landing as what arrived after a single fishing trip, from a boat or on foot. We recorded as many landings at each landing site as possible for each observation day unless the fisher did not agree to be interviewed. These landing forms recorded Barangay name, date, a generic gleaner ID number, gender of the fisher, their age, the weight of each catch item, location of where the catch was taken and time spent fishing (**Supplementary Table 1**).

Adaptive Capacity

Adaptive capacity variables fall within ecosystem, socio-economic, fisheries, and governance criteria (**Table 3** and **Figure 2**). For fisheries, socio-economic, and governance criteria, we used household and fisher interviews, and barangay statistics, while for ecosystem criteria, we used field survey data and spatial analysis of seagrass and mangroves.

Blue Carbon Ecosystem Adaptive Capacity

To assess blue carbon ecosystem adaptive capacity, we determined habitat patchiness along the coastline and the presence of adjacent habitat. We conducted field surveys for seagrass species composition in specific beds in each barangay. Mangrove resilience and recovery potential are largely due to close their proximity and connectivity with neighboring stands of healthy mangroves (McLeod and Salm, 2006). Seagrass recovery potential is based on species' life-history strategies, with climax species like *Enhalus acoroides* and *Thalassia hemprichii* growing slower because they need more time to anchor in the sediment (Bjork et al., 2008).

Socio-Economic Adaptive Capacity

To assess socio-economic adaptive capacity, we collected data from household interviews to ascertain the proportion of fishers with other sources of income and the proportion of households with salaried income. Households with salaried income have less reliance on fisheries resources (Cinner et al., 2009). We used fisher interviews to determine the level of schooling of fishers. The level of education positively influences fishers to exit the fisheries (Muallil et al., 2011), is positively related to more diverse livelihood opportunities (Pauly, 1997), and literacy rate contributes to an islands' social-ecological vulnerability score (Siegel et al., 2019).

Fisheries Adaptive Capacity

To assess blue carbon ecosystem fisheries adaptive capacity, we used household interviews to ascertain alternative livelihoods to fishing, and used fisher interviews to obtain the average years fishing experience per fisher. Alternative livelihoods are a key indicator of adaptive capacity (Allison et al., 2009; Muallil et al., 2011).

Governance Adaptive Capacity

For governance criteria, we conducted key informant interviews to get data on access to scientific knowledge and community-level organization. Access to scientific knowledge was measured by the presence of an active NGO project. Greater weight was given to projects working specifically with blue carbon ecosystems versus more general natural resource management. Access to scientific information through government programs or universities affects adaptive capacity (Ekstrom et al., 2015), as do institutions with environmental initiatives (Orencio and Fujii, 2013). We determined community-level action by counting the number of active People's Organizations (POs). Local organizations influences potential political action (Ekstrom et al., 2015), and organization and participation in action within communities works to reduce policy & institutional vulnerability (Orencio and Fujii, 2013).

Spatial Analysis

We limited our spatial analysis of seagrass and mangroves within the boundaries of the 10 barangays in Busuanga Island. We used Barangay boundaries from the latest Environmentally Critical Areas Network (ECAN) reports (Abrenica et al., 2013; Bautista et al., 2017), but when they did not overlap with the mapped barangay boundaries from household interviews, we adjusted the barangay boundaries to encompass the individual households surveyed.

Busuanga Island has two municipal capitals, Coron and Salvacion, which correspond to the municipalities of Coron and Busuanga, respectively. To calculate the impact of urban centers on each of the 10 barangays, we calculated the weighted average distance to the nearest municipal capital, using human population as the weighted measure. Urban living increases Exposure due to overcrowded living conditions, lack of services for adequate housing, nutrition and healthcare (Baker, 2012). The population of Coron is projected at 18,883 (a) in 2020, while the population in Salvacion is projected at 3,639 (b) in 2020 (Abrenica et al., 2013; Bautista et al., 2017). To calculate the "weight" of each population center, we divided the population of that capital by the total population of both municipal capitals. Coron had a weight of 0.84 (a/(a + b)) while Salvacion had a weight of 0.16 (b/(a + b)). We then multiplied the distance from each barangay center to each municipal capital and its weight to get the weighted average distance. We calculated the distance between barangays and municipal capitals using the main transportation network roads.

To calculate the coastline covered by blue carbon ecosystems, we used a hybrid approach, using remotely sensed data, on the ground assessments and expert opinion. For mangrove cover, we used the Mangrove Vegetation Index (MVI), implemented in Google Earth Engine to create a mangrove extent map of the Philippines (Baloloy et al., 2020). For seagrass cover, we used a linear spectral unmixing method on Landsat 8 images, with pure spectra or endmembers from August to December 2019. To validate the remotely sensed seagrass images, we used ground assessments of seagrasses and expert opinion to increase the reliability of the maps, because accuracy depends on the environmental conditions of the study area (Veettil et al., 2020). We did not validate the mangrove coverage map because it was well validated with field data and drone images, with an accuracy ranging from 94% in Calauit Island, to 96% in Binguan, Coron and 100% in Sagrada and Bugtong, Busuanga (Baloloy et al., 2020).

To calculate the proportion of mangroves covering each barangay's coastline, we overlaid Busuanga's MVI map on the Philippine Barangay boundary map and calculated the length of coastline with mangroves (considering a 100-m buffer distance) using ArcGIS 10.7.1. We divided the length of the mangrove forest by the total length of each barangay's coastline to get a proportion of mangroves covering the coastline. This approach however ignores the width and hence the area, for simplicity.

To calculate the proportion of seagrass covering the reef flat, we obtained the coral reef base layer from UNEP (UNEP-WCMC et al., 2018) and overlaid it with the validated seagrass map. To calculate the proportion of the reef flat (area covered by the coral reef) covered by seagrasses, we divided the seagrass area in each barangay by the reef flat area.

To calculate the patchiness versus connectivity of seagrass and mangroves along the coastline, we created a continuous grid of 500-meter cells of mangrove forest and seagrass beds, averaging around 500 – 1000 meters from the coastline, with a maximum of 2.5 km from the coastline because some riverine mangrove forests were distributed inland. We used the focal statistics function of ArcGIS to calculate the contiguous area of 3 cells with seagrass or mangroves, separately. We divided the focal analysis score per barangay by the number of 500-meter cells covered by that barangay's coastline to create a ratio of connectivity for seagrass and mangroves along the coast. We rated small, fragmented habitats with focal analysis ratios of less than 25% as patchy, ratios of between 25% and 60% as medium patchiness, and ratios greater than 60% as contiguous.

To calculate presence of adjacent habitat, the same 500-meter cells were assigned a connectivity score between zero and two, with one habitat (seagrass, mangrove or coral) found present in a cell, given a score of zero, two habitats (seagrass/mangrove, seagrass/coral or coral/mangrove), given a score of one, and all three habitats present, given a score of two. Like the patchiness ratio, we divided the total cells in that barangay's grid by the cumulative connectivity score to get a connectivity score. We rated low connectivity as a score of less than 1, medium connectivity with a score between 1 and 1.5, and high connectivity if the score was greater than 1.5.

RESULTS

Status of Blue Carbon Ecosystems

Mangroves covered greater than 50% of all barangay coastlines, while seagrasses covered around 50% and greater of barangays' coastlines (**Figure 2**). Mangrove forests did not stay within barangay boundaries but extended beyond individual barangay coastlines into adjacent barangays. Patchiness of seagrass and mangrove habitat was low, with at least 40% of the coastline with contiguous habitat. Blue carbon ecosystems were relatively well-connected with adjacent habitat such as coral reefs and other mangroves and seagrasses. These results show that blue carbon ecosystems are relatively intact in Busuanga Island. Perceived conditions of seagrasses and mangroves varied, ranging from low exposure to high exposure of both habitats. The results of our spatial analysis (**Figure 2**) and household interviews concerning perceived condition of blue carbon ecosystems (**Figure 3** and **Supplementary Tables 3**, **4**) showed that in some locations, past blue carbon ecosystems were more extensive than current conditions, with households referring to significant damage due to typhoon Yolanda/Haiyan in 2013.

Exposure

Our exposure variables were based on the perceived condition of blue carbon ecosystems and the degree of indirect threats or perturbations from the socio-economic influence of urbanism and tourism. Peri-urban barangays in Busuanga are Salvacion and New Busuanga, and urban barangays in Coron are Barangay Poblacion, Barangays 1 through 6, and Tagumpay. Barangays with the greatest exposure were more urbanized and exposed to tourism (Barangay 5 and Tagumpay), while rural barangays and barangays with little or no tourism had less exposure (Quezon and Borac). Rural barangays influenced by tourism (Concepcion, New Busuanga and San Jose) had greater exposure than rural barangays that not influenced by tourism (**Figures 3**, **4**, **Table 5**, and **Supplementary Tables 3**, **4**, **Figure 5A**).

Sensitivity

The most sensitive barangays were urban barangays Barangay 5 and Tagumpay, and the least sensitive was rural barangay Quezon. Borac, Turda and Quezon had lower blue carbon ecosystem sensitivity than Barangay 5, Tagumpay and Concepcion. Quezon had lower fisheries and socio-economic sensitivity than the other barangays. Barangays with high

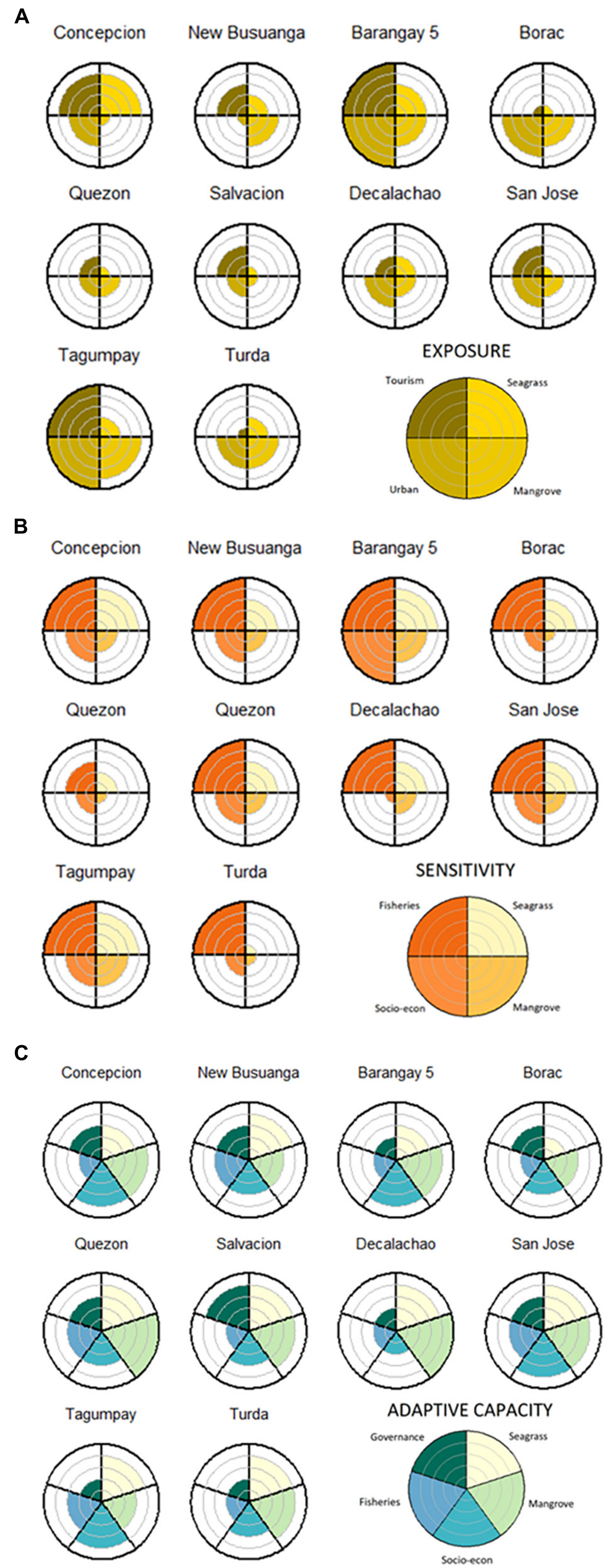

FIGURE 3 | (Continued)

FIGURE 3 | Radar plots showing cumulative scores of criteria scaled to values between 0 and 5, indicated by the gray concentric lines. Criteria are separated by black radial lines. **(A)** Exposure criteria: (1) Perception of changes to seagrass cover, (2) Perceptions of changes to mangrove cover, (3) Urban gradient, (4) Tourism gradient. **(B)** Sensitivity criteria (1) Seagrass Sensitivity (seagrass cover, seagrass species number, coastal area covered with seagrass), (2) Mangrove Sensitivity (coastal area covered with mangroves, mangrove forest type), (3) Socio-economic Sensitivity (fishing income, human population density, tourism income), (4) Fisheries Sensitivity (catch composition, seagrass catch rate, mangrove catch rate). **(C)** Adaptive Capacity criteria: (1) Seagrass Adaptive Capacity (seagrass species composition, seagrass habitat connectivity), (2) Mangrove Adaptive Capacity (presence of adjacent habitat, mangrove habitat connectivity), (3) Socio-economic Adaptive Capacity (fishers with other sources of income, salaried income, fisher education level), (4) Fisheries Adaptive Capacity (alternative livelihoods to fishing, average fishing experience), (5) Governance Adaptive Capacity (non-governmental organizations, people's organizations).

TABLE 5 | Raw vulnerability scores, summed for each criteria, ranked using **Table 4** with low (L), medium (M) and high (H) scores.

Parameters	Criteria (score range)	Concepcion	New Busuanga	Salvacion	Quezon	Borac	Decalachao	Brgy 5	Tagumpay	San Jose	Turda
Exposure (E)		12 (M)	9 (L)	7 (L)	7 (L)	9 (L)	9 (L)	16 (H)	16 (H)	9 (L)	9 (L)
Sensitivity (S)	Seagrass (1-15)	10	7	8	6	7*	7	11	12	7	3
	Mangrove (1-10)	5	5	6	3	2	6	7	7	6	7
	Socio-economic (1-15)	7	7	9	5	5	3	13	9	9	6
	Fisheries (1-15)	15	15	15	9	9	14	13	15	15	15
	Overall Sensitivity	37 (M)	34 (M)	38 (M)	23 (L)	23 (L)	30 (M)	44 (H)	43 (H)	37 (M)	31 (M)
Adaptive Capacity (AC)	Seagrass (1-10)	5	7	7	8	3*	7	6	7	7	7
	Mangrove (1-10)	7	6	8	9	6	9	7	6	7	8
	Socio-economic (1-15)	10	8	9	9	7	4	12	12	10	8
	Fisheries (1-10)	3	5.5	3	6	4	3	4	4.5	5.5	4
	Governance (1-10)	8	9	10	9	7	6	6	6	8	6
	Overall Adaptive Capacity	33 (M)	35.5 (M)	37 (M)	41 (M)	27 (L)	29 (M)	35 (M)	35.5 (M)	37.5 (M)	33 (M)
Overall Vulnerability V = E + S - AC		16 (M)	7.5 (L)	8 (L)	−11 (L)	5 (L)	10 (M)	25 (H)	23.5 (H)	8.5 (L)	7 (L)

**Borac has little naturally occurring seagrass, so we gave a sensitivity score of 1 to its Sensitivity criteria except criteria S2, where we had available remotely sensed data. We assigned an adaptive capacity score of 1 to its seagrass Adaptive Capacity criteria.*

sensitivities had coastal fringing mangroves, seagrass beds with low seagrass cover, reliance on nearshore seagrass and mangrove fisheries catch, and more tourism income. Barangays with low sensitivities had extensive seagrass and mangroves along their coastlines, low human population density and alternative incomes to fishing (**Table 5**, **Figures 3**, **4** and **Supplementary Table 5**, **6**, **Figure 5B**).

Blue carbon ecosystem sensitivity was medium to high due to relatively low seagrass percent cover in some barangays and the presence of scrub-fringing mangroves, which is the mangrove forest type more sensitive to changes. Seagrass sensitivity was higher in monocultures and lower in multi-species seagrass meadows. Urban barangays like Barangay 5 and Tagumpay had higher seagrass sensitivity due to degraded seagrass habitat. Rural barangays like Quezon and Turda had less seagrass sensitivity due to high seagrass percent cover and diverse seagrass species present (**Figure 3** and **Supplementary Tables 5**, **6**, **Figures 1A**, **3B**).

Mangrove sensitivity was defined by mangrove forest type with scrub-fringing mangroves, the most sensitive but also the most common mangrove forest type found in Salvacion, Barangay 5, Tagumpay and Turda. Rural barangays like

Concepcion, New Busuanga, Quezon and Borac had less mangrove sensitivity because they were dominated by riverine-basin-fringing forests, the least sensitive mangrove forest type. The mangrove types with medium sensitivity were the riverine-fringing and scrub fringing mangroves found in Decalachao and San Jose (**Figure 3** and **Supplementary Tables 5**, **6**, **Figures 1A**, **3B**).

Socio-economic sensitivity was medium for most barangays. The exceptions were due to greater reliance on tourism income and greater population densities in urbanized barangays. The rural barangay, San Jose also had high socio-economic sensitivity due to a greater reliance on tourism income. Socio-economic sensitivity ranged from a minimum sensitivity score of 3 for Decalachao, with low population density, low reliance on tourism income and low reliance on fisheries, to a maximum sensitivity score of 13 for Barangay 5, with high population density, high reliance on tourism income but low reliance on fisheries (**Figure 3** and **Supplementary Figures 1B, 3B**, **Tables 5**, **6**).

Blue carbon ecosystem fisheries are highly sensitive fisheries due to their nearshore catch composition and low catch per unit effort, with mangrove fisheries having a slightly lower sensitivity due to greater catch per unit effort. Fisheries sensitivity was high for all barangays except for Quezon, due to its high catch per unit effort for both seagrass and mangrove catch. Since there was minimal natural seagrass habitat in Borac and no seagrass fisheries, we assigned Borac's seagrass fishery and seagrass species sensitivity variables with the lowest possible score, 1 (**Figure 3** and **Supplementary Figures 1B, 3B**, **Tables 5**, **6**).

Adaptive Capacity

The barangay with the greatest adaptive capacity was Quezon, while the barangays with the least adaptive capacity were Concepcion and Turda. Borac and Tagumpay had relatively lower blue carbon ecosystem and fisheries adaptive capacity than the rest of the barangays, while Barangay 5, Tagumpay and Decalachao had relatively lower socio-economic and governance adaptive capacity than the rest of the barangays. Barangays with low adaptive capacity did not have alternative livelihoods to fishing, had fishers with low education and a high average fishing experience per fisher. Barangays with high adaptive capacity had high connectivity between seagrass and mangrove patches, the presence of adjacent habitats, had fishers with other sources of income, and the presence of NGOs and POs (**Table 5**, **Figures 3**, **4**, and **Supplementary Tables 7**, **8**, and **Figure 5C**).

Mangrove adaptive capacity was higher than seagrass adaptive capacity (**Supplementary Figure 4C**). Mangrove adaptive capacity was medium to high due to medium to high connectivity of mangrove patches along the coast and the presence of adjacent habitat (**Figure 4** and **Supplementary Figures 2A**, **3C**, **4C**). Seagrass adaptive capacity was low in *Enhalus acoroides* dominated meadows, and medium in mixed meadows with *Enhalus-Thalassia* dominated and *Thalassia-Cymodocea-Halodule* seagrasses. Seagrass adaptive capacity was medium to low, due to medium to low connectivity of seagrass patches along the reef flat and the predominance of *Enhalus* and *Enhalus-Thalassia* dominated seagrass beds, which are climax species and need more time to grow and recover from loss (Bjork et al., 2008). While Borac does not have a significant amount of naturally occurring seagrass, remote sensing analysis predicted a small patch of seagrass, so we were able to assign a low adaptive capacity score for Borac's seagrass habitat extent (**Figure 3** and **Supplementary Figures 2A**, **3C**, **4C**).

Each barangay's socio-economic adaptive capacity was constrained by low fisher education (<10 years of education), but adaptive capacity increased with diversified livelihoods (Muallil et al., 2011; Licuanan et al., 2015) (**Figure 3** and **Supplementary Figures 2B**, **3C**, **4C**). Among socio-economic variables, education had the lowest scores across all barangays (**Supplementary Table 8**). Decalachao had the lowest socio-economic adaptive capacity score because fishers did not have other sources of income besides fishing and had low education levels (**Table 5** and **Supplementary Table 8**). We found a low proportion of households with salaried income in the urban barangays, Barangay 5 and Tagumpay. Rural barangays New Busuanga, Borac and Turda also had little or no households with salaried income (**Figure 3** and **Supplementary Figures 2B**, **3C**, **4C**).

The fisheries sector variables had the lowest adaptive capacity due to high average fishing experience. However, the presence of alternative livelihoods to fishing helped to increase adaptive capacity. The exceptions were Concepcion and Decalachao, where fishers had few alternative livelihoods to fishing. Across all barangays, average fishing experience was high (>20 years of fishing experience) showing a low likelihood of exiting the fishery, therefore a lack of adaptive capacity (**Figure 3** and **Supplementary Figures 2A**, **3C**, **4C**).

Governance adaptive capacity was medium due to the presence of NGOs and POs (especially for Concepcion, New Busuanga, and Salvacion), which increased the information available to communities and the capacity for community organization and action. The exceptions were the urban barangays of Barangay 5 and Tagumpay, and Turda because they had lower numbers of POs (**Figure 3** and **Supplementary Figures 2B**, **3C**).

Overall Vulnerability

Overall, rural barangays had less exposure and lower sensitivity to blue carbon ecosystem loss than urban barangays. Across all barangays, diversified livelihoods increased adaptive capacity. The barangays with the highest exposure and sensitivity were the urban barangays of Barangay 5 and Tagumpay, while the barangays with lowest exposure and sensitivity were rural Quezon and Borac. All barangays had medium overall adaptive capacity. The lowest overall vulnerability was Quezon, followed by Borac, and the highest overall vulnerabilities were Barangay 5 and Tagumpay (**Table 5** and **Figure 4**).

DISCUSSION

Overview

Our analyses revealed a range in coastal barangay social vulnerabilities, showing the complex relationship between blue

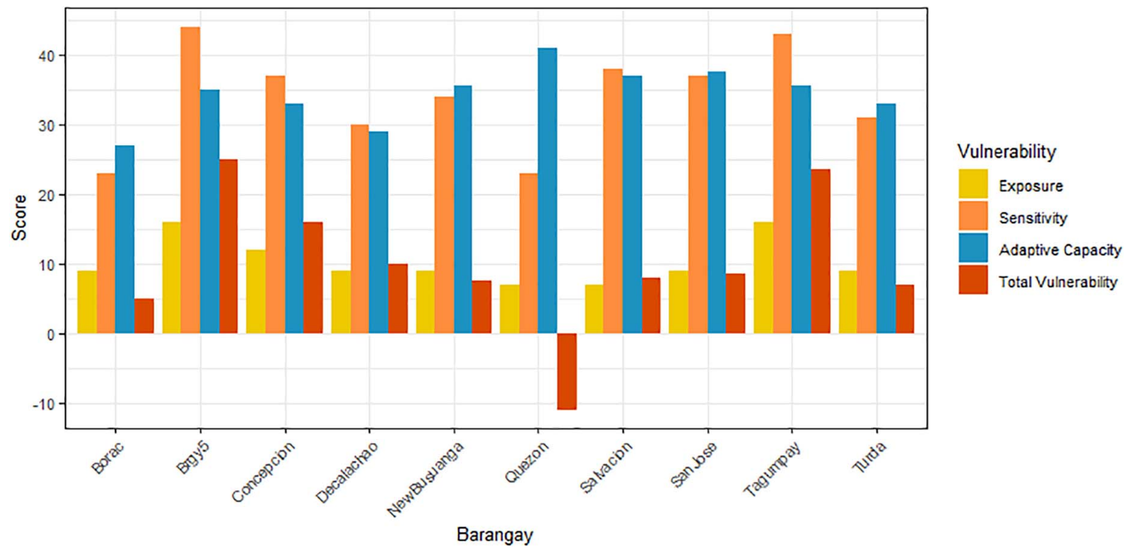

FIGURE 4 | Bar plots showing the sum of all scores for Exposure (E), Sensitivity (S) and Adaptive Capacity (AC) criteria, and the total Vulnerability score (V = E + S-AC) in 10 barangays. The 10 barangays include in the Municipality of Busuanga: Quezon, Concepcion, Salvacion, New Busuanga, in the Municipality of Coron: San Jose, Decalachao, Turda, Borac, Tagumpay, Barangay 5.

carbon ecosystems and human communities, even within one island. We found that seagrass and mangrove ecosystems in Busuanga Island were relatively intact. This is a good sign for coastal communities in Busuanga.

The main factors contributing to community vulnerability in other contexts were food security factors, followed by economic/livelihood, policy and institutional factors (Orencio and Fujii, 2013). Our work differed from previous studies because it combined methodologies that were used to examine climate change vulnerabilities of fisheries (Mamauag et al., 2013; Licuanan et al., 2015) with an examination of social vulnerability (Cutter et al., 2008; Ekstrom et al., 2015; Quiros et al., 2018). While there are vulnerability studies on mangroves that combine environmental criteria with human management criteria, these focused mostly on physical processes (Ellison, 2015). Multi-criteria vulnerability studies on seagrass are scarce, with most focusing on environmental criteria (Waycott et al., 2007) or compiling expert knowledge from workshops (Grech et al., 2012; Tan et al., 2018). Our study is novel because it used vulnerability analysis on empirical data for both mangroves and seagrasses and human communities, highlighting these links in the social-ecological system.

Blue Carbon Ecosystem Vulnerability

Healthy blue carbon ecosystems can mitigate against social vulnerabilities in human communities by being less sensitive to threats and better able to recover from loss. Our spatial analysis revealed healthy blue carbon ecosystems, as measured by proportion of coastline covered, low patchiness and high continuity of mangroves along the coastline, the presence of adjacent habitat, and type of seagrass bed and mangrove forest present. Interestingly, mangrove fisheries occurred in both riverine-basin-fringing forests (least sensitive) as well as the scrub-fringing (most sensitive) mangrove forests. Certain mangrove forest types are more sensitive than others, and certain spatial contexts (low connectivity with other mangrove forest habitats and limited extent) result in more sensitive mangrove ecosystems. For sensitive mangroves like scrub-fringing mangroves or mangroves with low connectivity and low extent along the coastline, managers can impose risk averse policies such as limiting use by fishers and coastal developers.

Seagrass habitat sensitivity ranged from low to high, which is evidence that among blue carbon ecosystems in Busuanga, seagrasses were more vulnerable. Field collected data and local perceptions showed there were greater negative changes to seagrasses. Seagrass habitat percent cover within quadrats ranged from low (11% in Concepcion) to high (95% in Quezon). This data corroborated with local perceptions of changes to seagrass with 77% of Concepcion respondents saying seagrass in their barangay was patchy, and 80% of Quezon respondents saying seagrass in their barangay was widespread. While the link between tourism and urbanism's effect on blue carbon ecosystems is indirect and our purpose was not to describe the mechanism, we must note that Concepcion is one of the barangays with growing tourism development and relatively close to a peri-urban town, Salvacion, while Quezon is a remote, rural barangay with very little tourism development (Quevedo et al., 2021). This is evidence of tourism's indirect impact on seagrass ecosystems. Furthermore, threats in Busuanga such as unsustainable agricultural and forest practices (Bautista et al., 2017) also play a role in blue carbon ecosystem health, but we did not investigate this relationship.

Socio-Economic Vulnerability

Busuanga households diversified their income sources beyond fishing, increasing their adaptive capacity. They engaged in farming, tourism, construction, transportation and salaried employment including working for pearl farms, schools, the service industry and retail. Salaried jobs mitigate a barangay's sensitivity to blue carbon ecosystem loss because salaried jobs do not rely on the health of the habitat, unlike tourism or fishing. One cause for concern was the low proportion of households with salaried income in the urban barangays, Barangay 5 and Tagumpay, which is opposite of what one may expect from an urban area, which should provide more reliable employment.

Education is a limiting criteria for socio-economic adaptive capacity. Poor educational attainment of fishers limits the livelihoods available to them in the future (Pauly, 1997). The rural barangays San Jose and Quezon do not have high schools. Residents attend high schools in neighboring barangays, making it more difficult to travel to school, especially during the rainy season with rough roads connecting barangays.

Tourism in Busuanga island is largely nature-based tourism, relying on healthy coastal ecosystems. With the degradation or loss of blue carbon ecosystems, the very base upon which Busuanga Island's tourism relies on is endangered. Tourism is the leading source of livelihoods in Coron (Abrenica et al., 2013), while in Busuanga, access to tourism is a problem (Bautista et al., 2017). Quevedo et al. (2021) found greater perceived tourism benefits in urban versus rural dwellers; these benefits were moderate overall, with slightly positive socio-cultural impacts and slightly negative economic and environmental impacts. In general, urban barangays had greater reliance on tourism income and hence, greater sensitivity, but greater reliance on tourism was also found in the rural barangay San Jose. These findings show that sensitivities are not only based on the rural-urban gradient but also on other aspects of the socio-economic context, such as tourism development.

Fisheries Sector Vulnerability

Our research revealed the highly sensitive nature of the seagrass and mangrove fisheries sectors. Seagrass fisheries are very important for coastal communities as evidenced by the high participation in gleaning activities around the world (Cullen-Unsworth et al., 2014; Quiros et al., 2018; Nordlund et al., 2018; Unsworth et al., 2018). However, seagrass and mangrove fisheries are highly sensitive and inherently vulnerable fisheries due to their low catch per fisher per day (Mamauag et al., 2009; Muallil et al., 2011). Seagrass and mangrove fisheries are largely unregulated in Busuanga Island. While gleaners are required to register as fishers, most are not registered and since most do not use boats, their gleaning activities go unseen by natural resource managers. This is cause for concern because Siegel et al. (2019) found that fisheries regulations increase socio-economic adaptive capacity due to more environmental monitoring and adaptive management.

Another issue with blue carbon fisheries is the low catch rate, which is an indicator of fishing effort and fishing pressure (Licuanan et al., 2015) on the seagrass and mangrove ecosystems. A policy intervention is establishing equitable fisheries regulations for blue carbon ecosystem fisheries. An exception to the low catch rates was the Quezon mangrove fishery which relies on Quezon's riverine-basin-fringing mangrove forest, which extends further west to Buluag's extensive riverine-basin-fringing mangrove forest and is bordered to the north by the mangroves of Calauit Island. Quezon's rich mangrove forest connected with the mangroves of neighboring barangays and islands provided the community with excellent catch.

Seagrass and mangrove fisheries have low adaptive capacity due to the high average fishing experience per fisher (Muallil et al., 2011). While more than 20 years fishing experience shows a decreased likelihood to exit the fishery (Muallil et al., 2011), we found that fishers exit the fishery when seagrass and mangrove habitat is degraded (Barangay 5 and Tagumpay), due to either low catch per unit effort or poor quality ("dirty") catch. Fishers in these barangays reported completely leaving the fishery and only glean recreationally in distant islands where the habitat is not degraded. Alternative incomes in retail, tourism and construction are available to fishers in these urban barangays.

Vulnerability in Governance

Access to information and community organization help improve governance (Orencio and Fujii, 2013; Ekstrom et al., 2015). Busuanga island has a healthy mix of NGOs dedicated to blue carbon ecosystems and relatively abundant community organizations (POs). Notable exceptions with low NGO and POs presence were urban Barangay 5 and Tagumpay, and rural Turda. We suggest a policy intervention to establish NGO programs in these urban barangays for blue carbon ecosystem management, hopeful that ease of access to these areas will make starting projects possible. Establishing NGO programs in remote Turda, however, will be a challenge. Since POs are not as dependent as NGOs on outside influence and funding, capacity building to enhance PO activities can be led by local barangay officials in both urban and rural settings.

OVERALL CONCLUSION

The vulnerability framework allows us to address multiple SDGs simultaneously, such as alleviating poverty and hunger, while tackling environmental issues, specifically the sustainable management of marine and terrestrial resources. Lessons learned from this vulnerability analysis revealed that good education and governance, along with proper natural resource management are multiple paths to achieve SDGs. Our multi-faceted look at coastal communities supports the need for an integrated approach to reach SDGs by managing socio-economic and livelihood concerns while conserving biodiversity and ecosystems (Mironenko et al., 2015).

Fine-scale analyses of this kind are important because the results can assist policymakers in identifying specific factors that influence vulnerability in individual coastal barangays (Mamauag et al., 2013). In other words, certain criteria may consistently increase vulnerability in communities, and therefore, can be targeted by policy makers as "low hanging fruit." One example are governance criteria, because in Busuanga Island, access to information (NGO presence) and organization by the community (PO presence) are open to interventions. Another intervention could be establishing a high school in each barangay, or providing reliable and equitable transportation (buses, road improvement) to neighboring barangays so children can have easier access to education beyond elementary school. A third intervention includes capacity building for equitable blue carbon ecosystem fisheries management.

Environmental factors, however, are not as easily open to interventions. The specific nature of blue carbon ecosystems, such as mangrove forest type or seagrass bed type, cannot be changed. Habitat types have inherent vulnerabilities, with some habitats having greater adaptive capacity (riverine mangrove forests or seagrass beds made of colonizing species). From our analysis, we suggest maintaining a portion of the coastline with intact habitat under protected area management to decrease sensitivity and increase adaptive capacity. We also suggest prioritizing sensitive mangrove habitat (scrub-fringing mangroves) under protected area management, managing fishing, and limiting tourism development in those habitats. Other interventions include mangrove conservation through planting and community-based mangrove forest management, blue carbon initiatives, and integrated coastal zone management (Carter et al., 2015; Song et al., 2021). A working example is the Busuanga Coastal Forest Project by the NGO, C3 Philippines, which rehabilitated and protected a total of 1,652.2 hectares of mangrove forests through successful community engagement in 2018.

Scaling up from community-level analyses with context-specific criteria, we can link local to global benefits. In Busuanga Island, Philippines, it appears that blue carbon ecosystems are healthy, and socio-economic conditions are medium, while the nearshore fisheries and governance criteria need improvement. It would be useful to compare the lessons learned in Busuanga to other sites in the coral triangle that may not have such healthy blue carbon ecosystems.

Overall, we found blue carbon ecosystem service provision depends on the socio-economic and environmental context. Reliance on blue carbon ecosystems for provisioning services occurred in both rural and urban settings, and diversified income across all sites has shown to be a pervasive and successful livelihood strategy. Since reliance on provisioning services of blue carbon ecosystems was ubiquitous across sites, maintaining healthy habitats are crucial to continuing these fisheries, but efforts must be made to negotiate equitable fisheries management. Using a vulnerability framework to compare coastal communities enabled us to find opportunities for potential conservation interventions that are applicable to local conditions.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

TQ, MN, and KS designed the study. TQ analyzed the vulnerability data and wrote the manuscript. TQ, MN, RR, HG, and MS collected the data in the field. TQ, HG, and MS designed the landing surveys, fisher interviews and household surveys. HG and MS translated the surveys. KS analyzed the spatial data. ABa, ABl, AT, and KN provided the remote sensing data sets. MN, KS, RR, ABa, ABl, AT, and KN helped improve the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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REFERENCES

Abrenica, M. A., Ilagan, G. A., Liuag, H. L., Napeñas, A., Tabion, R. A., and Tamina, R. C. (2013). *Municipality of Coron ECAN Resource Management Plan* 2017-2022. Available online at: https://pcsd.gov.ph/wp-content/uploads/2020/12/06.-Coron-ECAN-Resource-Management-Plan.pdf

Allison, E. H., Perry, A. L., Badjeck, M. C., Neil Adger, W., Brown, K., Conway, D., et al. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish Fish.* 10, 173–196. doi: 10.1111/j.1467-2979.2008.00310.x Available online at: https://pcsd.gov.ph/wp-content/uploads/2020/12/06.-Coron-ECAN-Resource-Management-Plan.pdf

Arias-Ortiz, A., Serrano, O., Masqué, P., Lavery, P. S., Mueller, U., Kendrick, G. A., et al. (2018). A marine heatwave drives massive losses from the world's largest seagrass carbon stocks. *Nat. Clim. Change* 8, 338–344. doi: 10.1038/s41558-018-0096-y

Baker, J. L. (ed.) (2012). *Climate Change, Disaster Risk, and the Urban Poor, Cities Building Resilience for a Changing World*. Washington, DC: The World Bank, 297.

Baloloy, A. B., Blanco, A. C., Raymund Rhommel, R. R. C., and Nadaoka, K. (2020). Development and application of a new mangrove vegetation index (MVI) for rapid and accurate mangrove mapping. *ISPRS J. Photogramm. Remote Sens.* 166, 95–117. doi: 10.1016/j.isprsjprs.2020.06.001

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., and Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* 81, 169–193. doi: 10.1890/10-1510.1

Bautista, M. A., Malolos, G. A., Magyaya, A., Palevino, M. L., and Suarez, M. (2017). *Municipality of Busuanga ECAN Resource Management Plan 2017-2022. Partnership With Municipal Government of Busuanga, Municipal ECAN Board, Palawan Council for Sustainable Development*. Available online at: https://pcsd.gov.ph/2020/12/11/07-busuanga-ecan-resource-management-plan/ (accessed December 24, 2020).

Beitl, C. M. (2015). Mobility in the mangroves: catch rates, daily decisions, and dynamics of artisanal fishing in a coastal commons. *Appl. Geogr.* 59, 98–106. doi: 10.1016/j.apgeog.2014.12.008

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., et al. (2016). Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World Dev.* 79, 177–196. doi: 10.1016/j.worlddev.2015.11.007

Berkes, F., Robin, M., McConney, P., Pollnac, R., and Pomeroy, R. (2001). *Managing Small-Scale Fisheries-Alternative Directions and Methods*. Ottawa: International Development Research Centre.Google Scholar.

Birkmann, J., Garschagen, M., Mucke, P., Schauder, A., Seibert, T., Welle, T., et al. (2014). *World Risk Report 2014*. Berlin: Institute for Environment and Human Security (UNU-EHS).

Bjork, M., Short, F., Mcleod, E., and Beer, S. (2008). *Managing Seagrasses for Resilience to Climate Change*. Gland: IUCN.

Blanco, A. C., Tamondong, A., Tagle, E., Fortes, M., and Nadaoka, K. (2014). "Change in seagrass fractional cover in Bolinao and Anda, Philippines derived from Landsat 2riori," in *35th Asian Conference on Remote Sensing 2014, ACRS 2014: Sensing for Reintegration of Societies*, Nay Pyi Taw.

Buckle, P., Marsh, G., and Smale, S. (2001). *Assessment of Personal and Community Resilience and Vulnerability. Report: EMA Project 15/2000*. Available online at: http://www.Radixonline.org/resources/assessment-of-personal-and-community-resilience.pdf. (accessed January 6, 2021).

Carter, H. N., Schmidt, S. W., and Hirons, A. C. (2015). An international assessment of mangrove management: incorporation in integrated coastal zone management. *Diversity* 7, 74–104. doi: 10.3390/d7020074

Cinner, J. E., McClanahan, T. R., Daw, T. M., Graham, N. A. J., Maina, J., Wilson, S. K., et al. (2009). Linking social and ecological systems to sustain coral reef fisheries. *Curr. Biol.* 19, 206–212. doi: 10.1016/j.cub.2008.11.055

Crooks, S., Orr, M., Emmer, I., von Unger, M., Brown, B., and Murdiyarso, D. (2014). *Guiding Principles for Delivering Coastal Wetland Carbon Projects*. Nairobi: UNEP and CIFOR, 57.

Cullen-Unsworth, L. C., Nordlund, L. M., Paddock, J., Baker, S., McKenzie, L. J., and Unsworth, R. K. F. (2014). Seagrass meadows globally as a coupled social-ecological system: implications for human wellbeing. *Mar. Pollut. Bull.* 83, 387–397. doi: 10.1016/j.marpolbul.2013.06.001

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., et al. (2008). A place-based model for understanding community resilience to natural disasters. *Glob. Environ. Chang.* 18, 598–606. doi: 10.1016/j.gloenvcha.2008.07.013

de la Torre-Castro, M., Di Carlo, G., and Jiddawi, N. S. (2014). Seagrass importance for a small-scale fishery in the tropics: the need for seascape management. *Mar. Pollut. Bull.* 83, 398–407. doi: 10.1016/j.marpolbul.2014.03.034

De La Torre-Castro, M., and Rönnbäck, P. (2004). Links between humans and seagrasses – An example from tropical East Africa. *Ocean Coast. Manag.* 47, 361–387. doi: 10.1016/j.ocecoaman.2004.07.005

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., and Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* 4, 293–297. doi: 10.1038/ngeo1123

Ekstrom, J. A., Suatoni, L., Cooley, S. R., Pendleton, L. H., Waldbusser, G. G., Cinner, J. E., et al. (2015). Vulnerability and adaptation of US shellfisheries to ocean acidification. *Nat. Clim. Chang.* 5, 207–214. doi: 10.1038/nclimate2508

Ellison, J. C. (2015). Vulnerability assessment of mangroves to climate change and sea-level rise impacts. *Wetl. Ecol. Manag.* 23, 115–137. doi: 10.1007/s11273-014-9397-8

Fabinyi, M. (2010). The intensification of fishing and the rise of tourism: competing coastal livelihoods in the Calamianes Islands. *Philippines. Hum. Ecol.* 38, 415–427. doi: 10.1007/s10745-010-9329-z

FAO (2007). *The World's Mangroves 1980-2005*. Rome: Food and Agriculture Organization, 77. FAO Forestry Paper 153.

FAO (2016). *The State of World Fisheries and Aquaculture 2016. Contributing to Food Security and Nutrition for All*. Rome: FAO, 200.

FAO, and WFP (2009). *The State of Food Insecurity in the World. Economic Crises – Impacts and Lessons Learned*. Rome: FAO.

Fortes, M. D., Ooi, J. L. S., Tan, Y. M., Prathep, A., Bujang, J. S., and Yaakub, S. M. (2018). Seagrass in Southeast Asia: a review of status and knowledge gaps, and a road map for conservation. *Bot. Mar.* 61, 269–288. doi: 10.1515/bot-2018-0008

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., et al. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nat. Geosci.* 5, 505–509. doi: 10.1038/ngeo1477

Goldberg, L., Lagomasino, D., Thomas, N., and Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Glob. Chang. Biol.* 26, 5844–5855. doi: 10.1111/gcb.15275

Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., et al. (2012). A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. *Environ. Res. Lett.* 7:024006. doi: 10.1088/1748-9326/7/2/024006

Green, E., and Short, F. (eds) (2003). *World Atlas of Seagrasses*. Berkeley, CA: University of California Press.

Green, S. J., White, A. T., Flores, J. O., Carreon, M. F. III, and Sia, A. E. (2003). "Philippine fisheries in crisis: A framework for management," in *Coastal Resource Management Project of the Department of Environment and Natural Resources*, Cebu City, 77.

Howard, J., Sutton-Grier, A., Herr, D., Kleypas, J., Landis, E., Mcleod, E., et al. (2014). Clarifying the role of coastal and marine systems in climate mitigation. *Front. Ecol. Environ.* 15:42–50. doi: 10.1002/fee.1451

Huxham, M., Whitlock, D., Githaiga, M., and Dencer-Brown, A. (2018). Carbon in the coastal seascape: how interactions between mangrove forests, seagrass meadows and tidal marshes influence carbon storage. *Curr. For. Rep.* 4, 101–110. doi: 10.1007/s40725-018-0077-4

Indo-Pacific Seagrass Network (IPSN). (2021). *Indo-Pacific Seagrass Network*. Avaliable online at: https://indopacificseagrass.network/ (accessed February 19, 2021).

IPCC (2012). "Managing the risks of extreme events and disasters to advance climate change adaptation," in *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, eds C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, et al. (Cambridge: Cambridge University Press), 582.

Jacinto, M. R., Songcuan, A. J. G., Von Yip, G., and Santos, M. D. (2015). Development and application of the fisheries vulnerability assessment tool (Fish Vool) to tuna and sardine sectors in the Philippines. *Fish. Res.* 161, 174–181. doi: 10.1016/j.fishres.2014.07.007

Jentoft, S. (2014). Walking the talk: implementing the international voluntary guidelines for securing sustainable small-scale fisheries. *Marit. Stud.* 13, 1–15. doi: 10.1186/s40152-014-0016-3

Licuanan, W. Y., Samson, M. S., Mamauag, S. S., David, L. T., Borja-del Rosario, R., Quibilan, M. C. C., et al. (2015). I-C-SEA Change: a participatory tool for rapid assessment of vulnerability of tropical coastal communities to climate change impacts. *Ambio* 44, 718–736. doi: 10.1007/s13280-015-0652-x

Long, J., Napton, D., Giri, C., and Graesser, J. (2014). A mapping and monitoring assessment of the Philippines' Mangrove forests from 1990 to 2010. *J. Coast. Res.* 30, 260–271. doi: 10.2112/JCOASTRES-D-13-00057.1

Mamauag, S. S., Aliño, P. M., Gonzales, R. O. M., and Deocadez, M. R. (2009). Patterns of demersal fish distribution derived from line fishing experiment in Calauag Bay, Philippines. *Philipp. Agric. Sci.* 92, 370–387.

Mamauag, S. S., Alino, P. M., Martinez, R. J. S., Muallil, R. N., Doctor, M. V. A., Dizon, E. C., et al. (2013). A framework for vulnerability assessment of coastal fisheries ecosystems to climate change — Tool for. *Fish. Res.* 147, 381–393. doi: 10.1016/j.fishres.2013.07.007

McClanahan, T. R., Castilla, J. C., White, A. T., and Defeo, O. (2009). Healing small-scale fisheries by facilitating complex socio-ecological systems. *Rev. Fish Biol. Fish.* 19, 33–47. doi: 10.1007/s11160-008-9088-8

McKenzie, L. J., and Campbell, S. J. (2002). "Seagrass-Watch," in *Manual for Community (citizen) Monitoring of Seagrass Habitat*, eds L. J. McKenzie and S. J. Campbell (Queensland: Department of Primary Industries Queensland), 43. Western Pacific Edition (QFS, NFC, Cairns).

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front. Ecol. Environ.* 9:552–560. doi: 10.1890/110004

McLeod, E., and Salm, R. V. (2006). *Managing Mangroves for Resilience to Climate Change*. Gland: IUCN, 64.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Synthesis*. Washington, DC: Island Press.

Mironenko, O., Lucas, P. L., Tarasova, N., and Zlinszky, J. (2015). Sustainable development goals: why do we need them? *Soc. Evol. Hist.* 14, 176–190.

Muallil, R. N., Geronimo, R. C., Cleland, D., Cabral, R. B., Doctor, M. V., Cruz-Trinidad, A., et al. (2011). Willingness to exit the artisanal fishery as a response to scenarios of declining catch or increasing monetary incentives. *Fish. Res.* 111, 74–81. doi: 10.1016/j.fishres.2011.06.013

Nordlund, L. M., Unsworth, R. K. F., Gullström, M., and Cullen-Unsworth, L. C. (2018). Global significance of seagrass fishery activity. *Fish Fish.* 19, 399–412. doi: 10.1111/faf.12259

Orencio, P. M., and Fujii, M. (2013). An index to determine vulnerability of communities in a coastal zone: a case study of baler. Aurora, Philippines. *Ambio* 42, 61–71. doi: 10.1007/s13280-012-0331-0

Pauly, D. (1997). "Small-scale fisheries in the tropics: marginality, rioritizingon, and some implications for fisheries management," in *Global Trends: Fisheries Management: American Fisheries Society Symposium 20*, eds E. K. Pikitch, D. D. Huppert, and M. P. Sissenwine (Bethesda, MA).

PCSD (2006). *In-Depth Coastal/Marine Resources Survey Report for Busuanga Municipality*. Puerto Princesa City: Palawan Council for Sustainable Development.

Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., et al. (2012). Estimating Global "Blue Carbon" emissions from conversion and degradation of vegetated coastal ecosystems. *PLoS One* 7:e0043542. doi: 10.1371/journal.pone.0043542

Plan Vivo (2015). *Mikoko Pamoja*. Edinburgh: Plan Vivo Foundation.

Pollnac, R. B., and Crawford, B. R. (2000). *Discovering Factors that Influence the Success of Community-Based Marine Protected Areas in the Visayas, Philippines*. Narragansett, RI: University of Rhode Island. Coastal Management Report # 2229. PCAMRD Book Series No. 33.

Quevedo, J. M. D., Uchiyama, Y., and Kohsaka, R. (2021). Linking blue carbon ecosystems with sustainable tourism: dichotomy of urban–rural local perspectives from the Philippines. *Reg. Stud. Mar. Sci.* 45:101820. doi: 10.1016/j.rsma.2021.101820

Quiros, T., Croll, D. A., Tershy, B. R., Fortes, M. D., and Raimondi, P. (2017). Land use is a better predictor of tropical seagrass condition than marine protection. *Biol. Conserv.* 209, 454–463.

Quiros, T. E. A. L., Beck, M. W., Araw, A., Croll, D. A., and Tershy, B. (2018). Small-scale seagrass fisheries can reduce social vulnerability?: A comparative case study. *Ocean Coast. Manag.* 157, 56–67. doi: 10.1016/j.ocecoaman.2018.02.003

Shah, K., Gupta, V., and Boyd, C. (2000). Tourism, the poor and other stakeholders: Experience in Asia. Overseas Development Institute. Fair Trade in Tourism Project. London, UK. 57. Available online at: https://odi.org/en/publications/tourism-the-poor-and-other-stakeholders-experience-in-asia/ (accessed December 24, 2020).

Siegel, K. J., Cabral, R. B., McHenry, J., Ojea, E., Owashi, B., and Lester, S. E. (2019). Sovereign states in the Caribbean have lower social-ecological vulnerability to coral bleaching than overseas territories. *Proc. R. Soc. B Biol. Sci.* 286:20182365. doi: 10.1098/rspb.2018.2365

Song, A. M., Dressler, W. H., Satizábal, P., and Fabinyi, M. (2021). From conversion to conservation to carbon: the changing policy discourse on mangrove governance and use in the Philippines. *J. Rural Stud.* 82, 184–195. doi: 10.1016/j.jrurstud.2021.01.008

Spalding, M., Kainuma, M., and Collins, L. (2010). *World Atlas of Mangroves*. London: Earthscan, 319.

Stankovic, M., Ambo-Rappe, R., Carly, F., Dangan-Galon, F., Fortes, M. D., Hossain, M. S., et al. (2021). Quantification of blue carbon in seagrass ecosystems of Southeast Asia and their potential for climate change mitigation. *Sci. Total Environ.* 783:146858. doi: 10.1016/j.scitotenv.2021.146858

Sudo, K., Quiros, T. E. A. L., Prathep, A., Luong, C. V., Lin, H.-J., Bujang, J. S., et al. (2021). Recent distribution, temporal change and conservation status of tropical seagrass beds in southeast Asia. *Front. Mar. Sci.* 8:637722. doi: 10.3389/fmars.2021.637722

Tamondong, A., Nakamura, T., Quiros, T. E. A., and Nadaoka, K. (2021). Time series analysis for monitoring seagrass habitat and environment in busuanga, Philippines using google earth engine. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* XLIII-B3-2021, 109–116. doi: 10.5194/isprs-archives-XLIII-B3-2021-109-2021

Tan, Y. M., Saunders, J. E., and Yaakub, S. M. (2018). A proposed decision support tool for rioritizing conservation planning of Southeast Asian seagrass meadows: combined approaches based on ecosystem services and vulnerability analyses. *Bot. Mar.* 61, 305–320. doi: 10.1515/bot-2017-0117

Thorhaug, A., Gallagher, J. B., Kiswara, W., Prathep, A., Huang, X., Yap, T. K., et al. (2020). Coastal and estuarine blue carbon stocks in the greater Southeast Asia region: seagrasses and mangroves per nation and sum of total. *Mar. Pollut. Bull.* 160:111168. doi: 10.1016/j.marpolbul.2020.111168

UNEP (2014). *The Importance of Mangroves to People: A Call to Action*, eds J. van Bochove, E. Sullivan, and T. Nakamura (Cambridge: United Nations Environment Programme World Conservation Monitoring Centre), pp 128.

UNEP-WCMC, WorldFish Centre, WRI, and TNC (2018). *Global Distribution of Warm-Water Coral Reefs, Compiled From Multiple Sources Including the Millennium Coral Reef Mapping Project. Version 4.0. Includes contributions from ImaRS-USF and IRD (2005), ImaRS-USF (2005) and Spalding et al. (2001). Cambridge (UK): UN Environment World Conservation Monitoring Centre*. Avaliable online at: http://data.unep-wcmc.org/datasets/1 (accessed February 18, 2021).

United Nations Environment Programme (UNEP) (2020). *Out of the Blue: The Value of Seagrasses to the Environment and to People*. Nairobi: UNEP.

Unsworth, R. K. F., Nordlund, L. M., and Cullen-Unsworth, L. C. (2018). Seagrass meadows support global fisheries production. *Conserv. Lett.* 12:e12566. doi: 10.1111/conl.12566

Valiela, I., Bowen, J. L., and York, J. K. (2001). Mangrove forests: one of the World's threatened major tropical environments. *Bioscience* 51, 807–815.

Veettil, B. K., Ward, R. D., Lima, M. D. A. C., Stankovic, M., Hoai, P. N., and Quang, N. X. (2020). Opportunities for seagrass research derived from remote sensing: a review of current methods. *Ecol. Indic.* 117:106560. doi: 10.1016/j.ecolind.2020.106560

Waycott, M., Collier, C., Mcmahon, K., Ralph, P., McKenzie, L., Udy, J., et al. (2007). *Vulnerability of Seagrasses in the Great Barrier Reef to Climate Change*. Joondalup WA: ECU Publications.

Waycott, M., Duarte, C. M., Carruthers, T. J. B., Orth, R. J., Dennison, W. C., Olyarnik, S., et al. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc. Natl. Acad. Sci. U.S.A.* 106, 12377–12381. doi: 10.1073/pnas.0905620106

Wylie, L., Sutton-Grier, A. E., and Moore, A. (2016). Keys to successful blue carbon projects?: lessons learned from global case studies. *Mar. Policy* 65, 76–84. doi: 10.1016/j.marpol.2015.12.020

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Confronting Complex Accountability in Conservation With Communities

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Increasingly, conservation organizations are conducting conservation activities with local communities. Many conservation organizations now position their work as contributing to sustainable development initiatives, and local involvement in conservation is understood to increase conservation and sustainability success. Aside from communities, however, conservation organizations are accountable to funders and partners, and values and priorities vary across actor type. Mismatched goals combine with power imbalances between conservation actors, and create decision-making conflict throughout conservation processes, from objective setting through implementation and evaluation. As a result, communities may lose local decision-making power or face new negative consequences, trust in organizational/community partnerships may be undermined, and conservation organizations' reputations (and the reputation of the sector as whole) may suffer. In this commentary we point out processes and conditions that can lead conservation organizations to privilege accountability to funders and others over accountability to communities, thereby undermining community-level success. We follow with suggestions for how funders, conservation organizations and others may improve community engagement and community-level outcomes, and improve their reputations in general and in their work with communities, by actively leveraging accountability to the community and involving local community members in decision-making.

Keywords: NGOs, accountability, local communities, sustainable development, community based conservation

INTRODUCTION

Conservation organizations – from large, international household-name non-profits to smaller, local ones – are ubiquitous educators, catalysts, facilitators, funders/funding conduits, and evaluators in community-based conservation schemes (see, for example, Austin and Eder, 2007; Aswani et al., 2012; Benson, 2012; Brooks et al., 2013; Cohen et al., 2015). Such organizations frame this work as led by, co-created with, or responsive to local communities. Scholars of marine conservation and management also see conservation organizations as advocates for and champions of local communities (see, for example, Agardy, 2011). However, both empirical evidence (Cinner et al., 2009; Aswani et al., 2012; Benson, 2012) and theories of non-governmental organizations (NGOs) raise questions about whether – in the face of the other forces at play in these processes – community needs and preferences are indeed addressed when conservation organizations engage locally.

In addition to the normative motivations reflected in their mission and vision statements, conservation organizations act in response to externally driven strategic and instrumental concerns (Yanacopulos, 2016), including needs to secure and maintain organizational funding and legitimacy (Prakash and Gugerty, 2010; Steffek and Hahn, 2010; Lang, 2013; Edwards, 2014). The larger institutional contexts within which NGOs operate, including funding structures, external governance, and interactions with peer organizations, thus influence conservation organizations' goals, strategies, and activities. Most saliently, those institutional contexts create complex and competing accountabilities (Balboa, 2018) which may hinder conservation success, defined as both benefits to target communities and successful protection of species and natural habitats. Specifically, conservation organizations face clearly defined, predictably structured upward accountabilities to funders and host governments. These accountabilities are laid out in contracts, legislation, and project objectives, and meeting them is necessary to immediate NGO survival. Downward accountabilities to local communities, in contrast, are more diffuse and changeable, less binding, riddled with uncertainties about the roles of different players and groups, and not tied to funding. As a result, NGOs prioritize upward accountability to funders over downward accountability to communities (Balboa, 2018). In Papua New Guinea, for example, funder-driven pressures to report successful coastal management led a conservation organization to downplay non-compliance and other challenges in both their upward reporting and as foci of project implementation, while dismissing clearly articulated community needs as unmanageable (Benson, 2012).

The literature dealing specifically with conservation organizations' involvement in conservation with communities is sparse and fragmented; indeed, Brooks et al.'s (2013) systematic review of outcomes across 136 community-based conservation projects omitted NGOs as an explanatory variable, despite the authors' initial interest, as the data were too sparse to support analysis. More generally, the increased attention given to the practice of "parachute science" – higher-income country researchers conducting field research in lower-income settings, with little to minimal engagement with host communities (Stefanoudis et al., 2021) – is salient here. Even conservation organizations that are deeply in embedded local contexts may still rely on Western scientific experts to identify and plan interventions. Work on parachute science shows that such reliance can (1) delegitimatize expert local knowledge by supplanting it with scientific "discovery" (West, 2016), and (2) create dependency on international expertise when institutions are primed to look to external researchers rather than locals, thus further limiting local capacity development (Stefanoudis et al., 2021).

This perspective contributes by synthesizing well-developed contemporary theories of NGOs and case studies of conservation with communities, in order to illuminate the structures of, and issues that arise from, the conflicting accountabilities operating in this field.

CONSERVATION ORGANIZATIONS AND COMPLEX ACCOUNTABILITY

Conservation organizations operate within networks of actors that span levels and scales, including, but not limited to, funders (e.g., private foundations, international aid agencies), government agencies and decision-makers (national, regional and local), other non-profits (conservation-oriented as well as those with other central concerns, operating at scales from international to local), and resource users (communities of place, cooperatives, etc.). Alcorn (2005) paints interactions within these networks as a masquerade ball at which Big Conservation (conservation organizations, first and foremost large international conservation NGOs) and Little Conservation (local users and communities) share a dance. In this scenario, while Little Conservation wonders what to make of the intent and promises of their new partner, Big Conservation is already beholden to others in the room – notably, government and funders (Alcorn, 2005).

Until now, we have been using NGO as a blanket term that captures all non-governmental, non-private sector bodies. However, in general, and in agreement with theoretical work on NGOs that recognizes the same division (Castells, 2008), the literature on conservation with communities commonly treats large, international conservation NGOs as distinct from local NGOs. To some extent, this differential treatment seems grounded in normative stances on the appropriate role for civil society in conservation and development, particularly issues arising from large, Global Northern NGOs' intervention in developing-world contexts and resulting questions of equity, representativeness, and power (e.g., Chapin, 2004). Below we highlight this distinction as needed.

Large Funders' Role in Furthering Short-Terms Outputs Versus Long-Term Outcomes

Conservation organizations require funding to survive. NGOs rely on limited funds from donors and must compete with other NGOs for that funding (Prakash and Gugerty, 2010; Schmitz et al., 2010), making donor goodwill – and especially the goodwill of large funders, including intergovernmental organizations such as the Word Bank, national development agencies such as USAID, and private foundations – necessary for organizational survival. Perhaps unsurprisingly, conservation NGOs have been shown to bound and focus work in conservation and development in response to large donors' preferences (e.g., Bebbington, 2005; Benson, 2012; Aldashev and Vallino, 2019). The need to maintain funder goodwill, combined with funder preferences and reinforced by funders' administrative requirements (including those designed to enhance accountability), pressure conservation organizations to prioritize upward accountability to donors (Steffek and Hahn, 2010). In particular, donor preferences for narratives of success and projects that follow pre-defined forms are a significant driver of NGO activity, and the proliferation of project-based approaches (Krause, 2014) to conservation with communities.

Projects are limited-term, well-defined interventions with set inputs and specific, predefined outputs (Krause, 2014). Scholars of conservation with communities have observed the project focus in practice (e.g., Blaikie, 2006), including a preference for measuring and reporting short-term outputs (such as number of marine protected areas created) rather than long-term outcomes of conservation and management (MPA implementation; socioeconomic and ecological impact) (Benson, 2012). The focus on donor-approved outputs rather than context-specific outcomes can lead organizations to game metrics, maximizing the former while underdelivering the latter (often understood as Goodhart's law: when a measure becomes a target, it ceases to be a good measure) (Strathern, 1997). Furthermore, a project focus restricts NGO engagement time frames, limiting full dissemination of the organization's technical expertise and potentially undermining conservation where ongoing expertise is required (Cinner et al., 2009). Short time frames, combined with a preference for easily tracked and reported metrics, also create challenges for full engagement with the complex and often conflicting needs and preferences of local communities. Indeed, a focus on projects may contribute to proliferation of formulaic approaches not sensitive to local context, as well as devotion to donor-defined metrics of success that are at best of little interest to local communities and at worst conflict with community understandings of success (Benson, 2012).

Pre-defined approaches to "community engagement" are one example of how prioritizing easy metrics and outputs can lead to negative consequences. In the interest of creating accountability, donors increasingly require specific approaches to or demonstrations of "community engagement" or "participation." However, where donors define working with existing local power structures as community engagement, or where NGOs themselves engage this way for utilitarian reasons, NGOs will be engaging primarily with traditional elites or local leaders. If those leaders are themselves unaccountable to the larger community, or if they are able to capture the benefits of NGO engagement or conservation and development for themselves (Christie, 2004), they may be less interested in supporting NGO delivery of an "inclusive" or "democratic" process. Thus elite mediation of downward accountability creates additional challenges for even well-intentioned NGOs. At the same time, however, undefined requirements for "participation" may result in little more than box-ticking by funded organizations. Where "participation" is left undefined, it may be construed in ways that give local communities little to no power: for example, as participation in implementing pre-defined projects, or as non-binding "consultation" during decision-making processes.

National- or local-level NGOs that rely on transnational NGOs for funding are subject to similar funding-related pressures, as transnational NGOs transmit the funding-related pressures they experience to the organizations they themselves fund. However, national or local NGOs that source funding from more proximate sources may be better placed to respond to community-level preferences and concerns. Austin and Eder (2007), for instance, attribute marine management project success in the Philippines in part to the involvement of local NGOs that are not overly beholden to funding from transnational NGOs or large international funders.

NGO Accountability and Government-Related Tensions

Conservation organizations are accountable to the governments, laws, and regulations of the states in which they work. Over the past two decades, states concerned about NGO accountability have tightened their laws in order to reduce potential influence of foreign interests (i.e., NGOs as "foreign agents"). These states are in some cases responding to unwelcome domestic politicization of environmental conservation, and the possibility that NGOs may create unaccountable parallel governance structures to administer and manage conservation projects. This is especially the case in so-called "weak states," which face gaps in their capacity to govern as well as in the legitimacy and security of their governance efforts (Brechin and Salas, 2011). Weak governments lead to decreased accountability of NGOs to the state, which may complicate accountability to local communities by obscuring and complicating both the objects and the subjects of accountability. Related issues vary from a state's inability to deliver services (Markham and Fonjong, 2016), and local community expectations that NGOs will fill the gap (Benson, 2012; Aldashev and Vallino, 2019), to a lack of transparency in which power structures the NGO should be accountable to (e.g., tribal rulers set the terms of engagement in addition to the formal government) (Markham and Fonjong, 2016). Accountability tensions in conservation projects might also arise from conflicting priorities between national and or local-level policy goals and needs. This may be the case, for example, where adherence to specific bureaucratic structures underpins formal, national-level recognition of community conservation, but associated requirements run counter to local community preferences. In Madagascar, where NGOs helped coastal community conservation initiatives to organize according to state mandated bureaucratic forms, some Malagasy communities who preferred temporary/rotating area closures to the permanent closures required by formal processes opted out of the project (Cinner et al., 2009).

Organizational Fields Transmit and Replicate Accountability Pressures

Organizational theory (e.g., DiMaggio and Powell, 1983) understands NGOs as operating within fields of similar organizations, all of which face uncertainty in navigating their environments and seek legitimacy in the eyes of their peers. Legitimacy-seeking creates isomorphic pressures that move organizations toward standard forms (DiMaggio and Powell, 1983). In the non-profit world, this process has been termed NGOization: NGOs evolve away from loose, voluntary confederacies and toward professional, hierarchically structured organizations (Lang, 2013). NGOization results in increased legitimacy within the organizational field, hence an improved ability to interact with donors and government (and receive the benefits of those interactions), but may also result in challenges to NGOs' ability to inclusively engage with or represent constituent voices (Lang, 2013). National or local conservation organizations that receive financial or personnel resources from large NGOs take on the organizational forms of their funding conduits, adopting similar hierarchical structures, rhetoric, and practices.

In turn, those national- or local-level NGOs are better able to demonstrate their legitimacy in international conservation-with-communities conversations; they become more attractive to funders and are better able to meet donor requirements that accompany funding. Such transformation may be accompanied by the creation of new elites within an organization, the simplification and repackaging of complex issues, and the marginalization of community interests that do not fit neatly within new structures and practices (e.g., Saruchera, 2004).

Moreover, NGOs and others that seek to engage with a community may preferentially seek cooperation with organizational forms that are familiar and perceived as legitimate. This may result in a proliferation of local NGOs or community-based organizations that act as the local point of contact but disempower actual communities. In the Philippines, for example: "Community participation is formalized by the establishment of a [formal] association…which serves as a proxy for 'community' interests. Through establishing a legal and financial 'identity,' these organizations participate by being conduits for international resources nominally targeted at increasing community participation in natural resource management, but, in practice, avenues for community participation are quite limited" (Selfa and Endter-Wada, 2008, p. 958).

Hierarchical organizational forms may also hinder downward accountability by diminishing the voices of the field staff who work most closely with communities. Central office staff sometimes hold less nuanced or sympathetic views of the communities they serve than the field staff who more regularly engage with those communities (Crosman, 2019). Where internal decision making and programmatic priorities are subject to internal hierarchies, central office staff hold responsibility for setting agendas, prioritizing approaches, and determining metrics of success. In such cases, field staff who are deeply invested in downward accountability may find their reflection of community voices diluted as it is passed upward. Indeed, relying on existing hierarchies, both those within funded organizations and those within local communities, to accurately transmit and accomplish the work, and report success, may diminish the voices of those with the most specialized expertise and the most salient lived experience.

Furthering Perceptions of Communities' Powerlessness and Dependency

Non-governmental organization rhetoric constructs target communities as dependents in need of aid (environmental education, capacity building, ecosystem restoration projects, technical support), reinforcing belief in communities' relative powerlessness on both sides (see Ingram et al., 2007). Conversely, NGOs are framed as powerful actors with largesse to distribute. To some extent, this dynamic is an accurate reflection of power realities: maintaining positive NGO relations can connect communities with resources that they would otherwise lack (Murtaza, 2012), from information to development aid (*via* NGOs themselves or NGO-mediated connections to funders and other organizations) (Crosman, 2019). However, NGOs also often depend on local knowledge and problem-solving capacity to accomplish their work.

Rhetorical claims that benefits from NGO engagement accrue primarily to local communities further reinforce the belief that communities should be grateful recipients rather than full partners in conservation. Such rhetoric obscures the benefits conservation organizations themselves derive from their work with communities, including claims of success that are necessary to maintain funding and legitimacy. That rhetoric also reinforces community dependence and undermines downward accountability. Unscrupulous organizations may thus encourage community dependence – or at least propagate narratives thereof – in order to advocate for continued funding while maintaining power hierarchies that meet organizational needs yet ignore community needs.

DISCUSSION: PATHWAYS FORWARD

Altering the dynamics outlined above will be challenging and require concerted effort from all groups of actors, not just conservation organizations. As the accountability issues outlined above are pressing, we here provide recommendations for each actor group. In light of the relative dearth of contemporary applied study of these issues, however, our recommendations should be coupled with the development and implementation of monitoring and evaluation schemes that focus specifically on conservation organizations' complex accountabilities and their effects. Funders and NGOs that embrace the frame of complex accountability, and commission independent, reflective evaluation of their own work, will be better placed to both implement and improve upon the recommendations offered below; academic researchers also have much to offer in this space. Analysis that focuses on both the issues outlined above and the strategies proposed below will lay the foundations for a better grounded understanding of existing accountability issues as well as contextually appropriate and effective correctives.

Given that funding structures create many of the organizational incentives facing NGOs, we begin with recommendations for funders.

Recommendations for funders:

- Create funding solicitation and reporting structures that circumvent existing hierarchies both between and within organizations and communities. Directly engage with proposed target communities during the funding proposal stage, and create reporting structures that are not mediated by NGOs, allowing community members to hold conservation organizations to account directly with funders. This will necessitate hiring program officers who are trained in conservation and community engagement.
- Make public accountability – broader public perceptions of legitimacy and salience of NGO activities – the strongest indicator of funding success and project implementation.
- Select additional measures of success that reflect outcomes and impacts (such as wellbeing metrics) rather than outputs (number of community consultation sessions). Such measures should be explicitly funded through grant line items.

- Reconsider project timelines, providing funding that targets ongoing activities such as provision of technical expertise, compliance monitoring, and ecological and socioeconomic data collection. Combine these with requirements for clear exit signals and strategies, to avoid long-term local dependence on NGOs.
- Enable learning and adaptive management within a single funding cycle. Longer-term funding should be fungible rather than rigidly tied to specific activities or outputs so that longer-term needs may be addressed as they arise.
- Move away from over- and under-defined requirements for preferred approaches (e.g., "participation") or programmatic priorities (e.g., "capacity building"). Accept a range of approaches, requiring that they are demonstrably appropriate to the local context and meet the salient intention.

Recommendations for international or national NGOs:

- Diversify funding sources. Seek funding from multiple types of funders as well as from a variety of large funders.
- Bring communities in early (i.e., at the proposal formulation phase) and give them meaningful voice and decision-making power throughout conservation processes. Treat communities as respected equal partners in both actions and rhetoric.
- Pay attention to community non-homogeneity and seek the full range of local input when engaging in consultative and participatory processes.
- Create operational structures that allow field staff influence over programmatic priorities and approaches, including grant proposals. Enable field staff to take an active role in ensuring downward accountability.
- Intentionally partner with and fund local organizations that do not conform to standard, hierarchical organizational forms. Enable these local organizations to take an active role in ensuring downward accountability.
- Be transparent with funders about the full suite of organizational and local needs, the insights, observations and specialist knowledge of organizational staff, and the constraints faced in working with local communities.
- Create voluntary federations of peer NGOs or use existing fora to develop standardized approaches for ensuring downward accountability, and to advocate for widespread acceptance of the importance of downward accountability among funders and government (Murtaza, 2012). Mechanisms might include, for example, enabling anonymous reports of accountability concerns at the peer-body level.

Recommendations for local NGOs:

- Be intentional about organizational form, and aware of its relationship to mission and vision. Resist inappropriate pressure to professionalize and/or reconstitute according to "standard" hierarchical structures, as these may undermine organizational mission or lead to local loss of legitimacy and relevance.
- Approach potential funding or partnership offers from larger organizations as a negotiation between equals rather than disbursement of conditional largesse.
- Advocate for downward accountability with funders, large NGOs, peers organizations, and local communities. Identify strategies to strengthen downward accountability (reporting structures, advisory boards, etc.) that are appropriate, workable and enforceable in the local context.

Recommendations for governments:

- Separate oversight of NGO community engagement from government/NGO partnerships.
- Create administrative requirements that enforce downward as well as upward accountability between all partners.
- Institutionalize accountability to larger publics beyond the directly involved and affected communities – for example, by way of regular and organized public discussion on conservation policy goals.

Recommendations for communities:

- Approach working with conservation organizations as a negotiation between equal partners rather than the receipt of conditional largesse. Advocate clearly and consistently for local needs and preferences.
- Insist on broad inclusion in conservation processes from initial planning to decision-making, and aim for consensus among heterogenous community members.
- Organize and share information with other communities who work with the same conservation organization and insist on downward accountability as a group (Murtaza, 2012).

As conservation organizations increasingly position the work they do as contributing to sustainable development, they will need to actively confront the charge laid out by Mac Chapin in 2004: that conservation groups and their funders face conflicts of interest that lead to negative outcomes for local people. Funders and NGOs should especially respond to the increased recent attention to equity issues in ocean development (Bennett et al., 2019), and just and sustainable transitions for oceans (Brodie Rudolph et al., 2020), in their work with coastal communities As they continue to benefit from local community cooperation, NGOs have the ongoing potential to contribute useful resources, skills, and support for local communities. But true partnership will require restructuring relationships based on upward, downward, and public accountability. For conservation to contribute to sustainable development it must do more than protect nature without concomitant concern for local people.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

KMC wrote the first draft of the manuscript. GGS and SL wrote sections of the manuscript. All authors contributed to the conceptualization of the manuscript and revision, read, and approved the submitted version.

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REFERENCES

Agardy, T. (2011). "Civil society and ecosystem-based fisheries management," in *Ecosystem-Based Management for Marine Fisheries: An Evolving Perspective*, eds A. Belgrano and C. W. Fowler (Cambridge, MA: Cambridge University Press).

Alcorn, J. B. (2005). "Dances around the Fire: conservation organizations and community-based natural resource management," in *Communities and Conservation*, Vol. 1, eds J. P. Brosius, A. L. Tsing, and C. Zerner (Lanham: AltaMira Press), 37–68.

Aldashev, G., and Vallino, E. (2019). The dilemma of NGOs and participatory conservation. *World Dev.* 123:104615. doi: 10.1016/j.worlddev.2019.104615

Aswani, S., Christie, P., Muthiga, N. A., Mahon, R., Primavera, J. H., Cramer, L. A., et al. (2012). The way forward with ecosystem-based management in tropical contexts: reconciling with existing management systems. *Mar, Policy* 36, 1–10.

Austin, R. L., and Eder, J. F. (2007). Environmentalism, Development, and participation on Palawan Island, Philippines. *Soc. Nat. Resour.* 20, 363–371.

Balboa, C. M. (2018). *The Paradox of Scale: How NGOs Build, Maintain, and Lose Authority in Environmental Governance*. Cambridge, MA: MIT Press.

Bebbington, A. (2005). Donor–NGO relations and representations of livelihood in nongovernmental aid chains. *World Dev.* 33, 937–950.

Bennett, N. J., Cisneros-Montemayor, A. M., Blythe, J., Silver, J. J., Singh, G., Andrews, N., et al. (2019). Towards a sustainable and equitable blue economy. *Nat. Sust.* 2, 991–993.

Benson, C. (2012). Conservation NGOs in Madang, Papua New Guinea: understanding community and donor expectations. *Soc. Nat. Resour.* 25, 71–86.

Blaikie, P. (2006). Is small really beautiful? Community-based natural resource management in Malawi and Botswana. *World Dev.* 34, 1942–1957.

Brechin, S. R., and Salas, O. (2011). Government-NGO networks & nature conservation in belize: examining the theory of the hollow state in a developing country context. *J. Nat. Resour. Policy Res.* 3, 263–274.

Brodie Rudolph, T., Ruckelshaus, M., Swilling, M., Allison, E. H., Österblom, H., Gelcich, S., et al. (2020). A transition to sustainable ocean governance. *Nat. Commun.* 11:3600. doi: 10.1038/s41467-020-17410-2

Brooks, J., Waylen, K. A., and Mulder, M. B. (2013). Assessing community-based conservation projects: a systematic review and multilevel analysis of attitudinal, behavioral, ecological, and economic outcomes. *Environ. Evid.* 2:2.

Castells, M. (2008). The new public sphere: global civil society, communication Networks, and Global Governance. *Ann. Am. Acad. Polit. Soc. Sci.* 616, 78–93. doi: 10.1177/0002716207311877

Chapin, M. (2004). *A Challenge to Conservationists*. Washington, DC: World Watch.

Christie, P. (2004). Marine protected areas as biological successes and social failures in Southeast Asia. *Am. Fish. Soc. Symp.* 42, 155–164.

Cinner, J. E., Wamukota, A., Randriamahazo, H., and Rabearisoa, A. (2009). Toward institutions for community-based management of inshore marine resources in the Western Indian Ocean. *Mar. Policy* 33, 489–496.

Cohen, P., Evans, L., and Govan, H. (2015). "Community-based, co-management for governing small-scale fisheries of the pacific: a solomon Islands' Case Study," in *Interactive Governance for Small-Scale Fisheries*, Vol. 13, eds S. Jentoft and R. Chuenpagdee (Berlin: Springer International Publishing), 39–59. doi: 10.1007/978-3-319-17034-3_3

Crosman, K. M. (2019). *Stakeholder Buy-In to Marine Resource Management Under Conditions of Complex Governance*. Doctoral Dissertation. Seattle: University of Washington.

DiMaggio, P. J., and Powell, W. W. (1983). The Iron cage revisited. *Am. Sociol. Rev.* 48, 147–160.

Edwards, M. (2014). *Civil Society*. Cambridge: Polity Press.

Ingram, H., Schneider, A. L., and DeLeon, P. (2007). "Social construction and policy design," in *Theories of the Policy Process*, ed. P. Sabatier (Boulder, CO: Westview Press).

Krause, M. (2014). *The Good Project*. Chicago, IL: The University of Chicago Press.

Lang, S. (2013). *NGOs, Civil Society and the Public Sphere*. Cambridge, MA: Cambridge University Press.

Markham, W. T., and Fonjong, L. (2016). *Saving the Environment in Sub-Saharan Africa: Organizational Dynamics and Effectiveness of NGOs in Cameroon*. London: Palgrave Macmillan, 274. doi: 10.1057/9781137507198

Murtaza, N. (2012). Putting the lasts first: the case for community-focused and peer-managed NGO accountability mechanisms. *Voluntas* 23, 109–125. doi: 10.1007/s11266-011-9181-9

Prakash, A., and Gugerty, M. K. (2010). "Advocacy organizations and collective action: an introduction," in *Advocacy Organizations and Collective Action*, Vol. 1, eds A. Prakash and M. K. Gugerty (Cambridge, MA: Cambridge University Press).

Saruchera, M. (2004). *The Context of Land and Resource Rights Struggles in Africa. Policy Brief: Debating Land Reform and Rural Development. No. 9 Pan-African Programme on Land and Resource Rights*. Cape Town: Program for Land and Agrarian Reform, University of the Western Cape.

Schmitz, H. P., Raggo, P. and van Vikfeijen, B. (2010). *New Standards, Old Habits: Transnational NGO Leaders' Perspectives on the What for, to Whom, and How of Being Accountable*. Syracuse: Moynihan Institute of Global Affairs.

Selfa, T., and Endter-Wada, J. (2008). The politics of community-based conservation in natural resource management: a focus for international comparative analysis. *Environ. Plan. A* 40, 948–965. doi: 10.1068/a39160

Stefanoudis, P. V., Licuanan, W. Y., Morrison, T. H., Talma, S., Veitayaki, J., and Woodall, L. C. (2021). Turning the tide of parachute science. *Curr. Biol.* 31, R184–R185. doi: 10.1016/j.cub.2021.01.029

Steffek, J., and Hahn, K. (2010). *Evaluating Transnational NGOS: Legitimacy, Accountability, Representation*. London: Palgrave.

Strathern, M. (1997). "Improving ratings": audit in the british university system. *Eur. Rev.* 5, 305–321. doi: 10.1017/s1062798700002660

West, P. (2016). "We are here to build your capacity": development as a vehicle for accumulation and dispossession," in *Dispossession and the Environment: Rhetoric and Inequality in Papua New Guinea*, (New York, NY: Columbia University Press), 63–86. doi: 10.7312/west17878-005

Yanacopulos, H. (2016). *International NGO Engagement, Advocacy, Activism: The Faces and Spaces of Change*. London: Palgrave Macmillan.

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Using Forecasting Methods to Incorporate Social, Economic, and Political Considerations Into Marine Protected Area Planning

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As the global environmental crisis grows in scale and complexity, conservation professionals and policymakers are increasingly called upon to make decisions despite high levels of uncertainty, limited resources, and insufficient data. Global efforts to protect biodiversity in areas beyond national jurisdiction require substantial international cooperation and negotiation, both of which are characterized by unpredictability and high levels of uncertainty. Here we build on recent studies to adapt forecasting techniques from the fields of hazard prediction, risk assessment, and intelligence analysis to forecast the likelihood of marine protected area (MPA) designation in the Southern Ocean. We used two questionnaires, feedback, and a discussion round in a Delphi-style format expert elicitation to obtain forecasts, and collected data on specific biophysical, socioeconomic, geopolitical, and scientific factors to assess how they shape and influence these forecasts. We found that areas further north along the Western Antarctic Peninsula were considered to be less likely to be designated than areas further south, and that geopolitical factors, such as global politics or events, and socioeconomic factors, such as the presence of fisheries, were the key determinants of whether an area was predicted to be more or less likely to be designated as an MPA. Forecasting techniques can be used to inform protected area design, negotiation, and implementation in highly politicized situations where data is lacking by aiding with spatial prioritization, targeting scarce resources, and predicting the success of various spatial arrangements, interventions, or courses of action.

Keywords: Antarctica, CCAMLR, conservation planning, expert elicitation, forecasting, marine conservation, marine protected areas, Southern Ocean

INTRODUCTION

In recent decades, the overexploitation of resources, habitat degradation and loss, and a rapidly changing climate have contributed to a precipitous decline in global marine biodiversity (Doney et al., 2012; Halpern et al., 2015; Kroodsma et al., 2018; IPBES, 2019). In response, the establishment of marine protected areas (MPAs) has been encouraged to combat these threats (Gaines et al., 2010; Spalding et al., 2013; Watson et al., 2014; Bell et al., 2018). For example, the Zero Draft of the Post-2020 Global Biodiversity Framework has recommended that countries use "protected areas and other effective area-based conservation measures" to protect "at least 30% of land and sea areas" by 2030 (CBD, 2020).

To aid in reaching these targets and national or regional priorities, scientists and conservation practitioners have used systematic conservation planning methods to guide engagement with stakeholders, prioritize key biodiversity areas, and allocate scarce resources (Margules and Pressey, 2000; Pressey and Bottrill, 2009; Groves and Game, 2015). However, the results of these approaches are commonly constrained because many planning exercises are characterized by high levels of uncertainty about the socio-political system and lack sufficient or reliable spatial/ecological data (Martin et al., 2012; McBride et al., 2012; Sutherland and Burgman, 2015). In situations such as these, expert elicitation can be used to inform protected area design and conservation decision-making in general (Cook et al., 2010; Martin et al., 2012; Sutherland et al., 2011; Wintle et al., 2018). Expert elicitation is the collection of expert knowledge, which has been defined as "substantive information on a particular topic that is not widely known by others" (Martin et al., 2012).

Expert elicitation has a long history of successful application in fields such as intelligence analysis, public health, engineering, and disaster preparedness (O'Hagan et al., 2006; Burgman et al., 2011b; Ungar et al., 2012) and has been increasingly crucial for environmental management and the success of many large-scale conservation assessments such as the IUCN Red List and IPCC Reports (O'Hagan et al., 2006; Mastrandrea et al., 2010; IUCN, 2012, 2016). To date, scientists have employed expert elicitation to assess the current state of the marine environment and cumulative anthropogenic impacts (Ward, 2014; Giakoumi et al., 2015), to assess the threats facing endangered species (Donlan et al., 2010; Wilcox et al., 2016), to parameterize Bayesian models (Choy et al., 2009; Kuhnert et al., 2010; Krueger et al., 2012a), and to collaboratively identify conservation research priorities and/or emerging issues (Kennicutt et al., 2014; Wildermann et al., 2018; Wintle et al., 2018).

Forecasting is one form of structured expert elicitation used to predict possible future outcomes that is increasingly relied upon by environmental scientists to inform conservation planning and natural resource management (Armstrong, 2001; Krueger et al., 2012b; Martin et al., 2012; O'Hagan, 2019). Forecasting methods can be used to obtain expert knowledge or judgments about uncertain quantities or events in probabilistic form (O'Hagan et al., 2006). Forecasting techniques have not, to our knowledge, been previously used to prioritize geographic areas for conservation, estimate the likelihood of MPA designation, or inform international environmental negotiations. Our study addresses this gap in the literature and uses forecasting techniques (expert-based predictions) to elicit single-event probabilities, i.e., the likelihood of occurrence, for MPA designation (from this point on, we use the terms "predicting" and "estimating" interchangeably). In doing so, we build on early systematic conservation planning frameworks (Margules and Pressey, 2000; Groves et al., 2002; Pressey and Bottrill, 2009) and attempt to pursue our research objectives in a way that complements parallel efforts to explore and operationalize the concepts of feasibility (Mills et al., 2013; Tulloch et al., 2014; Jones et al., 2018), social acceptability (Klein et al., 2008; Adams et al., 2011), social vulnerability (Thiault et al., 2017, 2018, 2019, 2021; Williamson et al., 2018), and uncertainty (Regan et al., 2002; Burgman, 2005; Halpern et al., 2006; Lechner et al., 2014; McCarthy et al., 2011).

Our specific elicitation focuses on predicting the likelihood of designating additional no-take MPAs [in the Southern Ocean context, no-take MPAs are referred to as General Protection Zones (GPZs)] along the Western Antarctic Peninsula and examining the relative influence of various biophysical, socioeconomic, geopolitical, and scientific factors in shaping those forecasts. We chose to investigate these factors' comparative influence because research has routinely demonstrated that socioeconomic and political factors influence conservation outcomes and vice versa (Ban et al., 2019; Naidoo et al., 2019; Cinner et al., 2020). As a more general methodological contribution, we describe data collection methods for conservation scientists who may be considering using probabilistic forecasts to inform conservation planning efforts. Therefore, the three main objectives of this research were to:

1) Use expert judgement to forecast the likelihood that various geographic areas along the Western Antarctic Peninsula will be designated as no-take MPAs (GPZs);
2) Assess the importance of biophysical, socioeconomic, geopolitical, and scientific factors underpinning expert forecasts; and
3) Measure the relative influence or strength of these factors on the estimated likelihood of MPA designation.

By pursuing these objectives, we assess the feasibility of using forecasting techniques to inform conservation planning, decision-making, and ongoing negotiations over expanding the existing network of MPAs in the Southern Ocean (Coetzee et al., 2017; Sykora-Bodie and Morrison, 2019; Brooks et al., 2020). Although forecasting techniques are not a substitute for traditional site selection algorithms and spatial prioritization methods, they can be used to supplement them. For example, forecasting methods can be used to inform the design of MPA proposals by: (1) identifying additional priority conservation areas missed due to gaps in spatial data; (2) assessing their relative social, economic, and political acceptability to decision-makers; and (3) providing insights into how these factors shape broader perceptions of acceptability. Additionally, we seek to show how forecasting techniques can provide insights into situations

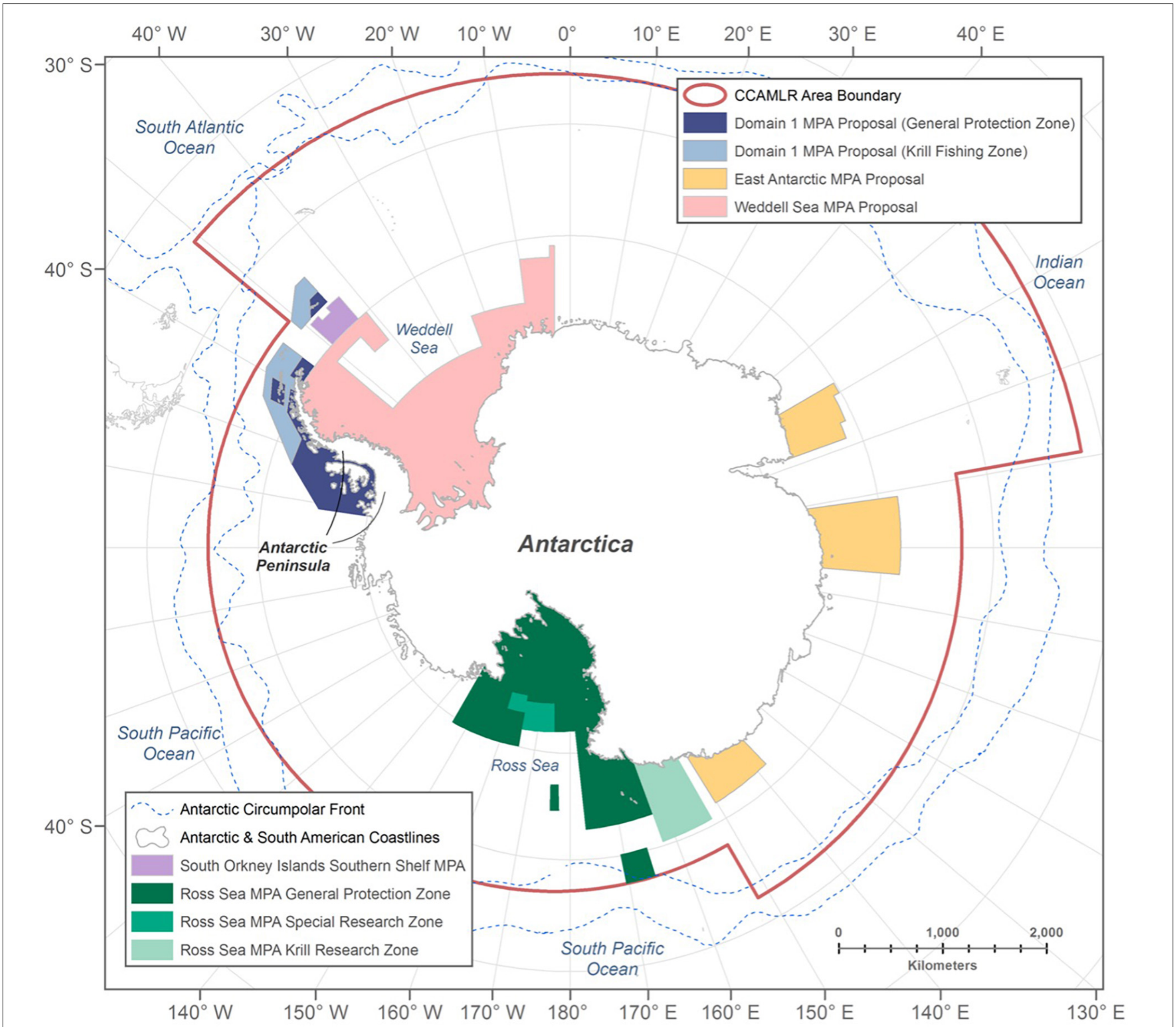

FIGURE 1 | The area managed by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) – The shaded areas show existing and proposed marine protected areas, including the proposed Domain 1 MPA (shown in blue). The Ross Sea region MPA's Krill Research Zone and the Special Research Zone permit limited fishing of krill and fish for scientific research purposes, while the General Protection Zone and entire South Orkney Islands Southern Shelf MPA prohibit commercial fishing.

characterized by high levels of uncertainty and unpredictability such as multi-national conservation negotiations (O'Hagan et al., 2006; Ungar et al., 2012).

METHODS AND DATA ANALYSIS

Case Study

Our geographic focus is on the Western Antarctic Peninsula in the Southern Ocean, which is managed under the auspices of the Convention on/Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) entrusted with "safeguarding the environment and protecting the integrity of the ecosystem of seas surrounding Antarctica" (CCAMLR, 1980). The Southern Ocean surrounding Antarctica is a highly biodiverse ecosystem and plays a key role in regulating the earth's climate (Doney et al., 2012; Constable et al., 2014; Rintoul, 2018). A growing tourism industry, expanding fisheries, and a rapidly changing climate are increasingly threatening this system that has remained relatively intact and unimpacted by human activity as compared to other global marine ecosystems (Ballance et al., 2006; Chown et al., 2015; Halpern et al., 2015).

The CAMLR Convention entered into force on April 7th, 1982 and established a consensus-based decision-making process by which CCAMLR implements a system of precautionary, ecosystem-based management and explicitly states in Article II (1) that the primary "objective of this Convention is the conservation of Antarctic marine living resources" (CCAMLR, 1980; Fabra and Gascón, 2008; Cordonnery et al., 2015). CCAMLR has long been considered unique among international environmental agreements due to its cooperative, consensus-based negotiating process, its early emphasis on ecosystem-based management (as opposed to the single-species management models common among regional fisheries management organizations), and its precautionary approach to decision-making that was established due to the region's remoteness and vast scale, and a commitment to the idea that a lack of data should not preclude taking action (Constable et al., 2000; Parkes, 2000; Miller and Slicer, 2014; Everson, 2015; Wenzel et al., 2016). CCAMLR is also frequently cited as a leader in high-seas conservation due to its successful efforts to reduce fishery bycatch, particularly of seabirds, the development of a Catch Documentation Scheme to combat illegal, unreported, and unregulated (IUU) fishing, the establishment of the CCAMLR Ecosystem Monitoring Program (CEMP), and a set of standards meant to systematize ecosystem monitoring throughout the Convention Area (Cullis-Suzuki and Pauly, 2010; Miller, 2011; Everson, 2015).

The Commission has also sought to designate a representative network of MPAs in the Southern Ocean to help achieve the objectives of the Convention by: (1) protecting a representative samples of ecosystems, biodiversity, and habitats at appropriate scales; (2) protecting key ecosystem processes; (3) protecting areas vulnerable to human impact; (4) protecting features critical to the function of local ecosystems; (5) establishing scientific reference areas; and (6) maintaining resilience to the effects of climate change (CCAMLR, 2011). The Commission first outlined these principles in Conservation Measure (CM) 91-04, a "General framework for the establishment of CCAMLR Marine Protected Areas," which standardized the process by which Members would propose, negotiate, and designate new MPAs within the Southern Ocean (Fabra and Gascón, 2008; CCAMLR, 2011; Everson, 2015). To date, CCAMLR has established two MPAs within the Convention Area—the South Orkney Islands Southern Shelf MPA (SOISSMPA) in 2009 and the Ross Sea region MPA (RSRMPA) in 2016 (CCAMLR, 2009, 2016). Additional MPAs have been proposed in East Antarctica by Australia, the European Union and its Member States, New Zealand, Norway, the United States, and Uruguay, in the Weddell Sea by Australia, the European Union and its Member States, New Zealand, Norway, the United States, and Uruguay, and in the Domain 1 planning area along the Western Antarctic Peninsula (**Figure 1**) by Argentina and Chile (Sykora-Bodie and Morrison, 2019; Brooks et al., 2020; Delegations of Argentina and Chile, 2020).

The process for establishing an MPA in the Southern Ocean begins with the development of a proposal by the sponsoring nations. Once drafted, this proposal is then formally submitted to CCAMLR's Scientific Committee (SC), which reviews the work to ensure that it is based upon the best available science. The SC then decides to either recommend further work on the proposal or determines it does represent the best available science and formally submits the proposal to the Commission for its consideration and potential adoption. Because CCAMLR operates as a consensus-based decision-making body, and Article XII states that all "matters of substance shall be taken by consensus," adoption in effect requires the absence of any objections from signatory states (CCAMLR, 1980). Throughout this process, we see two main stages when forecasts can be complementary and informative: (1) during the proponents' initial development of the proposal when forecasts can be employed to parameterize and refine the results of spatial optimization tools or to otherwise inform discussions about the spatial configuration of MPA proposals; and (2) during the Commission's deliberations, when forecasts can help to prioritize objectives and provide insights into the various (sometimes implicit) social, economic, and political barriers and opportunities underpinning decision-making.

Structured Expert Elicitation Protocol

We used a Delphi-style format that relied on two elicitation rounds [investigate (1); estimate (3)] and one discussion round [Discuss (2); **Figure 2**] to obtain quantitative forecasts and gather data on the underlying factors that influenced experts' estimates of the likelihood that specific geographic areas will be designated as no-take MPAs within the next eight years[1] (MacMillan and Marshall, 2006; Martin et al., 2012; Hemming et al., 2017). The purpose of a Delphi-style approach is to reduce some of the common biases associated with eliciting information from individuals and groups (e.g., anchoring or overconfidence) and to provide participants with the opportunity to consider their colleagues' estimates (and their underlying rationale) and then reconsider or revise their own forecasts (MacMillan and Marshall, 2006; O'Hagan et al., 2006; Hemming et al., 2018).

For this elicitation, we selected experts (also referred to as "participants") based on their membership in the Domain 1 MPA expert working group that consisted of 29 individuals from various CCAMLR member countries. Then, we solicited input from members of the Domain 1 MPA expert working group to refine our list of experts to be invited as participants in the elicitation process. To do this, we first identified and removed from our initial list those individuals who were perceived to be inactive in group discussions, meetings, and the planning/advising process in general. Second, we used snowball and triangulation techniques to identify other individuals who were not officially part of the Domain 1 MPA expert working group, but who were perceived by the other participants to be highly knowledgeable about, or able to influence, the process of developing the Domain 1 MPA proposal. The final list consisted of 25 individuals from 14 delegations who we invited

[1] We chose an eight-year timeframe because the literature suggests that five years is too short (it provides insufficient time for events to progress or occur) and ten years is too long (it is difficult for participants to conceptualize/predict that far into the future). However, eight years aligns with the duration of two presidential terms, the Olympic cycle, COP meetings, etc., which is more easily conceptualized by participants for forecasting purposes.

FIGURE 2 | The elicitation format – The Delphi format elicitation consisted of a preparation stage, the three-round elicitation (numbered 1, 2, 3), and final data aggregation and analysis. Quantitative and qualitative data were collected during steps one and three.

to participate with a short project description and confidentiality statement/consent agreement (Duke University IRB #2018-0072). Participants included diplomats, independent scientists, academics, and scientists associated with their countries' national Antarctic research programs. Although our participation rate was affected by the COVID-19 pandemic and several individuals were unable to take part in the study due to personal circumstances, our invitation to participate was accepted by ten individuals bringing perspectives from Australia, Germany, New Zealand, the United Kingdom, and the United States, and the Association of Responsible Krill harvesting companies (ARK; industry) and Oceanites (penguin conservation) delegations. Many of these individuals are quoted throughout this paper, but their names have not been included because they participated under an agreement that their comments would remain anonymous.

We selected ten geographic areas along the Western Antarctic Peninsula (**Figure 3**) to develop our forecasts. We did this by relying on spatial data that were collected for an expert elicitation in which participants identified areas they thought to be in need of protection or areas where experts believed there to be opportunities for designating MPAs along the Western Antarctic Peninsula (Sykora-Bodie et al., 2021). That project used ArcGIS 10.6.4 to combine 100+ expert elicited polygons and overlayed them with a hexagonal planning mesh to create hotspot maps and conduct additional spatial analyses. Based on these data, we identified spatial clusters, combined the hexagons, and smoothed the outer boundaries to create our geographic areas. This resulted in thirteen clusters, which we reduced to ten to avoid participant burnout (Fowler, 2013; National Academies, 2016). The ten sites used in this study were selected because they substantially overlap with areas included in the proposed Domain 1 MPA but differed enough that we were not directly commenting on the proposal itself, which could have interfered with ongoing negotiations. These ten sites were also selected to represent geographic diversity and a variety of human activities and natural environments, thus providing relevant examples of the type of areas that could be designated in actual negotiations over the proposed Domain 1 MPA.

We used a questionnaire (**Supplementary Appendix A**) and the Qualtrics data collection and management platform to conduct a remote elicitation that collected quantitative forecasts, identified drivers, and gauged their relative strength (Bernard, 2011; Rolstad et al., 2011; Fowler, 2013). We structured our elicitation according to the IDEA Protocol ("Investigate," "Discuss," "Estimate," "Aggregate"; **Figure 2**), which is designed to elicit low, high, and best probabilistic estimates between 0 and 100% (Hanea et al., 2016; Hemming et al., 2018). We selected this format because previous studies have shown that it substantially reduces overconfidence when forming probabilistic estimates (Speirs-Bridge et al., 2010).

In the first elicitation round ("Investigate"), we used our questionnaire to present experts with a list of 21 pre-identified factors (shown in **Table 1A** of the Results section) that could shape participants' opinions and CCAMLR negotiations, and ultimately influence whether an MPA is designated by CCAMLR. These factors were previously identified by Sykora-Bodie and Morrison (2019), who used interviews and document analysis to identify a comprehensive list that influenced the 2016 designation of the Ross Sea Region MPA. This list of factors was further refined and used during a participatory mapping elicitation by Sykora-Bodie et al. (2021) to structure the collection of associated qualitative attribute data. In the first round, experts reviewed and confirmed that the list of pre-identified factors was comprehensive, and no additional factors were added.

In preparation for round two ("Discuss"), we summarized the first round of quantitative estimates and qualitative responses and presented them to the experts. They in turn directly corresponded with each other via email to explain the reasoning behind some of their forecasts and respond to other individuals' explanations and comments. The text of this discussion was qualitatively analyzed to assess the importance of various factors on the forecasts (research objective 2) and to measure their relative influence (research objective 3).

For our third round, we carried forward the ten factors most commonly selected by experts and asked them to choose at least one and up to five factors that influenced their estimates (**Supplementary Appendix A**, Question 2). We also asked experts two open-ended questions about (1) why they changed their forecasts (if they did so) between the first and second questionnaires, and (2) which factors influenced their forecasts the most. Changes to forecasts between rounds 1 and 2 were minor, but — as expected — they generally converged closer to the group average, and participants highlighted perspectives shared by others as the primary motivations for changing their quantitative forecasts.

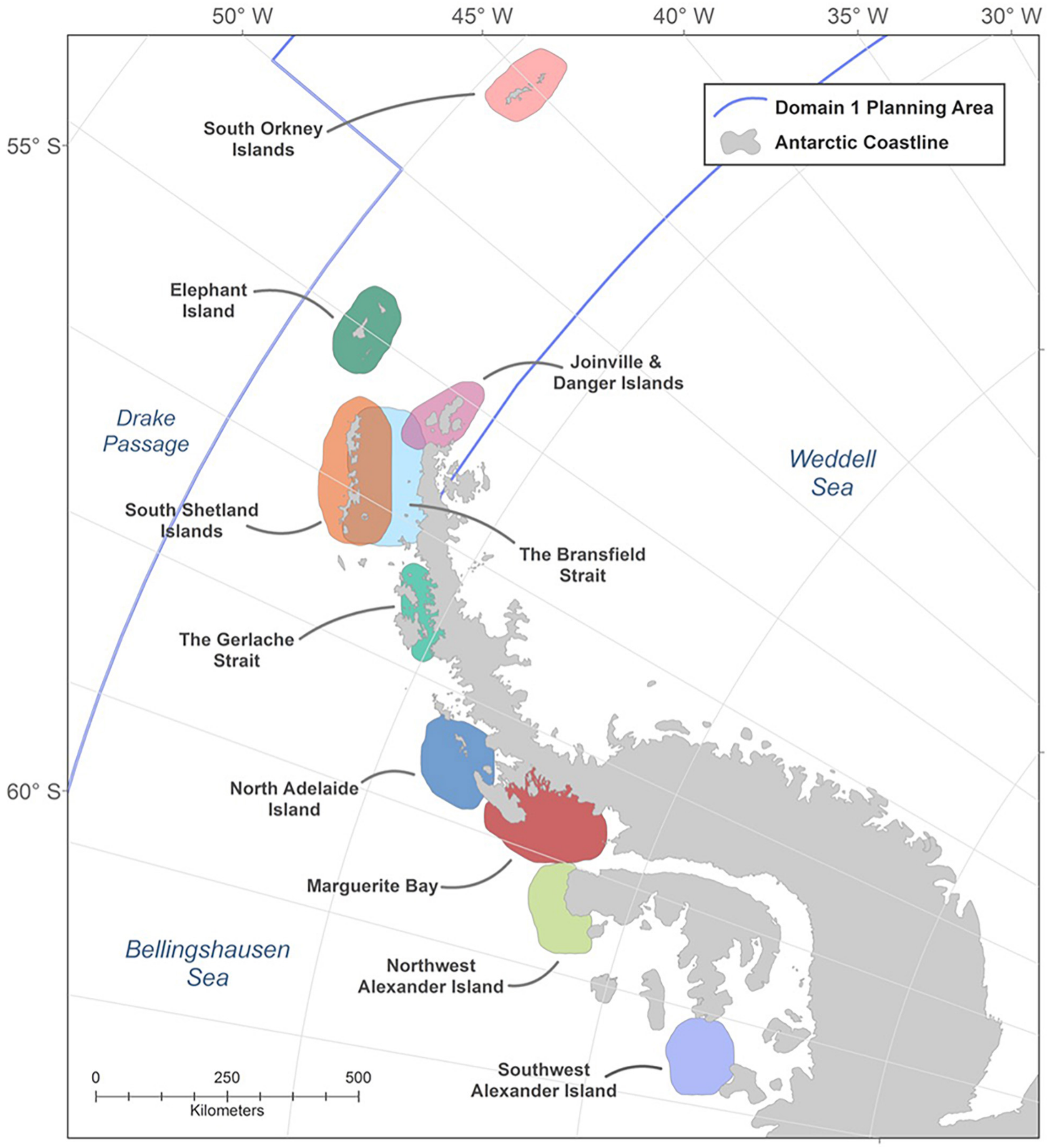

FIGURE 3 | Geographic areas considered in the forecasting elicitation – This area along the Western Antarctic Peninsula is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The blue line shows the boundary of the Domain 1 planning area and the shaded polygons show the ten geographic areas that were presented to experts during the elicitation as notional MPA areas. These ten areas were based on earlier participatory mapping research (see Sykora-Bodie et al., 2021) and were selected to reflect the wide range of areas currently under consideration for designation by CCAMLR.

Data Analysis

Quantitative Probability Forecasts

To forecast the likelihood of MPA designation within the next eight years (research objective 1), we imported experts' individual forecasts from the questionnaires into the statistical analysis program R 3.6.3 (and RStudio 1.2.5) for data organization and cleaning. We calculated three arithmetic means for experts' low, best, and high scores, and combined them into credible interval

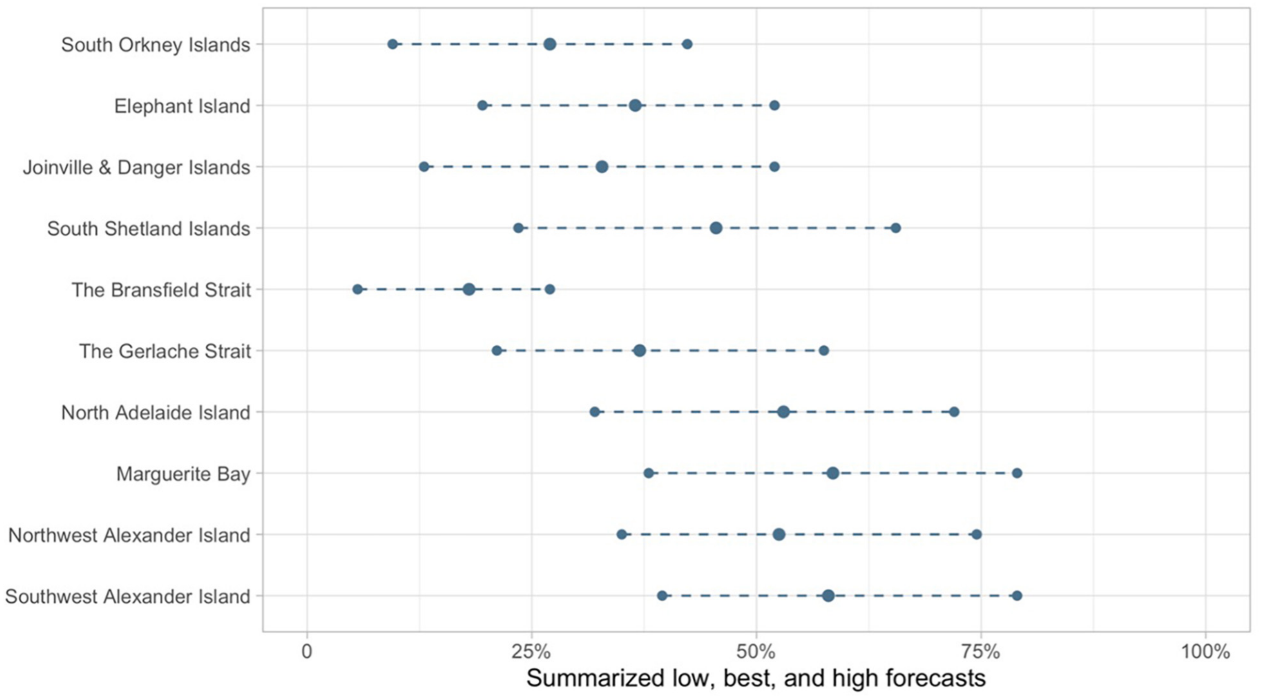

FIGURE 4 | Final quantitative forecasts of the likelihood of MPA designation – These forecasts represent three (low, best, high) separate arithmetic mean estimates of the likelihood that each area "is designated or included within a no-take (e.g., 'general protection zone') MPA within the next eight years." The lower end, dot, and upper end of each line represent the low, best, and high estimates, respectively, rather than a single estimate with two other points representing the extent of its associated confidence interval. Here, the forecasts are arranged latitudinally (north to south) on the y-axis.

forecasts (lowest forecast to highest forecast) for each of the ten areas under consideration along the Western Antarctic Peninsula (O'Leary et al., 2009; Speirs-Bridge et al., 2010; Hemming et al., 2017). We created boxplots for the "best" forecast scores to visualize the variation in experts' responses and calculated the mean and standard deviation (**Supplementary Appendix C**). We ranked the ten most influential factors identified in round three by selection frequency to gain insight into how much influence each exerts on forecasted outcomes (**Supplementary Appendix A**, question 3).

Qualitative Data

To answer our second (describing the importance of influential factors) and third (to measure and/or quantify their relative strength) research objectives, we coded and analyzed the responses from the questionnaire and the round two email discussion in the qualitative data analysis software QSR NVivo 12.6.0. We used a pre-determined qualitative coding structure (**Supplementary Appendix B**) that was based on earlier research that identified the key factors that influence negotiated conservation outcomes at CCAMLR meetings (Sykora-Bodie and Morrison, 2019). There were 21 of these factors, which were organized into four main categories of drivers—biophysical, socioeconomic, geopolitical, and scientific—which we used as the primary organizational lens for our analysis and reporting in later sections. We built upon this research and used this coding structure to organize experts' responses and identify key patterns and themes throughout the data (**Supplementary Appendix B**). After coding our data, we reviewed and synthesized each category to better understand the drivers influencing their forecasts, as well as the relative weight that each of the four categories was exerting on those forecasts.

RESULTS

Forecasting the Likelihood of MPA Designation

Our results ranged from a mean "best" forecasted likelihood of 18% for the Bransfield Strait to 59% for Marguerite Bay (**Figure 4**; the dot in the middle of each forecast). These forecasts showed a latitudinal gradient with northern areas of the Western Antarctic Peninsula being perceived to have a lower likelihood of designation than southern areas. As one expert stated during the discussion round, "I think the general broad direction is pretty clear, i.e., a latitudinal gradient where the northern areas are less likely to be included in an MPA network while the southern areas are more likely." Additionally, this latitudinal gradient was apparent when we compared the range of forecasts provided for each location. Focusing solely on the variation in the "best" forecasts (**Supplementary Appendix C**), we found that northern areas (e.g., the South Orkney Islands, Joinville and the Danger Islands, and the Gerlache Strait) had wider ranges of estimates

TABLE 1 | First round selection frequency of factors influencing quantitative forecasts – The factors below were presented to experts based on prior research (Sykora-Bodie and Morrison, 2019; Sykora-Bodie et al., 2021).

	Factors shaping forecasts presented to participants in the first round	Round 1 selection frequency	Carried forward?
Biophysical factors	Important habitat areas (e.g. foraging grounds)	47	✓
	Large/important wildlife aggregations (e.g. penguin colonies)	41	✓
	Anticipated impacts from climate change	32	✓
	Sensitive or threatened wildlife populations	29	✓
	Geophysical environment, excluding wildlife (e.g. Deception Island)	10	✗
Socioeconomic factors	Existing fisheries	54	✓
	A lack of fisheries or interest in developing any	32	✓
	Potential/exploratory fisheries	28	✓
	Existing tourist operations	14	✗
	Potential tourist operations	12	✗
	Market influences (e.g. prices of fish)	9	✗
	A lack of tourist operations	6	✗
	Illegal fishing	0	✗
Geopolitical factors	Objections to proposed no-take areas (GPZs)	60	✓
	Global political forces (i.e. foreign policy)	57	✓
	This area is sovereign territory (e.g. sub-Antarctic Islands)	21	✗
	Global conservation pressures (e.g. Aichi Targets, or 30 by 30)	16	✗
	Existing territorial claims (i.e., those on hold under the Antarctic Treaty)	2	✗
Scientific factors	A lack of scientific data	26	✓
	Existing research programs or CEMP sites	9	✗
	Antarctic Specially Protected/Managed Areas	3	✗

	Top ten factors shaping forecasts presented to participants in the second round	Round 2 selection frequency	Factor rank (1-10)
Biophysical factors	Important habitat areas (e.g. foraging grounds)	46	4
	Anticipated impacts from climate change	35	5
	Large/important wildlife aggregations (e.g. penguin colonies)	34	6
	Sensitive or threatened wildlife populations	17	10
Socioeconomic factors	Existing fisheries	51	3
	A lack of fisheries or interest in developing any	27	7
	Potential/exploratory fisheries	18	9
Geopolitical factors	Global political forces (i.e. foreign policy)	59	1
	Objections to proposed no-take areas (GPZs)	57	2
Scientific factors	A lack of scientific data	24	8

Selection frequency is the number of times experts noted the factor as being important [out of a possible total of 100 (ten participants × ten areas)]. "Carried forward" indicates whether or not it ranked in the top ten and was therefore selected for use in the second round of the elicitation. Table includes all ten of the factors carried forward and presented to experts in the second round of the elicitation.

on average than southern areas (e.g., North Adelaide Island, Southwest Alexander Island) suggesting that experts thought the presence of more extensive human activity makes the likelihood of designation in this region more unpredictable.

When looking at individual locations, three sites were noticeable for various reasons: the Bransfield Strait, the area surrounding the Joinville/Danger Islands, and the Gerlache Strait (qualitative data; **Figure 4** and **Supplementary Appendix C**). The Bransfield Strait stood out because it: (1) did not conform to the overall latitudinal pattern; (2) was considered much less likely to be included within an MPA designation than adjacent locations (e.g., Elephant Island and the South Shetland Islands) due to the presence and density of fishing activity; and (3) had the narrowest "best" estimate range of any location under consideration (**Supplementary Appendix C**) indicating high agreement between experts.

As for the Joinville/Danger Islands, this area was notable due to experts' divergent forecasts. On the one hand, some experts provided higher forecasts, which they justified based on the region's current inaccessibility due to sea ice, the fact that fishing in the area has significantly decreased in recent years, and important aggregations sensitive of wildlife such as Adélie penguins on Heroina Island. On the other, some experts provided lower forecasts, which they justified based on the potential for a changing climate to reduce sea ice coverage and make this area more accessible to fishing vessels.

When we looked solely at the "best" estimates for the Gerlache Strait (**Supplementary Appendix C**), we found a wider range of forecasts than any other location. The qualitative data indicated that existing fisheries and the complexity of setting aside such a highly trafficked area led some experts to provide lower forecasts, whereas extensive tourism, dense aggregations of whales, and the relatively small geographic size of the area caused other experts to provide higher forecasts. For example, one individual noted that "The second site [the Gerlache Strait] is key for humpback whales, a recovering krill-dependent species. Given the public perception of this species, coupled with the tourist penetration into this area, CCAMLR could achieve a second 'easier' win. In the case of the Gerlache, it might not be feasible to argue for year-round protection, but seasonal protection should be feasible. It could be a PR [public relations] coup for CCAMLR."

Key Factors Influencing Experts' Forecasts and Their Relative Weight in Determining Successful Outcomes

In the following section, we discuss the ranking of factors influencing the forecasts and the rationale given by expert respondents (research objectives two and three) and organize our reporting by using the four categories of factors identified by Sykora-Bodie and Morrison (2019)—biophysical, socioeconomic, geopolitical, and scientific. We define them as follows:

1) Biophysical—relating to the natural environment or processes, including wildlife, ecosystems, and climate change;
2) Socioeconomic—relating to human activities of a cultural, educational, commercial or economic nature;
3) Geopolitical—relating to international politics including territorial integrity/expansion, security, or conservation; and
4) Scientific—relating to scientific research or the pursuit of knowledge.

Geopolitical Factors

Of the five geopolitical factors presented in the first elicitation round, three were not carried forward into the final elicitation round (**Table 1**). Territorial claims received only two selections in the first round between all experts and locations, which is unsurprising given that participants may have been unlikely to suggest to researchers and others in the Delphi process that they play a role in negotiations since territorial claims are officially on hold under the terms of the Antarctic Treaty (Antarctic Treaty, 1959).

The two geopolitical factors that were carried forward ["global political forces (i.e., foreign policy related)," and politically motivated "objections to proposed no-take areas (GPZs)"] were identified as being the first and second most important factors shaping experts' forecasts, respectively (**Table 1**). This is what we anticipated given the contentious nature of the debate over expanding the network of MPAs (CCAMLR, 2017, 2018) and as one individual stated, "Geopolitics and the need for a win will be the drivers that put this over the top, no science arguments will convince extractive interests to compromise." Finally, "Objections to proposed no-take areas (GPZs)" was more frequently selected for northern areas (**Figure 5**, column 8) and the qualitative data showed that this was partially linked to the presence of active fisheries.

Socioeconomic Factors

Experts selected the three socioeconomic factors linked to fishing to carry forward (**Table 1**) and then ranked them 3rd, 7th, and 9th, respectively (**Table 1**), with the two lower rankings perhaps resulting from how the factors were worded and structured as exclusive/inverse categories ("existing fisheries" ranked high while "no fisheries" ranked low). This makes sense given that fisheries are currently the sole extractive economic activity taking place in the Southern Ocean and one of the primary objections to MPA proposals has been that they will constrain or displace fisheries, which was also raised during the round two discussion. The qualitative data supported this interpretation with most experts agreeing that areas where fisheries currently operate are much less likely to be designated. Individuals repeatedly highlighted the perceived difficulty of implementing closures in heavily fished areas, as noted in the following statements: "The overlap of several areas with existing or historical krill fishing grounds pose a significant hurdle to adoption as general protection zones"; "Currently, there is no opportunity to declare as an MPA an area with active fishing"; and "All areas with existing fisheries will be extremely difficult to include in a GPZ [general protection zone]."

Areas that were historically more heavily fished also led to divergent opinions (**Supplementary Appendix D**). Some

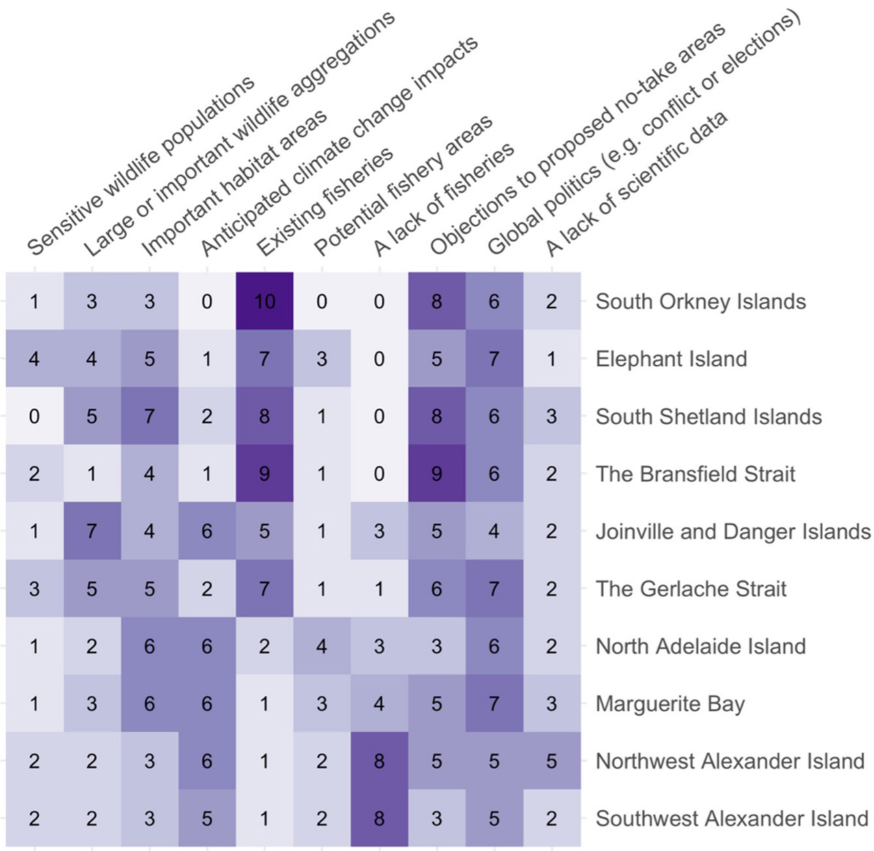

FIGURE 5 | A heatmap of the number of times factors were selected as being influential for each area under consideration. The y-axis is arranged latitudinally, north to south.

individuals thought areas where fishing has decreased are more likely to be designated after being abandoned by the industry. For example, certain areas around the South Shetlands, Elephant Island, and Joinville Island have seen less fishing in recent years and might be better candidates for spatial closures than the quantitative forecasts suggest. As one individual stated, "I feel that there is some hope for developing official CCAMLR spatial management in a couple of places [tip of the Peninsula (Joinville and Danger Islands) and the Gerlache]. The first of these sites is not heavily fished and has never been heavily fished, even though it clearly is a location with a lot of krill. The tip of the Peninsula is often ice covered, so inaccessible. Thus, it is an important site for Adélie penguins, but not accessible to the fishery. It should be an easy win." Alternatively, others noted that localized overfishing, led to decreased fishing activity, which in turn has resulted in stock recovery. This stock recovery may lead to renewed fishing interest around places like the South Shetland Islands.

In combination, the existence of fisheries and political objections to establishing MPAs were the most frequently cited factors influencing experts' forecasts (**Table 1**). This was supported with numerous qualitative statements. For example, one individual wrote that "Overall, the major hurdle to designation by the Commission remains their ability to resolve the trade-off between current fishing and geopolitical positions on the one hand versus an MPA's ability to mitigate climate threats and provide protections for threatened and vulnerable populations on the other."

Biophysical Factors

Experts frequently cited the importance of biophysical factors in shaping their quantitative forecasts with concerns about "important habitat" ranking 4th, "anticipated impacts from climate change" ranking 5th, "large aggregations of wildlife" ranking 6th, and finally concerns about "sensitive wildlife populations" ranking 10th (**Table 1**). "Anticipated impacts from climate change" had higher selection frequency further south, which was initially counterintuitive until qualitative data revealed that experts were selecting this factor with the understanding that southern areas of the Peninsula would be more likely to be gazetted as no-take zones given their ability to serve as refugia for species fleeing warming temperatures to the north (**Figure 5**, column 4). Joinville and the Danger Islands were clear exceptions to this latitudinal trend (**Figure 5**, column 4) because their unique local oceanographic conditions (cold water intrusion from the Weddell Sea), which led experts to suggest they may serve as cold-water refugia. As one stated, "The tip of the Peninsula is a critical environment, not just for penguins and krill, it is an area that will remain relatively cold (in the water column and on the sea bottom) because of the direct influence of the Weddell Sea. Other areas [at higher latitude WAP (Western Antarctic Peninsula)] are likely to have warmer bottom waters as offshore waters invade the shelf. Therefore, the tip could be. . . a refuge (or potential refugia) for more highly polar taxa."

The qualitative responses reinforced that experts perceive specific geographic locations to be more likely to be designated as no-take areas if they harbor large aggregations of wildlife such as Adélie penguin mega-colonies in the Danger Islands (**Figure 5**, column 2) or seasonal aggregations of foraging whales in the Gerlache Strait. Experts also noted that a location's contribution to the health and functioning of the broader ecosystem, for example as a krill nursery area around the South Shetland Islands (**Figure 5**, column 3), make it more likely to be designated in the future. As one individual stated in explaining their forecast suggesting that the Gerlache Strait is more likely than many other areas to be designated, they said that it "harbors important ecosystem processes and large concentrations of marine mammals and could serve as refugia in the event of environmental change."

Scientific Factors

Only one scientific factor ("a lack of scientific data") was carried forward into the second round by experts, in which they ranked it 8th overall (**Table 1**). Qualitative responses were mixed, with some experts saying that resolving scientific knowledge gaps is key to designating additional MPAs, while others suggested that even though gaps do exist, they do not preclude designations and are only a convenient excuse used by opponents to block consensus on proposed MPAs. One of the areas highlighted as an existing knowledge gap or area of scientific uncertainty is around predator-prey dynamics and how krill fisheries in the northern areas of the peninsula may be harming predators. To help reduce some of the uncertainty or solve some of the complexity associated with krill fishery management around specific areas like the Bransfield Strait, CCAMLR is considering implementing a new krill fishery management mechanism. However, nearly all experts agreed that doing so is incredibly complex and that it may be impossible given the current understanding of habitat-krill-predator dynamics along the Western Antarctic Peninsula. The seasonal dynamics of predator-prey interaction led several experts to suggest that seasonal closures would be more appropriate, but they cautioned that it would likely be more difficult to design and implement these types of triggers and rules than permanent spatial closures.

DISCUSSION

Many conservation planning efforts are characterized by high levels of uncertainty and a lack of sufficient spatial/ecological data (Martin et al., 2012; McBride et al., 2012; Sutherland and Burgman, 2015). In these instances, forecasting techniques can be used to inform efforts such as MPA planning. Our research sought to fill this gap in the literature in ways that are both broadly theoretical/methodological and narrowly applied/case specific. From a theoretical/methodological standpoint, we presented data collection methods and a roadmap for conservation scientists who may be considering how to use probabilistic judgements to support various types of environmental decision-making such as spatial prioritization or allocation of management resources. From an applied standpoint, our elicitation focuses on predicting the likelihood of designating additional no-take MPAs along the Western Antarctic Peninsula and examining the relative influence of various biophysical, socioeconomic, geopolitical, and scientific factors in shaping those forecasts and serving as barriers or opportunities to further action.

Quantitative Forecasts

Because this is the first use of forecasting techniques to prioritize spaces and predict their likelihood of designation (in our case varying between 18 and 59%), we lack relevant comparative examples to help interpret their magnitude in the forecasts (should they be considered high or low?). Forecasted values are context dependent and will be interpreted differently depending on the arena. For example, a forecast that a little over 60% of marine turtles entangled in fishing lines, nets, or traps will perish may be considered high by marine turtle experts and conservation practitioners (Wilcox et al., 2016), but this example does not suggest how we should interpret our forecasts.

It is also difficult to provide context for our forecasts because proponents of the Domain 1 MPA may interpret these numbers positively and point to them as evidence that those involved in the process believe certain locations are more likely than not to be designated (North Adelaide Island, Marguerite Bay, and Northwest and Southwest Alexander Island). Similarly, though, opponents may feel positively about the fact that even these four highest forecasts are between 50% and 60%. In short, these numbers should be interpreted with care and within the constrained context of the study, and we caution against their direct use to support or oppose specific proposals. However, much of the "value" of these forecasts stems from the fact that they show a collective estimate that is stronger than anecdotal evidence. Forecasting can be used to inform negotiating strategies and future iterations of MPA proposals, and they provide insights into each area's relative likelihood of designation. On this last point, we mean that they suggest CCAMLR members are more likely to include Marguerite Bay in a future designation than the Bransfield Strait or, alternatively, that protecting the Bransfield Strait would require significantly more negotiating effort.

Drivers of Perceived Outcomes and the Relative Strength of Various Factors

Our results highlighted the key role that geopolitical and socioeconomic factors play in shaping MPA boundaries and perceptions of the likelihood of designation, which, ultimately, further influence negotiations to designate MPAs within our study context (**Supplementary Appendix D**). This finding is consistent with literature on conservation planning literature (Walmsley and White, 2003; Pollnac et al., 2010; Giakoumi et al., 2011; Rossiter and Levine, 2014; Gurney et al., 2015) and

Antarctica (Dodds and Hemmings, 2013; Hodgson-Johnston, 2015; Bray, 2020).

The qualitative data that we collected from experts highlighted the role of socioeconomic interests and the interplay between them and geopolitical factors. As one individual noted, and others echoed in similar comments, "It is clear that the most important factor in determining whether a CCAMLR MPA has a chance of being adopted is the [presence or absence of a] fishery." This emphasizes the common sentiment among many experts that fisheries are one of the primary barriers impeding the further evolution of a CCAMLR ecosystem-based management regime (i.e., the establishment of a representative network of MPAs) that is consistent with the Convention's primary objective of achieving "the conservation of Antarctic marine living resources" (CCAMLR, 1980; Miller and Slicer, 2014; Everson, 2015; Liu and Brooks, 2018).

Geographic/Spatial Patterns

Additionally, the strong latitudinal gradient indicating that southern areas are more likely to be designated than northern areas (**Figures 3**, **4**) mimics the recent evolution of the Domain 1 MPA proposal. The preliminary 2017 Domain 1 MPA proposal contained more no-take 'General Protection Zones' to the north, but following objections from opponents, these were shifted further south in the 2018/2019 proposals (Delegations of Argentina and Chile, 2017, 2019) to areas that are similarly ecologically valuable but also perceived to be more politically acceptable to opponents (Brown et al., 2019; Sykora-Bodie et al., 2021). To what extent access to fisheries, geopolitical objections, and the potential benefit of southern areas as "climate refugia" (**Supplementary Appendix D**) have each influenced these revisions is unknown, but they collectively motivate opponents' objections, and have therefore contributed to the proposal's revision (CCAMLR, 2017, 2018).

Although it is possible that the evolution of the proposal influenced experts' responses during the elicitation, we do not believe this to be the case for several reasons. First, these individuals are not drawing the boundaries for the proposal themselves, but rather providing data, serving as conduits to their national delegations, and commenting or advising on the work of the Argentinean and Chilean Domain 1 proposal planning team. Additionally, the shift of the proposal to cover more southern areas is not being driven internally by members of the planning team, but externally, by CCAMLR members wishing to protect access to existing commercial fishing grounds located further north.

Conservation Implications

Although spatially referenced ecological data remains the foundation of protected area design, this paper illustrates how forecasting techniques can complement these data, site selection algorithms, and spatial prioritization methods by accounting for and incorporating additional social, economic, and political considerations. Forecasting methods can inform protected area planning and decision making similar to how fisheries data, social-ecological vulnerability mapping, and spatially referenced social, economic, and political considerations have been used to identify areas that are more or less likely to have unacceptable socioeconomic impacts on local communities and resource users or to identify socio-political opportunities (Guerrero and Wilson, 2016; Thiault et al., 2017; Sykora-Bodie et al., 2021). In the case of the Southern Ocean, for example, these data can be used to identify areas of conservation importance that diplomats could prioritize for achieving consensus sooner, while also identifying areas that may require additional information or discussions to successfully designate. In this case, a multi-stage approach could be taken, where consideration of the more controversial areas is delayed while more focused discussion or research occurs as has happened with the proposed Weddell Sea MPA, and as was relied upon to extend the Heard Island and McDonald Islands MPA after it was originally designated (Welsford et al., 2011). Although this is not the ideal approach for selecting areas to set aside for conservation purposes, MPA designation is a political act that alters stakeholders' access to and control over resources. As a result, we may as well accept the often overtly political nature of the process (e.g., the inclusion of the Krill Research Zone in the RSRMPA to gain Chinese support) and adapt planning processes to incorporate additional considerations that are important from a political perspective.

One concern for conservation planners is that although forecasts can inform MPA site prioritization, they have the potential to inadvertently undermine conservation efforts if not used cautiously. By identifying and highlighting areas perceived to be more socially, economically, and/or politically acceptable, forecasts may incentivize the designation of areas that provide few (if any) conservation benefits. These "residual reserves" occur when planners prioritize minimizing opportunity costs to humans and fail to separate or protect biodiversity from the human activities threatening its persistence (Devillers et al., 2014; Pressey et al., 2015). As a result, we must be clear that forecasts are not a substitute for ecological or socioeconomic data or a precautionary approach, and they should not be used as the primary method for identifying high-priority conservation areas for decision-makers to designate as MPAs. Rather, forecasting techniques are most useful when they are used to inform discussions and to supplement traditional site selection algorithms and spatial prioritization methods (Guerrero and Wilson, 2016; Thiault et al., 2017; Sykora-Bodie et al., 2021). In particular, we see two times during the broader conservation planning process that forecasting techniques can best inform decision-making: (1) during the proposal and negotiation phase to prioritize sites for inclusion (as explained above); and, not included in our study, (2) after designation, to help managers allocate resources for monitoring and enforcement, prioritize management interventions such as fire management or removing invasive species, or predict the likelihood of the successful application of these interventions.

Finally, regardless of the specific context, the conservation planning literature encourages more effective stakeholder participation and suggests the planning process itself is critical for sharing knowledge and building consensus (Pressey and Bottrill, 2009; Gleason et al., 2010; Groves and Game, 2015). In the case of the Southern Ocean, MPA proponents can (and are, in the case of the Domain 1 planning process) use a collaborative conservation planning process to strategically engage various stakeholders, build consensus, and advocate for preferred outcomes. Forecasting techniques can be similarly used as a consensus-building tool by providing a forum for stakeholder discussion.

Limitations of the Study

Consistent with guidance on expert elicitation processes, we assembled an adequate group of experts, in terms of size and diversity that represented the range of delegations and perspectives relevant to the topic. However, including the views of some additional key member countries (e.g., Argentina, Chile, China, Russia) could certainly bring additional differing viewpoints that could contribute to understanding the complex political processes being studied. Therefore, we caution that while our data is informative, and worth considering, it should not be considered exhaustive of differing viewpoints (Morgan, 2014). Similar forecasting exercises have relied on 12–15 individuals (Burgman et al., 2011a) or 13–25 individuals (Burgman et al., 2011b), and Aspinall (2010) recommends between 8 and 15 individuals and Hemming et al. (2017) 10–20 individuals (Aspinall, 2010; Hemming et al., 2017). Although we used a format designed to reduce individual and group biases, we have followed standard practice and reported the results in probabilistic terms that reflect the difficulties associated with forecasting. Developing forecasts of any event (e.g., fishery yields or species extinction risk) is difficult, but predicting human behavior is even more complex and the likelihood of various outcomes may even change in response to these forecasts—hence the field's traditional use of Bayesian models to incorporate new data into forecasts and decision-making.

Additionally, while some research suggests that expert elicitations benefit from in-person workshops (Brown et al., 2014), other elicitations have successfully tested the efficacy of remote methods for capturing accurate assessments (McBride et al., 2012). In our case, we believe that an in-person workshop would have improved the quality of discussion during the second round by permitting more interaction and debate between the experts, but we were limited by the COVID-19 pandemic. For similar future efforts, we recommend attempting (where feasible) a remote, online discussion following the first round of forecasts. It is, however, important to remember that consensus is not the objective, and that even in a workshop, individuals must still develop their own independent first and second round estimates (Hemming et al., 2018).

Finally, structuring the ranking of factors section of the questionnaire to permit the experts to narrow the list themselves has some drawbacks. For one, this resulted in uneven lists of factors within each of the four primary categories. The result was a potential dilution of 'votes' for each factor that made it more difficult to clearly understand which factors played the greatest role in shaping perceptions. Were socioeconomic factors the most important, or would geopolitical factors have been selected more frequently if there had been a third option in the second round of the questionnaire? Were scientific factors truly less influential as the first round indicated? Or did the structure of the second questionnaire disadvantage them? Similarly, this approach to narrowing the categories led to somewhat overlapping categories in several instances. For example, "sensitive wildlife populations" likely overlaps with "large aggregations of wildlife", and the inverse relationship between "existing fisheries" and "no fisheries" could be a problem. However, concerns about these very problems were the reason that we also directly asked them about the relative strength of the factors and then used the qualitative data to more closely examine what the ranking data actually represents.

Future Research

Although our elicitation consisting of ten individuals is consistent with guidance provided by the literature, we would like to test how doubling or tripling the group size to include a greater number of experts affects the precision and robustness of the forecasts. By this we mean to determine the group size at which the addition or removal of any individual forecast fails to lead to significantly different forecasts. Statistical theory suggests that larger groups would be less sensitive to the loss or addition of a single expert's forecasts, therefore, it would be interesting to compare random subsets of forecasts to assess how many participants are required to create a more robust sample that is less sensitive to outlying forecasts. Similarly, this type of elicitation is influenced by a wide range of individual biophysical, socioeconomic, geopolitical, and scientific factors, many of which are linked to or informed by an even smaller subset of the participating experts. As a result, a larger group might make driver-based conclusions more robust by strengthening the individual factors that contribute to collective forecasts are (e.g., krill-sea ice dynamics). The challenge is that this will likely create a group that is too large for a single discussion. This might be addressed by breaking the group into sub-groups or possibly rotating participants so that they all interact with each other.

Finally, several comments during the discussion round suggested reconsidering the size of proposed no-take areas. Although larger areas are more likely to be representative and to allow species to move and adapt to the impacts of a changing climate (McLeod et al., 2009; Howard et al., 2017; Roberts et al., 2017), both of which are key objectives of CCAMLR MPAs (CCAMLR, 2011), several comments suggested that smaller areas may still provide conservation benefits while also being more politically acceptable.

CONCLUSION

In situations where conservation planning efforts lack sufficient spatial/ecological data or are characterized by high levels of uncertainty, we have demonstrated how expert elicitation and forecasting techniques can be an additional input into decision-making. In particular, these methods can be integrated during the early design phase by structuring data collection, during negotiations to designate an MPA, and after establishment by helping environmental decision-makers allocate resources, prioritize management interventions, or predict the likelihood of their success. Our findings show that experts can help to identify and then prioritize spaces for conservation using forecasting techniques, supports the potential application of structured expert elicitation techniques to collate, analyze and interpret judgments, which can facilitate effective knowledge sharing and consensus building through systematic and transparent processes. This is particularly true in politically charged negotiations and international environmental regimes such as CCAMLR that are highly politicized, characterized by complexity and uncertainty, and whose decisions have significant implications for global efforts to conserve biodiversity.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the lead author upon request. However, any information that could be used to identify respondents will be removed to protect confidentiality.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Duke University Institutional Review Board. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SS-B conceived of the study, secured funding for the project, managed the data collection, analyzed the data with input from NB, GM, and DG, and created the figures and led the writing of the manuscript. SS-B, JÁ-R, GM, and DG designed the questionnaire and elicitation. JA, AD, JH, GH, CJ, PS, KT, PT, and DW participated in the expert elicitation. JÁ-R, JA, AD, JH, GH, CJ, PS, KT, PT, DW, NB, GM, and DG provided edits and revisions to the final manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.669135/full#supplementary-material

REFERENCES

Adams, V. M., Mills, M., Jupiter, S. D., and Pressey, R. L. (2011). Improving social acceptability of marine protected area networks: a method for estimating opportunity costs to multiple gear types in both fished and currently unfished areas. *Biol. Conserv.* 144, 350–361. doi: 10.1016/j.biocon.2010.09.012

Antarctic Treaty (1959). *The Antarctic Treaty*. Washington, DC: Antarctic Treaty.

Armstrong, J. S.(ed). (2001). *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Norwell, MA: Kluwer Academic Publishers.

Aspinall, W. (2010). A route to more tractable expert advice. *Nature* 463, 294–295. doi: 10.1038/463294a

Ballance, L. T., Pitman, R. L., Hewitt, R. P., Siniff, D. B., Trivelpiece, W. Z., Clapham, P. J., et al. (2006). "The removal of large whales from the Southern Ocean: evidence for long-term ecosystem effects," in *Whales, Whaling, and Ocean Ecosystems*, eds J. A. Estes, D. P. DeMaster, D. F. Doak, T. M. Williams, and R. L. Brownell Jr. (Oakland, CA: University of California Press), 215–230. doi: 10.1525/j.ctt1ppsvh.22

Ban, N. C., Gurney, G. G., Marshall, N. A., Whitney, C. K., Mills, M., Gelcich, S., et al. (2019). Well-being outcomes of marine protected areas. *Nat. Sustainab.* 19, 1–9. doi: 10.1038/s41893-019-0306-2

Bell, E., Kingston, N., Burgess, N., Sandwith, T., Ali, N., and MacKinnon, K. (eds) (2018). *Protected Planet Report*. Gland: IUCN.

Bernard, H. R. (2011). *Research Methods in Anthropology*, 4th Edn. New York, NY: Altamira Press.

Bray, D. (2020). The geopolitics of Antarctic governance: sovereignty and strategic denial in Australia's Antarctic policy. *Aust. J. Int. Aff.* 70, 256–274. doi: 10.1080/10357718.2015.1135871

Brooks, C. M., Chown, S. L., Douglass, L. L., Raymond, B. P., Shaw, J. D., Sylvester, Z. T., et al. (2020). Progress towards a representative network of southern ocean protected areas. *PLoS One* 15:e0231361. doi: 10.1371/journal.pone.0231361

Brown, G., Donovan, S., Pullar, D., Pocewicz, A., Toohey, R., and Ballesteros-Lopez, R. (2014). An empirical evaluation of workshop versus survey PPGIS methods. *Appl. Geogr.* 48, 42–51. doi: 10.1016/j.apgeog.2014.01.008

Brown, G., McAlpine, C., Rhodes, J., Lunney, D., Goldingay, R., Fielding, K., et al. (2019). Integration of social spatial data to assess conservation opportunities and priorities. *Biol. Conserv.* 236, 452–463. doi: 10.1016/j.biocon.2019.06.002

Burgman, M. A. (2005). *Risks and Decisions for Conservation and Environmental Management*. Cambridge: Cambridge University Press.

Burgman, M. A., Carr, A., Godden, L., Gregory, R., McBride, M., Flander, L., et al. (2011a). Redefining expertise and improving ecological judgment. *Conserv. Lett.* 4, 81–87. doi: 10.1111/j.1755-263X.2011.00165.x

Burgman, M. A., McBride, M., Ashton, R., Speirs-Bridge, A., Flander, L., Wintle, B., et al. (2011b). Expert status and performance. *PLoS One* 6:e22998. doi: 10.1371/journal.pone.0022998

CBD (2020). *Zero Draft for the Post-2020 Global Biodiversity Framework*. Peabody, MA: CBD.

CCAMLR (1980). *Convention on the Conservation of Antarctic Marine Living Resources*. Canberra, ACT: CCAMLR.

CCAMLR (2009). *Conservation Measure 91-03*. HOBART, TAS: CCAMLR.

CCAMLR (2011). *Conservation Measure 91-04*. Hobart, TAS: CCAMLR.

CCAMLR (2016). *Conservation Measure 91-05*. Hobart, TAS: CCAMLR.

CCAMLR (2017). *Report of the Thirty-Sixth Meeting of the Commission*. Hobart, TAS: CCAMLR.

CCAMLR (2018). *Report of the Thirty-Seventh Meeting of the Commission*. Hobart, TAS: CCAMLR.

Chown, S. L., Clarke, A., Fraser, C. I., Cary, S. C., Moon, K. L., and McGeoch, M. A. (2015). The changing form of Antarctic biodiversity. *Nature* 522, 431–438. doi: 10.1038/nature14505

Choy, S. L., O'Leary, R., and Mengersen, K. (2009). Elicitation by design in ecology: using expert opinion to inform priors for Bayesian statistical models. *Ecology* 90, 265–277. doi: 10.1890/07-1886.1

Cinner, J. E., Zamborain-Mason, J., Gurney, G. G., Graham, N. A. J., MacNeil, M. A., Hoey, A. S., et al. (2020). Meeting fisheries, ecosystem function, and biodiversity goals in a human-dominated world. *Science* 368, 307–311. doi: 10.1126/science.aax9412

Coetzee, B. W. T., Convey, P., and Chown, S. L. (2017). Expanding the protected area network in Antarctica is urgent and readily achievable. *Conserv. Lett.* 10, 670–680. doi: 10.1111/conl.12342

Constable, A., Melbourne-Thomas, J., Corney, S. P., Arrigo, K. R., Barbraud, C., Barnes, D. K. A., et al. (2014). Climate change and southern ocean ecosystems I: how changes in physical habitats directly affect marine biota. *Glob. Change Biol.* 20, 3004–3025. doi: 10.1111/gcb.12623

Constable, A. J., de la Mare, W. K., Agnew, D. J., Everson, I., and Miller, D. (2000). Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the convention on the conservation of antarctic marine living resources (CCAMLR). *ICES J. Mar. Sci.* 57, 778–791. doi: 10.1006/jmsc.2000.0725

Cook, C. N., Hockings, M., and Carter, R. B. (2010). Conservation in the dark? The information used to support management decisions. *Front. Ecol. Environ.* 8:181–186. doi: 10.1890/090020

Cordonnery, L., Hemmings, A. D., and Kriwoken, L. (2015). Nexus and imbroglio: CCAMLR, the madrid protocol and designating antarctic marine protected areas in the southern ocean. *Int. J. Mar. Coast. Law* 30, 727–764. doi: 10.1163/15718085-12341380

Cullis-Suzuki, S., and Pauly, D. (2010). Failing the high seas: a global evaluation of regional fisheries management organizations. *Mar. Policy* 34, 1036–1042. doi: 10.1016/j.marpol.2010.03.002

Delegations of Argentina and Chile (2017). *Domain 1 Marine Protected Area Preliminary Proposal PART A-1: Priority Areas for Conservation*. Commission for the Conservation of Antarctic Marine Living Resources.

Delegations of Argentina and Chile (2019). *Revised proposal for a conservation measure establishing a Marine Protected Area in Domain 1 (Western Antarctic Peninsula and South Scotia Arc)*. Hobart, Tasmania: Commission for the Conservation of Antarctic Marine Living Resources.

Delegations of Argentina and Chile (2020). *Revised proposal for a conservation measure establishing a Marine Protected Area in Domain 1 (Western Antarctic Peninsula and South Scotia Arc)*. Hobart, Tasmania: Commission for the Conservation of Antarctic Marine Living Resources.

Devillers, R., Pressey, R. L., Grech, A., Kittinger, J. N., Edgar, G. J., Ward, T., et al. (2014). Reinventing residual reserves in the sea: are we favouring ease of establishment over the need for protection? *Aquat. Conserv.* 25, 480–504. doi: 10.1002/aqc.2445

Dodds, K., and Hemmings, A. D. (2013). Britain and the British Antarctic Territory in the wider geopolitics of the Antarctic and the Southern Ocean. *Int. Aff.* 89, 1–16.

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., et al. (2012). Climate change impacts on marine ecosystems. *Annu. Rev. Mar. Sci.* 4, 11–37. doi: 10.1146/annurev-marine-041911-111611

Donlan, J. C., Wingfield, D. K., Crowder, L. B., and Wilcox, C. (2010). Using expert opinion surveys to rank threats to endangered species: a case study with sea turtles. *Conserv. Biol.* 24, 1586–1595. doi: 10.1111/j.1523-1739.2010.01541.x

Environmental Systems Research Institute (ESRI) (2019). *ArcGIS Release 10.6.4*. Redlands, CA: ESRI.

Everson, I. (2015). Designation and management of large-scale MPAs drawing on the experiences of CCAMLR. *Fish Fish.* 18, 145–159. doi: 10.1111/faf.12137

Fabra, A., and Gascón, V. (2008). The convention on the conservation of antarctic marine living resources (CCAMLR) and the ecosystem approach. *Int. J. Mar. Coast. Law* 23, 567–598. doi: 10.1163/092735208x331854

Fowler, F. J. Jr. (2013). *Survey Research Methods*, 5th Edn. Thousand oaks, CA: SAGE Publications.

Gaines, S. D., White, C., Carr, M. H., and Palumbi, S. R. (2010). Designing marine reserve networks for both conservation and fisheries management. *Proc. Natl. Acad. Sci. U.S.A.* 107, 18286–18293. doi: 10.1073/pnas.0906473107

Giakoumi, S., Grantham, H. S., Kokkoris, G. D., and Possingham, H. P. (2011). Designing a network of marine reserves in the mediterranean Sea with limited socio-economic data. *Biol. Conserv.* 144, 753–763. doi: 10.1016/j.biocon.2010.11.006

Giakoumi, S., Halpern, B. S., Michel, L. N., Gobert, S., Sini, M., Boudouresque, C.-F., et al. (2015). Towards a framework for assessment and management of cumulative human impacts on marine food webs. *Conserv. Biol.* 29, 1228–1234. doi: 10.1111/cobi.12468

Gleason, M., McCreary, S., Miller-Henson, M., Ugoretz, J., Fox, E., Merrifield, M., et al. (2010). Science-based and stakeholder-driven marine protected area network planning: a successful case study from north central California. *Ocean Coast. Manag.* 53, 52–68. doi: 10.1016/j.ocecoaman.2009.12.001

Groves, C. R., and Game, E. T. (2015). *Conservation Planning: Informed Decisions for a Healthier Planet*. Greenwood Village, CO: Roberts and Company Publishers.

Groves, C. R., Jensen, D. B., Valutis, L. L., Redford, K. H., Shaffer, M. L., Scott, J. M., et al. (2002). Planning for biodiversity conservation: putting conservation science into practice. *Bioscience* 52, 499–512. doi: 10.1641/0006-3568(2002)052[0499:pfbcpc]2.0.co;2

Guerrero, A. M., and Wilson, K. A. (2016). Using a social-ecological framework to inform the implementation of conservation plans. *Conserv. Biol.* 31, 290–301. doi: 10.1111/cobi.12832

Gurney, G. G., Pressey, R. L., Ban, N. C., Álvarez-Romero, J. G., Jupiter, S., and Adams, V. M. (2015). Efficient and equitable design of marine protected areas in Fiji through inclusion of stakeholder-specific objectives in conservation planning. *Conserv. Biol.* 29, 1378–1389. doi: 10.1111/cobi.12514

Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., et al. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat. Commun.* 6:7615. doi: 10.1038/ncomms8615

Halpern, B. S., Regan, H. M., Possingham, H. P., and McCarthy, M. A. (2006). Accounting for uncertainty in marine reserve design. *Ecol. Lett.* 9, 2–11. doi: 10.1111/j.1461-0248.2005.00827.x

Hanea, A. M., McBride, M. F., Burgman, M. A., Wintle, B. C., Fidler, F., Flander, L., et al. (2016). Investigate discuss estimate aggregate for structured expert judgement. *Int. J. Forecast.* 33, 267–279. doi: 10.1016/j.ijforecast.2016.02.008

Hemming, V., Burgman, M. A., Hanea, A. M., McBride, M. F., and Wintle, B. C. (2017). A practical guide to structured expert elicitation using the IDEA protocol. *Methods Ecol. Evol.* 9, 169–180. doi: 10.1111/2041-210X.12857

Hemming, V., Walshe, T. V., Hanea, A. M., Fidler, F., and Burgman, M. A. (2018). Eliciting improved quantitative judgements using the IDEA protocol: a case study in natural resource management. *PLoS One* 13:e0198468. doi: 10.1371/journal.pone.0198468

Hodgson-Johnston, I. (2015). Australian politics and Antarctic sovereignty: themes, protagonists and antagonists. *Aust. J. Marit. Ocean Aff.* 7, 183–202. doi: 10.1080/18366503.2015.1101811

Howard, J., McLeod, E., Thomas, S., Eastwood, E., Fox, M., Wenzel, L., et al. (2017). The potential to integrate blue carbon into MPA design and management. *Aquatic Conserv: Mar. Freshw. Ecosyst.* 27, 100–115. doi: 10.1002/aqc.2809

IPBES (2019). *Summary for Policymakers of the Global Assessment Report on BIODiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, eds S. Díaz, J. Settele, E. S.

Brondízio, H. T. Ngo, M. Guèze, J. Agard, et al. (Bonn: IPBES secretariat), 56. doi: 10.5281/zenodo.3553579.

IUCN (2012). *IUCN Red List Categories and Criteria*. Gland: The IUCN Species Survival Commission.

IUCN (2016). *Rules of Procedure for IUCN Red List assessments 2017-2020*. Gland: IUCN.

Jones, K. R., Maina, J. M., Kark, S., McClanahan, T. R., Klein, C. J., and Beger, M. (2018). Incorporating feasibility and collaboration into large-scale planning for regional recovery of coral reef fisheries. *Mar. Ecol. Prog. Ser.* 604, 211–222. doi: 10.3354/meps12743

Kennicutt, M. C., Chown, S. L., Cassano, J. J., Liggett, D., Massom, R., Peck, L. S., et al. (2014). Six priorities for Antarctic science. *Nature* 512, 23–25. doi: 10.1038/512023a

Klein, C. J., Chan, A., Kircher, L., Cundiff, A. J., Gardner, N., Hrovat, Y., et al. (2008). Striking a balance between biodiversity conservation and socioeconomic viability in the design of marine protected areas. *Conserv. Biol.* 22, 691–700. doi: 10.1111/j.1523-1739.2008.00896.x

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F., et al. (2018). Tracking the global footprint of fisheries. *Science* 359, 904–908. doi: 10.1126/science.aao5646

Krueger, T., Page, T., Hubacek, K., Smith, L., and Hiscock, K. (2012a). The role of expert opinion in environmental modelling. *Environ. Model. Softw.* 36, 4–18. doi: 10.1016/j.envsoft.2012.01.011

Krueger, T., Page, T., Smith, L., and Voinov, A. (2012b). A guide to expert opinion in environmental modelling and management. *Environ. Model. Softw.* 36, 1–3. doi: 10.1016/j.envsoft.2012.01.006

Kuhnert, P. M., Martin, T. G., and Griffiths, S. P. (2010). A guide to eliciting and using expert knowledge in Bayesian ecological models. *Ecol. Lett.* 13, 900–914. doi: 10.1111/j.1461-0248.2010.01477.x

Lechner, A. M., Raymond, C. M., Adams, V. M., Polyakov, M., and Gordon, A. (2014). Characterizing spatial uncertainty when integrating social data in conservation planning. *Conserv. Biol.* 28, 1497–1511. doi: 10.111/cobi.12409

Liu, N., and Brooks, C. M. (2018). China's changing position towards marine protected areas in the southern ocean: implications for future Antarctic governance. *Mar. Policy* 94, 189–195. doi: 10.1016/j.marpol.2018.05.011

MacMillan, D. C., and Marshall, K. (2006). The delphi process–an expert-based approach to ecological modelling in data-poor environments. *Anim. Conserv.* 9, 11–19. doi: 10.1111/j.1469-1795.2005.00001.x

Margules, C. R., and Pressey, R. L. (2000). Systematic conservation planning. *Nature* 405, 243–253. doi: 10.1038/35012251

Martin, T. G., Burgman, M. A., Fidler, F., Kuhnert, P. M., Low-Choy, S., McBride, M., et al. (2012). Eliciting expert knowledge in conservation science. *Conserv. Biol.* 26, 29–38. doi: 10.1111/j.1523-1739.2011.01806.x

Mastrandrea, M. D., Field, C. B., Stocker, T. F., Edenhofer, O., Ebi, K. L., Frame, D. J., et al. (2010). *Guidance Note for Lead Authors of the IPCC 5th Assessment Report on Consistent Treatment of Uncertainties*. Jasper Ridge, CA: Intergovernmental Panel on Climate Change, 1–7.

McBride, M. F., Garnett, S. T., Szabo, J. K., Burbidge, A. H., Butchart, S. H. M., Christidis, L., et al. (2012). Structured elicitation of expert judgments for threatened species assessment: a case study on a continental scale using email. *Methods Ecol. Evol.* 3, 906–920. doi: 10.1111/j.2041-210X.2012.00221.x

McCarthy, M. A., Thompson, C. J., Moore, A. L., and Possingham, H. P. (2011). Designing nature reserves in the face of uncertainty. *Ecol. Lett.* 14, 470–475. doi: 10.1111/j.1461-0248.2011.01608.x

McLeod, E., Salm, R., Green, A., and Almany, J. (2009). Designing marine protected area networks to address the impacts of climate change. *Front. Ecol. Environ.* 7:362–370. doi: 10.1890/070211

Miller, D. (2011). "Sustainable management in the southern ocean: CCAMLR science," in *Science Diplomacy Antarctica, Science, and the Governance of International Spaces*, eds P. A. Berkman, M. A. Lang, D. W. H. Walton, and O. R. Young (Washington, DC: Smithsonian Institution Scholarly Press).

Miller, D., and Slicer, N. M. (2014). "CCAMLR and Antarctic conservation: the leader to follow?," in *Governance of Marine Fisheries and Biodiversity Conservation*, eds S. M. Garcia, J. Rice, and A. Charles (West Sussex: John Wiley & Sons, Ltd), 253–270. doi: 10.1002/9781118392607.ch18

Mills, M., Pressey, R. L., Ban, N. C., Foale, S., Aswani, S., and Knight, A. T. (2013). Understanding characteristics that define the feasibility of conservation actions in a common pool marine resource governance system. *Conserv. Lett.* 6, 418–429. doi: 10.1111/conl.12025

Morgan, G. M. (2014). Use (and abuse) of expert elicitation in support of decision making for public policy. *Proc. Natl. Acad. Sci. U.S.A.* 111, 7176–7184. doi: 10.1073/pnas.1319946111

Naidoo, R., Gerkey, D., Hole, D., Pfaff, A., Ellis, A. M., Golden, C. D., et al. (2019). Evaluating the impacts of protected areas on human well-being across the developing world. *Sci. Adv.* 5:eaav3006. doi: 10.1126/sciadv.aav3006

National Academies (2016). "Reducing response burden in the american community survey," in *Proceedings of a Workshop* (Washington, DC: The National Academies Press). doi: 10.17226/23639

Neuwirth, E. (2014). *RColorBrewer: ColorBrewer Palettes. R package version 1.1-2*. Available online at: https://CRAN.R-project.org/package=RColorBrewer.

O'Hagan, A. (2019). Expert knowledge elicitation: subjective but scientific. *Am. Stat.* 73, 69–81. doi: 10.1080/00031305.2018.1518265

O'Hagan, A., Buck, C. E., Daneshkhah, A., Eiser, J. R., Garthwaite, P. H., Jenkinson, D. J., et al. (2006). *Uncertain Judgements*. Chichester: John Wiley & Sons, Ltd.

O'Leary, R. A., Choy, S. L., Murray, J. V., Kynn, M., Denham, R., Martin, T. G., et al. (2009). Comparison of three expert elicitation methods for logistic regression on predicting the presence of the threatened brush—tailed rock—wallaby *Petrogale penicillata*. *Environmetrics* 20, 379–398. doi: 10.1002/env.935

Parkes, G. (2000). Precautionary fisheries management: the CCAMLR approach. *Mar. Policy* 24, 83–91. doi: 10.1016/S0308-597X(99)00015-9

Pollnac, R., Christie, P., Cinner, J. E., Dalton, T., Daw, T. M., Forrester, G. E., et al. (2010). Marine reserves as linked social-ecological systems. *Proc. Natl. Acad. Sci. U.S.A.* 107, 18262–18265. doi: 10.1073/pnas.0908266107

Pressey, R. L., and Bottrill, M. C. (2009). *Approaches to Landscape- and Seascape-Scale Conservation Planning: Convergence, Contrasts and Challenges*. Cambridge: Cambridge University Press.

Pressey, R. L., Visconti, P., and Ferraro, P. J. (2015). Making parks make a difference: poor alignment of policy, planning, and management with protected-area impact, and ways forward. *Philos. Trans. R. Soc. B. Biol. Sci.* 370:20140280.

R Core Team (2017). *R: A language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing.

R Studio Team. (2019). *RStudio: Integrated Development for R*. Boston, MA: R Studio, Inc.

Regan, H. M., Colyvan, M., and Burgman, M. A. (2002). A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecol. Appl.* 12, 618–628.

Rintoul, S. R. (2018). The global influence of localized dynamics in the Southern Ocean. *Nature* 558, 209–218. doi: 10.1038/s41586-018-0182-3

Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., et al. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proc. Natl. Acad. Sci. U.S.A.* 114, 6167–6175. doi: 10.1073/pnas.1701262114

Rolstad, S., Adler, J., and Rydén, A. (2011). Response burden and questionnaire length: is shorter better? A review and meta-analysis. *Value Health* 14, 1101–1108. doi: 10.1016/j.jval.2011.06.003

Rossiter, J. S., and Levine, A. S. (2014). What makes a "successful" marine protected area? The unique context of Hawaii's fish replenishment areas. *Mar. Policy* 44, 196–203. doi: 10.1016/j.marpol.2013.08.022

Spalding, M. D., Meliane, I., Milam, A., Fitzgerald, C., and Hale, L. Z. (2013). Protecting marine spaces:global targets and changing approaches. *Ocean Yearbook* 27, 213–248.

Speirs-Bridge, A., Fidler, F., McBride, M., Flander, L., Cumming, G., and Burgman, M. A. (2010). Reducing overconfidence in the interval judgments of experts. *Risk Anal.* 30, 512–523. doi: 10.1111/j.1539-6924.2009.01337.x

Sutherland, W. J., and Burgman, M. A. (2015). Use experts wisely. *Nature* 526, 317–318.

Sutherland, W. J., Fleishman, E., Mascia, M. B., Pretty, J., and Rudd, M. A. (2011). Methods for collaboratively identifying research priorities and emerging issues in science and policy. *Methods Ecol. Evol.* 2, 238–247. doi: 10.1111/j.2041-210X.2010.00083.x

Sykora-Bodie, S. T., Álvarez-Romero, J. G., Adams, V. M., Gurney, G. G., Cleary, J., Pressey, R. L., et al. (2021). Methods for identifying spatially referenced conservation needs and opportunities. *Biol. Conserv.* 21, 1–15. doi: 10.1016/j.biocon.2021.109138

Sykora-Bodie, S. T., and Morrison, T. H. (2019). Drivers of consensus−based decision−making in international environmental regimes: lessons from the Southern Ocean. *Aquatic Conserv. Mar. Freshw. Ecosyst.* 8, 311–325. doi: 10.1002/aqc.3200

Thiault, L., Gelcich, S., Marshall, N., Marshall, P., Chlous, F., and Claudet, J. (2019). Operationalizing vulnerability for social-ecological integration in conservation and natural resource management. *Conserv. Lett.* 13:e12677. doi: 10.1111/conl.12677

Thiault, L., Jupiter, S. D., Johnson, J. E., Cinner, J. E., Jarvis, R. M., Heron, S. F., et al. (2021). Harnessing the potential vulnerability of assessments for managing social-ecological systems. *Ecol. Soc.* 26:1. doi: 10.575/ES-12167-260201

Thiault, L., Marshall, P., Gelcich, S., Collin, A., Chlous, F., and Claudet, J. (2017). Mapping social-ecological vulnerability to inform local decision making. *Conserv. Biol.* 32, 447–456. doi: 10.1111/cobi.12989

Thiault, L., Marshall, P., Gelcich, S., Collin, A., Chlous, F., and Claudet, J. (2018). Mapping social-ecological vulnerability to inform local decision making. *Conserv. Biol.* 32, 447–456.

Tulloch, A. I. T., Tulloch, V. J. D., Evans, M. C., and Mills, M. (2014). The value of using feasibility models in systematic conservation planning to predict landholder management uptake. *Conserv. Biol.* 28, 1462–1473. doi: 10.1111/cobi.12403

Ungar, L., Mellors, B., Satopää, V., Baron, J., Tetlock, P., Ramos, J., et al. (2012). *The Good Judgment Project: A Large Scale Test of Different Methods of Combining Expert Predictions AAAI Fall Symposium-Technical report*, Association for the Advancement of Artificial Intelligence, 37–42.

Walmsley, S. F., and White, A. T. (2003). Influence of social, management and enforcement factors on the long-term ecological effects of marine sanctuaries. *Environ. Conserv.* 30, 388–407. doi: 10.1017/S0376892903000407

Ward, T. J. (2014). The condition of Australia's marine environment is good but in decline-an integrated evidence-based national assessment by expert elicitation. *Ocean Coast. Manag.* 100, 86–100. doi: 10.1016/j.ocecoaman.2014.07.012

Watson, J. E. M., Dudley, N., Segan, D. B., and Hockings, M. (2014). The performance and potential of protected areas. *Nature* 515, 67–73. doi: 10.1038/nature13947

Welsford, D. C., Constable, A. J., and Nowara, G. B. (2011). The heard island and McDonald islands marine reserve and conservation zone– a model for southern ocean marine reserves? *Cybium* 35, 297–304. doi: 10.26028/cybium/2011-35SP-034

Wenzel, L., Gilbert, N., Goldsworthy, L., Tesar, C., McConnell, M., and Okter, M. (2016). Polar opposites? Marine conservation tools and experiences in the changing Arctic and Antarctic. *Aquatic Conserv. Mar. Freshw. Ecosyst.* 26, 61–84. doi: 10.1002/aqc.2649

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York, NY: Springer-Verlag.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., et al. (2019). Welcome to the tidyverse. *J. Open Source Softw.* 4:1686. doi: 10.21105/joss.01686

Wickham, H., and Bryan, J. (2019). *readxl: Read Excel Files. R package version 1.3.1*. Available online at: https://CRAN.R-project.org/package=readxl

Wickham, H., François, R., Henry, L., and Müller, K. (2020). *dplyr: A Grammar of Data Manipulation. R package version 0.8.5*. Available online at: https://CRAN.R-project.org/package=dplyr

Wilcox, C., Mallos, N. J., Leonard, G. H., Rodriguez, A., and Hardesty, B. D. (2016). Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife. *Mar. Policy* 65, 107–114. doi: 10.1016/j.marpol.2015.10.014

Wildermann, N. E., Gredzens, C., Avens, L., Barrios-Garrido, H. A., Bell, I., Blumenthal, J., et al. (2018). Informing research priorities for immature sea turtles through expert elicitation. *Endanger. Species Res.* 37, 55–76. doi: 10.3354/esr00916

Williamson, M. A., Schwartz, M. W., and Lubell, M. N. (2018). Spatially explicit analytical models for social–ecological systems. *Bioscience* 68, 885–895. doi: 10.1093/biosci/biy094

Wintle, B. C., Kennicutt, M. C., and Sutherland, W. J. (2018). "Scanning horizons in research, policy and practice," in *Conservation Research, Policy And Practice*, eds W. J. Sutherland, P. Brotherton, Z. Davies, N. Pettorelli, B. Vira, and J. Vickery (Cambridge: Cambridge University Press), 29–47.

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frontiers in Marine Science

BRIEF RESEARCH REPORT
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Effectiveness of Large-Scale Marine Protected Areas in the Atlantic Ocean for Reducing Fishing Activities

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The implementation of large-scale marine protected areas (MPAs) depends upon scarce conservation resources, while their effects on biodiversity conservation are rarely assessed to date. Quantitative evaluations are necessary to assess the effectiveness of large-scale MPAs in enhancing ecosystem resilience, protecting biodiversity, and mitigating expanding threats. In this study, the effectiveness of large-scale MPAs, which are remotely managed and in offshore areas of the southwestern Atlantic Ocean (Brazil), was assessed concerning the occurrence of fishing activities within their boundaries before and after their implementation. Two sets of MPAs surrounding the São Pedro and São Paulo archipelago (SPSP) and the Trindade-Martin Vaz Islands (TMV) were established in early 2018, each comprising one no-take (i.e., fully-protected) and one multiple-use (i.e., partially-protected) area. For this assessment, I used satellite detections of Vessel Monitoring System transmission to quantify the fishing pressure (i.e., "likely fishing days") from commercial fisheries spanning 5 years (2015–2019). I then derived three metrics – fishing area, intensity, and density – to compare fishing activity within each MPA and year. The results showed that the effectiveness of the multiple-use MPAs was variable and contrasting, with SPSP experiencing a reduction in the fishing intensity and area and TMV experiencing an increase in both measures. An inverted pattern was evident for the no-take MPAs: while the one in the SPSP region experienced an increase in the fishing density after its establishment following a squeeze factor, the no-take MPA in the TMV region observed a decrease in the fishing density when comparing years before and after MPA implementation. These outputs can support managers in planning the implementation of further conservation strategies, such as monitoring and enforcement plans, and the analyses here also contribute to enhancing our understanding on the implications and challenges of adopting large-scale MPAs in the offshore environment as a high-profile strategy of ocean conservation.

Keywords: large marine protected areas, marine conservation, conservation assessment, commercial fishing, vessel tracking, vessel monitoring system, Brazil, fisheries

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INTRODUCTION

Fishing is a leading cause of disturbances in the marine realm with consequences such as trophic cascade (Mumby et al., 2006; Shears et al., 2008) and loss of habitats (Kaiser et al., 2002; Lundquist et al., 2018). Moreover, overfishing in targeted and by-catch fisheries causes population decline in several species of the megafauna, including sharks, seabirds, and marine mammals (Dulvy et al., 2014; White et al., 2017). The global expansion of fisheries to meet the demand for fisheries resource extraction and the continued development of gear technology both have expanded and intensified the activity, with fishing occurring even in the remotest parts of the ocean (Sala et al., 2018).

Globally, fishing activity requires robust management measures to mitigate its impacts on marine biodiversity. Although there are several frameworks concerned with improving fisheries management (e.g., Booth et al., 2020), the designation of marine protected areas (MPAs) is the most applied tool to maintain biodiversity and fisheries at a sustainable level (Lubchenco and Grorud-Colvert, 2015). Several countries, including Brazil, are making compelling cases for historical progress toward achieving the international targets for marine protection under the Convention on Biological Diversity and the Sustainable Development Goals (Friedlander et al., 2016; Magris and Pressey, 2018; Claudet et al., 2021). As a consequence, recent years have also seen an increase in the development of large-scale MPAs (i.e., larger than 100,000 km^2) over offshore and deep areas (Boonzaier and Pauly, 2016), following an *ad hoc*, opportunistic process (O'Leary et al., 2018). However, for these conservation efforts to drive outcomes for biodiversity, they must translate into significant mitigation of human impacts, particularly derived from fishing activity. This requires overcoming the monitoring and enforcement challenges associated with the large-scale governance of dynamic and remote seascapes (De Santo, 2013; Brooks et al., 2019).

Overall, there are several ways of measuring MPA effectiveness, and several frameworks have been proposed (Pomeroy et al., 2005; Pajaro et al., 2010; Zupan et al., 2018a). Percentages of an area under protection (i.e., MPA coverage), although commonly used, are misleading indicators of conservation success (Roberts et al., 2018). Indicators of MPA management effectiveness are intended to show how well MPAs are working towards their objectives (Pajaro et al., 2010), but they are usually evaluated using only managers' perceptions of good governance and MPA impacts (de Oliveira Júnior et al., 2021). Improvements of ecological conditions, such as the increase in species abundance, are seen as more accurate determinants of MPA effectiveness, but evaluations of offshore MPAs in remote areas are difficult due to data paucity and budgetary constraints related to the development of monitoring programs in such areas (Ban et al., 2017). Finally, a quantitative assessment of how well MPAs can abate the threatening processes provides an alternative, practical assessment of effectiveness (Zupan et al., 2018a) until detailed post-implementation monitoring data have been collected.

Vessel Monitoring System (VMS) data can help fill the gap in effectiveness assessments of large-scale, offshore MPAs and are widely used to evaluate fishing activity (Chang and Yuan, 2014; Delfour-Samama and Leboeuf, 2014; Rowlands et al., 2019). VMS can track vessel movements in near real-time using satellite transponders. Although the system is not tamper-proof (Appleby et al., 2018), it might be the only tool available to assess patterns of fishing activity and provides historical valuable information such as the vessel's identity, position, and associated fishing gear. These data can thus provide a unique baseline for determining whether MPAs are effective at reducing threats in the absence of other monitoring tools. Here, I used a long-term, large dataset tracking the movements of commercial fishing vessels before and after the two of the largest MPAs in the southern Atlantic Ocean (within Brazil's exclusive economic zone) were established – i.e., between the years 2015 and 2019 – to provide evidence of their effectiveness at reducing fishing pressure.

METHODS

Case Study Description

To meet global MPA commitments and in recognition of the relatively poor development of protected areas associated with the marine realm in Brazil, the Ministry of the Environment declared two sets of large-scale MPAs in the Southwestern Atlantic Ocean in early 2018: (i) two MPAs surrounding the São Pedro and São Paulo Archipelago (SPSP), which is formed by rocky islands in the mid-Equatorial North Atlantic Ocean (0°55′N; 29°20′W), distant about 1,000 km from the mainland; and (ii) two MPAs surrounding the Trindade Island and the Martin Vaz Archipelago (TMV), which is formed by the emerged part of the Vitória – Trindade submarine chain in the south-western tropical Atlantic Ocean (29°18′S; 20°30′W), distant 1,160 km from the mainland (see **Supplementary Figure 1** for detailed zoomed views of both regions). These islands have among the highest fish biomass across Brazilian reefs (Morais et al., 2017), notable endemism (Simon et al., 2013; Pinheiro et al., 2020), and globally threatened fauna (Almeida et al., 2011; Duarte-Neto et al., 2012). Despite their biodiversity significance, both regions are also threatened by commercial fisheries and climate change (Magris et al., 2020). The MPAs comprise the territorial sea and exclusive economic zones of the islands.

The no-take MPA at the SPSP region (i.e., considered to be fully protected, and referring to the IUCN category III) was created to protect the southern portions of the archipelago and seamounts of the Mid-Atlantic Ridge, with a total size of 47,263.18 km^2. The multiple-use MPA (i.e., considered to be partially protected, and referring to the IUCN category IV) embraces the no-take one, including the majority of the small islands and a large open-ocean area, with a size of 407,052.36 km^2. The no-take MPA at the TMV region (same IUCN category as the no-take MPA at the SPSP region) was created to protect portions of the shallow reef habitats and the terrestrial environment, with a size of 67,696.71 km^2. This no-take is also nested within a multiple-use MPA of the same category as the SPSP described above, with a size of 402,377.1 km^2. Although all these MPAs have not been fully implemented (i.e., they have not elaborated their management plans), they correspond to about 95% of the total marine area protected in Brazil.

Commercial Fishing Activity

I used a 5-year dataset (January 2015–December 2019) of the spatial distribution of commercial fishing activity entering the study regions. The dataset was obtained from the processed VMS data provided by the National Program for tracking fishing vessels in Brazil (i.e., PREPS). The movement of fishing vessels is remotely tracked using a transponder, which transmits signals of vessel's position and behavior via satellite to ground stations on an hourly basis. To identify the behavior of vessels (e.g., navigating, fishing, and mooring), the signals are automatically processed based on spatial movement patterns and speed. I filtered out those records not associated with fishing activity and then included in the analysis only the positions by which vessels are very likely fishing. I identified a total of 1,844,902 transmitted signals that were associated with 152 active vessels and indicative of fishing operations within the study regions over the studied period. VMS is legally required for all fishing vessels larger than 15 m in Brazil, which is suitable for assessing fishing pressure in remote, offshore areas.

By using a database of fishing gears associated with each vessel, I could obtain more details about the fishing operations. For example, I found that most of the fishing operations were associated with pelagic longline (i.e., >80%), although I also registered other fishing gears such as bait boat – pole-and-line fishing, pelagic handline, and bottom trawl (registered exclusively for the TMV region). This information requires certain caution because the type of fishing gear associated with each vessel can be modified through the renewing process of fishing licenses, without being automatically updated into the system.

I collapsed the data points from all transmitted signals for each vessel into single days to derive a metric of fishing activity (i.e., "likely fishing days") and accumulated this value for all vessels per 10 × 10 km grid cell within each year assessed. I also assigned the metrics to each no-take or multiple-use MPA by overlying the MPA boundaries and fishing data. I extracted the MPA shapefiles from the dataset held by the Brazilian Ministry of Environment[1]. To determine the spatial similarity of total fishing days within each MPA among years, I calculated the Kendall correlation coefficient. This coefficient is a pairwise statistic that measures the degree of agreement among years.

Lastly, I summarized the following measures of fishing pressure within each MPA and year: (i) the total number of cells with fishing days >1 as a proxy of "fishing area"; (ii) the sum of fishing days as a proxy of "fishing intensity"; and (iii) the quotient of the total number of fishing days and the fishing area as a measure of "fishing density." Following White et al. (2020), I sought to partially control for changes in fishing pressure not related to the modification of the protection status of the study regions. For this last set of analyses, I compared each measure of fishing pressure calculated as above against the same metrics associated with cells randomly selected across Brazil's EEZ, and limited to the corresponding total size of one set of large-scale MPAs (i.e., 455,000 km^2). I generated the random selection of cells as described in Magris et al. (2020). I restricted the cells selection within other areas of Brazil's EEZ because international waters can have different fisheries management regulations. I excluded fully-protected MPAs from the random selection as they might be effective at restricting fishing activities within their boundaries. I also allowed coastal areas to be selected because the commercial fishing fleet using the assessed gears is widely distributed across the entire Brazil's EEZ (Magris et al., 2020).

[1]http://www.mma.gov.br/areas-protegidas/cadastro-nacional-de-ucs

RESULTS

Considering the whole period from 2015 to 2019, I identified 28,226 total days of fishing activity in the SPSP region (93% of them within the area of the multiple-use MPA and about 7% within the no-take one) and 54,164 in the TMV region (82% of them within the area of the multiple-use MPA and about 18% within the no-take one).

For the SPSP region (**Figure 1**), I recorded a hotspot of likely fishing days on the northwestern portion of the multiple-use MPA, between the years 2015 and 2016, and on the southern portion of this MPA for the year 2017. Hotspots of fishing within the no-take MPA followed the same spatial pattern of the multiple-use one for the years prior to MPA establishment. After MPA creation, hotspots of fishing activity were well distributed in 2018, and more spatially concentrated on the western portions of both MPAs in 2019.

For the TMV region (**Figure 2**), I identified that hotspots of fishing activity clustered on the central parts of the region in 2017 and were well dispersed in the previous years. After MPA establishment, large areas of the multiple-use MPA could be identified as hotspots of fishing activity, mainly in its left half, closer to the mainland. While hotspots of fishing activity were identified within no-take MPAs in 2018, fishing activity was substantially reduced in 2019 for this MPA.

When I performed the correlation matrix analysis, three results emerged (**Figure 3**): (i) there was no agreement between the fishing activities occurring at each year within the multiple-use MPA in the SPSP region (Kendall coefficient: −0.09–0.14; **Figure 3A**); (ii) there was a strong agreement between the fishing activities occurring at several years before and after MPA establishment within the no-take MPA in the TMV region (Kendall coefficient: 0.94–0.96; **Figure 3D**); and (iii) there was only a substantial agreement between the fishing activities occurring in the years 2018–2019 within the no-take MPA in the SPSP region (Kendall coefficient = 1; **Figure 3B**), and within the multiple-use MPA in the TMV region (Kendall coefficient = 0.67; **Figure 3C**). While the first two cases imply that these specific MPAs might have little influence on the spatial patterns of fishing activity, the second situation indicates that the creation of those MPAs might have affected spatial patterns of fishing activity.

Analysis of fishing pressure within each MPA (**Figure 4**; top panels) revealed that the amount of fished area was reduced after MPA establishment for the SPSP region, which was not the case for the TMV region. The observed reduction in the SPSP region was followed by a decrease in the fishing intensity within the multiple-use MPA (middle panel) and an increase in the fishing density within the no-take MPA after their establishment (bottom panel). This was because fishing activity became more

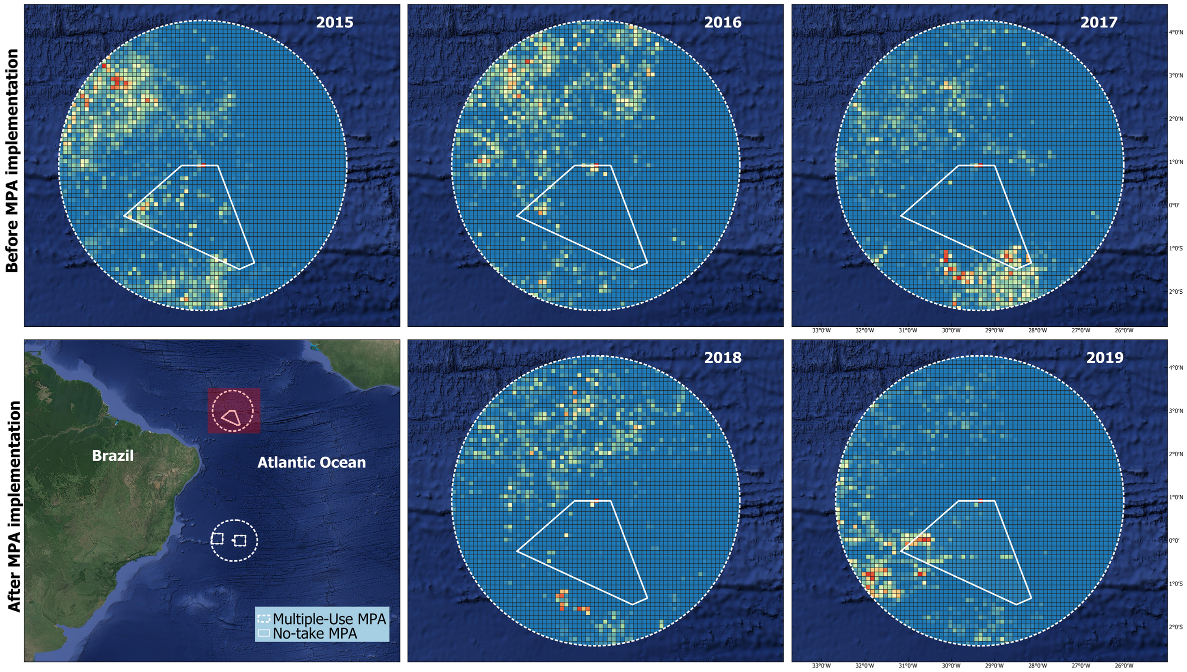

FIGURE 1 | Occurrence of fishing activity ("likely fishing days") within the no-take and multiple-use large-scale marine protected areas (MPAs) surrounding the São Pedro and São Paulo Archipelago (SPSP) over 5 years: 2015–2017 (*top row*), when the MPAs had not been declared; and 2018–2019 (*bottom row*), when the MPAs have been established.

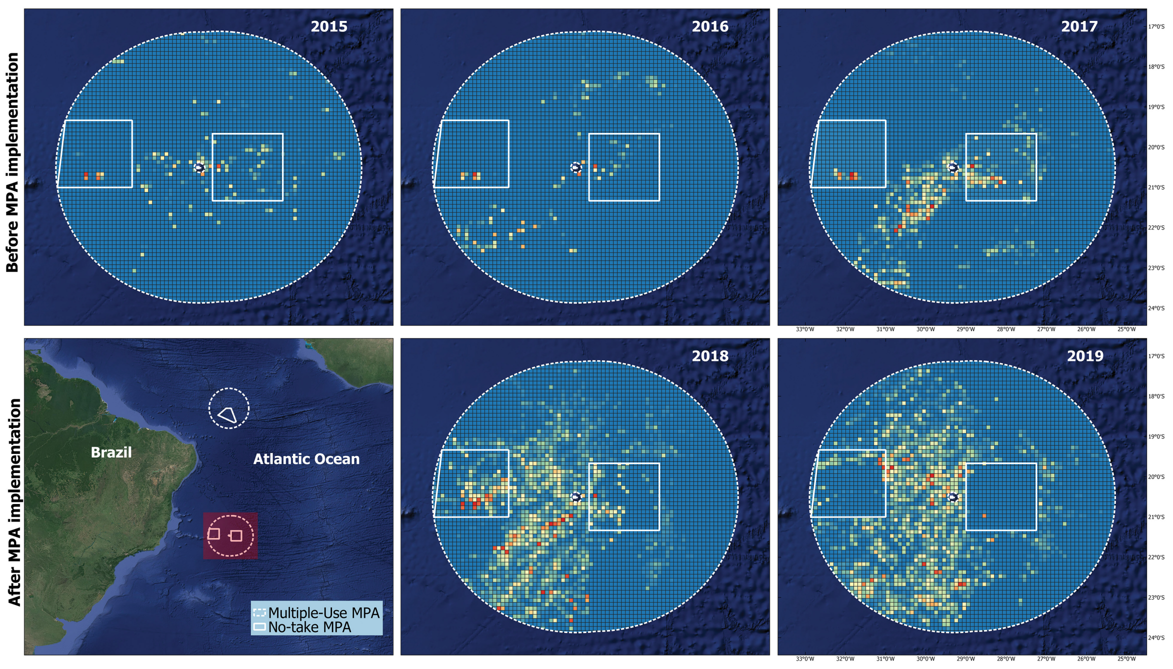

FIGURE 2 | Occurrence of fishing activity ("likely fishing days") within the no-take and the multiple-use large-scale MPAs surrounding the Trindade Island and the Martin Vaz Archipelago (TMV) over 5 years: 2015–2017 (*top row*), when the MPAs had not been declared; and 2018–2019 (*bottom row*), when the MPAs have been established.

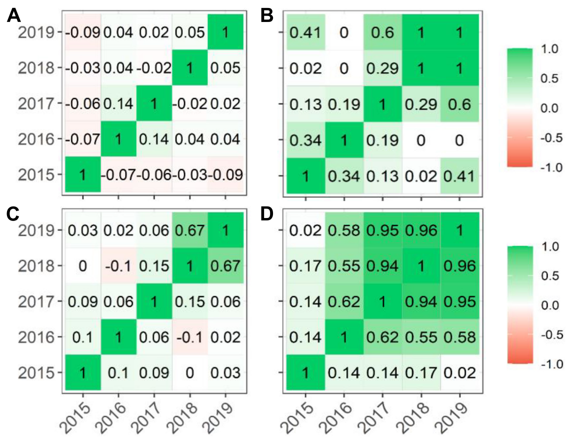

FIGURE 3 | Kendall correlation index for the relationship between fishing activity within each year for all MPAs (**A**: multiple-use MPA in the SPSP region; **B**: no-take MPA in the SPSP region; **C**: multiple-use MPA in the TMV region; and **D**: no-take MPA in the TMV region).

concentrated over smaller areas of this MPA. Overall, I also found a large increase in the fishing intensity within the multiple-use MPA for TMV (middle panel), which was also reported for the no-take MPA at least for the first year after MPA establishment (2018). When assessing the measure of fishing density for this region, I found that there was a small reduction of this measure in the no-take MPA. It was noticeable that fishing density seems not to change with MPA establishment for the multiple-use MPAs in both regions. I identified comparable and high levels of fishing pressure on the random areas that did not restrict commercial fisheries throughout the time assessed, regardless of the measure of fishing pressure used (**Supplementary Figures 2–4**).

DISCUSSION

The results presented here provide the first assessment of the conservation effectiveness of large-scale MPAs in the Southwestern Atlantic Ocean and contribute to the ongoing discussion about the benefits of this conservation strategy to mitigate threats from fishing (O'Leary et al., 2018). Results indicated that the effectiveness of the large-scale MPAs was variable and depended on the measure of fishing pressure used. Overall, there was a reduction in the fishing area and intensity in the SPSP region, but fishing became particularly intense over smaller areas ("squeeze factor"), particularly within the no-take MPA. On the other hand, while fishing area and intensity increased for the TMV region, a reduction in the fishing density was observed because the activity became spread over larger areas. More positively, a reduction in all measures of fishing pressure became apparent in 2019 for the no-take MPA in TMV. Fishing pressure is thus significant within these large-scale MPAs and monitoring and enforcement efforts to effectively promote their reduction over time needs to be encouraged.

I estimated that between 3 and 10% of the no-take MPA in the SPSP region, and between 12 and 38% of the no-take MPA in the TMV region remained potentially fished. This supports the existence of illegal fishing even in the remote places of the ocean as previously identified (Arias et al., 2016). Although there is some uncertainty in the VMS data to provide evidence of the magnitude of fishing activity as a result of the need to combine this technology with other forms of evidence gathering (Appleby et al., 2018), this is unlikely to change this result significantly. With the challenges associated with patrolling offshore and remote areas in the ocean, a more realistic approach to build evidence of illegal fishing would be to combine different data sources that are sufficient to lead to a prosecution, making enforcement effective.

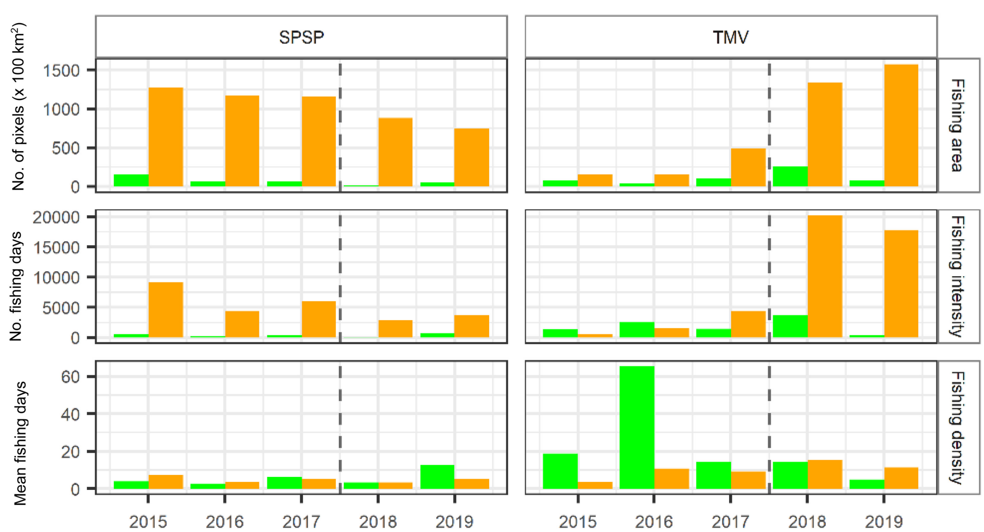

FIGURE 4 | Summaries of fishing pressure on each large-scale MPA off Brazil (green for no-take and orange for multiple-use ones) across 2015–2019 in terms of fishing area, intensity, and density. Panels on the right are results for the TMV region and on the left for the SPSP region. The dashed line indicates the time of MPA establishment.

As previously suggested (Magris and Pressey, 2018), the effects of multiple-use, large-scale MPAs have been marginal, at least in the short term. Indeed, multiple-use MPAs have been claimed to have a limited impact on biodiversity conservation (Giakoumi et al., 2017; Zupan et al., 2018b) when assessed in terms of improving biodiversity conditions *in situ*. On the other hand, some have argued that their contribution to ocean conservation would be to prevent mining expansion in the future (Giglio et al., 2018; Miller et al., 2018). While these conservation outcomes are not realized, several management recommendations could be derived for this category of MPAs to improve its effectiveness in the present. Areas identified as more important for biodiversity within their boundaries (Magris et al., 2020; Vilar et al., 2020) could be targeted for more strict fishing regulations through a zoning process. Moreover, fishing activity could be particularly required to adopt practices that reduce the risk of fishing mortality (Booth et al., 2019). Strengthening regulations and establishing adequate governance are key ingredients for increasing conservation benefits expected from effective MPAs.

Recent evidence has suggested that large-scale MPAs maintain fishing levels at a low level (White et al., 2020). The results presented here do not support this pattern at least for those MPAs affording partial protection. Multiple-use MPAs did not interfere in the spatial patterns of fishing activity over the time assessed and, in some instances, fishing intensity within no-take MPAs had even increased shortly after the creation of MPAs. These contrasting findings can be explained by the intrinsic difference between the sources of fishing detection systems (VMS *versus* Automatic Information Systems – AIS). At least in Brazil, the AIS system misses a considerable fraction of fishing vessels, rendering assessments based on that system misleading. For example, tracking the global footprint of fisheries using AIS across the national waters off Brazil, as well as other exclusive economic zones, has shown minimal fishing effort within this area (Kroodsma et al., 2018), which is a misreport of the activity.

A major challenge to quantifying the conservation effectiveness of large-scale MPAs is the dynamic context in which threats operate over vast areas and data availability. The assessment of the threat reduction capacity of these MPAs might be influenced by other environmental conditions such as ocean currents, temperature, and distance from the mainland. Ongoing efforts to gather and analyze data for their influence on the occurrence of fishing activity will possibly result in the revised estimates of the conservation effectiveness of large-scale MPAs, allowing more comprehensive assessments of their role in reducing fishing pressure.

Though there are venues for further development and refinement, this study constitutes an important first step in quantifying the effects of large-scale MPAs off Brazil. The case study highlights that, unlike other regions, fishing activity remains operating within multiple-use MPAs, and that avoiding illegal fishing within no-take MPAs is an urgent need. While remote sensing technologies provide spatially and temporally continuous assessment of fishing activities, it would need to be combined with other evidence-based tools on fishing effort for increasing existing levels of compliance and enforcement. The variations in fishing pressure among MPA types over time affirm the dynamic nature of managing offshore marine systems.

DATA AVAILABILITY STATEMENT

The processed data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

RAM was the sole author of this manuscript, developed the research question and protocol, conducted data collection and analysis, and wrote the content of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.711011/full#supplementary-material

REFERENCES

Almeida, A. P., Moreira, L. M. P., Bruno, S. C., Thomé, J. C. A., Martins, A. S., Bolten, A. B., et al. (2011). Green turtle nesting on trindade island, Brazil: abundance, trends, and biometrics. *Endanger. Species Res.* 14, 193–201. doi: 10.3354/esr00357

Appleby, T., Studley, M., Moorhouse, B., Brown, J., Staddon, C., and Bean, E. (2018). Sea of possibilities: old and new uses of remote sensing data for the enforcement of the Ascension Island marine protected area. *Mar. Policy* 127:103184. doi: 10.1016/j.marpol.2018.06.012

Arias, A., Pressey, R. L., Jones, R. E., Álvarez-Romero, J. G., and Cinner, J. E. (2016). Optimizing enforcement and compliance in offshore marine protected areas: a case study from Cocos Island, Costa Rica. *Oryx* 50, 18–26. doi: 10.1017/S0030605314000337

Ban, N. C., Davies, T. E., Aguilera, S. E., Brooks, C., Cox, M., Epstein, G., et al. (2017). Social and ecological effectiveness of large marine protected areas. *Glob. Environ. Change* 43, 82–91. doi: 10.1016/j.gloenvcha.2017.01.003

Boonzaier, L., and Pauly, D. (2016). Marine protection targets: an updated assessment of global progress. *Oryx* 50, 27–35. doi: 10.1017/S0030605315000848

Booth, H., Squires, D., and Milner-Gulland, E. J. (2019). The neglected complexities of shark fisheries, and priorities for holistic risk-based management. *Ocean Coast. Manag.* 182:104994. doi: 10.1016/j.ocecoaman.2019.104994

Booth, H., Squires, D., and Milner-Gulland, E. J. (2020). The mitigation hierarchy for sharks: a risk-based framework for reconciling trade-offs between shark conservation and fisheries objectives. *Fish Fish.* 21, 269–289. doi: 10.1111/faf.12429

Brooks, C. M., Epstein, G., and Ban, N. C. (2019). Managing marine protected areas in remote areas: the case of the subantarctic heard and McDonald Islands. *Front. Mar. Sci.* 6:631. doi: 10.3389/fmars.2019.00631

Chang, S. K., and Yuan, T. L. (2014). Deriving high-resolution spatiotemporal fishing effort of large-scale longline fishery from vessel monitoring system (VMS) data and validated by observer data. *Can. J. Fish. Aquat. Sci.* 71, 1363–1370. doi: 10.1139/cjfas-2013-0552

Claudet, J., Loiseau, C., and Pebayle, A. (2021). Critical gaps in the protection of the second largest exclusive economic zone in the world. *Mar. Policy* 124:104379. doi: 10.1016/j.marpol.2020.104379

de Oliveira Júnior, J. G. C., Campos-Silva, J. V., Santos, D. T. V., Ladle, R. J., and da Silva Batista, V. (2021). Quantifying anthropogenic threats affecting marine protected areas in developing countries. *J. Environ. Manag.* 279:111614. doi: 10.1016/j.jenvman.2020.111614

De Santo, E. M. (2013). Missing marine protected area (MPA) targets: how the push for quantity over quality undermines sustainability and social justice. *J. Environ. Manag.* 124, 137–146. doi: 10.1016/j.jenvman.2013.01.033

Delfour-Samama, O., and Leboeuf, C. (2014). Review of potential legal frameworks for effective implementationand enforcement of MPAs in the high seas. *ICES J. Mar. Sci.* 278:97. doi: 10.1038/278097a0

Duarte-Neto, P., Higa, F. M., and Lessa, R. P. (2012). Age and growth estimation of bigeye tuna, *Thunnus obesus* (Teleostei: Scombridae) in the southwestern Atlantic. *Neotrop. Ichthyol.* 10, 149–158. doi: 10.1590/s1679-62252012000100014

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., et al. (2014). Extinction risk and conservation of the world's sharks and rays. *Elife* 3, 1–34. doi: 10.7554/elife.00590

Friedlander, A. M., Wagner, D., Gaymer, C. F., Aulani Wilhelm, T., Lewis, N., Brooke, S., et al. (2016). Co-operation between large-scale MPAs: successful experiences from the Pacific Ocean. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 26, 126–141. doi: 10.1002/aqc.2645

Giakoumi, S., Scianna, C., Plass-Johnson, J., Micheli, F., Grorud-Colvert, K., Thiriet, P., et al. (2017). Ecological effects of full and partial protection in the crowded Mediterranean Sea: a regional meta-analysis. *Sci. Rep.* 7, 1–12. doi: 10.1038/s41598-017-08850-w

Giglio, V. J., Pinheiro, H. T., Bender, M. G., Bonaldo, R. M., Costa-Lotufo, L. V., Ferreira, C. E. L., et al. (2018). Large and remote marine protected areas in the South Atlantic Ocean are flawed and raise concerns: comments on Soares and Lucas (2018). *Mar. Policy* 96, 13–17. doi: 10.1016/j.marpol.2018.07.017

Kaiser, M. J., Collie, J. S., Hall, S. J., Jennings, S., and Poiner, I. R. (2002). Modification of marine habitats by trawling activities: prognosis and solutions. *Fish Fish.* 3, 114–136. doi: 10.1046/j.1467-2979.2002.00079.x

Kroodsma, D. A., Mayorga, J., Hochberg, T., Miller, N. A., Boerder, K., Ferretti, F., et al. (2018). Tracking the global footprintof fisheries of Fisheries. *Science* 359, 904–908.

Lubchenco, J., and Grorud-Colvert, K. (2015). Making waves: the science and politics of ocean protection. *Science* 350, 382–385. doi: 10.1126/science.aad5443

Lundquist, C. J., Bowden, D., Cartner, K., Stephenson, F., Tuck, I., and Hewitt, J. E. (2018). Assessing benthic responses to fishing disturbance over broad spatial scales that incorporate high environmental variation. *Front. Mar. Sci.* 5:405. doi: 10.3389/fmars.2018.00405

Magris, R. A., Costa, M. D. P., Ferreira, C. E. L., Vilar, C. C., Joyeux, J.-C., Creed, J. C., et al. (2020). A blueprint for securing Brazil's marine biodiversity and supporting the achievement of global conservation goals. *Divers. Distrib.* 27, 198–215. doi: 10.1111/ddi.13183

Magris, R. A., and Pressey, R. L. (2018). Marine protected areas: just for show? *Science* 360, 723–724. doi: 10.1126/science.aat6215

Miller, K. A., Thompson, K. F., Johnston, P., and Santillo, D. (2018). An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. *Front. Mar. Sci.* 4:418. doi: 10.3389/fmars.2017.00418

Morais, R. A., Ferreira, C. E. L., and Floeter, S. R. (2017). Spatial patterns of fish standing biomass across Brazilian reefs. *J. Fish Biol.* 91, 1642–1667. doi: 10.1111/jfb.13482

Mumby, P. J., Dahlgren, C. P., Harborne, A. R., Kappel, C. V., Micheli, F., Brumbaugh, D. R., et al. (2006). Fishing, trophic cascades, and the process of grazing on coral reefs. *Science* 311, 98–101. doi: 10.1126/science.1121129

O'Leary, B. C., Ban, N. C., Fernandez, M., Friedlander, A. M., García-Borboroglu, P., Golbuu, Y., et al. (2018). Addressing criticisms of large-scale marine protected areas. *BioScience* 68, 359–370. doi: 10.1093/biosci/biy021

Pajaro, M. G., Mulrennan, M. E., Alder, J., and Vincent, A. C. J. (2010). Developing MPA effectiveness indicators: comparison within and across stakeholder groups and communities. *Coast. Manag.* 38, 122–143. doi: 10.1080/08920751003633094

Pinheiro, H. T., Macena, B. C. L., Francini-Filho, R. B., Ferreira, C. E. L., Albuquerque, F. V., Bezerra, N. P. A., et al. (2020). Fish biodiversity of Saint Peter and Saint Paul's archipelago, Mid-Atlantic Ridge, Brazil: new records and a species database. *J. Fish Biol.* 97, 1143–1153. doi: 10.1111/jfb.14484

Pomeroy, R. S., Watson, L. M., Parks, J. E., and Cid, G. A. (2005). How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas. *Ocean Coast. Manag.* 48, 485–502. doi: 10.1016/j.ocecoaman.2005.05.004

Roberts, K. E., Valkan, R. S., and Cook, C. N. (2018). Measuring progress in marine protection: a new set of metrics to evaluate the strength of marine protected area networks. *Biol. Conserv.* 219, 20–27. doi: 10.1016/j.biocon.2018.01.004

Rowlands, G., Brown, J., Soule, B., Boluda, P. T., and Rogers, A. D. (2019). Satellite surveillance of fishing vessel activity in the Ascension Island exclusive economic zone and marine protected area. *Mar. Policy* 101, 39–50. doi: 10.1016/j.marpol.2018.11.006

Sala, E., Mayorga, J., Costello, C., Kroodsma, D., Palomares, M. L. D., Pauly, D., et al. (2018). The economics of fishing the high seas. *Sci. Adv.* 4, 1–14. doi: 10.1126/sciadv.aat2504

Shears, N. T., Babcock, R. C., and Salomon, A. K. (2008). Context-dependent effects of fishing: variation in trophic cascades across environmental gradients. *Ecol. Appl.* 18, 1860–1873. doi: 10.1890/07-1776.1

Simon, T., Macieira, R. M., and Joyeux, J. C. (2013). The shore fishes of the Trindade-martin Vaz insular complex: an update. *J. Fish Biol.* 82, 2113–2127. doi: 10.1111/jfb.12126

Vilar, C. C., Magris, R. A., Loyola, R., and Joyeux, J.-C. (2020). Strengthening the synergies among global biodiversity targets to reconcile conservation and socio-economic demands. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 30, 497–513. doi: 10.1002/aqc.3269

White, T. D., Carlisle, A. B., Kroodsma, D. A., Block, B. A., Casagrandi, R., De Leo, G. A., et al. (2017). Assessing the effectiveness of a large marine protected area for reef shark conservation. *Biol. Conserv.* 207, 64–71. doi: 10.1016/j.biocon.2017.01.009

White, T. D., Ong, T., Ferretti, F., Block, B. A., McCauley, D. J., Micheli, F., et al. (2020). Tracking the response of industrial fishing fleets to large marine protected areas in the Pacific Ocean. *Conserv. Biol.* 34, 1571–1578. doi: 10.1111/cobi.13584

Zupan, M., Bulleri, F., Evans, J., Fraschetti, S., Guidetti, P., Garcia-Rubies, A., et al. (2018a). How good is your marine protected area at curbing threats? *Biol. Conserv.* 221, 237–245. doi: 10.1016/j.biocon.2018.03.013

Zupan, M., Fragkopoulou, E., Claudet, J., Erzini, K., Horta e Costa, B., and Gonçalves, E. J. (2018b). Marine partially protected areas: drivers of ecological effectiveness. *Front. Ecol. Environ.* 16:381–387. doi: 10.1002/fee.1934

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Cellular, Hormonal, and Behavioral Responses of the Holothuroid *Cucumaria frondosa* to Environmental Stressors

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Holothuroids (sea cucumbers) are one of the most ubiquitous groups of benthic animals found across diverse marine ecosystems. As echinoderms, they also occupy an important place in the evolutionary hierarchy, sitting close to vertebrates in the deuterostome clade, making them valuable multidisciplinary model organisms. Apart from being ecologically and phylogenetically important, many species are commercially exploited for luxury seafood markets. With the global rise of aquaculture and fisheries, management and protection of these valuable species relies on a better understanding of how their immune systems respond to environmental and anthropogenic stressors. Here, the cellular, hormonal and behavioral indicators of stress in the North Atlantic sea cucumber *Cucumaria frondosa* were examined. The immediate and carry-over (post recovery) effects of a 1-hour exposure to low salinities or to emersion (at two temperatures) highlighted that morphoplasticity in *C. frondosa* was accompanied by shifts in all monitored indicators. From baseline levels measured in controls, densities of free coelomocytes increased, showing successions of specific cell types and subsequent coelomocyte aggregations, combined with a rise in cortisol levels. These responses mirrored increased fluctuations in cloacal opening rates, decreased force of attachment to the substrate, and enhanced movements and active buoyancy adjustment with increasingly severe stressors. The findings suggest that many systems of sea cucumbers are impacted by stresses that can be associated with harvesting and handling methods, with likely implications for the quality of the processed products. Gaining a deeper understanding of immune and hormonal responses of sea cucumbers is not only of broad ecological and evolutionary value, but also helpful for the development of sustainable fisheries and aquaculture practices, and conservation programs.

Keywords: echinoderm, aquaculture, coelomocytes, cortisol, stress, salinity, temperature, sea cucumber

INTRODUCTION

Sea cucumbers (Echinodermata: Holothuroidea) are globally fished as a luxury seafood and many populations worldwide are fully or overfished (Purcell et al., 2013). Their commercial value, which can reach over 2000 USD kg^{-1} (Purcell, 2014) depends on the species, and a suite of visual and organoleptic properties, such as size, shape, odor, and color (Toral-Granda et al., 2008). Harvesting, holding and processing conditions all have an impact on these characteristics as well as on the nutritional quality of the final products (Yang et al., 2015; Gianasi et al., 2016; Qi et al., 2016). There is even a perceived difference in quality between wild-caught and farmed sea cucumbers, which determines their respective prices on the retail markets (Hossain et al., 2020). In addition to being economically valuable, holothuroids are an important model organism (Zhang et al., 2017) due to their position as an echinoderm in the deuterostome clade, this places them closer to vertebrates than the vast majority of other non-chordates in the evolutionary hierarchy (Smith et al., 2018).

While the anatomy of sea cucumbers appears quite simple, they have developed many unique adaptations that allow them to thrive in different marine environments across the globe. They can be suspension feeders, using branching oral tentacles to capture particulate matter from the water, or deposit feeders ingesting sedimented organic matter. They have traditionally been considered to live a fairly sedentary lifestyle apart from their free swimming larval phases (Young and Chia, 1982; Hamel and Mercier, 1996; Grantham et al., 2003), yet the recent discovery of active buoyancy adjustment (ABA) has revealed that they can travel large distances through manipulation of their water-to-flesh ratio in response to stressful situations (Hamel et al., 2019). The internal anatomy of sea cucumbers includes two main coeloms, the perivisceral cavity and the hydrovascular system. The former is the central body cavity holding most organs. The latter is comprised of the ampullae of the tube feet, the vesicle of the tentacles and the Polian vesicle, as well as numerous canals and the madreporite, which aid in a variety of processes including locomotion, feeding, and immunity (Li et al., 2013).

The two coeloms of sea cucumbers host populations of free coelomocytes (free floating in the fluid), which are considered among the most promising markers of stress (Bang, 1975; Coteur et al., 2002; de Freitas Rebelo et al., 2013; Li et al., 2013; Franchi and Ballarin, 2017; Caulier et al., 2020). Moreover, coelomocytes play pivotal roles in immune functions; they have been described across different classes of echinoderms as the first line of immune defense against foreign particles/cells, including in Asteroidea (sea stars; Smith and Davidson, 1992, 1994); Echinoidea (sea urchins; Pinsino et al., 2007; Brothers et al., 2016) and Holothuroidea (sea cucumbers; Ramírez-Gómez et al., 2010; Galimany et al., 2018). Among Holothuroidea, coelomocytes have consistently been classified as phagocytes, morula cells, hemocytes, fusiform cells, and crystal cells (Caulier et al., 2020). They are known to play roles in recognition of non-self-materials, cytotoxic defense, fluid circulation, clotting, and encapsulation (Canicatti et al., 1989; Chia and Xing, 1996; Smith et al., 2018). Phagocytes are the most prominent coelomocytes and they are documented to undergo transformation from petaloid to filopodial morphologies (Edds, 1980; Chia and Xing, 1996; Smith et al., 2018). Coelomocytes that were monitored in sea cucumbers undergoing physical harm, intense disturbance/relocation and illness were shown to increase in abundance as both free and aggregated forms (Gross et al., 1999; Hou et al., 2019; Caulier et al., 2020) a phenomenon also recorded in sea urchins (Ridder and Jangoux, 1984; D'Andrea-Winslow et al., 2012; Majeske et al., 2013; Branco et al., 2014; Chiaramonte et al., 2019).

The aggregation of free coelomocytes in echinoderms has been superficially mentioned in the literature but its drivers and roles have long remained poorly understood (Ridder and Jangoux, 1984; Canicatti and Seymour, 1991; Jans et al., 1995). In addition, aggregates are known under different terms in echinoderms, including encapsulates, bodies, aggregates or syncytia (Dan-Sohkawa et al., 1995a,b; Söderhäll, 2010), and as nodules in insects (Satyavathi et al., 2014). In Holothuroidea, they were historically described as brown bodies (Hetzel, 1965; Ridder and Jangoux, 1984; Canicatti and Quaglia, 1991) despite the various colors that characterize them, making aggregates a more accurate designation. Caulier et al. (2020) provided a detailed study of coelomocytes in the sea cucumber *Cucumaria frondosa* that included the formation of aggregates and their transition from un-pigmented to red and brown variants. The study also showed that their abundance rose with increasing severity of applied stressors, including exposure to a predator and injury.

Along with cellular markers, cortisol is a well-established hormonal marker of stress in vertebrate model systems (Xu et al., 2019; Sandner et al., 2020; Uren Webster et al., 2020). Only recently have researchers begun testing cortisol levels in sea cucumbers (Pei et al., 2012; Chen et al., 2018a; Hou et al., 2019) and other non-vertebrate taxa like mussels (Chen et al., 2018a; Binder et al., 2019). Cortisol levels in the sea cucumber *Apostichopus japonicus* rose from 4 mmol L^{-1} to above 6 mmol L^{-1} when individuals were placed in situations known to cause stress or agitation, e.g., high conspecific density, emersion or starvation (Pei et al., 2012; Xia et al., 2017; Hou et al., 2019).

The sea cucumber *Cucumaria frondosa* is common and abundant in North Atlantic and Arctic waters (Gianasi et al., 2020). It is also one of the most important emerging commercial species in the North Atlantic and is being considered a promising candidate for multitrophic aquaculture (Nelson et al., 2012; Sun et al., 2020). Over the years, behavioral responses of *C. frondosa* have been studied and correlated with their well-being (Gianasi et al., 2020). Among them, the rhythm of cloacal opening provides a metric to evaluate respiration rates, which were demonstrated to increase when individuals were exposed to various stressors (Gianasi et al., 2015; Ammendolia et al., 2018). The force of attachment of the ambulacral podia to the substrate was also used (Hamel et al., 2019). Detachment from the substrate combined with increased motility through active buoyancy adjustments have been triggered by high conspecific densities, encounters with predators, sudden decreases in salinity, and increased turbidity (Sun et al., 2018; Hamel et al., 2019).

The present study took an integrative approach, seeking to explore the link between behavioral and internal biomarkers of health and stress in the sea cucumber *Cucumaria frondosa*.

The objective was to tease out the relationship between free coelomocyte abundance and the specificity, type and abundance of their aggregates, cortisol levels in the fluid of the hydrovascular system, and known behaviors. The various components of immune defense were examined in individuals exposed to stressors selected to mimic situations commonly experienced by sea cucumbers as they are harvested (e.g., exposure to air, temperature shocks, and salinity changes) as stated in Gianasi et al. (2016). Exploring the link between cellular and hormonal responses could help devise more reliable means of monitoring, quantifying, and comparing the stress responses of sea cucumbers with a dual aim to help mitigate their impacts on the commercial products and provide a framework for conservation and evolutionary studies. The main hypothesis was that an increase in free coelomocytes and aggregates would be proportional to the severity of the stressors and would follow a rise in cortisol levels in the hydrovascular system.

MATERIALS AND METHODS

Collection and Holding Conditions

Individuals of *Cucumaria frondosa* were collected in the subtidal zone (10.5-12 m depth) of Tors Cove, Newfoundland and Labrador (47.2172°N, 52.8515°W) during the fall of 2019. To minimize stress during transport and holding, all individuals were hand collected by divers and transported at low densities inside large coolers filled with seawater. Special measures were taken to ensure that individuals were handled gently and never exposed to air at any time throughout their relocation. Individuals were distributed in a 500 L tank supplied with unfiltered, running ambient seawater at a rate of 250 L h^{-1}. Sea cucumbers were held in these conditions for a minimum acclimation period of 2 weeks prior to experimental use. The water temperature in the holding tank fluctuated naturally over the annual cycle between 0 and 8°C, at a salinity around 35 psu, and a natural photoperiod with peak light intensity of $\leq$200 lux (measured using Traceable® Dual Display Light Meter) was provided through large windows. All individuals fed on natural seston present in the ambient unfiltered seawater. Only healthy individuals of medium size (13.5 $\pm$ 2.2 cm SD contracted length) that were firmly attached to the substrate, with tentacles periodically extended and showing no sign of injuries, were used in the experiments.

Experiments were conducted in clear bare tanks of 20 L (267 $\times$ 394 $\times$ 216 mm), using a single sea cucumber per tank. Both control and exposure tanks were randomly distributed in shelves, and all were lined with white corrugated plastic along the bottom to enhance contrast between the background and the brown sea cucumbers for time-lapse photography. Illumination provided by fluorescent lights covered in a mesh shade was adjusted to 200 lux, as per Gianasi et al. (2015). Black tarps were used to isolate the tanks from other light sources. Where applicable, the flow rate in the tanks was set to 42 L h^{-1}. Sea cucumbers were always moved from holding to experimental tanks inside 1-2 L large beakers filled with seawater to keep them submerged at all times; surgical gloves were used as needed to avoid touching them directly. The exposure treatments began directly following relocation.

To assess both the acute and carry-over effects of stressors, five control and five exposed individuals for each treatment group were processed at two points, the first was immediately after 1 h exposure to the stressor (described below) and the second was following 1 h of exposure to the stressor plus a recovery period of 23 h under control conditions (similar to holding conditions) totaling a 24 h treatment. After the exposure and recovery (after 1 h and 24 h, respectively), all individuals were first photographed and their whole-body wet weight (after draining for 3 min on paper towel), mid-length circumference and contracted length were recorded.

Treatments

Air Exposure Treatments

Two air temperatures were tested using bare tanks: 17 and 5°C. The higher setting (16.8 $\pm$ 0.6°C) is typically experienced by sea cucumbers at capture and during offloading in summer; and was achieved by keeping the tanks at room temperature. The lower setting (5.2 $\pm$ 0.8°C) is experienced by sea cucumbers stored in ship hauls and refrigerated trucks during transport to the plants, as per Gianasi et al. (2016). It was achieved by placing the experimental tank into a larger 40-L vessel filled with crushed ice (**Supplementary Figure 1**). During both experiments, the temperature was recorded using a digital thermometer (Zacro®, Model FBA_ZDT1-AUX-1). To minimize desiccation of sea cucumber epithelia and reduce air movements, a lid was used to seal and keep the humidity inside the bare tanks at ~91%, measured with a hygrometer/thermometer (Thomas scientific Traceable®). The controls for each of the two air-exposure treatments consisted of five individuals transferred to separate seawater-filled tanks under environmental conditions similar to holding tanks (described above; mean of 7.3°C).

Salinity Exposure Treatments

Two salinities commonly experienced by sea cucumbers during transport post-harvesting were tested (15 and 22 psu) and compared to ambient salinity typical off the coast of Newfoundland (control, 35 psu). To reduce the salinity, natural seawater at 35 psu was mixed with filtered, demineralized freshwater until the desired level (measured with a Milwaukee MA871 Refractometer) was reached (**Supplementary Figure 1**). As salinity experiments were conducted under static conditions, dissolved oxygen (O_2) was measured periodically (Oakton^{TM} DO Six + Meter) to ensure its levels remained optimal and comparable to flow-through conditions for the duration of the exposure period. Under salinities of 35, 15 and 22 psu, the dissolved oxygen levels were 104.2 $\pm$ 8.6% SD, 91.7 $\pm$ 8.5% SD, and 98.3 $\pm$ 12.1% SD, respectively, i.e., in the range of normoxia and well above hypoxia (Suh et al., 2014; Huo et al., 2018, 2019).

Biomarker Analyses

Cellular Markers (Free and Aggregated Coelomocytes)

The body wall of each sea cucumber was opened longitudinally from anus to mouth between two rows of tube feet using scissors or a scalpel, keeping the incision shallow to avoid puncturing the hydrovascular system and allow the removal of an intact Polian vesicle (PV). While drawing fluid across the body wall using a syringe has commonly been used (e.g., Fontaine and Lambert, 1977; Galimany et al., 2018; Hou et al., 2019), this blind technique does not guarantee that only coelomic fluid is sampled because the respiratory tree, intestine, gonad, and hydrovascular system can be accidentally punctured during the process. On the other hand, the PV has not only been shown to provide a suitable source of coelomocytes and their aggregates for quantitative assessments (Li et al., 2019; Caulier et al., 2020; Hamel et al., 2021), but it has two major advantages: (i) it ensures the collection of fluid holding uncontaminated coelomocytes and aggregates, and (ii) it standardizes the origin and volume of samples across individuals, for increased reproducibility. The whole PV was emptied into a 25 mL Falcon tube to record fluid volume. To determine the number and type of coelomocytes, the fluid was resuspended using a mini vortexer (MV 1 from IKA^{TM}) for 3 s and 10 μl was loaded in an hemocytometer (Neubauer, LW Scientific). Contrary to conventional protocol, the coverslip was placed on the chamber after (rather than before) it was loaded to make sure naturally formed coelomocyte aggregates would enter the chamber. Because clotting is a main issue when working with coelomocytes (Smith et al., 2018; Caulier et al., 2020), the samples had to be analyzed immediately after sampling (within 5 min). It should also be noted that the use of anticoagulants (like ethylenediamine tetraacetic acid) was explored as a possible solution to coelomocyte clotting post extraction. However, anticoagulants can cause pre-existing coelomocyte aggregates to break down, creating bias in the results. Free coelomocytes (individual cells) and aggregates (coelomocytes found in groups or clumps) were measured (Feret diameter; i.e., the longest possible diameter) and photographed under a light microscope (Nikon Eclipse 80i) coupled to a digital camera (Olympus DP73). Identification of free coelomocyte types was based on Caulier et al. (2020) for *Cucumaria frondosa*, complemented by studies of other holothuroids (Chia and Xing, 1996; Smith et al., 2018). Phagocytes were subdivided in two categories, i.e., inactive (pseudopodial fans still wrapped around the nucleus also known as the bladder form; **Supplementary Figure 2A**), and active (microtubule fans extended as petaloid or filapodial forms; **Supplementary Figures 2B,C**; Kindred, 1924). The presence of morula cells, fusiform cells, and crystal cells was also assessed (**Supplementary Figures 2D–H**).

The coelomocyte aggregates were divided in two classes: small and large, which corresponded nearly perfectly with early and mature forms, respectively, based on the classification proposed by Caulier et al. (2020). The small aggregates were characterized by a diameter <200 μm and mostly composed of translucent coelomocytes (with minimum size of ∼5 μm in diameter). These small aggregates were counted using a hemocytometer (method described above). Large aggregates were composed of coelomocytes grouped in reddish clumps measuring ≥200 μm in diameter (maximum size of 6600 μm in Feret diameter). Because these aggregates were too large to be analyzed with the hematocytometer, a 2 mL subsample of PV fluid was diluted with 10 mL of filtered seawater and poured into a gridded Petri dish (square, 36 grids, 10000 mm^2). Large aggregates were counted in five grid sections selected by a random number generator (CalculatorSoup©).

Hormonal Marker (Cortisol)

Two subsamples of fluid (1 mL) from the extracted PV fluid were transfer into separate Eppendorf vials and stored at −80°C within 10 min of extraction, to be used for cortisol analysis. The frozen subsamples were thawed, and their pH lowered to 1.5 – 2.0 using 0.5 M HC1 before washing once with 4 mL of undiluted methylene chloride, following standard procedure for a competitive cortisol ELISA assay (Cayman Chemical – Item 500360). To wash, methylene chloride was added to the fluid sample and vortexed for 5 s. After being allowed several minutes to separate, the clear bottom layer of methylene chloride was removed, and the remainder was evaporated under a nitrogen stream before adding 250 μL of ELISA buffer. Preparation of assay-specific reagents followed the ELISA kit protocol (Cayman, Item No. 500360). Before plating, each sample of extracted cortisol was centrifuged at 4000 rpm for 5 min. A 96-well plate was used to run all reagents and samples in duplicate (e.g., experimental samples, the 9-point standard curve, blank, total activity, non-specific binding, and maximum binding wells). Following standard protocol, the plate was left to incubate for 24 h, washed and then shaken on an orbital shaker for 90 min. The plate was then shaken mechanically for 3 s on the microplate reader (Molecular Devices SpectraMax® M5) and read using a wavelength of 420 nm and the SoftMax® Pro v7.1 software. Data were analyzed using an Excel program designed by Cayman Chemical for this ELISA kit and publicly available (ELISADouble[1]). Any readings outside the standard curve were removed as per Binder et al. (2019).

Behavioral Markers

Force of Attachment and Cloacal Opening

The force of attachment of the sea cucumbers to the substrate was quantified by attaching a zip tie to the mid-circumference of the body and pulling perpendicularly with a spring balance (Ohaus®, Model 8008-MO) as per Hamel et al. (2019). The weight necessary to detach the individual was converted to force in Newtons (1 N = 101.9716 g). To quantify cloacal opening rhythm in *Cucumaria frondosa*, based on the work of Gianasi et al. (2015), the frequency of opening/closing of the anus (inspiration/expiration) was visually assessed for seven min in triplicates.

Behavioral Scores

All other behavioural activity levels measured over the recovery period (**Supplementary Table 1**) were monitored using time-lapse videography. Two cameras were used (Brinno TLC 200 Pro and Brinno MAC 200 DN) combined with infrared lighting (ICAMI IR Illuminators, 96 pcs), which allowed continuous recording (night and day). They were mounted above the tanks to capture the entire experimental arena and set to take one picture every 10 s, which were automatically stitched into clips by the camera software. Each metric (i.e., movement and speed, degree

[1]https://www.caymanchem.com/analysisTools/elisa

of attachment to the substrate, body inflation) was assigned a cumulative score on a scale from 0–4, with 0 indicating baseline levels (normal shape, immobile, firmly attached to the substrate with tentacles either extended or retracted) and 4 indicating extreme behavior [ABA or full inflation of the body cavity, tentacle retraction combined with complete detachment from the substrate, as per Hamel et al. (2019)]. Intermediate scores (0.5–3.5) reflected the extent to which one or more parameters were affected, including body contractions, locomotion or rolling, bloating of the body wall with or without ambulacral podia extended (details in **Supplementary Table 1**).

Data Analysis

Two-way analysis of variance (ANOVA) was conducted for each treatment (17, 5°C, 15, 22 psu) to compare the cellular and hormonal data over both the exposure (exposed vs. control) and time (1 h vs. 24 h). All assumptions for parametric tests were met and any metrics of significance were investigated using pairwise comparison (Holm-Sidak method). Any extreme outliers were removed within each category provided that their removal did not change any overarching trends. The results from control individuals in the cortisol treatment group were not significantly different and were pooled together. All tests were performed with SigmaPlot statistical software and evaluated using α = 0.05 to indicate strong significance, although p-values < 0.1 were noted as potential indicators of moderate significance based on Fisher's sorting method (Fisher, 1934). This approach is based on calls from statisticians to move away from arbitrary measures of significance (Yoccoz, 1991; Wasserstein and Lazar, 2016; Dushoff et al., 2019; Wasserstein et al., 2019).

To calculate percent increase in cell densities relative to baseline, the difference between the initial and final density in each exposed individual was divided by the mean baseline (control) cellular density, multiplied by 100 and averaged (mean ± SD). For comparisons of cell densities across time points, the difference between the means of each group were compared as a percentage.

RESULTS

Cellular Markers

Free Coelomocytes

Individuals exposed to stressors, globally displayed higher densities of free coelomocytes in the PV fluid than their respective controls (**Figure 1**). Specifically, an increase in coelomocyte density occurred after 1 h in three of the four treatments (17°C air, 15 and 22 psu salinities, **Figures 1A,C,D**) while it occurred only after 24 h under the 5°C air treatment (**Figure 1B**; for statistics see **Supplementary Table 2**). All treatments except 22 psu generated a greater departure from baseline coelomocyte densities after the recovery period (24 h) than immediately after exposure (1 h) (**Figure 1** and **Supplementary Table 3**).

Analysis of coelomocyte types showed that the most abundant were the phagocytes in all control and treatment groups (**Figure 2**). They represented 81.3 ± 8.8% of free coelomocytes after 1 h and 92.0 ± 2.8% after 24 h under 17°C air exposure (**Figure 2A**). Similar proportions were also seen under 5°C air, and both salinities (**Figures 2B–D**). In comparisons with baseline levels, phagocyte densities under 17°C air exposure were higher after both 1 h and 24 h, with peak increase occurring in the latter (216.7 ± 84.3%; $F_{1,23}$ = 4.45, p = 0.046; **Figure 2A**). In air at 5°C, phagocyte densities showed no departure from baseline after 1 h (**Figure 2B**) and were 88.0 ± 75.4% higher after 24 h; this increase was too variable to be supported statistically ($F_{1,25}$ = 1.15, p = 0.30; **Figure 2B**). When sea cucumbers were exposed to 15 or 22 psu salinity, phagocyte densities showed no clear departure from baseline (**Figures 2C,D**).

Looking at other coelomocyte types, when sea cucumbers were exposed to 17°C air, the density of fusiform cells showed a variable increase of 140.0 ± 309.8% after 1 h and 114.3 ± 327.3% after 24 h ($F_{1,23}$ = 1.05, p = 0.32; **Figure 2A**). Both morula and crystal cells, which were absent from the controls, appeared in low numbers after 1 h (**Figure 2A**). Despite the fact that the density of morula cells remained higher than baseline after 24 h, the crystal cells disappeared (**Figure 2A**). After 1 h under 5°C air, the fusiform cell densities remained comparable to baseline, but densities of morula and crystal cells were higher by 50 ± 41.7% and 100.0 ± 122.2%, respectively, ($F_{1,25}$ = 0.71, p = 0.41; $F_{1,25}$ = 4.66, p = 0.040; **Figure 2B**). When exposed to 15 psu salinity, the fusiform cells increased after 1 h, the morula cells (absent in the controls) became detectable (35,000 ± 19,512 cells; $F_{1,16}$ = 0.48, p = 0.50; t = 2.67, p = 0.0.016, respectively) and no crystal cells were recorded after 1 h. After 24 h, the fusiform and morula cells disappeared (**Figure 2C**). At 22 psu, the morula cells increased compared to controls after 1 h ($F_{1,20}$ = 2.96, p = 0.10; **Figure 2D**). However, the fusiform cells decreased by 49.4 ± 133.9% relative to baseline and no crystal cells were noted (**Figure 2D**). After 24 h, the fusiform cells were slightly higher than baseline, morula cells showed an increase of 188.0 ± 245.6% ($F_{1,20}$ = 0.0030, p = 0.96; $F_{1,20}$ = 1.51, p = 0.25), and the crystal cells appeared for the first time in low numbers (∼2000 cells).

Phagocytes were further subdivided into inactive and active cells. After 1 h under 17°C air exposure, the inactive forms represented roughly half that of exposed individuals (32.6 ± 20.8%; $F_{1,23}$ = 3.86, p = 0.061; **Figure 3A**). After 24 h, proportions were similar in controls and exposed individuals (**Figure 3A**). An increase in inactive phagocytes was observed under 17 and 5°C air after 1 h, at 15 psu salinity after both 1 and 24 h and at 22 psu after 24 h only (**Figures 3B,C**). Inverse trends were noticed under 5°C air exposure after 24 h and at 22 psu salinity after 1 h, whereby the percentage of inactive phagocytes in exposed individuals compared to controls decreased although not significantly from 53.2 ± 27.6% to 36.3 ± 26.1% and 57.1 ± 19.6 to 43.8 ± 37.7%, respectively (t = 0.11, p = 0.92; t = 1.64, p = 0.12; **Figures 3B–D**).

Small Coelomocyte Aggregates

In groups exposed to 17°C air, the density of small (early stage) aggregates increased by 38.3 ± 45.6% after 1 h (t = 2.73, p = 0.012) and returned to baseline values after 24 h (**Figure 4A** and **Supplementary Table 2**). Inversely, under 5°C air exposure, small aggregate densities were similar between control and treatment groups after 1 h but were 91.5 ± 81.9% higher in

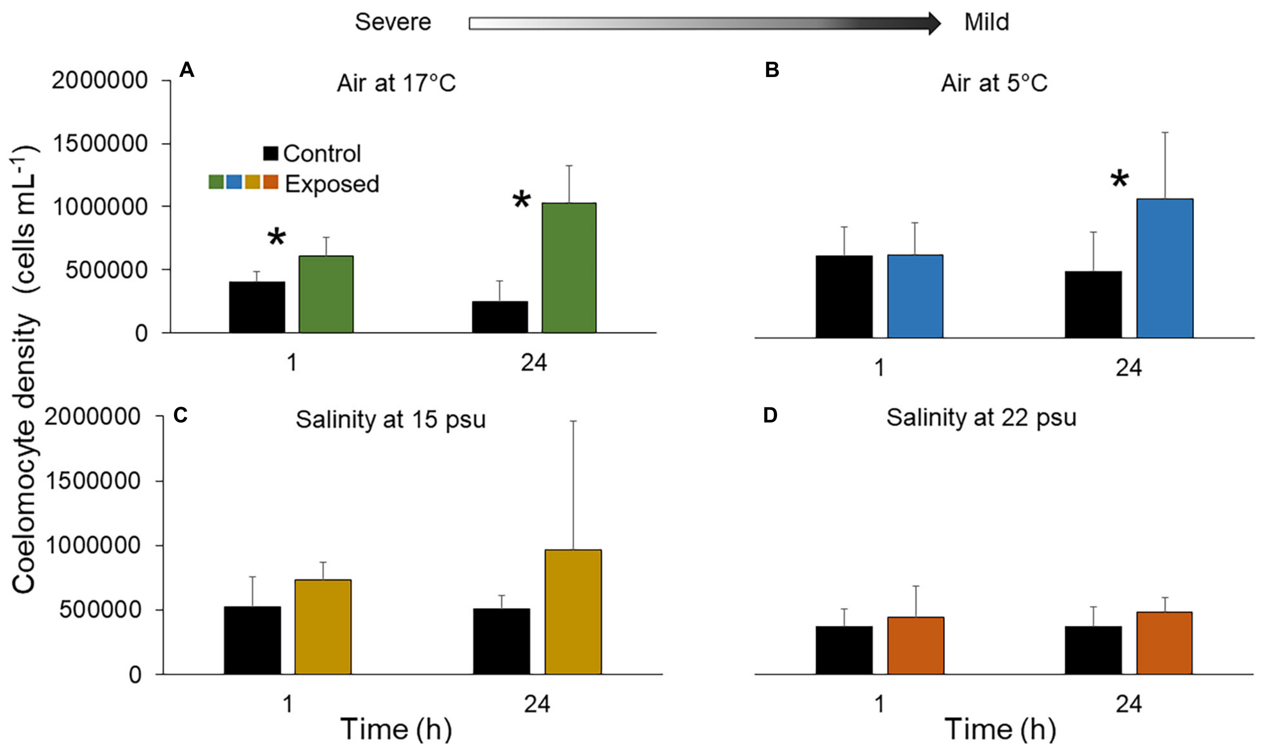

FIGURE 1 | Density of free coelomocytes in fluid of the Polian vesicle (mean ± SD, n = 5–10) after exposure of sea cucumbers to **(A)** 17°C air **(B)** 5°C air **(C)** 15 psu salinity and **(D)** 22 psu salinity. The asterisk (*) indicates significant differences between control and exposed individuals ($p < 0.05$) at each time point. There is no statistical difference between treatment groups at different time points ($p > 0.05$). Arrow indicates severe and mild stressors relative to the control. Measurements were made immediately after the exposure (1 h) and after a 23 h recovery period (total of 24 h). Main statistical results are shown in **Supplementary Table 2**.

exposed individuals after 24 h ($F_{1,16} = 3.86$, $p = 0.061$; **Figure 4B**). In individuals exposed to 15 psu salinity, the small aggregates increased compared to controls after 1 h ($F_{1,16} = 0.070$, $p = 0.80$) and fell to control levels after 24 h. The trend was inversed at 22 psu, where densities of small aggregates in individuals hovered around baseline after 1 h, and the difference amplified to 196.4 ± 59.9% after 24 h ($t = 2.39$, $p = 0.028$; **Supplementary Table 2** and **Figure 4D**).

Large Coelomocyte Aggregates

Densities of large (mature stage) aggregates were overall quite variable. Under 17°C air exposure, the density fluctuated around baseline after both 1 and 24 h (**Figure 5A** and **Supplementary Table 2**). Under 5°C air, no clear departure occurred after 1 h but densities were 159.6 ± 411.0% higher after 24 h (**Figure 5B**; $t = 1.7$, $p = 0.10$). In the salinity treatments, individuals exposed to 15 psu displayed an increase in large aggregates by 500.0 ± 300.0% after 24 h only ($F_{1,12} = 0.049$, $p = 0.83$; **Figure 5C**), whereas individuals exposed to 22 psu showed elevated densities both after 1 h exposure and 24 h recovery, by 33.3 ± 103.3% and 100.0 ± 282.8%, respectively (**Figure 5D**).

Hormonal Marker

Overall, cortisol levels in the PV were variable but increased in all treatments after 1 h, except exposure to air at 5°C (**Figure 6** and **Supplementary Table 2**). This increase was statistically significant when individuals were exposed to 17°C air, passing from a mean of 25.2 pg mL^{-1} in controls to 112.0 pg mL^{-1} under the stressor (an increase of ∼345%; **Figure 6A**). Values returned to baseline after 24 h (**Figure 6A**). Under 5°C air, no cortisol increase was noted at any time point (**Figure 6B**). In individuals exposed to 15 psu, mean cortisol level was 21.6 pg mL^{-1} under control and 33.0 pg mL^{-1} under the stressor (representing an increase of ∼64%); values remained elevated until the end of the experiment (**Figure 6C**). In individuals exposed to 22 psu salinity, the mean cortisol level after 1 h showed an increased from 14.6 pg mL^{-1} in the control to 54.9 pg mL^{-1} under the stressor (∼276%; **Figure 6D**). Values remained higher than in controls until the end of the experiment (**Figure 6D**).

Behavioral Markers

Cloacal Opening Rhythms and Force of Attachment to the Substrate

All sea cucumbers that were used for the experiments showed around 1.5 cloacal openings min^{-1} in holding conditions (**Supplementary Figure 3**). When they were exposed to air, regardless of temperature, an interruption of the cloacal movements was noted, with their anus closed most of the time (**Supplementary Figure 3A**). However, release of water from the respiratory tree was observed on a regular basis, with no air intake during the process in all emersed individuals.

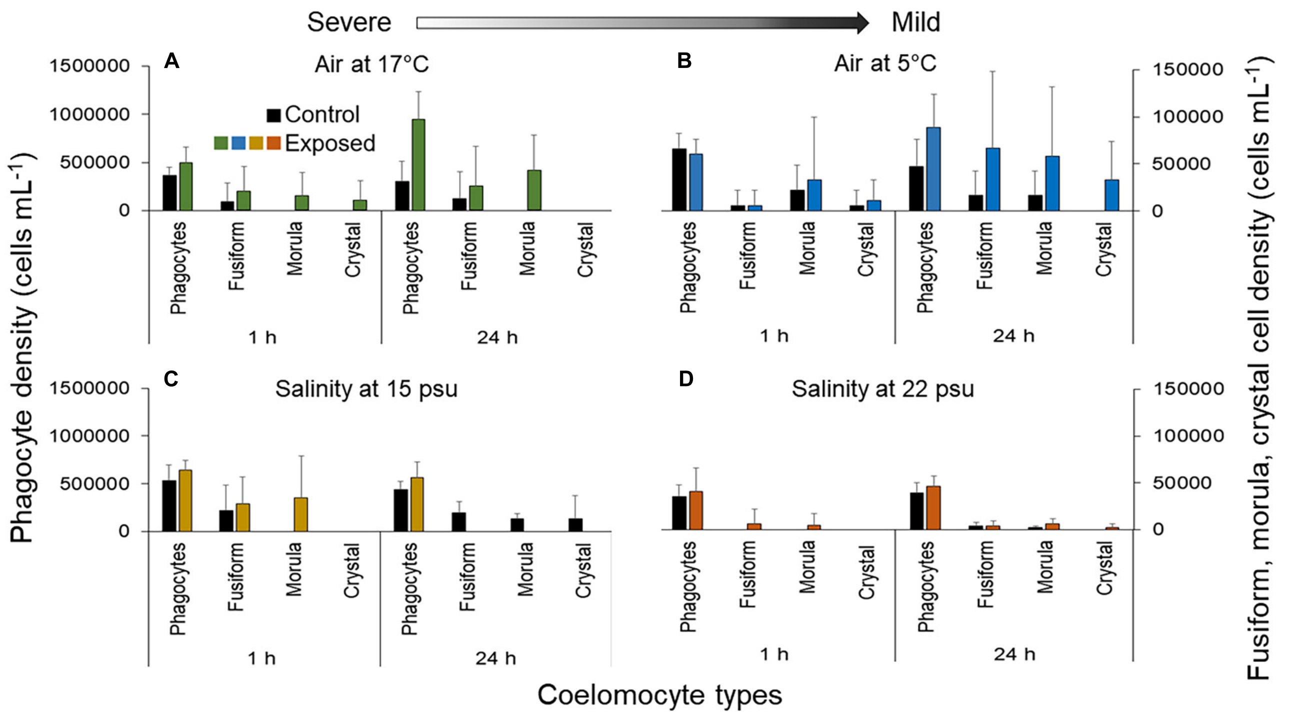

FIGURE 2 | Number of free coelomocytes (separated by cell type) per mL of fluid in the Polian vesicle fluid of sea cucumbers (mean ± SD, n = 5–10) following exposure to **(A)** 17°C air, **(B)** 5°C air, **(C)** 15 psu salinity, and **(D)** 22 psu salinity. Values on the left axis correspond to the density of phagocytes and values on the right axis correspond to the density of fusiform, morula and crystal cells (note the order of magnitude difference in scales). Measurements were made immediately after the exposure (1 h) and after a 23 h recovery period (total duration of 24 h). Arrow indicates severe and mild stressors relative to the control.

When these individuals were resubmerged in seawater for the recovery period, cloacal opening resumed and increased from 0 to 1.9 and 0 to 2.2 openings min^{-1}after 1.5 h for 17 and 5°C treatments, respectively, (**Supplementary Figure 3A**). At times 2 and 3 h, individuals exposed to 17°C air exhibited cloacal opening rhythms that were 11 to 23% faster than controls (t = 5.79, p < 0.001; t = 5.46. p < 0.001). Values decreased to 2 openings min^{-1} after 23–24 h and were too erratic to clearly differ from control values (t = 2.27, p = 0.29; t = 2.71, p = 0.11). Under 5°C air, cloacal movements were faster than controls after 2 h at 2 openings min^{-1} but decreased back to control values after 2.5 and 3 h, remaining low at 1.5 opening min^{-1} until the end of the recovery period (t = 1.90, p = 0.69; t = 0.99, p = 0.99; t = 0.85, p = 0.98; t = 0.58, p = 0.98, respectively). Individuals exposed to salinities of either 15 or 22 psu demonstrated an immediate decrease in cloacal opening rates relative to the baseline, from 1.41 to 0.86 and 1.0 openings min^{-1} for 15 and 22 psu, respectively ($F_{1,77} = 1.95$, $p = 0.057$; $t = 5.16$, $p < 0.001$). After 1 h, the rhythm remained low at 1.0 openings min^{-1} under 15 psu but was higher at 1.4 openings min^{-1} under 22 psu (t = 3.94, p = 0.0060; **Supplementary Figure 3B**). From 1.5 h, individuals exposed to 22 psu exhibited baseline values until the end of the experiment ($t = 1.28$, $p = 1.00$). Under 15 psu, the average rate of cloacal opening remained low for the duration of the exposure to lowered salinity (0.8 openings min^{-1}). After transfer to the recovery tank, cloacal openings started to increase, peaking at about 1.6 openings min^{-1} after 2 h. Cloacal opening rhythm returned to baseline levels by 2.5 h and remained stable until the end of the recovery (**Supplementary Figure 3B**).

Under both air treatments (17 and 5°C) the sea cucumbers remained unattached to the substratum over the 1 h exposure, resulting in a null force of attachment (0 N; **Supplementary Figure 4**). Under low salinity treatments, sea cucumbers showed a force of attachment of 0 N at 15 psu and 0.41 ± 1.00 N at 22 psu (**Supplementary Figures 4C,D**). After the recovery period, individuals in both air exposure treatments had returned to control values (17°C, 2.86 ± 2.53 N; 5°C 2.65 ± 1.93 N; control, 2.71 ± 1.90 N). However, individuals exposed to 15 and 22 psu salinities did not return to control levels, showing values of 1.23 ± 2.35 N and 2.53 ± 3.26 N, respectively, after 24 h, which were lower than controls (6.60 ± 8.08 N).

Behavioral Scores

Immediately after transfer to the 5 or 17°C air treatment (time 0), individuals showed increased activity scores compared to control individuals (**Figure 7A**). Individuals had stronger behavioral responses after 0.5 h, with scores up to 2.3 at 17°C and 1.5 at 5°C. While the scores remained high after 2.5 h under 17°C air, individuals exposed to 5°C air returned to control values after 1.5 h and remained thus until the end of the experiment. Individuals exposed to 17°C returned to baseline values after 3 h. Individuals exposed to both 5 and 17°C air

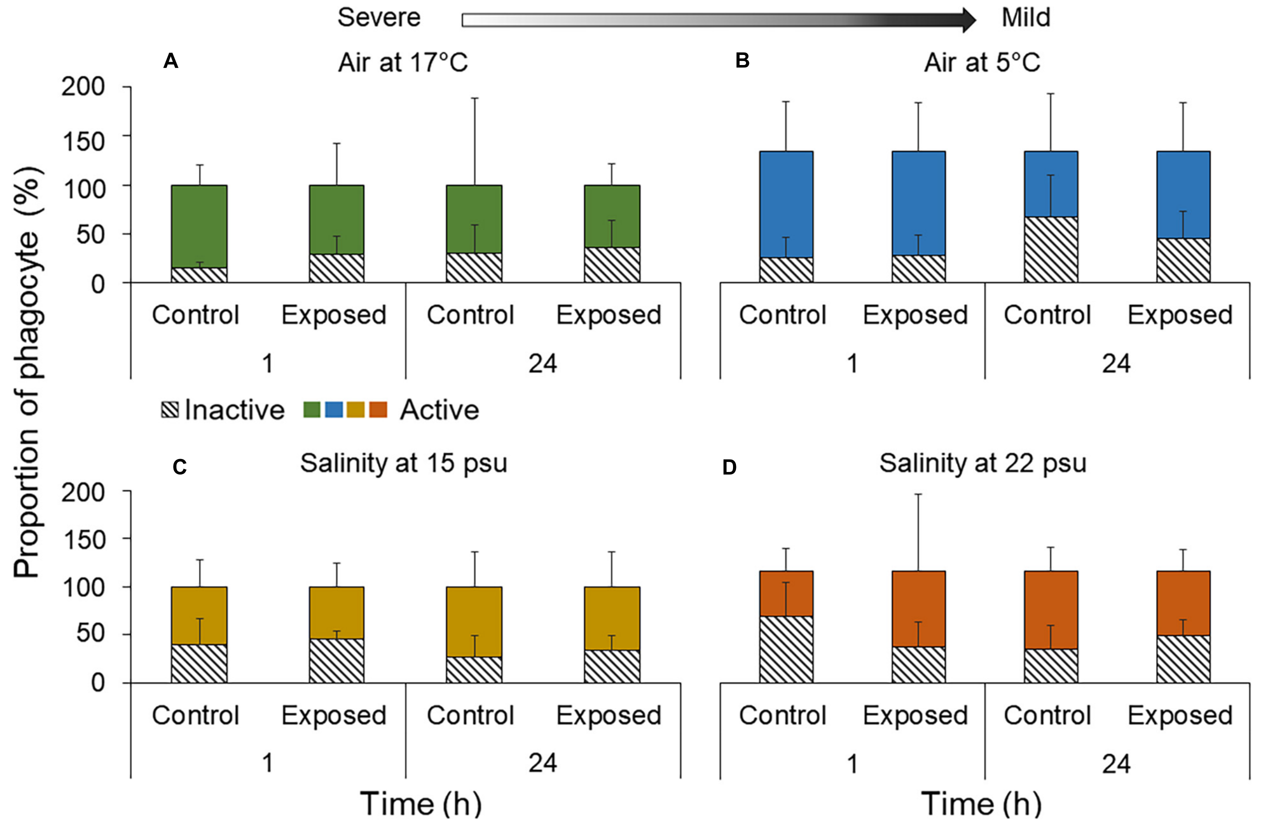

FIGURE 3 | Proportion of phagocytes (active vs. inactive) per mL of Polian vesicle fluid (mean ± SD, *n* = 5–10) following exposure to **(A)** 17°C air, **(B)** 5°C air, **(C)** 15 psu salinity, and **(D)** 22 psu salinity. Measurements were made immediately after the exposure (1 h) and after a 23 h recovery period (total duration of 24 h). Arrow indicates severe and mild stressors relative to the control.

showed minimum scores values of 0.5 after 23.5–24 h, similar to controls (**Figure 7A**).

The behavioral scores of individuals exposed to 15 psu salinity showed an increased from time 0 to a maximum after 2.5–3 h; subsequently the scores decreased slowly to values around 1.4 after 23.5–24 h, still higher than controls (**Figure 7B**). Individuals exposed to 22 psu salinity exhibited a sharper increase in scores over the first 1.5 h. The scores stabilized after 2 h and slightly decreased to reach 1.7 after 3 h. At the end of the recovery period (23.5 and 24 h), a few individuals still demonstrated slow movement, keeping the average scores around 1.4 for 15 psu and 0.5 for 22 psu, which were higher than controls (**Figure 7B**).

DISCUSSION

Unlike most other marine species of commercial value, e.g., fishes, crabs, lobsters, shrimps, scallops, mussels, and sea urchins, sea cucumbers are not protected by any scales or hard exoskeleton that may buffer sudden environmental changes. Thus, exposure to air during natural events (e.g., washing ashore after storms) or fishing activities and exposure to salinity drops during spring thaw or live storage on ice (Gianasi et al., 2016; Hamel et al., 2019) represent acute challenges for soft-bodied sea cucumbers. In addition, sea cucumbers may undergo autolysis when they are stressed (Sun et al., 2012; Qi et al., 2016). Any deterioration of the body wall and underlying collagenous and muscle tissues, which together constitute the chief marketable products of sea cucumbers, will likely translate into commercial products of a lower grade (Purcell, 2014). In the present study, the response of the sea cucumber *Cucumaria frondosa* to realistic environmental stressors showed cellular, hormonal, and behavioral activity levels that related proportionally to the severity of the stressor. The greater the departure from optimal salinity and temperature conditions determined for the species (Hamel and Mercier, 1996), the stronger the response recorded, showing possible physiological and biological strategies that would confer resilience.

The results presented here are comparable to those of Wang et al. (2008) where the sea cucumber *Apostichopus japonicus* experienced greater challenges to its immune capacity (including phagocytic abilities and respiration) when exposed to increased water temperature than when exposed to low water temperature and lowered salinity. Here, emersion at the highest temperature and immersion at the lowest salinity elicited the greatest increase in free coelomocytes after 1 h, and subsequent spike in small aggregates, cortisol level in the coelomic fluid and the most dramatic change in cloacal opening rhythm (irrigation

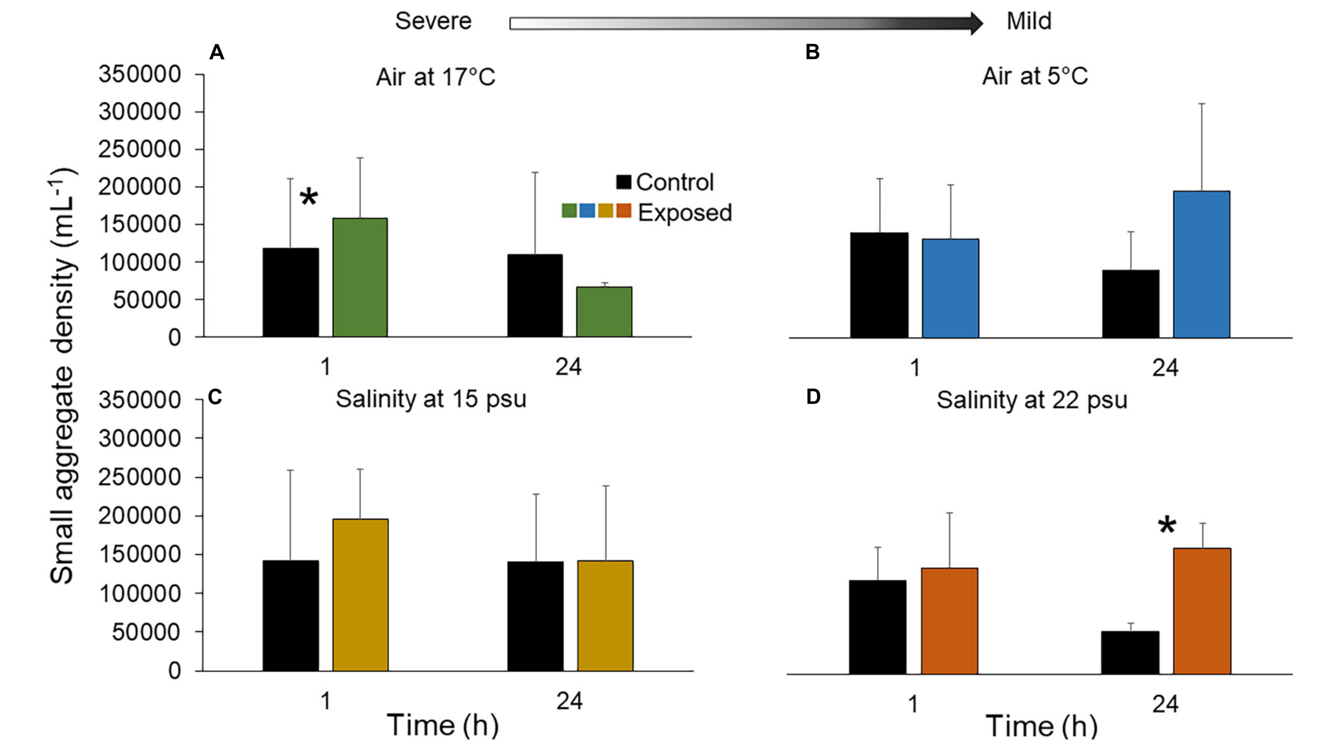

FIGURE 4 | Density of small aggregates in fluid of the Polian vesicle (mean ± SD, n = 5–10) after exposure of sea cucumbers to **(A)** 17°C air **(B)** 5°C air **(C)** 15 psu salinity and **(D)** 22 psu salinity. The asterisk (*) indicates significant differences between control and exposed individuals (p < 0.05) at each time point. There was no statistical difference between treatment groups at different time points (p > 0.05). Arrow indicates severe and mild stressors relative to the control. Measurements were made immediately after the exposure (1 h) and after a 23 h recovery period (total of 24 h). Main statistical results are shown in **Supplementary Table 2**.

of respiratory tree), indicating they were most stressful for *Cucumaria frondosa*. These severe treatments could result in more energy expenditure to cope with tissular damages, as suspected by Gianasi et al. (2016) or other internal fluctuations through processes like the removal of dead cells. A flight reaction was shown to be elicited by the moderately low salinity (22 psu) in this species (Hamel et al., 2019) but not by the lowest salinity (15 psu), likely because it is below the tolerance threshold. Accordingly, *C. frondosa* was described to occur in brackish zones of the St. Lawrence Estuary (Québec, eastern Canada) but never below 22–25 psu (J-F Hamel, personal observation in Port-au-Saumon and Grande-Bergeronne).

Exposure to suboptimal conditions, even to the most severe treatments discussed above, did not generate visible damages but instead activated an arsenal of specific defenses. Lack of visible lesions is possibly due to the short exposure time, i.e., not sustained enough to completely overwhelm defense mechanisms in *Cucumaria frondosa*. A closer look at the various cell types involved provides some interesting insight. For instance, both exposure to air and lower salinities triggered an increase in phagocytes similar to results presented by Caulier et al. (2020) after injection of foreign particles and following trawl collection. Phagocyte counts also aligned with the cellular reaction reported by Hamel et al. (2021) who exposed *C. frondosa* to the predatory sea star *Solaster endeca*. Phagocytes were previously described as immune cells involved in phagocytosis of pathogens and in the release of humoral agents (Beck and Habicht, 1996; Rinkevich and Müller, 1996; Xue et al., 2015), suggesting that a form of internal damage occurred in sea cucumbers exposed to the most severe stressors in the present study. Fusiform cells in *C. frondosa* increased most markedly during emersion, as shown in *A. japonicus* by Xing et al. (2008), however, the function of these cells in echinoderms is still unknown (Söderhäll, 2010). Studies of fusiform cells in bivalves suggest that they aid in wound healing (Sparks, 1976), which may be occurring in the most directly exposed tissues of *C. frondosa* like the ambulacral podia and epithelium of the respiratory tree (both part of the hydrovascular system). Morula cells spiked during emersion under both air temperatures and immersion in low salinity, similar to a study by San Miguel-Ruiz and García-Arrarás (2007) on the sea cucumber *Holothuria glaberrima* who documented increasing densities of those cells in direct response to body-wall injuries. Moreover, Byrne (1986) indicated that morula cells multiplied in individuals of *Eupentacta quinquesemita* exposed to physical abrasion and hypothesized that these cells provide the foundation for tissue repair. Consequently, the proliferation of these cells may be triggered by many types of challenges, including in response to emersion and exposure to low salinity. Moreover, these cells reportedly secrete humoral effectors responsible for pathogen detection (Byrne, 1986; Melillo et al., 2018) suggesting that increasing density results directly from immune stress. Crystal cells in sea cucumbers were

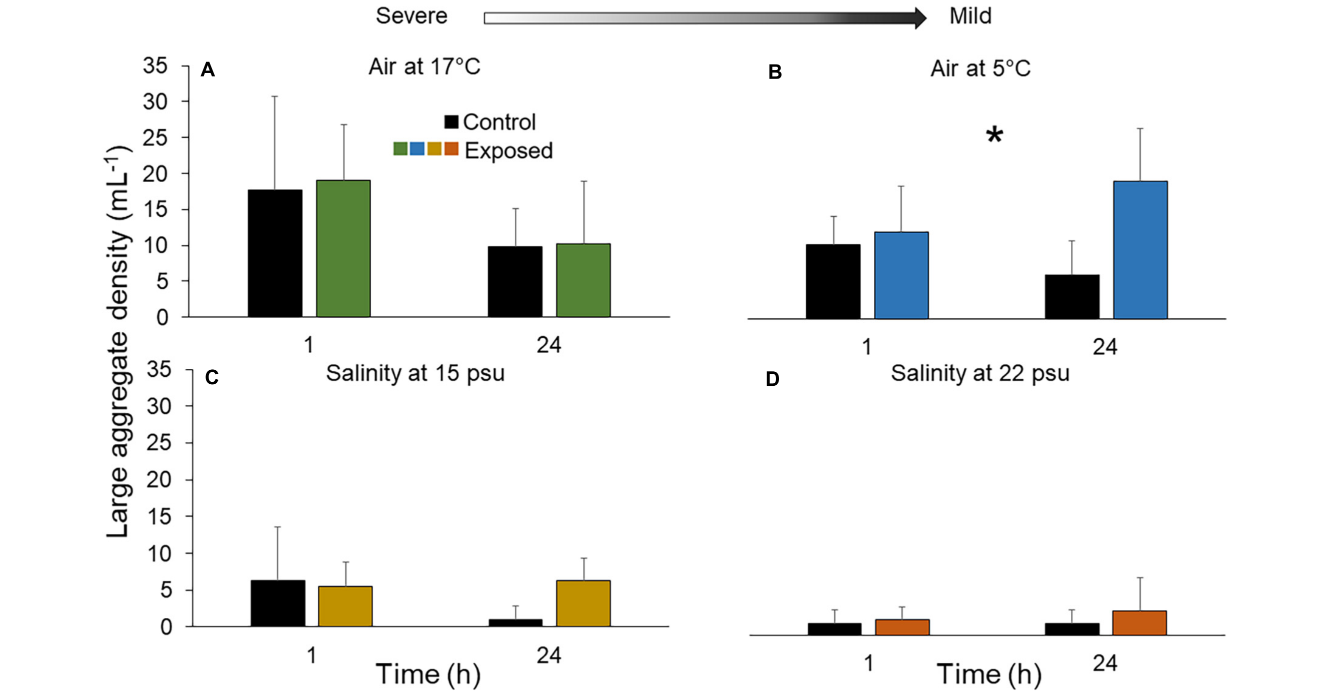

FIGURE 5 | Density of large aggregates in fluid of the Polian vesicle (mean ± SD, n = 5–10) after exposure of sea cucumbers to **(A)** 17°C air **(B)** 5°C air **(C)** 15 psu salinity and **(D)** 22 psu salinity. The asterisk (*) indicates significant differences within one treatment group ($p < 0.05$), however, pairwise comparisons showed no statistical significance between control and exposed individuals at either time point (1 and 24 h). There was no statistical difference between treatment groups at different time points ($p > 0.05$). Arrow indicates severe and mild stressors relative to the control. Measurements were made immediately after the exposure (1 h) and after a 23 h recovery period (total of 24 h). Main statistical results are shown in **Supplementary Table 2**.

previously suggested to play a role in osmoregulation (Eliseikina and Magarlamov, 2002). Xing et al. (2008) mentioned that osmotic pressure changes triggered a reversible crystallization of the intravacuolar material in crystal cells, thereby normalizing the osmotic pressure. However, these cells did not display any detectable change or proliferation in *C. frondosa* during exposure to any of the low salinity treatments. In fact, the only condition where an increase in crystal cells was noticed is exposure to cold air, downplaying any role in osmoregulation, at least in *C. frondosa*. Importantly, holothuroids do not have integral osmoregulation mechanisms and are found strictly in marine environments (Russell, 2013). Despite this, some species like *Holothuria scabra* can colonize brackish areas and sustain freshwater runoff during rainy seasons, although they cope by burrowing into the sediment (Mercier et al., 1999). On the other hand, *C. frondosa* occurs exclusively on the surface of rocky substrata and consequently cannot burrow to withstand salinity drops. Instead, they can use active buoyancy behavior to roll or float away with the current (Hamel et al., 2019), likely to limit exposure time.

Despite the fact that phagocytes were the most common coelomocytes found in the coelomic fluid of the Polian vesicle in both control and exposed individuals of *Cucumaria frondosa*, these cells were not always found in their active form, which was presumed to correspond to the active form reported by Kindred (1924). Surprisingly, elevated numbers of active phagocytes were only present in individuals exposed to a salinity of 22 psu and not in the other treatments. Caulier et al. (2020) showed that the finite pool of available free phagocytes (demarginated) in the hydrovascular fluid of *C. frondosa* can decrease rapidly as they aggregate around foreign particles. In line with this principle, individuals exposed to the most severe stressors in the present study exhibited the lowest number of active phagocytes, suggesting that they were utilized to form aggregates, as supported by the higher number of small aggregates under those conditions. In contrast, at 22 psu, it is possible that a lower demand for tissue repair/healing was sustained by the pool of active and inactive phagocytes already available in the hydrovascular fluid.

Under most conditions tested, free coelomocytes had formed small and large aggregates immediately after the 1-h exposure. These aggregates were described as the precursor step in the expulsion of foreign particles, damaged cells, and pathogenic materials, both from the hydrovascular system and the periviceral coelom (Caulier et al., 2020). Jans et al. (1995) showed formation of "brown bodies" (i.e., aggregates in the present study) in the sea cucumber *Holothuria tubulosa* within 24 h of the initial immune challenge. Similarly, cell aggregations were noticed after 24 h in the sea urchin *Strongylocentrotus droebachiensis* (Majeske et al., 2013) and after 5 h in the sea star *Asterias rubens* (Gorshkov et al., 2009). In *Cucumaria frondosa*, their presence was noticed as early as within 1 h of exposure, suggesting that clumping

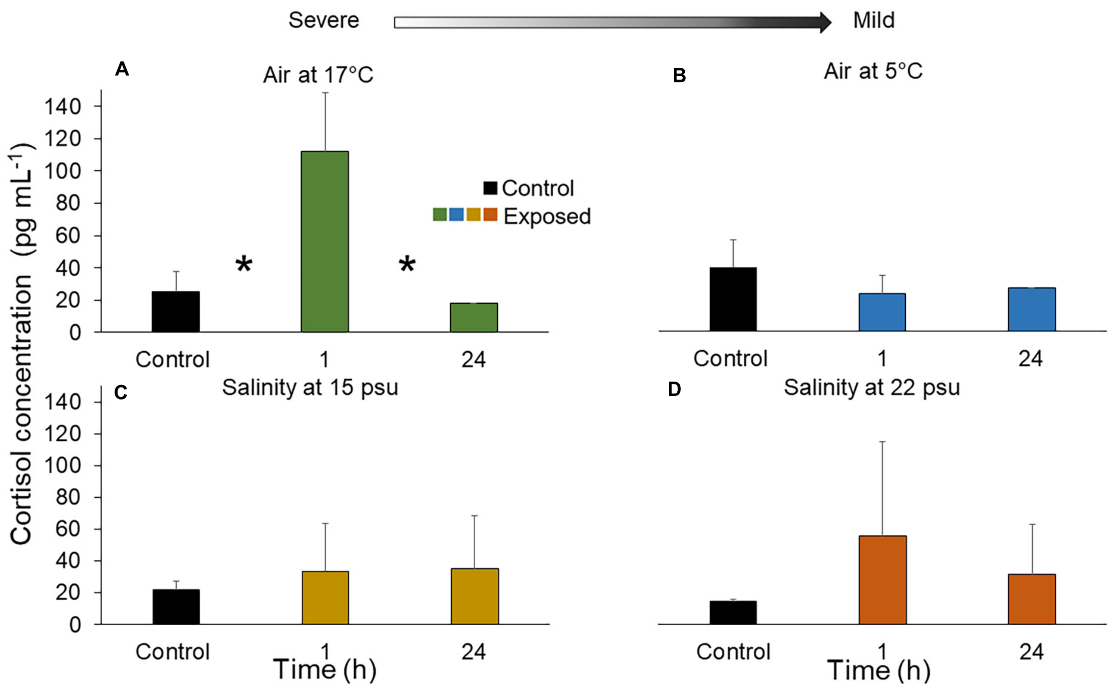

FIGURE 6 | Cortisol concentration (pg mL^{-1}) after exposure of sea cucumbers to **(A)** 17°C air **(B)** 5°C air **(C)** 15 psu salinity and **(D)** 22 psu salinity. The asterisk (*) indicates significant differences within one treatment group ($p < 0.05$), in this case **(A)** the concentration between control individuals and those sampled at the 1 h mark was significantly different as well as the cortisol concentration between those sampled at 1 and 24 h. There was no statistical difference between the control and exposed individuals after 24 h ($p > 0.05$). Arrow indicates severe and mild stressors relative to the control. Measurements were made immediately after the exposure (1 h) and after a 23 h recovery period (total of 24 h). Main statistical results are shown in **Supplementary Table 2**.

occurred concurrently with the increase of free coelomocytes, i.e., almost immediately upon exposure to the stressor and faster than what was expected based on previously published works. It can be assumed that dead cells from tissue damage were being packaged for expulsion. This occurred in all conditions except emersion in cold air, possibly indicating that the latter generates less immediate damage than the other acute conditions tested. Accordingly, Gianasi et al. (2016) suggested that keeping *C. frondosa* damp, outside water, at 4–5°C would yield the least severe tissue damage and highest survival rate during transport from the wharfs to the plants. Here, sea cucumbers emersed at cold temperature also showed the slowest cloacal openings rhythm (upon being immersed again), even below controls, suggesting they rapidly resumed a resting state. This trend is substantiated by the behavioral scores; i.e., individuals exposed to warm air temperature reached peak scores early during the experiment (indicative of stress), in contrast to individuals exposed to cold air, which maintained scores similar to baseline values.

As anticipated, the cellular immune responses in *Cucumaria frondosa* mirrored the increasing trend in cortisol levels recorded under the most severe stressors tested. While previous studies have described a cortisol increase in sea cucumbers (*A. japonicus*) exposed to stressors (Hou et al., 2019) or reported rises in coelomocytes and in cortisol under stress (Chen et al., 2018a,b; Hou et al., 2019), to our knowledge a link between the two factors has never been reported, although hormone research in vertebrates has shown that glucocorticoids (including cortisol) are the regulators of immune responses (i.e., increase in leukocytes and granulocytes; Ince et al., 2019). While the correlation between the rises in cortisol and in coelomocyte densities remains fragmentary in the present study, it highlights the need to tease out the link between the cellular and hormonal responses in Holothuroidea. Recently, Hou et al. (2019) determined that peak cortisol levels in *A. japonicus* were reached several hours into emersion and then slowly dropped toward baseline levels over the following 20 h. In *C. frondosa* the rise in cortisol could be necessary to generate a pool of free coelomocytes from their marginated (i.e., attached to the body wall) forms, as seen in Caulier et al. (2020). In line with this, cortisol increases were noticed in three of the four conditions tested, but emersion in warm air generated the most defined trend, which in combination with the other biomarkers (behavioral and cellular), points to this being the most detrimental treatment tested. In support, So et al. (2010) demonstrated that water temperatures above 18°C were deleterious for juveniles and adults of *C. frondosa*. Inversely, emersion in cold air coincided with a minimal cellular response, no measurable cortisol increase, and mild behavior scores, reinforcing that it is not an immediately threatening condition, at least for a short time, as suggested by Gianasi et al. (2016) in the study of transport methods.

Based on most markers measured after 23 h of recovery post exposure, it emerges that stressors may have long-lasting effects (i.e., beyond 24 h) on the wellbeing of sea cucumbers. Small

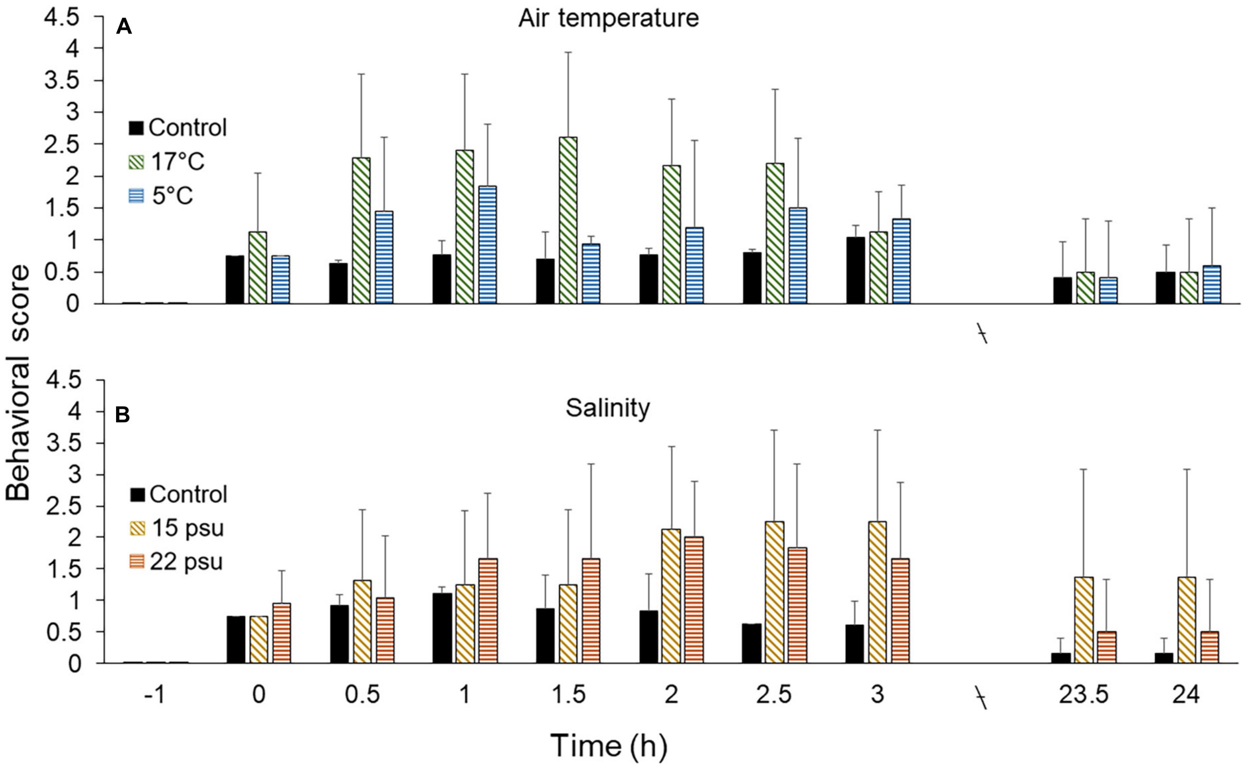

FIGURE 7 | Behavioral intensity (0 = resting/baseline state, 4 = maximum stress) in *Cucumaria frondosa* at various time points (–0.5 h = negative control, 0–24 h = positive control). **(A)** Comparison between controls and individuals exposed to 17 and 5°C air (±SD, *n* = 6). **(B)** Comparison between controls and individuals exposed to 15 and 22 psu salinity (mean ± SD, *n* = 4–6).

aggregates showed an increase during recovery from cold air emersion and low salinity, and large aggregates multiplied during recovery from all conditions. There was no mortality in any of the treatments, but the presence of cell aggregates underlies the expulsion of materials resulting from infections or damaged tissues. Strangely, the stressors that elicited the mildest acute responses after 1 h (cold air and 22 psu salinity) yielded the highest counts of small and large aggregates during recovery, either due to a delayed response to the stress or to secondary infections. Inversely, the most severe acute responses (warm air and 15 psu) corresponded to the lowest aggregate counts during recovery, possibly because the immune response peaked earlier and had already begun to wane. It must be emphasized that while the stressors tested here reflected common harvesting and handling practices, the temporal scale is a conservative estimate of what sea cucumbers could endure over the preprocessing period, which may last 48 h – 1 week (Gianasi et al., 2016; S. Jobson, personal communication). Prolonged exposures to stress may lead to more severe damage and possibly more drastic immune responses, which may in turn translate into mortality and into economic loss (Wu et al., 2013; Qi et al., 2016).

Globally, the present study showed the potential of using multiple biometrics to characterize the immediate and long-term effects of stress on economically and ecologically important species like *Cucumaria frondosa*. Further studies might seek to refine the methodologies necessary to integrate the use of cortisol levels in the coelomic fluid as a rapid non-invasive biomarker of health in this and other species of invertebrates. Such a tool would greatly assist the design of sustainable harvesting, aquaculture and preprocessing protocols. Insights were also garnered from an ecological standpoint. While the optimal environmental conditions under which feeding, reproduction and development occur in *C. frondosa* are typically oceanic (Hamel and Mercier, 1996; So et al., 2010), this species has apparently developed notable capabilities to cope with harsh, even improbable, conditions in the short term. Such plasticity may explain its high biomasses and broad distribution range throughout a diversity of temperate and polar marine environments (Gianasi et al., 2020).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

SJ, J-FH, and AM were responsible for conception of ideas, design, and writing of drafts. SJ and TH conducted the data collection and analysis. All authors contributed to the manuscript and approved the final version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.695753/full#supplementary-material

REFERENCES

Ammendolia, J., Hamel, J.-F., and Mercier, A. (2018). Behavioural responses to hydrostatic pressure in selected echinoderms suggest hyperbaric constraint of bathymetric range. *Mar. Biol.* 165:145. doi: 10.1007/s00227-018-3399-7

Bang, F. B. (1975). A search in *Asterias* and *Ascidia* for the beginnings of vertebrate immune responses. *Ann. N.Y. Acad. Sci.* 266, 334–342. doi: 10.1111/j.1749-6632.1975.tb35115.x

Beck, G., and Habicht, G. S. (1996). Immunity and the invertebrates. *Sci. Am.* 275, 60–66. doi: 10.1038/scientificamerican1196-60

Binder, A. R. D., Pfaffl, M. W., Hiltwein, F., Geist, J., and Beggel, S. (2019). Does environmental stress affect cortisol biodistribution in freshwater mussels? *Conserv. Physiol.* 7:coz101. doi: 10.1093/conphys/coz101

Branco, P., Figueiredo, D., and da Silva, J. (2014). New insights into innate immune system of sea urchin: coelomocytes as biosensors for environmental stress. *OA Biol.* 18, 1–7.

Brothers, C. J., Harianto, J., McClintock, J. B., and Byrne, M. (2016). Sea urchins in a high CO_2 world: the influence of acclimation on the immune response to ocean warming and acidification. *Proc. R. Soc. B* 283:20161501. doi: 10.1098/rspb.2016.1501

Byrne, M. (1986). The ultrastructure of the morula cells of *Eupentacta quinquesemita* (Echinodermata: Holothuroidea) and their role in the maintenance of the extracellular matrix. *J. Morphol.* 188, 179–189. doi: 10.1002/jmor.1051880205

Canicatti, C., D'Ancona, G., and Farina-Lipari, E. (1989). The *Holothuria polii* brown bodies. *Ital. J. Zool.* 56, 275–283. doi: 10.1080/11250008909355651

Canicatti, C., and Quaglia, A. (1991). Ultrastructure of *Holothuria polii* encapsulating body. *J. Zool.* 224, 419–429. doi: 10.1111/j.1469-7998.1991.tb06035.x

Canicatti, C., and Seymour, J. (1991). Evidence for phenoloxidase activity in *Holothuria tubulosa* (Echinodermata) brown bodies and cells. *Parasitol. Res.* 77, 50–53. doi: 10.1007/BF00934385

Caulier, G., Hamel, J.-F., and Mercier, A. (2020). From coelomocytes to colored aggregates: cellular components and processes involved in the immune response of the holothuroid *Cucumaria frondosa*. *Biol. Bull.* 239, 95–114. doi: 10.1086/710355

Chen, J., Ren, Y., Li, Y., and Xia, B. (2018a). Regulation of growth, intestinal microbiota, non-specific immune response and disease resistance of sea cucumber *Apostichopus japonicus* (Selenka) in biofloc systems. *Fish Shellfish Immunol.* 77, 175–186. doi: 10.1016/j.fsi.2018.03.053

Chen, J., Ren, Y., Wang, G., Xia, B., and Li, Y. (2018b). Dietary supplementation of biofloc influences growth performance, physiological stress, antioxidant status and immune response of juvenile sea cucumber *Apostichopus japonicus* (Selenka). *Fish Shellfish Immunol.* 72, 143–152. doi: 10.1016/j.fsi.2017.10.061

Chia, F.-S., and Xing, J. (1996). Echinoderm coelomocytes. *Zool. Stud.* 35, 231–254.

Chiaramonte, M., Inguglia, L., Vazzana, M., Deidun, A., and Arizza, V. (2019). Stress and immune response to bacterial LPS in the sea urchin *Paracentrotus lividus* (Lamarck, 1816). *Fish Shellfish Immunol.* 92, 384–394. doi: 10.1016/j.fsi.2019.06.017

Coteur, G., DeBecker, G., Warnau, M., Jangoux, M., and Dubois, P. (2002). Differentiation of immune cells challenged by bacteria in the common European starfish, *Asterias rubens* (Echinodermata). *Eur. J. Cell Biol.* 81, 413–418. doi: 10.1078/0171-9335-00254

D'Andrea-Winslow, L., Radke, D. W., Utecht, T., Kaneko, T., and Akasaka, K. (2012). Sea urchin coelomocyte arylsulfatase: a modulator of the echinoderm clotting pathway. *Integr. Zool.* 7, 61–73. doi: 10.1111/j.1749-4877.2011.00279.x

Dan-Sohkawa, M., Morimoto, M., and Kaneko, H. (1995a). In vitro reactions of coelomocytes against sheep red blood cells in the solitary ascidian *Halocynthia roretzi*. *Zool. Sci.* 12, 411–417. doi: 10.2108/zsj.12.411

Dan-Sohkawa, M., Morimoto, M., Mishima, H., and Kaneko, H. (1995b). Characterization of coelomocytes of the ascidian *Halocynthia roretzi* based on phase-contrast, time-lapse video and scanning electron microscopic observations. *Zool. Sci.* 12, 289–301. doi: 10.2108/zsj.12.289

de Freitas Rebelo, M., de Souza Figueiredo, E., Mariante, R. M., Nóbrega, A., de Barros, C. M., and Allodi, S. (2013). New insights from the oyster *Crassostrea rhizophorae* on bivalve circulating hemocytes. *PLoS One* 8:e57384. doi: 10.1371/journal.pone.0057384

Dushoff, J., Kain, M. P., and Bolker, B. M. (2019). I can see clearly now: reinterpreting statistical significance. *Methods Ecol. Evol.* 10, 756–759. doi: 10.1111/2041-210X.13159

Edds, K. T. (1980). The formation and elongation of filopodia during transformation of sea urchin coelomocytes. *Cell Motil.* 1, 131–140. doi: 10.1002/cm.970010110

Eliseikina, M. G., and Magarlamov, T. Y. (2002). Coelomocyte morphology in the holothurians *Apostichopus japonicus* (Aspidochirota: Stichopodidae) and *Cucumaria japonica* (Dendrochirota: Cucumariidae). *Russ. J. Mar. Biol.* 28:6. doi: 10.1023/A:1016801521216

Fisher, R. A. (1934). *Statistical Methods for Research Workers*, 5th Edn. London: Oliver and Boyd.

Fontaine, A. R., and Lambert, P. (1977). The fine structure of the leucocytes of the holothurian, *Cucumaria miniata*. *Can. J. Zool.* 55, 1530–1544. doi: 10.1139/z77-198

Franchi, N., and Ballarin, L. (2017). Immunity in protochordates: the tunicate perspective. *Front. Immunol.* 8:674. doi: 10.3389/fimmu.2017.00674

Galimany, E., Baeta, M., and Ramón, M. (2018). Immune response of the sea cucumber *Parastichopus regalis* to different temperatures: implications for aquaculture purposes. *Aquaculture* 497, 357–363. doi: 10.1016/j.aquaculture.2018.08.005

Gianasi, B. L., Hamel, J.-F., and Mercier, A. (2016). Experimental test of optimal holding conditions for live transport of temperate sea cucumbers. *Fish. Res.* 174, 298–308. doi: 10.1016/j.fishres.2015.11.004

Gianasi, B. L., Hamel, J.-F., Montgomery, E. M., Sun, J., and Mercier, A. (2020). Current knowledge on the biology, ecology, and commercial exploitation of the sea cucumber *Cucumaria frondosa*. *Rev. Fish. Sci. Aquac.* doi: 10.1080/23308249.2020.1839015

Gianasi, B. L., Verkaik, K., Hamel, J.-F., and Mercier, A. (2015). Novel use of pit tags in sea cucumbers: promising results with the commercial species *Cucumaria frondosa*. *PLoS One* 10:e0127884. doi: 10.1371/journal.pone.0127884

Gorshkov, A. N., Blinova, M. I., and Pinaev, G. P. (2009). Ultrastructure of coelomic epithelium and coelomocytes of the starfish *Asterias rubens* L. in norm and after wounding. *Cell Tiss. Biol.* 3, 477–490. doi: 10.1134/S1990519X09050113

Grantham, B. A., Eckert, G. L., and Shanks, A. L. (2003). Dispersal potential of marine invertebrates in diverse habitats. *Ecol. Appl.* 13, 108–116. doi: 10.1890/1051-0761(2003)013[0108:dpomii]2.0.co;2

Gross, P. S., Al-Sharif, W. Z., Clow, L. A., and Smith, L. C. (1999). Echinoderm immunity and the evolution of the complement system. *Dev. Comp. Immunol.* 23, 429–442. doi: 10.1016/S0145-305X(99)00022-1

Hamel, J.-F., Jobson, S., Caulier, G., and Mercier, A. (2021). Evidence of anticipatory immune and hormonal responses to predation risk in an echinoderm. *Sci. Rep.* 11:10691. doi: 10.1038/s41598-021-89805-0

Hamel, J.-F., and Mercier, A. (1996). Early development, settlement, growth, and spatial distribution of the sea cucumber *Cucumaria frondosa* (Echinodermata: Holothuroidea). *Can. J. Fish. Aquat. Sci.* 53, 253–271. doi: 10.1139/f95-186

Hamel, J.-F., Sun, J., Gianasi, B. L., Montgomery, E. M., Kenchington, E. L., Burel, B., et al. (2019). Active buoyancy adjustment increases dispersal potential in benthic marine animals. *J. Anim. Ecol.* 88, 820–832. doi: 10.1111/1365-2656.12943

Hetzel, H. R. (1965). Studies on holothurian coelomocytes. ii. The origin of coelomocytes and the formation of brown bodies. *Biol. Bull.* 128, 102–111. doi: 10.2307/1539393

Hossain, A., Dave, D., and Shahidi, F. (2020). Northern sea cucumber (*Cucumaria frondosa*): a potential candidate for functional food, nutraceutical, and pharmaceutical sector. *Mar. Drugs* 18:274. doi: 10.3390/md18050274

Hou, S., Jin, Z., Jiang, W., Chi, L., Xia, B., and Chen, J. (2019). Physiological and immunological responses of sea cucumber *Apostichopus japonicus* during desiccation and subsequent resubmersion. *PeerJ* 7:e7427. doi: 10.7717/peerj.7427

Huo, D., Sun, L., Ru, X., Zhang, L., Lin, C., Liu, S., et al. (2018). Impact of hypoxia stress on the physiological responses of sea cucumber *Apostichopus japonicus*: respiration, digestion, immunity and oxidative damage. *PeerJ* 6:e4651. doi: 10.7717/peerj.4651

Huo, D., Sun, L., Zhang, L., Ru, X., Liu, S., and Yang, H. (2019). Metabolome responses of the sea cucumber *Apostichopus japonicus* to multiple environmental stresses: heat and hypoxia. *Mar. Pollut. Bull.* 138, 407–420. doi: 10.1016/j.marpolbul.2018.11.063

Ince, L. M., Weber, J., and Scheiermann, C. (2019). Control of leukocyte trafficking by stress-associated hormones. *Front. Immunol.* 9:3143. doi: 10.3389/fimmu.2018.03143

Jans, D., Dubois, P., and Jangoux, M. (1995). Defensive mechanisms of holothuroids (Echinodermata): formation, role, and fate of intracoelomic brown bodies in the sea cucumber *Holothuria tubulosa*. *Cell Tissue Res.* 283, 99–106. doi: 10.1007/s004410050517

Kindred, J. E. (1924). The cellular elements in the perivisceral fluid of echinoderms. *Biol. Bull.* 46, 228–251. doi: 10.2307/1536725

Li, Q., Qi, R., Wang, Y., Ye, S., Qiao, G., and Li, H. (2013). Comparison of cells free in coelomic and water-vascular system of sea cucumber, *Apostichopus japonicus*. *Fish Shellfish Immunol.* 35, 1654–1657. doi: 10.1016/j.fsi.2013.07.020

Li, Q., Ren, Y., Luan, L., Zhang, J., Qiao, G., Wang, Y., et al. (2019). Localization and characterization of hematopoietic tissues in adult sea cucumber, *Apostichopus japonicus*. *Fish Shellfish Immunol.* 84, 1–7. doi: 10.1016/j.fsi.2018.09.058

Majeske, A. J., Bayne, C. J., and Smith, L. C. (2013). Aggregation of sea urchin phagocytes is augmented in vitro by lipopolysaccharide. *PLoS One* 8:e61419. doi: 10.1371/journal.pone.0061419

Melillo, D., Marino, R., Italiani, P., and Boraschi, D. (2018). Innate immune memory in invertebrate metazoans: a critical appraisal. *Front. Immunol.* 9:1915. doi: 10.3389/fimmu.2018.01915

Mercier, A., Battaglene, S. C., and Hamel, J.-F. (1999). Daily burrowing cycle and feeding activity of juvenile sea cucumbers *Holothuria scabra* in response to environmental factors. *J. Exp. Mar. Biol. Ecol.* 239, 125–156. doi: 10.1016/S0022-0981(99)00034-9

Nelson, E. J., MacDonald, B. A., and Robinson, S. M. C. (2012). The absorption efficiency of the suspension-feeding sea cucumber, *Cucumaria frondosa*, and its potential as an extractive integrated multi-trophic aquaculture (IMTA) species. *Aquaculture* 370, 19–25. doi: 10.1016/j.aquaculture.2012.09.029

Pei, S., Dong, S., Wang, F., Tian, X., and Gao, Q. (2012). Effects of density on variation in individual growth and differentiation in endocrine response of Japanese sea cucumber *Apostichopus japonicus* (Selenka). *Aquaculture* 356, 398–403. doi: 10.1016/j.aquaculture.2012.04.032

Pinsino, A., Thorndyke, M. C., and Matranga, V. (2007). Coelomocytes and post-traumatic response in the common sea star *Asterias rubens*. *Cell Stress Chaperones* 12:331. doi: 10.1379/CSC-288.1

Purcell, S. W. (2014). Value, market preferences and trade of beche-de-mer from Pacific island sea cucumbers. *PLoS One* 9, 1–8. doi: 10.1371/journal.pone.0095075

Purcell, S. W., Mercier, A., Conand, C., Hamel, J.-F., Toral-Granda, M. V., Lovatelli, A., et al. (2013). Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing: management of sea cucumber fisheries. *Fish Fish.* 14, 34–59. doi: 10.1111/j.1467-2979.2011.00443.x

Qi, H., Fu, H., Dong, X., Feng, D., Li, N., Wen, C., et al. (2016). Apoptosis induction is involved in UVA-induced autolysis in sea cucumber *Stichopus japonicus*. *J. Photoch. Photobio. B.* 158, 130–135. doi: 10.1016/j.jphotobiol.2016.02.034

Ramírez-Gómez, F., Aponte-Rivera, F., Méndez-Castaner, L., and García-Arrarás, J. E. (2010). Changes in holothurian coelomocyte populations following immune stimulation with different molecular patterns. *Fish Shellfish Immunol.* 29, 175–185. doi: 10.1016/j.fsi.2010.03.013

Ridder, C., and Jangoux, M. (1984). Intracoelomic parasitic: sporozoa in the burrowing spatangoid echinoid *Echinocardium cordatum*: coelomocyte reaction and formation of brown bodies. *Helgolander Meeresunters* 37, 225–231. doi: 10.1007/BF01989307

Rinkevich, B., and Müller, W. E. G. (1996). *Invertebrate Immunology*, Vol. 15. Berlin: Spring Sci Business Media.

Russell, M. P. (2013). Echinoderm responses to variation in salinity. *Adv. Mar. Biol.* 66, 171–212. doi: 10.1016/B978-0-12-408096-6.00003-1

San Miguel-Ruiz, J. E., and García-Arrarás, J. E. (2007). Common cellular events occur during wound healing and organ regeneration in the sea cucumber *Holothuria glaberrima*. *BMC Dev. Biol.* 7:1–19. doi: 10.1186/1471-213X-7-115

Sandner, M., Lois, G., Streit, F., Zeier, P., Kirsch, P., Wüst, S., et al. (2020). Investigating individual stress reactivity: high hair cortisol predicts lower acute stress responses. *Psychoneuroendocrino* 118:104660. doi: 10.1016/j.psyneuen.2020.104660

Satyavathi, V. V., Minz, A., and Nagaraju, J. (2014). Nodulation: an unexplored cellular defense mechanism in insects. *Cell Signal.* 26, 1753–1763. doi: 10.1016/j.cellsig.2014.02.024

Smith, L. C., Arizza, V., Barela Hudgell, M. A., Barone, G., Bodnar, A. G., Buckley, K. M., et al. (2018). "Echinodermata: the complex immune system in echinoderms," in Advances in Comparative Immunology, ed. E. Cooper (Cham: Springer), 409–501.

Smith, L. C., and Davidson, E. H. (1992). The echinoid immune system and the phylogenetic occurrence of immune mechanisms in deuterostomes. *Immunol. Today.* 13, 356–362. doi: 10.1016/0167-5699(92)90172-4

Smith, L. C., and Davidson, E. H. (1994). The echinoderm immune system: characters shared with vertebrate immune systems and characters arising later in deuterostome phylogeny. *Ann. NY Acad. Sci.* 712, 213–226. doi: 10.1111/j.1749-6632.1994.tb33575.x

So, J. J., Hamel, J.-F., and Mercier, A. (2010). Habitat utilisation, growth and predation of *Cucumaria frondosa*: implications for an emerging sea cucumber fishery. *Fish. Manag. Ecol.* 17, 473–484. doi: 10.1111/j.1365-2400.2010.00747.x

Söderhäll, K. (ed.) (2010). *Invertebrate Immunity*. New York, N.Y: Springer Science + Business Media.

Sparks, A. K. (1976). Inflammation and wound repair in oysters. *Mar. Fish. Rev.* 38, 2–4. doi: 10.1111/j.1524-475x.2011.00754.x

Suh, S. S., Hwang, J., Park, M., Park, S. Y., Ryu, T. K., Lee, S., et al. (2014). Hypoxia-modulated gene expression profiling in sea urchin (*Strongylocentrotus nudus*) immune cells. *Ecotox. Environ. Safe.* 109, 63–69. doi: 10.1016/j.ecoenv.2014.08.011

Sun, J., Hamel, J.-F., Gianasi, B. L., Graham, M., and Mercier, A. (2020). Growth, health and biochemical composition of the sea cucumber *Cucumaria frondosa* after multi-year holding in effluent waters of land-based salmon culture. *Aquacult. Environ. Interact.* 12, 139–151. doi: 10.3354/aei00356

Sun, J., Hamel, J.-F., and Mercier, A. (2018). Influence of flow on locomotion, feeding behaviour and spatial distribution of a suspension-feeding sea cucumber. *J. Exp. Biol.* 221, jeb189597. doi: 10.1242/jeb.189597

Sun, L., Chen, M., Yang, H., Wang, T., Liu, B., Shu, C., et al. (2012). Large scale gene expression profiling during intestine and body wall regeneration in the sea cucumber *Apostichopus japonicus*. *Comp. Biochem. Phys. D Genomics Proteomics* 6, 195–205. doi: 10.1016/j.cbd.2011.03.002

Toral-Granda, V., Lovatelli, A., and Vasconcellos, M. (2008). Sea cucumbers: a global review of fisheries and trade. *FOA Fish. Tech. Pap.* 516:317. doi: 10.1111/j.1467-2979.2010.00397.x

Uren Webster, T. M., Rodriguez-Barreto, D., Consuegra, S., and Garcia de Leaniz, C. (2020). Cortisol-related signatures of stress in the fish microbiome. *Front. Microbiol.* 11:1621. doi: 10.3389/fmicb.2020.01621

Wang, F., Yang, H., Gao, F., and Liu, G. (2008). Effects of acute temperature or salinity stress on the immune response in sea cucumber, *Apostichopus japonicus*. *Comp. Biochem. Phys. A Mol. Integr. Physiol.* 151, 491–498. doi: 10.1016/j.cbpa.2008.06.024

Wasserstein, R. L., and Lazar, N. A. (2016). The ASA statement on p-values: context, process, and purpose. *Am. Stat.* 70, 129–133. doi: 10.1080/00031305.2016.1154108

Wasserstein, R. L., Schirm, A. L., and Lazar, N. A. (2019). Moving to a world beyond "$p < 0.05$". *Am. Stat.* 73(sup 1), 1–19. doi: 10.1080/00031305.2019.1583913

Wu, H. T., Li, D. M., Zhu, B. W., Sun, J. J., Zheng, J., Wang, F. L., et al. (2013). Proteolysis of noncollagenous proteins in sea cucumber, *Stichopus japonicus*, body wall: characterisation and the effects of cysteine protease inhibitors. *Food Chem.* 141, 1287–1294. doi: 10.1016/j.foodchem.2013.03.088

Xia, B., Ren, Y., Wang, J., Sun, Y., and Zhang, Z. (2017). Effects of feeding frequency and density on growth, energy budget and physiological performance of sea cucumber *Apostichopus japonicus* (Selenka). *Aquaculture* 466, 26–32. doi: 10.1016/j.aquaculture.2016.09.039

Xing, K., Yang, H., and Chen, M. (2008). Morphological and ultrastructural characterization of the coelomocytes in *Apostichopus japonicus*. *Aquat. Biol.* 2, 85–92. doi: 10.3354/ab00038

Xu, B., Lang, L., Li, S. Z., Guo, J. R., Wang, J. F., Wang, D., et al. (2019). Cortisol excess-mediated mitochondrial damage induced hippocampal neuronal apoptosis in mice following cold exposure. *Cells* 8:612. doi: 10.3390/cells8060612

Xue, Z., Li, H., Wang, X., Li, X., Liu, Y., Sun, J., et al. (2015). A review of the immune molecules in the sea cucumber. *Fish Shellfish Immunol.* 44, 1–11. doi: 10.1016/j.fsi.2015.01.026

Yang, H., Hamel, J.-F., and Mercier, A. (2015). *The Sea Cucumber Apostichopus japonicus: History, Biology and Aquaculture*. Cambridge, MA: Academic Press.

Yoccoz, N. G. (1991). Use, overuse, and misuse of significance tests in evolutionary biology and ecology. *Bull. Ecol. Soc. Am.* 72, 106–111.

Young, C. M., and Chia, F. S. (1982). Factors controlling spatial distribution of the sea cucumber *Psolus chitonoides*: settling and post-settling behavior. *Mar. Biol.* 69, 195–205. doi: 10.1007/BF00396899

Zhang, X., Sun, L., Yuan, J., Sun, Y., Gao, Y., Zhang, L., et al. (2017). The sea cucumber genome provides insights into morphological evolution and visceral regeneration. *PLoS Biol.* 15:e2003790. doi: 10.1371/journal.pbio.2003790

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Functionality and Effectiveness of Marine Protected Areas in Southeastern Brazilian Waters for Demersal Elasmobranchs

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Ensuring the efficacy of Marine Protected Areas (MPAs) requires that adequate management strategies be implemented according to the MPA's objectives. Within the scope of species conservation, achieving MPA objectives demands understanding of the role played by MPAs for the target species. In 2014, Brazilian stakeholders and experts set the action plan for elasmobranchs' conservation, which intended to create new protected areas and expand the existing ones. Nevertheless, more than 65% of Brazilian elasmobranch species are threatened by anthropogenic pressures such as fisheries and habitat loss. In addition, their ecological aspects are not well studied, which might jeopardize the success of the proposed actions. To assess the functionality and effectiveness of two no-take MPAs for sixteen demersal species, the Wildlife Refuge of Alcatrazes (WRA) and the Tupinambás Ecological Station (TES), we evaluated the community structure, space-time variations in functional diversity and changes in fishery indicators. Community dynamics were driven by inshore intrusion and time persistent effects of a cold and nutrient-rich water mass, the South Atlantic Central Water, which increased the relative abundance of species, functional groups, and overall diversity. Spatially, the heterogeneity of benthic habitats, due to the action of stronger waves in specific parts of the MPAs, reflects a diverse community of benthic invertebrates, explaining differences in relative abundance and similarities in space use by the functional groups. Regarding effectiveness, the MPAs make up a key network with the surrounding protection areas to support the ecosystem maintenance on the central and northern coast of the São Paulo state. The establishment of the TES has positively influenced the community throughout the years while the recent creation of the WRA may have promoted some improvements in fisheries indicators for a threatened guitarfish. We propose different functions of the Alcatrazes archipelago for each species and suggest some measures to enhance not only elasmobranch conservation but also the MPAs' effectiveness.

Keywords: Alcatrazes archipelago, management strategies, habitat use, community structure, fishery indicators, elasmobranch conservation, functional diversity

INTRODUCTION

For decades, governments have been using Marine Protected Areas (MPAs) to manage use of ocean resources. MPAs can address socioenvironmental issues by supporting traditional fishing communities, avoiding fisheries depletion and marine habitat degradation, and maintaining ecological services (Halpern, 2003; Fox et al., 2012). They are usually employed as a tool for conservation of critical habitats and dependent organisms, accounting for different requirements through a species' life stages that can be safeguarded from anthropogenic disturbances (Claudet et al., 2010; Grüss et al., 2011; Wiegand et al., 2011; Knip et al., 2012; Rolim et al., 2019). Since the accomplishment of multiple objectives is challenging and success indicators, such as fishery sustainability, go beyond the MPA boundaries, coordination between MPA design and other management strategies (e.g., measures of control and restriction, networks of reserves, and adaptive management) are mandatory to achieve effectiveness (Fox et al., 2012; Lubchenco and Grorud-Colvert, 2015; Hilborn, 2016).

Previous works have highlighted the importance of adopting multiple strategies, especially when the MPA goals involve long-lived and mobile species like elasmobranchs (Chapman et al., 2005; Wiegand et al., 2011; Knip et al., 2012). For instance, Brazil is home to more than 14% of the worldwide biodiversity of sharks, skates and rays, driving experts and stakeholders to determine that conservation actions including MPAs are needed for the taxon (i.e., The action plan for elasmobranch conservation; ICMBio, 2016a). Currently, at least 65% of the species recorded in Brazilian waters are threatened or have insufficient data (ICMBio, 2016b; IUCN, 2021) and this lack of information might jeopardize the success of conservation and management actions (Gill et al., 2017; Giakoumi et al., 2018).

Among the strategic regions delimited by the action plan (ICMBio, 2016a) two marine reserves call attention: The Wildlife Refuge of Alcatrazes (WRA) and the Tupinambás Ecological Station (TES). They were established three decades apart seeking ecosystems preservation by restriction of human interference (Brazil, 1987, 2016). First, TES was created in 1987 to secure coastal and offshore rock formations, covering two coastal islands in northern São Paulo (i.e., Cabras and Palmas islands) and the islets, shallow flats and submerged pinnacles of the Alcatrazes archipelago. Later, in 2016, the WRA was implemented to shelter a greater area of the archipelago, especially the Alcatrazes island, becoming the largest marine reserve in south and southeastern Brazil. Both are no-take zones and although their delimitations overlap, they have different management plans. TES is the most restrictive, allowing only scientific and educational activities, while the WRA allows supervised visits to general public (ICMBio, 2017; Marconi et al., 2020).

At present, WRA and TES are part of a critical network for biodiversity maintenance that includes adjacent protected areas on the central and northern coasts of the São Paulo state (São Paulo, 2008). It is located at the middle continental shelf, which makes the Alcatrazes archipelago a unique area that interfaces parallel and perpendicular gradients of granulometry and organic matter in relation to the coast (Mahiques et al., 1999, 2004, 2011). Furthermore, it is near temperate and subtropical transition zones, being markedly influenced by mesoscale physical processes that promote seasonal changes in water properties (Castro-Filho et al., 1987; Campos et al., 2000). From late spring through summer, the prevalence of north and northeast winds carries superficial waters offshore, composed by the Coastal and Tropical water masses. This process promotes bottom inshore intrusions of the South Atlantic Central Water (SACW), a colder water mass that stratifies the water column (Castro-Filho et al., 1987).

The archipelago is ecologically important, presenting greater values of species richness, abundance and biomass of fish assemblages compared to the fished areas inshore, as well as the other no-take areas in the region (Gibran and Moura, 2012; Morais et al., 2017; Rolim et al., 2019). These trends reflect a complex ecosystem primarily regulated by top-down effects, with higher heterogeneity of functional groups when compared to the previously mentioned areas (Rolim et al., 2019). The high abundance of larger individuals of fishery target species (e.g., Epinephelidae, Kyphosidae, Carangidae, and Scaridae) suggests a great spillover potential to adjacent zones (Rolim et al., 2019). However, for elasmobranchs, especially the demersal species, the relationship of local species with environmental features is unknown and available information is restricted to community studies that focus mainly in actinopterygians. Approximately seventeen elasmobranch species are reported in the area (Hoff, 2015; ICMBio, 2017; Rolim et al., 2019), which exhibit differences in feeding and reproductive strategies, and behavioral ecology (Lessa et al., 1986; Soares et al., 1992; Vögler et al., 2003; Vooren and Klippel, 2005; Aguiar and Valentin, 2010), highlighting the variety of roles that the WRA and TES MPAs may play according to habitat use by the species.

Obtaining knowledge on the ecology of these species is crucial since fishing pressure and habitat degradation on coastal and inner shelf regions have disturbed the ichthyofauna, resulting in population depletion, diversity loss, and ecosystem unbalancing (Imoto et al., 2016; Dias et al., 2017; Prado et al., 2019; Rolim et al., 2019; Trevizani et al., 2019). Thus, the present study aimed to assess the functionality and effectiveness of the two MPAs to assist the decision making process that involves the conservation of demersal elasmobranchs. Our findings are important not only to understand the local and regional dynamics, but also to enhance policies for species conservation, in order to underlie the MPAs' management. We hypothesize that those species use the archipelago for distinct purposes, which would reflect in different population structures. Differences in species distributions and in diversity metrics are also expected throughout space and time. Furthermore, we believe that variations in the relative abundance of functional groups as well as of their species, are related to the seasonal dynamics of the environment and to the heterogeneity of habitats. Finally, we expect that the size structure of a threatened guitarfish changes significantly due to the protection of a newer and larger MPA (i.e., the WRA).

MATERIALS AND METHODS

Ethics Statement

The animal study was reviewed and approved by the Ethics Committee of Animal Use of the Oceanographic Institute of the University of São Paulo (CEUA IO-USP) and by the Chico Mendes Institute for Biodiversity Conservation (ICMBio) under the survey permit SISBIO/55824.

Sampling

Biotic and abiotic data used in this study were obtained from five oceanographic expeditions performed by the following projects: Contributions to the Tupinambás Ecological Station Management Plan: oceanography and marine biodiversity (September/2011), Biotic Integrity of the Alcatrazes Archipelago Ecosystems (January/2014) and Geohabitat of the demersal ichthyofauna of the Alcatrazes region: an environmental assessment (September/2015, December/2018, and July/2019). Position of the oceanographic stations was defined according to the objectives of each project. Thus, they were set at different locations throughout the archipelago, except to 2019, when the 2018 stations were re-sampled (**Figure 1**). Sampling of sea water and sediments as well as capture of elasmobranchs were carried out at fifty oceanographic stations between 28 and 53 m depth.

Abiotic Data

The assessment of temperature and salinity data was performed through different methods. Both variables were directly assessed using a conductivity-temperature-depth probe (CTD) (2011 and 2015) and a multiparameter probe (2018). Samples of bottom water taken by Nansen bottles, in 2014 and 2019, were used to measure temperature and salinity values using reversing thermometers and a refractometer, respectively. The sediment mosaic of the MPA region was characterized from samples collected through a van *Veen* grab in 2011 (Palóczy et al., 2012) and 2019. The area was classified into five zones, calculated as buffers of 2.5, 5, 7.5, 10, and 12.5 km from the center of Alcatrazes island, according to the home ranges of the caught specimens (or nearest taxa, i.e., genus) (Cartamil et al., 2003; Collins et al., 2007; Farrugia et al., 2011; Tilley et al., 2013). These zones were intended to capture any potential changes in benthic ecology with distance from the Alcatrazes island. Species with relatively small home ranges might have home ranges at a finer scale than these zones, while more wide-ranging species would encompass multiple zones.

Biotic Data

Demersal elasmobranch specimens were collected through otter trawl nets (20–21 m in the foot rope, 40–60 mm mesh in the body as well as in the sleeves and 25–30 mm in the cod-end), which were operated from 10 to 20 min at a speed of two knots by the R/Vs Alpha Delphini (IO-USP) and Soloncy Moura (ICMBio). On board, specimens were accommodated in boxes with seawater and information was collected concerning their sex, total length (TL), disc width (DW), and total weight (TW). To ensure correct identification, pictures of each specimen were taken and identification to species level was conducted in accordance with Figueiredo (1977), Viana et al. (2016), and Gomes et al. (2019). After data collecting, all live elasmobranchs were released to the sea. The specimens that did not survive (i.e., less than 5% of the elasmobranch catches) were cooled and brought to the Oceanographic Institute (USP), being stored at the teaching collection. The non-elasmobranch species, such as the actinopterygians, were sacrificed through a solution of 400 mg L^{-1} of eugenol (Fernandes et al., 2017), cooled and also brought to the Oceanographic Institute to be used as research material in studies of community ecology, reproductive biology and so on.

Hydrographic and Sedimentological Analyses

According to Rossi-Wongtschowski and Paes (1993), the community structure of actinopterygians and elasmobranchs of the northern coast of São Paulo was related to sediment distribution and to the SACW presence. Thus, granulometric and hydrographic analyses were performed, as well as the estimation of calcium carbonate concentrations ($CaCO_3$) of sediment.

In 2014, the refractometer did not operate correctly. Thus, based on the SACW properties, we fixed salinity values at 35.7 to water samples collected at depths where temperature was below 17°C, for this year only. For the whole dataset, values of temperature and salinity of each oceanographic expedition were combined in diagrams and potential densities with pressure equals zero (σ_θ) were calculated. We set diagrams with isopycnal curves through the oce package (Kelley et al., 2021) using $\sigma_\theta = 25.8$ (Stramma and England, 1999; Mémery et al., 2000) as a threshold to identify the SACW presence. To define the sediment type of each oceanographic station, we combined available information about sedimentological parameters of the 2011 samples (Palóczy et al., 2012; Hoff et al., 2015) with data obtained in 2019. Sediment granulometry was determined by application of the sieve-pipette method (Suguio, 1973) to 50 g of the 2019 samples, followed by Folk and Ward (1957) classification. Further, concentrations of $CaCO_3$ were estimated through weight differences after digestion by 10% solution of hydrochloric acid. Gravimetric results were used to characterize the oceanographic stations in accordance with Larsonneur et al. (1982).

Three main factors determine the energy dynamic in the Alcatrazes island surroundings: its Y-shaped morphology, the abrupt change in the bathymetry and the predominance of incident waves from south and southeast. Together, they act as mitigating elements and reflect a more stable environment in the north and toward the coast, due to the indirect incidence of waves as well as energy loss by the decreasing bathymetry. Furthermore, regions are more energetic in the south, with waves varying slightly through the seasons and years (Takase et al., 2021). These factors rule the deposition process in the archipelago, forming sediment features that are sustained over time. Thus, the same characteristics of 2011 and 2019 samples were assumed for unsampled sediments of the other years. Both classifications were applied to the nearest oceanographic stations (**Supplementary Table 3**) with distances ranging from 0.38 to 3.17 km.

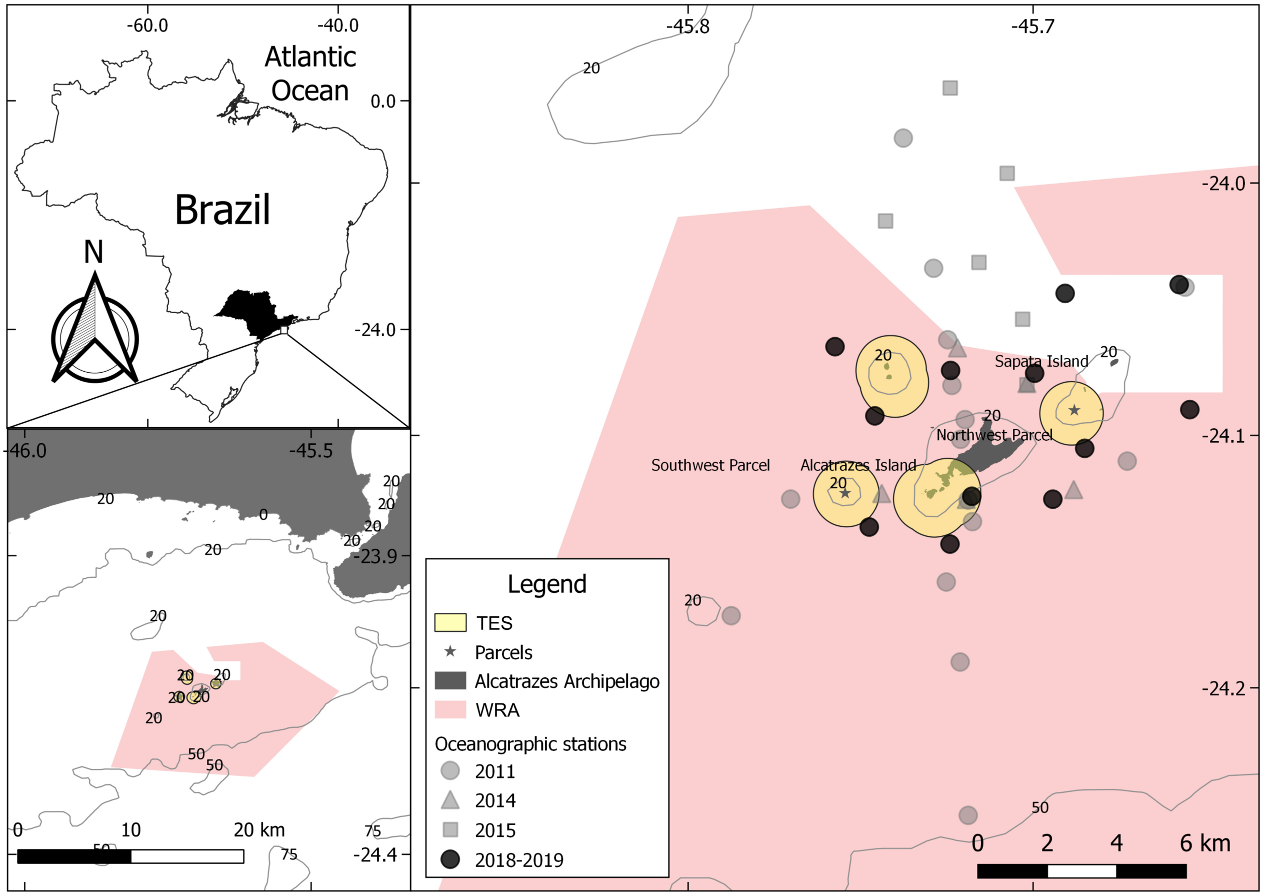

FIGURE 1 | Map showing the Alcatrazes Archipelago area, its marine protected areas (MPAs) delimitations [Wildlife Refuge of Alcatrazes (WRA) and Tupinambás Ecological Station (TES)] and oceanographic stations by expedition.

Ecological Analyses

A bibliographic survey was performed to gather information regarding the size at maturity, reproductive strategies, and food items of each species. They were used to classify specimens as juvenile or adult based on the size at first maturity and to identify functional groups through the reproductive and feeding guilds (**Supplementary Tables 1, 2**). Thus, species were classified into six groups by embryonic feeding method (trophonemata, oviparous, or lecithotrophic) and by trophic category (hyperbenthivorous, infauna consumers, or piscivorous), according to Elliott et al. (2007). Due to spatial variations in terms of biological and ecological aspects we used information of specimens from the closest regions.

To estimate changes in diversity patterns over time, we calculated species richness, the Shannon-Wiener diversity (H') and the Pielou evenness (J') for each year (Begon et al., 2006). Due to differences in sampling effort among years, instead of comparing raw species counts, we estimated rarefaction curves and species richness through non-parametric estimators (Chao and Chiu, 2016). Those estimators take into account underestimations in richness due to low sampling effort and differences in detection probability of species, since some species might have not been caught despite being present (Chao and Chiu, 2016). Quantities of juveniles and adults, sex ratios, and frequencies of TL/DW classes were counted for the most abundant species (>25 specimens caught). Deviations from 1:1 of sex ratios and contingency tables of species by life stages were evaluated by chi-square tests (χ^2). Distributions of TL/WD frequency classes between sexes were compared by two-sample Kolmogorov-Smirnov tests (Zar, 2009).

Next, to test our hypothesis that species use spatial areas differently, and thus elucidate the roles played by WRA and TES, we conducted a three-step analyses. First, for each oceanographic station, we estimated the Bray-Curtis dissimilarities of the functional group abundances and performed principal coordinate analysis (PCoA) (Borcard et al., 2011) using the *"cmdscale"* function in R. Then, the relationship of the two first ordination scores and buffers were modeled by smoothed splines fitted using the *"ordisurf"* function. This function uses generalized additive models (GAMs) to fit non-linear response surfaces of predictor variables to ordinations (Oksanen et al., 2020). Maps of species' relative abundance by oceanographic expedition were set and compared to the PCoA results to identify spatial-temporal variations in the community composition.

Influences of abiotic features on the relative abundance of species and functional groups were evaluated through generalized linear models (GLMs). Before model fitting, the predictive variables temperature, salinity, depth, year, seasons, the SACW presence, buffers, sediment type, and classes of $CaCO_3$ concentrations were centralized and the collinearity of continuous and ordinal variables were estimated among pairs using the Spearman's correlation coefficient (Zuur et al., 2009, 2010). Since the SACW presence was correlated (>80%) with temperature, and sediment type was correlated (>0.80) with classes of $CaCO_3$ concentrations, only one of each pair of variables was included in each model. According to Larsonneur et al. (1982), sediments with $CaCO_3$ concentrations above 30% are substantially composed of biogenic sources (i.e., animal and vegetal debris), being classified as litho-bioclastic (from 30 to 50%), bio-lithoclastic (from 50 to 70%) and bioclastic (>70%). Therefore, for model fitting, the sediment variable was set as one of two categories: lithoclastic (up to 30% of $CaCO_3$) and biogenic sediments. Fixed effect models of the count of each species per trawl with the log of swept area (in meters per seconds) as offset term were set up according to prior information about which variables were likely to be relevant for each species (Oddone and Vooren, 2004; Vögler et al., 2008; Menni et al., 2010; Barbini et al., 2011; Palmeira, 2012; Schlaff et al., 2014). Models were fitted using *"glm"* and *"glm.nb"* functions with Poisson and Negative Binomial error distributions (Zuur et al., 2009). Alternative models were compared by the second order Akaike information criterion (AICc) with ΔAICc < 2 as a threshold to evaluate them regarding their descriptive capacity (Burnham and Anderson, 2002). If more than one model was ranked as plausible, model averaging was applied and parameters estimates were weighted by the Akaike weights (*Wi*) (Burnham and Anderson, 2002). To evaluate the model fits, scaled residuals were analyzed through plots generated by the DHARMa package in R (Hartig and Lohse, 2020). DHARMa residuals are estimated as quantiles of one thousand simulated draws from the distribution used to calculate the likelihood corresponding to each observation. Deviations from the expected values of a uniform distribution as well as of variances in relation to predicted values were compared by qq-plots and residual plots, respectively.

Finally, the WRA effect was assessed through changes in size structure over time only for the most common species: the lesser guitarfish, *Zapteryx brevirostris* (Müller and Henle, 1841). None of the other species had a large enough sample size to calculate these size-based indicators. The TL data of *Z. brevirostris* were grouped in two periods (2011–2015 and 2018–2019) according to the MPA establishment in 2016 (Brazil, 2016). We set a linear model with interactions between season and time period ($TL \sim period \times season$) to test whether differences in mean TL are an effect of the MPA creation or due to sampling different seasons (Zar, 2009). Also, indicators of fishery sustainability for each period were estimated. Fishing mortality relative to natural mortality (*F/M*) and spawning potential ratios (SPR, defined as the spawning stock biomass relative to unfished SSB) are indicators of stock status. They measure how much higher is the mortality experienced by a fished population and how much lower is its potential fecundity (Goodyear, 1993), respectively, compared to unfished conditions. The *F/M* indicator was calculated under two different methods with different assumptions about selectivity. First, in the mean length method, total mortality (*Z*) was estimated by the Beverton and Holt (1957) estimator assuming the same catchability of specimens over the minimum fully exploited size (L_c). The second method, length-based spawning potential ratio (LBSPR), assumes that catchability increases logistically with the length of specimens and estimates the logistic parameters as well as the average *F/M* and SPR that best fits the length-frequency data, assuming variability in length at age (Hordyk et al., 2015).

Life history parameters were required to estimate fishery indicators. However, most of them have not been calculated for Alcatrazes population, so we used values of populations from nearby regions. To estimate L_c and other parameters, such as the mean and variance of natural mortality (*M*), methods proposed by Babcock et al. (2013, 2018) were implemented (see **Supplementary Table 4** for details about parameters and indicators). Uncertainties of parameters' estimates were obtained by ten thousand Monte Carlo simulations. They were performed with bootstrapped samples of the observed length data and values of the life history parameters drawn from a multivariate normal distribution. Then, the 90% confidence interval (CI) of each indicator was set as the 5 and 95% quantiles of the simulated values (Babcock et al., 2018).

To evaluate whether a difference in mean length should be expected in the before vs. after MPA samples, the necessary time after the establishment of a MPA for the *Z. brevirositris* population to reach an unfished level of the mean length was assessed considering several selectivity assumptions. Life history values of a fished population (**Supplementary Table 4**) were used to calculate the numbers (Hilborn and Walters, 1992) and lengths at age (von Bertalanffy growth model, Beverton and Holt, 1957) assuming both natural and fishing mortalities before the WRA, and only natural mortality after its establishment. Then, we calculated the mean length of specimens larger than L_c, which is the mean length that is used for the Beverton-Holt estimator, in each year after the founding of the MPA.

All analyses were performed using the R environment (R Core Team, 2020) through the vegan (Oksanen et al., 2020), SpadeR (Chao et al., 2016), MASS (Ripley et al., 2021), MuMIn (Bartoń, 2020), DHARMa, mvtnorm (Genz et al., 2020), and LBSPR (Hordyk, 2019) packages.

RESULTS

Hydrographic and Sedimentological Features

Temperature and salinity diagrams (**Supplementary Figure 1**) showed that the influence of SACW has changed over the years and across the MPA area. The water mass was detected in all years except 2019, which was characterized by higher values of temperature/salinity and homogeneity in the water column with the majority of temperature records from 22.4 to 23.5°C. Despite the absence of σ_0 reference values in 2014, low temperatures (18°C<) were verified by reversing thermometers up to 25 m above the bottom, indicating the presence of SACW. In terms of distribution through the area, the SACW was identified at all oceanographic stations until 2015. Although the 2018 campaign was conducted in summer, the SACW was only detected at oceanographic stations exposed to the open ocean (#08, #09, #10, #11, and #12) and in the area between the Sapata and Alcatrazes islands (#05). These variations in the water mass coverage indicate that the intrusion process was beginning, since the samples were collected at the onset of the season. Sediments of both MPAs were defined by fine grains (fine and very fine sand > 85%) and poor $CaCO_3$ composition (i.e., lithoclastic sediments). However, bio-lithoclastic and bioclastic sediments with large quantities of biogenic $CaCO_3$ (making up by 79% of sediment content) were assessed on patches of coarse and very coarse sand. The distribution of these patches was limited to nearby regions of the Alcatrazes island and especially to the island side that is exposed to open ocean (i.e., the south side). Hydrographic and sedimentological compiled data are presented in **Supplementary Table 3**.

Diversity and Community Structure

A total of 562 specimens were recorded, belonging to 16 species of seven families. Species richness across all years was estimated as 16.33–17, depending on the estimation method used, with CIs ranging from 16.02 to 27.05 species (**Table 1**). Two families, the Trygonorrhinidae and Arhynchobatidae, were the most common, accounting for almost 85% of the elasmobranchs sampled (**Supplementary Table 5**). Trygonorrhinidae was represented by just one species, *Z. brevirostris*, which was recorded in 86% of the oceanographic stations and showed the highest number of individuals caught (n = 257; **Supplementary Table 5**). Following *Z. brevirostris*, the Rio skate, *Rioraja agassizii* (Müller and Henle, 1841), made up around 15% of the total sample (n = 81; **Supplementary Table 5**) and despite its absence in 2015, the species was recorded in 60% of all oceanographic stations.

According to the estimates of diversity, evenness, and species richness, changes in demersal community composition were identified over the time. Overall, the number of observed species and specimens caught were lower (**Table 2**) in oceanographic expeditions of smaller sampling effort: the summer of 2014 (five trawls) and spring of 2015 (six trawls). However, rarefaction curves did not reach asymptotes (**Supplementary Figure 2**) and the 95% upper CI limits revealed the potential for greater values of estimated richness (**Supplementary Table 5**). Diversity and evenness of those oceanographic expeditions were quite similar with higher estimates of the other spring and summer expeditions (2011 and 2018, respectively), which were carried out with a sampling effort almost three times greater (**Table 2**). In this sense, a trend in diversity and evenness was observed, with estimates increasing through the seasons, from the lowest ones in the winter (2019' oceanographic expedition) to the highest during the summer (**Table 2**).

Altogether, lengths were measured for 554 and sexes for 549 specimens, of which 499 were from six species that had a samples size of at least 25 (**Supplementary Table 5**). Species showed significant differences in the distribution of life stage classes (χ^2 = 105.6, df = 5, p < 0.05). The community was mainly composed of adults for *Z. brevirostris*, *R. agassizii*, the zipper sand skate, *Psammobatis extenta* (Garman, 1913) and the groovebelly stingray, *Dasyatis hypostigma* Santos and Carvalho, 2004. However, for two species of the Arhynchobatidae family, the spotback skate, *Atlantoraja castelnaui* (Miranda Ribeiro, 1907) and the eyespot skate, *Atlantoraja cyclophora* (Regan, 1903), the number of juveniles were substantially higher (over

TABLE 1 | Species richness estimates by non-parametric estimators.

Estimators	Estimate	SE	95% CI
Total			
Chao1 (Chao, 1984)	17.00	1.87	16.09–27.05
Chao1-bc	16.33	0.93	16.02–21.96
iChao1 (Chiu et al., 2014)	17.00	1.87	16.09–27.05
ACE (Chao and Lee, 1992)	16.95	1.48	16.11–24.38
2011			
Chao1 (Chao, 1984)	9.17	0.53	9.01–12.51
Chao1-bc	9.00	0.79	9.00–11.64
iChao1 (Chiu et al., 2014)	9.17	0.53	9.01–12.51
ACE (Chao and Lee, 1992)	9.84	1.41	9.09–17.14
2014			
Chao1 (Chao, 1984)	7.00	0.53	7.00–8.55
Chao1-bc	7.00	0.53	7.00–8.55
iChao1 (Chiu et al., 2014)	7.25	0.53	7.02–10.21
ACE (Chao and Lee, 1992)	7.43	0.97	7.03–13.00
2015			
Chao1 (Chao, 1984)	5.98	2.16	5.07–18.3
Chao1-bc	5.98	2.16	5.07–18.3
iChao1 (Chiu et al., 2014)	5.98	2.16	5.07–18.3
ACE (Chao and Lee, 1992)	7.09	3.51	5.22–25.21
2018			
Chao1 (Chao, 1984)	12.17	0.53	12.01–15.52
Chao1-bc	12.00	0.82	12.00–14.68
iChao1 (Chiu et al., 2014)	12.17	0.53	12.01–15.52
ACE (Chao and Lee, 1992)	12.43	0.89	12.03–17.36
2019			
Chao1 (Chao, 1984)	14.46	7.13	10.49–50.53
Chao1-bc	11.49	2.58	10.15–24.95
iChao1 (Chiu et al., 2014)	15.46	5.04	11.17–35.46
ACE (Chao and Lee, 1992)	12.06	2.78	10.28–25.16

Notations: standard error (SE), lower and upper limits of 95% confidence intervals (95% CI).

TABLE 2 | Relative abundance, number of species and ecological index estimates by oceanographic expedition of demersal elasmobranchs.

OEs	*n*	*N*	H′	J′
2011	9	98	0.79	0.77
2014	7	95	1.19	0.76
2015	5	58	0.74	0.73
2018	12	196	1.31	0.86
2019	10	101	0.79	0.65

Notations: oceanographic expeditions (OEs), observed number of species (n), relative abundance (N), Shannon-Wiener diversity (H') and Pielou's evenness (J') indexes.

75% of each species abundance). Deviations in sex ratios from 1:1 were verified of both Arhynchobatidae species, with males outnumbered by females (0.33:1, $\chi^2_{A.\ castelnaui} = 25$, d$f = 1$, $p < 0.05$; 0.4:1, $\chi^2_{A.\ cyclophora} = 18.37$, d$f = 1$, $p < 0.05$). Concerning the species length ranges, no significant differences among sexes were found for either of these two species ($D_{A.\ castelnaui} = 0.26$, $p > 0.05$; $D_{A.\ cyclophora} = 0.26$, $p > 0.05$; **Figure 2**).

Conversely, for the other two skate populations, more than 70% of collected specimens were adults. Differences in sex ratios were also verified with more females of *R. agassizii* (0.57:1, $\chi^2 = 7.44$, d$f = 1$, $p < 0.05$) and of *P. extenta* (0.54:1, $\chi^2 = 8.84$, d$f = 1$, $p < 0.05$). For the latter, TL frequencies did not differ ($D = 0.20$, $p > 0.05$), however, females of *R. agassizii* exhibited larger sizes ($D = 0.43$, $p < 0.05$) prevailing in TL classes above 40 cm (**Figure 2**). The same pattern was observed for *Z. brevirostris* with more than 70% of the analyzed specimens as adults. The ratio between males and females was equal (0.88:1, $\chi^2 = 0.44$, d$f = 1$, $p > 0.05$) and as for *R. agassizii*, females were larger than males ($D = 0.19$, $p < 0.05$). For *D. hypostigma*, there were no differences among sex ratios (0.75:1, $\chi^2 = 2.04$, d$f = 1$, $p > 0.05$) and life stage classes were also similar (**Supplementary Table 5**). Although the majority of males showed smaller sizes (**Figure 2**), no significant differences were found in DW distributions by sex ($D = 0.38$, $p > 0.05$).

Habitat Functionality

The first two axis of the PCoA explained 55.6% of the data variance (PCoA1 = 32.4 and PCoA2 = 23.20), being correlated with distances from the Alcatrazes island (i.e., buffers) as shown by the contour lines (**Figure 3**). The slight differences in space use by the functional groups appeared to be more related to the species' trophic categories than to their reproductive modes. While the hyperbenthivorous and infauna consumers were common in regions of intermediate distances, the piscivorous species were mainly caught at the farthest oceanographic stations (i.e., those positively loaded on the PCoA1 and negatively loaded on the PCoA2). Regarding the reproductive guilds, such oceanographic stations were also the most different, being separated even from those of other lecithotrophic species (i.e., negatively loaded on the PCoA1). Fifteen individuals of two shark species, the angular angel shark, *Squatina guggenheim* Marini, 1936 and the dogfishes, *Squalus albicaudus* Viana et al., 2016 and *Squalus sp.* were classified as lecithotrophic and piscivore (**Supplementary Table 5**). They were caught at seven oceanographic stations that were characterized by low temperatures ($\mu = 18.1°C$), presence of the SACW and predominance of finer grains without biogenic $CaCO_3$.

Differences in relative abundances were observed through the archipelago (**Figure 4**). In general, the functional groups were present in all regions of the archipelago, however, the region that corresponds to the exposed side of the Alcatrazes island showed higher values of relative abundance and was more heterogeneous in terms of species composition than the northwest side. Some species were widely distributed while occurrence of the other ones was occasional and restricted to certain regions. *A. castelnaui and A. cyclophora* were abundant in the surroundings of the Alcatrazes island and were present through almost the entire sampling period. Similarly, *R. agassizii* and *Z. brevirostris* were ubiquitous in terms of space-time occurrence. However, in 2019 a pattern was identified with concentrations of the skate in the northeast and of the guitarfish in the northwest and south regions. Also, in 2019 large groups of *D. hypostigma* and solitary individuals of the bullnose eagle ray, *Myliobatis freminvillei* Lesueur, 1824 were observed in the northeast region. Still in the northeast, juveniles of *S. albicaudus* were recorded in 2018. Congeneric species, such as the cownose rays and the angel sharks, were not caught together in any of the trawls, indicating possible spatial segregation with the exposed region being mainly used by *Rhinoptera brasiliensis* Müller, 1836 and *S. guggenheim* and the northwest side by *Rhinoptera bonasus* (Mitchill, 1815) and *Squatina occulta* Vooren and Silva, 1991.

According to the most parsimonious models (ΔAICc < 2), temperature and seasons were the predominant variables that explained shifts in abundance of the species and functional groups (**Table 3**). Except for the trophonemata-hyperbenthivorous (i.e., species that produce lipid-rich liquid through trophonemas to supplement embryo nutrient provision and feed on benthic invertebrates which live above the sediment, respectively), the relative abundance of all groups was inversely related to bottom water temperature (**Table 4**). Moreover, significant differences between summer and spring were found with higher abundances of oviparous-hyperbenthivorous (i.e., species of which embryos depend solely on the yolk-sac reserves, developing inside encapsulated eggs that were deployed in the environment) and lecithotrophic-infauna consumers (i.e., species of which embryos also feed mainly on the yolk-sac reserves, but develop inside the mother uterus and, in later life' stages, feed on benthic invertebrates which live in the sediment) in the former season.

Similar trends were exhibited by the species (**Table 5**). For example, the relative abundance of *A. castelnaui* changed seasonally, with higher values in the summer, the same trend seen for its group (i.e., oviparous-hyperbenthivorous). Increases in *A. cyclophora* as well as in the most representative species of lecithotrophic-infauna consumers, *Z. brevirostris*, were related to temperature decrease and, particularly for some skates, salinity had an inverse effect (e.g., *P. extenta*). Spatial variations were mainly explained by depth and differences among buffers. For the oviparous-hyperbenthivorous group, the number of specimens were higher at farther buffers and increased with depth (**Table 4**). Overall, the relative abundance of this group, and specifically of *A. castelnaui* (**Table 5**), appear to be lower in shallow regions. However, none of the skates varied in relative abundance among buffers and only *R. agassizii* showed significant differences with $CaCO_3$ content (**Table 5**). Its lower abundance in biogenic than in lithoclastic sediments might reflect the patterns of the functional group, since oceanographic stations with higher $CaCO_3$ concentrations were found in the vicinity of Alcatrazes island.

MPA Effectiveness for *Z. brevirostris*

No significant differences in mean lengths of *Z. brevirostris* were identified before and after the WRA MPA establishment when

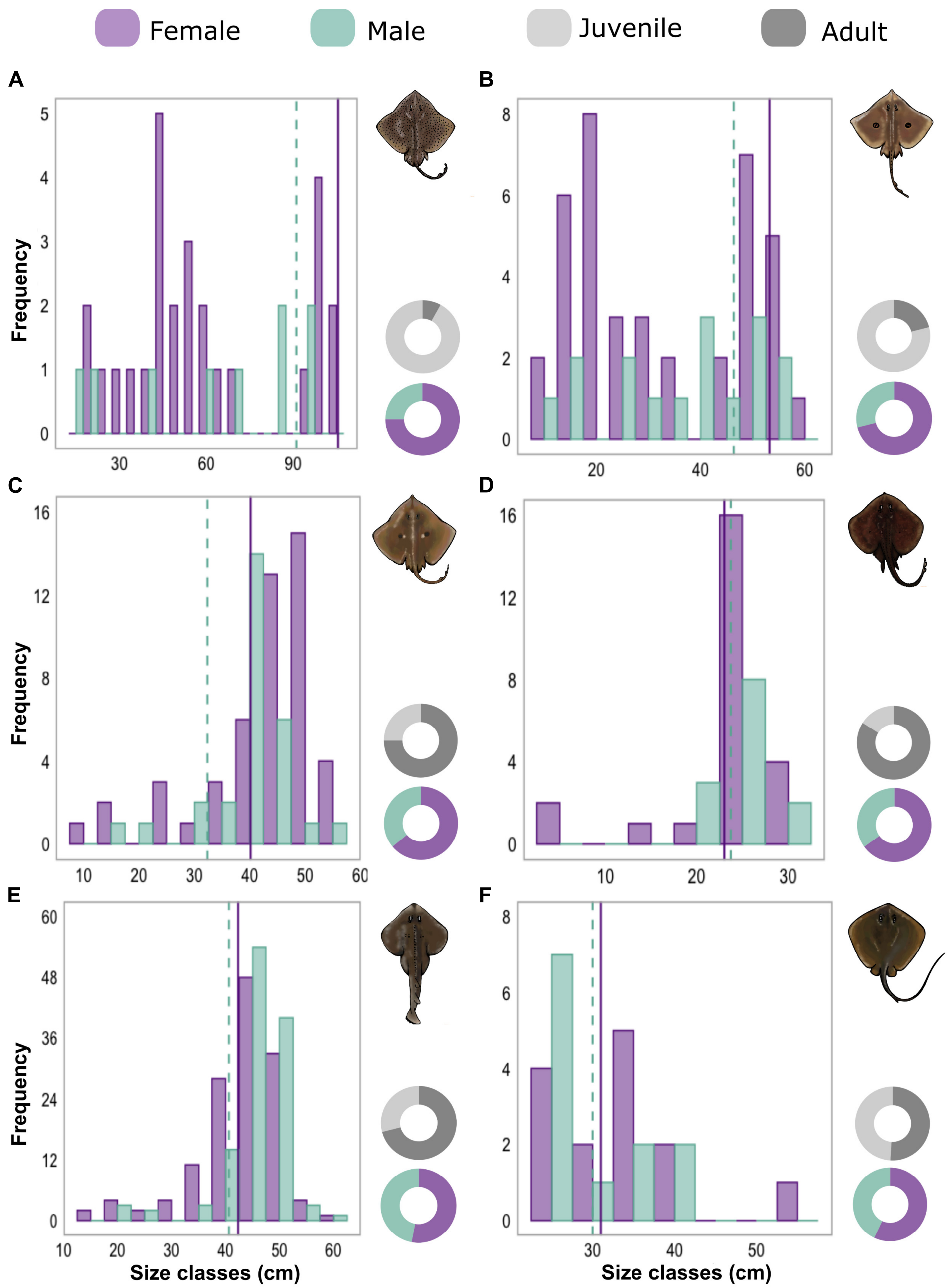

FIGURE 2 | Histograms shows the total length or disk width frequency classes of females (purple) and males (green) of **(A)** *Atlantoraja castelnaui*, **(B)** *A. cyclophora*, **(C)** *Rioraja agassizii*, **(D)** *Psammobatis extenta*, **(E)** *Zapteryx brevirostris*, and **(F)** *Dasyatis hypostigma*. Sizes of first maturity taken from the literature are indicated by purple solid (females) and green dashed (males) vertical lines. Donut charts represent sex ratios and proportions of juveniles and adults.

season was included in the model ($\beta_{before\ +\ summer} = 44.89 \pm 1.33$; $\beta_{after\ +\ summer} = 45.14 \pm 0.77$, $t = -0.19$, $p = 0.85$). On the other hand, there was a significant effect of seasons, with higher mean TL in summer than in spring (**Table 6**). The number of specimens of sizes above L_c, meaning they were susceptible to fishery harvest, was 168 (before MPA: $n = 65$, after: $n = 103$) and the small increase in mean length implied a small decrease in the mean F/M for fish larger than Lc estimated by the Beverton-Holt method although the effect was not significant judging by the overlapping CIs. According to LBSPR, which estimates F/M of fully selected (i.e., large) individuals, assuming a logistic selectivity curve, the mean estimated fishing mortalities increased and CIs of $(F/M)_{LBSPR}$ overlapped, being above the overfishing threshold (>1) (**Supplementary Figure 3A**). These numbers are not directly comparable because they correspond to fish of different sizes. Nevertheless, large values of either

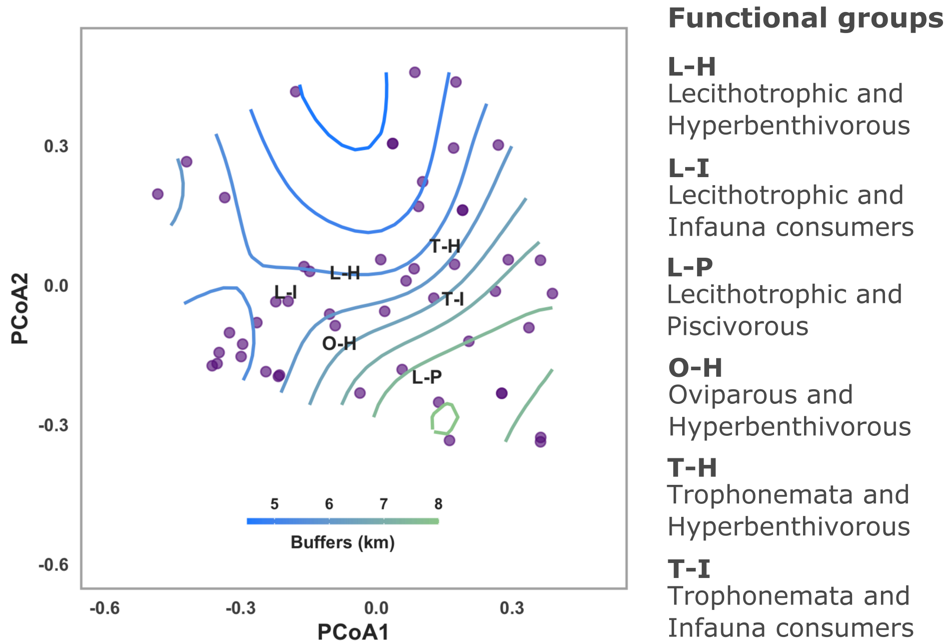

FIGURE 3 | Principal coordinate analysis (PCoA) results showing the space use configuration by functional groups in relation to distances (km) from the Alcatrazes island. Purple points are the oceanographic stations, initials represent the functional groups that most contributed to dissimilarities among oceanographic stations and the contour lines are the fitted splines of the distances from the Alcatrazes island (i.e., buffers) from closer (blue) to farther (green) zones.

metric can be taken as evidence of overfishing. The CIs of SPR also overlapped, although the mean increased slightly (current SPR > 0.4) (**Supplementary Figure 3B**). According to our simulation, if fishing was completely eliminated, the mean length of guitarfish larger than L_c would be expected to increase after the WRA establishment, reaching the unfished level in approximately 5 or 6 years depending on the assumed selectivity of the fishery (**Supplementary Figure 4**).

DISCUSSION

MPA's Functionality

Oceanographic Features Driving the Community Dynamics

Marine communities are usually characterized by a few predominant species that are continuously present and many other species that have relative low abundances and occasional occurrences associated with natural events (Magurran and Henderson, 2003). Our findings showed such patterns with shifts in the Alcatrazes elasmobranch fauna, and consequently in the MPA's functional diversity, being driven by thermohaline and chemical changes in the water column through the seasons. The inshore intrusion of the SACW is known for lowering water temperatures, raising primary production in the euphotic zone, and enriching the bottom by the input of particulate organic matter during spring and summer. Therefore, increases in diversity metrics were likely a response of the enhancement of feeding resources, given that the energy surplus advantages the benthic megafauna, and is also a consequence of the expansion of the SACW's associated species (Pires-Vanin et al., 1993; Castro-Filho and de Miranda, 1998; Muto et al., 2000). On average, 60% of the species caught are temperate species that are probably related to the water mass (Menni and Stehmann, 2000; Menni et al., 2010). Higher abundances of functional groups in spring and summer (e.g., lecithotrophic-infauna consumers and oviparous-hyperbenthivorous) and their increase with a decrease in temperature, indicate the same association with the SACW. Even though variations could be explained by the input of individuals, the reproductive cycle of such species appears to be synchronized to periods of more suitable conditions. Reported peaks on mating, birth or egg-laying of *A. cyclophora*, *A. castelnaui*, *R. agassizii*, *Z. brevirostris*, the Brazilian guitarfish, *Pseudobatos horkelii* (Müller and Henle, 1841), and *S. occulta*, coincides with the timing of the SACW influence (Lessa et al., 1986; Ponz-Louro, 1995; Oddone and Vooren, 2005; Vooren and Klippel, 2005; Oddone et al., 2007, 2008; Colonello et al., 2011, 2012). This could enable energy recovery by females and access to food by the newborns.

On the other hand, when the SACW retreats to deeper zones (>100 m) in autumn and winter, the Tropical Water mass dominates the middle shelf, increasing the temperature and salinity of the water (Castro-Filho and de Miranda, 1998; Campos et al., 2000). Our results show that under the Tropical Water influence, the community became less diverse although some of the recorded species had never been caught before (e.g., *R. bonasus* and *R. brasiliensis*). The cownose rays are trophonemata species that display reproductive traits of high energetic demand to improve likelihood of offspring success (Rangel et al., 2020). Seasonal migrations to nursery areas

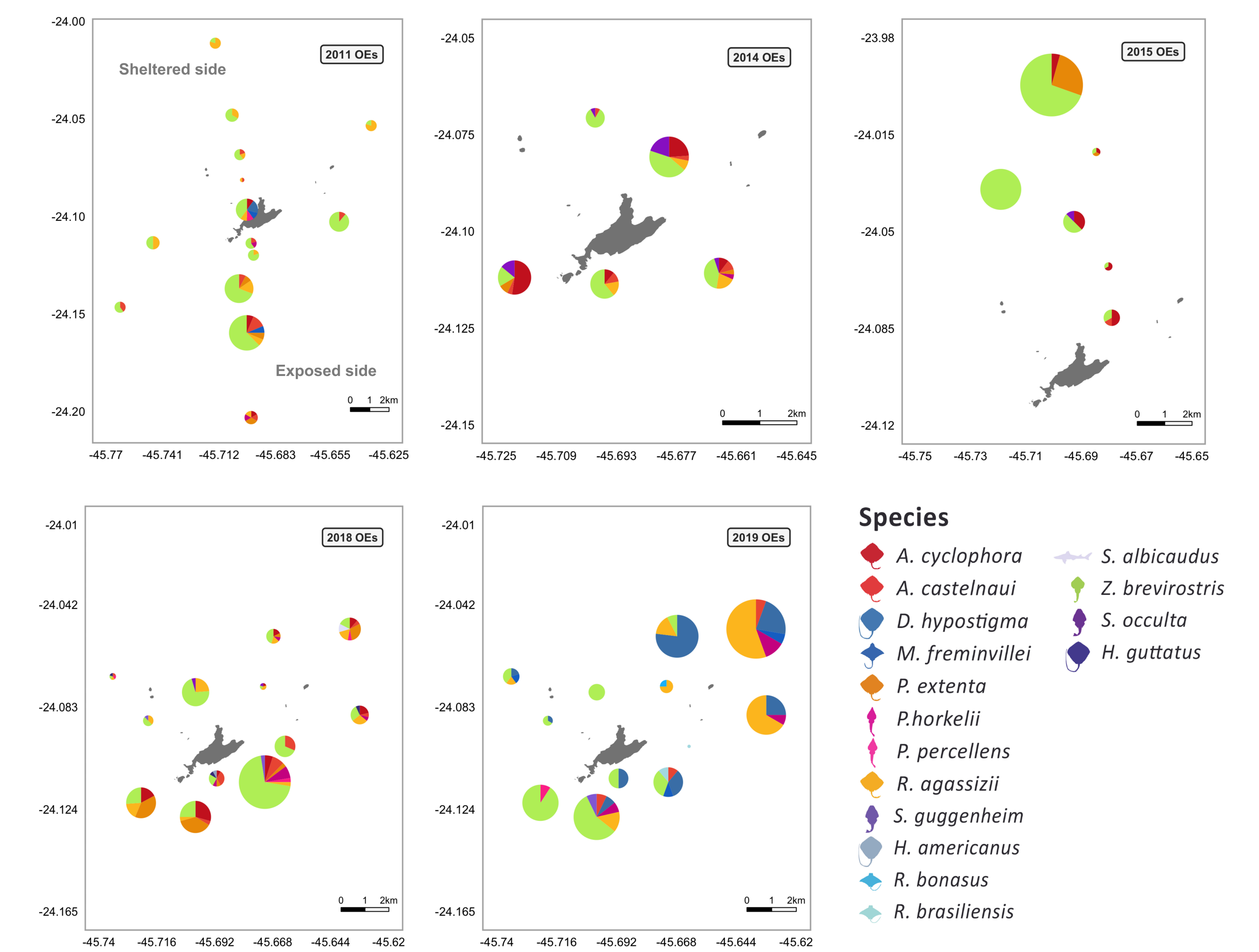

FIGURE 4 | Maps of spatial-temporal variation of species relative abundance through the Alcatrazes archipelago. Colors indicate species relative abundance by oceanographic station and pie chart sizes represent the contribution of each oceanographic station to the total catch by expedition. The sides of the archipelago that are exposed to the open ocean and turned to the continent (sheltered) are present in the first map.

along the coast have been suggested, with parturition from late spring through summer (Rangel et al., 2018). Thus, the recorded specimens might have been caught while foraging for more energetic resources to improve reserves before mating or during gestation (e.g., Rangel et al., 2021). After stronger SACW events, the availability of potential food items, including higher level species of the benthic megafauna, are more abundant on the middle shelf, making Alcatrazes a productive foraging area (Pires-Vanin et al., 1993; De Léo and Pires-Vanin, 2006; Shimabukuro et al., 2016).

Spatially, while the northwest and northeast parts were predominantly characterized by finer grains and poor $CaCO_3$ content, the south (i.e., part exposed to the open ocean), could be distinguished in two regions: the eastern portion, that is similar to the first two, and the western, with presence of coarse sands and higher $CaCO_3$ concentrations. According to Takase et al. (2021), this region is highly influenced by energetic waves which explains the sediment configuration by the displacement of finer grains to the east. Consequently, the heterogeneity of habitats in the exposed part resulted in a more diverse fauna in comparison to the northern area. Higher abundances of oviparous and hyperbenthivorous species at farther offshore and deeper locations might be related to the distribution of preys. For example, organisms of biogenic source such as mollusks, starfishes, and corals, are not part of the *R. agassizii* diet, which like *P. extenta*, feeds significantly on small crustaceans of the benthic macrofauna (Soares et al., 1992; Aguiar and Valentin, 2010; Bornatowski et al., 2014). Moreover, brachyuran and portunid crabs are main preys of *A. castelnaui* and *A. cyclophora*, respectively (Soares et al., 1992, 2008). Thus, great densities of the macrobenthos on the inner and outer shelf (Pires-Vanin, 2008) and presence of such crabs (e.g., *Persephona punctata*, *Libinia spinosa*, *Portunus spinimanus*, and *Callinectes sapidus*), which were found in trawls performed at deeper oceanographic stations, would have attracted the skates to those regions, consistent with our findings. Likewise, spatial differences between angel sharks

TABLE 3 | Best ranked models for the number of individuals of functional groups and species.

Models	k	AICc	ΔAICc	Wi
Lecithotrophic and Infauna consumers				
Seas + Temp	5	271.27	0	0.49
Temp	3	273.02	1.75	0.21
Oviparous and Hyperbenthivorous				
Seas + Temp + Buffers	9	243.78	0	0.29
Seas + Dep + Buffers	9	243.81	0.03	0.28
Seas + Temp	5	244.50	0.72	0.20
Seas	4	245.48	1.70	0.12
Trophonemata and Hyperbenthivorous				
Temp	3	95.92	0	0.62
Atlantoraja cyclophora				
Temp + Sal	4	121.89	0	0.62
Atlantoraja castelnaui*				
Seas + Dep + $CaCO_3$	5	104.18	0	0.36
Seas + Dep	4	104.22	0.04	0.36
Seas + $CaCO_3$	4	106.05	1.87	0.14
Rioraja agassizii				
$CaCO_3$	3	177.14	0	0.61
Seas + $CaCO_3$	5	178.66	1.52	0.28
Psammobatis extenta				
Sal + Dep	4	106.09	0	0.30
Sal	3	106.17	0.08	0.29
Sal + $CaCO_3$	4	107.47	1.38	0.15
Zapteryx brevirostris				
Seas + Temp	5	269.24	0	0.46
Seas + Temp + $CaCO_3$	6	270.71	1.47	0.22

Log of swept area was included as an offset in all models. Notations: k (number of parameters estimated), AICc (Akaike's second-order information criterion), ΔAICc (AICci – AICcmin), Wi (Akaike weight), seasons (Seas), bottom water temperature (Temp), bottom water salinity (Sal), depth (Dep), distance from the Alcatrazes island (Buffers) and $CaCO_3$ classes ($CaCO_3$).
**Poisson GLMs were fitted for A. castelnaui.*

TABLE 4 | Estimated parameters of variables from the best models that explain the number of individuals of functional groups.

Variables	β	SE	Z-value	P-value
Lecithotrophic and Infauna consumers				
Intercept	−7.07	0.20	34.92	**<0.01**
Temp	−0.28	0.13	2.21	**0.03**
Spring	−0.63	0.25	2.43	**0.02**
Winter	0.46	0.59	0.77	0.44
Oviparous and Hyperbenthivorous				
Intercept	−7.34	0.42	17.32	**<0.01**
Temp	−0.25	0.11	2.17	**0.03**
Buffer 5 km	0.64	0.34	1.86	0.06
Buffer 7.5 km	0.97	0.39	2.40	**0.02**
Buffer 10 km	1.23	0.41	2.90	**<0.01**
Buffer 12.5 km	1.51	0.51	2.91	**<0.01**
Spring	−1.11	0.28	3.90	**<0.01**
Winter	−0.64	0.66	0.96	0.34
Dep	0.05	0.02	2.61	**<0.01**
Trophonematas and Hyperbenthivorous*				
Intercept	−9.84	0.35	−28.16	**<0.01**
Temp	0.57	0.13	4.26	**<0.01**

Parameters with significant P-value (<0.05) were highlighted. Notations: estimated coefficients (β), standard error (SE), Z test (Z-value) and significance in Z test (P-value).
**Except for Throphonematas and Hyperbenthivorous parameters of other groups were weighted by the Akaike weight (Wi) of the best models in which variables were present.*

were probably related to the resource distribution. Abundance of infauna invertebrates (e.g., polychaetas), may be higher in the northwest part due to sediment composition and higher levels of organic matter (Hoff et al., 2015). Thus, whereas *S. guggenheim* are strictly piscivorous, eating demersal, and pelagic species (Vögler et al., 2003), the *S. occulta* diet, which consists of polychaetas and nematodes, relies on configurations of benthic habitats (Aguiar and Valentin, 2010; Domingos et al., 2021).

Groupings of mature males (i.e., calcified clasper) of *R. agassizii* and *Z. brevirostris*, in different parts of the archipelago, suggest formation of shoals for reproductive purposes (Paijmans et al., 2019). Although specific evidence of females' maturity stage has not been assessed, the majority of recorded specimens in 2019 were bigger than the published size of first maturity (**Supplementary Table 1**). Those results support the reproductive cycle defined by Oddone et al. (2007) and Colonello et al. (2011). Nevertheless, it is possible that the lesser guitarfishes of tropical waters perform two mating periods, since mature males were also recorded during summer oceanographic expeditions. Colonello et al. (2011) previously highlighted the asynchrony of reproductive females when comparing populations from temperate regions and the northern São Paulo coast (Ponz-Louro, 1995). Catches of *D. hypostigma* and *M. freminvillei* at the same oceanographic stations may indicate formation of mixed-species shoals. Despite the fact that both species are hyperbenthivorous and the diet overlap could increase species competition, interspecific associations may also increase foraging efficiency (Paijmans et al., 2019). Stingrays perform foraging traits which expose the benthic fauna (Freitas et al., 2019), facilitating prey catchability.

Community Structure and Use of the MPA

Overall, dissimilarities regarding the population structures from other Brazilian regions may be related to geographical features, sexual segregation, and ontogenetic changes in habitat use (Schlaff et al., 2014). Despite the substantial presence of adults, most of them were individuals just over the reference size of first maturity. In almost all species, juveniles were present, but only *A. castelnaui* and *A. cyclophora* were dominated by them, which will be discussed later. The sex ratio favoring females was similar to what was found with populations of *A. castelnaui*, from the northern coast of São Paulo (Ponz-Louro, 1995) and of *R. agassizii,* along the southeastern Brazil (Oddone and Amorim, 2007). In contrast, the sex ratio of the northern state population of *P. extenta* did not deviate from 1 (Martins et al., 2005) which was not consistent with our findings of a female dominated sex ratio. Furthermore, Martins et al. (2005) found variations in habitat use through the species' life span. This does not seem to be our case as young juveniles, older juveniles, and adults were

TABLE 5 | Estimated parameters of variables from the best models that explain the number of individuals of elasmobranch species.

Variables	β	SE	*Z*-value	*P*-value
Atlantoraja cyclophora*				
Intercept	−9.95	0.41	−24.18	**<0.01**
Temp	−0.68	0.18	−3.88	**<0.01**
Sal	−3.16	0.90	−3.52	**<0.01**
Atlantoraja castelnaui				
Intercept	−8.85	0.27	31.79	**<0.01**
Spring	−0.82	0.37	2.19	**0.03**
Winter	−1.54	0.62	2.43	**0.02**
Dep	0.07	0.03	2.36	**0.02**
Bio sed	0.72	0.41	1.71	0.09
Rioraja agassizii				
Intercept	−8.00	0.26	30.24	**<0.01**
Bio sed	−1.01	0.45	2.20	**0.03**
Spring	−0.70	0.40	1.70	0.09
Winter	−0.08	0.43	0.17	0.86
Psammobatis extenta				
Intercept	−9.74	0.49	19.51	**<0.01**
Sal	−3.79	1.33	2.79	**<0.01**
Dep	0.09	0.06	1.61	0.11
Bio sed	0.84	0.85	0.96	0.34
Zapteryx brevirostris				
Intercept	−7.14	0.25	28.20	**<0.01**
Temp	−0.28	0.14	2.01	**<0.05**
Spring	−0.52	0.28	1.81	0.07
Winter	0.28	0.66	0.41	0.68
Bio sed	0.29	0.27	1.03	0.30

Parameters with significant P-value (< 0.05) were highlighted. Notations: estimated coefficients (β), standard error (SE), Z test (Z-value), significance in Z test (P-value) and class of sediment composed by biogenic sources (Bio sed).
**Except for A. cyclophora parameters of other groups were weighted by the Akaike weight (Wi) of the best models in which variables were present.*

TABLE 6 | Effects of the Wildlife Refuge of Alcatrazes (WRA) establishment and seasons in mean total length (TL) of *Zapteryx brevirostris*.

Variables	β	SE	*t*-value	*P*-value
After WRA + Summer	45.14	0.77	58.75	**<0.01**
Before WRA	−0.25	1.33	−0.19	0.85
Spring	−3.28	1.31	−2.49	**0.01**
Winter	1.95	1.45	1.34	0.18

Parameters with significant P-value (<0.05) were highlighted. Summer was the only season in which specimens of Z. brevirostris were caught before and after the MPA establishment.

found in Alcatrazes. No significant deviations from 1 were found for *A. cyclophora* in southern and southeastern Brazil (Oddone and Vooren, 2004; Oddone and Amorim, 2007). The evaluated specimens of both studies came from different, and even deeper regions (over 100 m), inside of a wider area, which might have caused those disparities. For *Z. brevirostris* and *D. hypostigma*, our results exhibited equal rates between sexes, which agreed with results of the northern guitarfishes evaluated by Ponz-Louro (1995). But, for the last one, no information about population structure was found, pointing out the necessity of efforts to broaden our understanding of the species.

Based on the structure results, evidence of reproductive availability and patterns found in the literature, we propose uses of the MPAs by each elasmobranch although further research regarding species movement ecology is essential to strengthen these conclusions (**Supplementary Table 5**). Like other insular regions in Brazil (Wetherbee et al., 2007; Aguiar et al., 2009), Alcatrazes is a nursery area specifically used for development by many species. Early life stages, such as neonates, young of the year and/or juveniles were found, supporting this hypothesis. Juveniles of angel sharks and stingrays (genus *Hypanus*) were found at deeper regions, whereas records of smaller specimens (e.g., *Hypanus americanus* (Hildebrand and Schroeder, 1928) and *S. albicaudus*), indicate that younger animals may use sheltered habitats (Aguiar et al., 2009; Farrugia et al., 2011), such as the shallow zones closer to rock formations and low energetic parts in the northeast. However, for two skates, *A. castelnaui* and *A. cyclopohora*, the area works not only as nursery, but also as mating place, as indicated by the lower frequencies of adults and seasonal records of mature males. The possibility that records of mature specimens of the other species may have been related to migratory behavior hampers the definition that the area was used only for reproduction by them. Thus, as proposed for cownose rays, which are species of large home ranges and exhibit key areas for population maintenance along the coast (Collins et al., 2007; Rangel et al., 2018), we suppose that the MPAs may be a seasonal feeding ground for *M. freminvillei* and *D. hypostigma*.

Connection between the inner and outer shelf may play a critical role in the species' reproductive success, especially for *P. horkelii* and the chola guitarfish, *Pseudobatos percellens* (Walbaum, 1792). Seasonal migrations of *P. horkelii*, from deeper regions (>100 m) to give birth and mate in coastal zones, is well described by Lessa et al. (1986). This might have been the case of the adult females of both species that were caught in spring and summer. Even though movements of great distances were not reported for *P. percellens*, embryonic diapause, which is a reproductive trait associated with the migratory behavior of *P. horkelii*, was proposed for the former species (Rocha and Gadig, 2013). This may suggest that *P. percellens* also displays such behavior, being consistent with the absence of neonates in our records. Finally, for *R. agassizii*, *P. extenta*, and *Z. brevirostris*, all length classes were collected, indicating their resident status. Nevertheless, their presence may be intermittent, particularly for the skates that were absent in some oceanographic expeditions. According to Martins et al. (2005), abundance fluctuations of *P. extenta* was observed in the northern coast, being higher in periods when the species were not recorded in Alcatrazes (e.g., 2009'expedition).

WRA Effectiveness for *Z. brevirostris* and Further Challenges to Conservation of the Species

Magnitude differences between the methods and uncertainties in fisheries indicators for *Z. brevirostris* may be caused in part by the small sample size, requiring larger datasets to obtain more precise and accurate results, especially for the LBSPR method. Despite the fact that our results did not find a significant positive effect of the WRA establishment, the decrease in mean $F/M_{(ML)}$ and increase in mean SPR may suggest some improvements in fisheries indicators. Our calculation of the expected time to show an improvement in mean length after MPA establishment suggests that under several possible selectivity patterns in the fishery, the WRA effect could be detectable within a few years of the MPA formation. However, further monitoring is needed to estimate the trends of the Alcatrazes population. The WRA is a novel MPA, for which the management plan was defined in 2017 (ICMBio, 2017), starting its initiatives 1 year before our last sampling campaign. Thus, our short-term evaluation and inconsistent sampling among seasons, might be the reason to the small changes we got in the mean length between periods. Furthermore, *Z. brevirostris* is a relative long-lived species that exhibits late maturity and low intrinsic rate of population growth (Caltabellotta, 2014; D'Alberto et al., 2019), which would increase the estimated times of recovery relative to more short lived species.

As previously mentioned, parts of the archipelago have been being protected by TES and even before its creation, by the Brazilian Navy, which used to perform tactical exercises, forbidding navigation in the surroundings (Hoff et al., 2015). At that time, the demersal fish community was represented by predominance of sole fishes (e.g., *Syacium micrurum*, *S. papillosum*, *Citharichthys macrops*, and *Symphurus jenynsi*) and poor diversity of elasmobranchs, with *Z. brevirostris* as the only one in the records (Paiva-Filho et al., 1989). Nowadays, the archipelago shows a well-structured community, with presence of higher-level predators (Rolim et al., 2019) and the apparent improvement of the *Z. brevirostris* population, since the great number of recorded specimens is comparable to other studies that were performed in wider areas along the coast (e.g., Marion et al., 2011; Caltabellotta et al., 2019). In this sense, our results provide a useful baseline for further evaluations of causal effects regarding the WRA. Some studies have pointed out the importance of tracking changes in ecological indicators of a MPA throughout time (Edgar et al., 2004, 2011) and between a control site (Villaseñor-Derbez et al., 2018). However, the historical safeguarding of the archipelago, the influence of physical processes (Castro-Filho et al., 1987), the higher complexity of ecological interactions (Rolim et al., 2019) and its great distance from coastal as well as other insular regions, increase the potential sources of variability (Edgar et al., 2014), making difficult the designation of control areas or comparisons with other MPAs.

The relevance of the MPAs for the local ichthyofauna is clear, especially the WRA, which broadened the protection, encompassing the Alcatrazes island and consequently, the essential habitats for elasmobranchs. Furthermore, both areas seem to play pivotal roles for endangered species, as more than 75% of the recorded elasmobranchs are in threatened categories (IUCN, 2021). Both MPAs together encompass an area of approximately 70,000 ha (ICMBio, 2017) which would cover the home ranges of the caught species (see Section "Abiotic Data"). Nevertheless, ontogenetic differences in their requirements may not be provided, so that for some species the archipelago was used only at specific life stages (i.e., non-resident species). Such differences imply movements to specific habitats outside the MPAs boundaries, raising the threats over the species and consequently affecting the efficiency of the protected areas. Chapman et al. (2005) discovered that the lack of connectivity among adjacent habitats was exposing reef and nursery sharks to the fisheries, demanding additional management measures for species conservation, and some Alcatrazes species may experience similar threats.

Similarly, the intense anthropogenic pressure in the surrounding area may compromise such functionality and thus, the effectiveness of TES and WRA. Alcatrazes is placed between two disturbed areas on the São Paulo coast. To southwest, the Santos Port is the largest port in Latin America and the most important industrial hub in Brazil (Luiz-Silva et al., 2002), producing great concentrations of mercury and plastic pellets, that reach adjacent (e.g., Santos Bay) (Siqueira et al., 2005; Ribeiro, 2020) and even farther regions, such as the archipelago. To northwest and closer to Alcatrazes, the São Sebastião Port will be expanded over the Araçá Bay (Angelini et al., 2018), an important nursery place (Contente et al., 2020). Besides the local impacts, its expansion could also affect the vicinities, disturbing the fauna by the carriage of pollutants and increase in underwater noise (Slabbekoorn et al., 2010; Barletta et al., 2016).

In addition, despite fishery activities being concentrated on the inner and middle shelf (Imoto et al., 2016), including inside the less restrictive protected areas (Carneiro et al., 2013), exploration of deeper zones has been increasing in the past decades (Pincinato and Gasalla, 2019). According to Imoto et al. (2016), great amounts of demersal catches were obtained by industrial fleets in those regions, raising the threat over species that use the archipelago seasonally for feeding or for mating, while also using the surrounding fished area. Currently, fishing of threaten elasmobranchs is forbidden or only allowed for subsistence in Brazilian waters (i.e., species classified as VU) (MMA, 2014). Nevertheless, they are still caught as bycatch by fleets that are known to directly impact the demersal fauna, such as gillnets, and otter, double-ring, and pair trawlers. Those activities are controlled in the surroundings of TES and WRA by the management plans of other two protected areas (i.e., Marine Environment Protection Area of the North and Central Coast – APA Norte and APA Centro) (Forestry Foundation, 2019, 2020) and different legislations of federal and state level. Inside the APAs, input measures, such as the restriction of industrial (APA Centro) and even traditional (APA Norte) pair trawlers until the 23.6 m isobath as well as the specification of day periods to operation of beach seines (São Paulo, 2009, 2012), are applied. Nevertheless, the fishing zonation become less restrictive as distance from the coast increases and despite seasonal closures of catfish and shrimp fishing occur from January to March (SUDEPE, 1984) and March to May (IBAMA, 2008), respectively, gillnets remain allowed (IBAMA, 2007).

Thus, based upon the MPAs use by elasmobranchs and the potential connectivity with other protected areas, we recommend that besides the creation/expansion of marine reserves, fishing control measures should be implemented. Temporal closures in winter as well as extension of the pre-existing ones through all summer months, and limitation of effort (Cochrane and Garcia, 2009), could reduce the pressure on species that make reproductive migrations and/or require larger home ranges (e.g., guitarfishes, eagle, and cownoses stingrays). Moreover, economic incentives (i.e., referred to "Seguro Desemprego," a category of social insurance in Brazil) (Brazil, 2003, 2009, 2015) could be provided to artisanal fishermen during the proposed temporal closures and to those who will not be able to fish or will have to change their techniques due to permanent spatial closures. Last, integrated evaluations of the effectiveness of conservation actions for benthic elasmobranchs and the Alcatrazes ecosystem must consider the associated areas, since they have provide essential services to the ecosystem's maintenance (Rolim et al., 2019; Contente et al., 2020). If these measures are taken into account, a network with key habitats along the coast (e.g., nursery, reproduction and feeding places) could be developed, assisting the conservation of elasmobranch populations in the southeastern Brazil and consequently, enhancing the WRA and TES efficacy.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The animal study was reviewed and approved by the Ethics Committee of Animal Use of the Oceanographic Institute of the University of São Paulo (CEUA IO-USP) and by the Chico Mendes Institute for Biodiversity Conservation (ICMBio) under the survey permit SISBIO/55824.

AUTHOR CONTRIBUTIONS

TK, JD, and EB conceptualized this study. TK, RG, and JD collected abiotic and biotic samples, with PP, identified functional groups. TK and RG performed the sedimentological analyses. TK, EB, and PP performed statistical analyses and results interpretation. TK prepared the original draft. EB, JD, PP, and RG reviewed the manuscript. All authors contributed to the manuscript elaboration and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.694846/full#supplementary-material

REFERENCES

Aguiar, A. A., and Valentin, J. L. (2010). Biologia e ecologia alimentar de elasmobrânquios (Chondrichthyes: Elasmobranchii): uma revisão dos métodos e do estado da arte no Brasil. *Oecol. Aust.* 14, 464–489. doi: 10.4257/oeco.2010.1402.09

Aguiar, A. A., Valentin, J. L., and Rosa, R. S. (2009). Habitat use by Dasyatis americana in a south-western Atlantic oceanic Island. *J. Mar. Biol. Assoc. U.K.* 89, 1147–1152. doi: 10.1017/S0025315409000058

Angelini, R., Contente, R. F., Rossi-Wongtschowski, C. L. D. B., Soares, L. S. H., Schaeffer-Novelli, Y., Lopes, R. M., et al. (2018). Ecosystem modeling as a framework to convert a multi-disciplinary research approach into a useful model for the Araçá Bay (Brazil). *Ocean Coast. Manag.* 164, 92–103. doi: 10.1016/j.ocecoaman.2018.02.007

Babcock, E. A., Coleman, R., Karnauskas, M., and Gibson, J. (2013). Length-based indicators of fishery and ecosystem status: Glover's Reef Marine Reserve, Belize. *Fish. Res.* 147, 434–445. doi: 10.1016/j.fishres.2013.03.011

Babcock, E. A., Tewfik, A., and Burns-Perez, V. (2018). Fish community and single-species indicators provide evidence of unsustainable practices in a multi-gear reef fishery. *Fish. Res.* 208, 70–85. doi: 10.1016/j.fishres.2018.07.003

Barbini, S. A., Lucifora, L. O., and Hozbor, N. M. (2011). Feeding habits and habitat selectivity of the shortnose guitarfish, *Zapteryx brevirostris* (Chondrichthyes, Rhinobatidae), off North Argentina and Uruguay. *Mar. Biol. Res.* 7, 365–377. doi: 10.1080/17451000.2010.515229

Barletta, M., Cysneiros, F. J. A., and Lima, A. R. A. (2016). Effects of dredging operations on the demersal fish fauna of a South American tropical-subtropical transition estuary. *J. Fish Biol.* 89, 890–920. doi: 10.1111/jfb.12999

Bartoń, K. (2020). *MuMIn: Multi-Model Inference*. Available online at: https://cran.r-project.org/web/packages/MuMIn/index.html (accessed August 10, 2021).

Begon, M., Townsend, C. R., and Harper, J. L. (2006). *Ecology: From Individuals to Ecosystems*, 4th Edn. Oxford: Blackwell Publishing.

Beverton, R. J. H., and Holt, S. J. (1957). *On the Dynamics of Exploited Fish Populations*. London: Chapman and Hall.

Borcard, D., Gillet, F., and Legendre, P. (2011). *Numerical Ecology with R*, eds R. Gentleman, K. Hornik, and G. G. Parmigiani (New York, NY: Springer). doi: 10.1007/978-1-4419-7976-6

Bornatowski, H., Wosnick, N., Do Carmo, W. P. D., Corrêa, M. F. M., and Abilhoa, V. (2014). Feeding comparisons of four batoids (Elasmobranchii) in coastal waters of southern Brazil. *J. Mar. Biol. Assoc. U.K.* 94, 1491–1499. doi: 10.1017/S0025315414000472

Brazil (1987). *Estações Ecológicas de Carijós, Pirapitinga e Tupinambás. Decreto No94.656 20 Julho 1987*. Available online at: http://www.planalto.gov.br/ccivil_03/decreto/1980-1989/1985-1987/D94656.htm (accessed March 14, 2021).

Brazil (2003). *Lei No 10.779, de 25 de Novembro de 2003*. Available online at: https://www.planalto.gov.br/ccivil_03/leis/2003/L10.779compilado.htm (accessed August 10, 2021).

Brazil (2009). *Lei No 11.959, de 29 de Julho de 2009*. Available online at: http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2009/Lei/L11959.htm#art24 (accessed August 10, 2021).

Brazil (2015). *Lei No 13.134, de 16 de Junho de 2015*. Available online at: http://www.planalto.gov.br/ccivil_03/_ato2015-2018/2015/lei/l13134.htm (accessed August 10, 2021).

Brazil (2016). *Refúgio da Vida Silvestre do Arquipélago de Alcatrazes no litoral norte do Estado de São Paulo. Decreto 2 Agosto 2016.* Available online at: https://www.icmbio.gov.br/portal/images/stories/biodiversidade/UC-RPPN/decreto_sem_numero_02ago2016_cria_Revis_do_Arquipelogo_de_Alcatrazes.pdf (accessed March 14, 2021).

Burnham, K. P., and Anderson, D. R. (2002). *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*, 2nd Edn. New York, NY: Springer.

Caltabellotta, F. P. (2014). *Dinâmica Populacional das raias-violas, Rhinobatos horkelli, Rhinobatos percellens e Zapteryx brevirostris (Chondrichthyes, Rhinobatidae) da Plataforma Continental de São Paulo*. Available online at: http://hdl.handle.net/11449/115721 (accessed August 10, 2021).

Caltabellotta, F. P., Siders, Z. A., Murie, D. J., Motta, F. S., Cailliet, G. M., and Gadig, O. B. F. (2019). Age and growth of three endemic threatened guitarfishes *Pseudobatos horkelii*, *P. percellens* and *Zapteryx brevirostris* in the western South Atlantic Ocean. *J. Fish Biol.* 95, 1236–1248. doi: 10.1111/jfb.14123

Campos, E. J. D., Velhote, D., and Silveira, I. C. A. (2000). Shelf break upwelling driven by Brazil Current cyclonic meanders. *Geophys. Res*. 27, 751–754.

Carneiro, M. H., de Almeida Kooling, J., Ávila-da-Silva, A. O., Mendonça, J. T., Namora, R. C., and de Miranda, L. V. (2013). *A Pesca nas Áreas de Proteção Ambiental Marinha do Estado de São Paulo, Brasil, entre Agosto de 2008 e julho 2009*. São Paulo: Instituto de Pesca.

Cartamil, D. P., Vaudo, J. J., Lowe, C. G., Wetherbee, B. M., and Holland, K. N. (2003). Diel movement patterns of the Hawaiian stingray, Dasyatis lata: implications for ecological interactions between sympatric elasmobranch species. *Mar. Biol.* 142, 841–847. doi: 10.1007/s00227-003-1014-y

Castro-Filho, B. M., and de Miranda, L. B. (1998). "Physical oceanography of the Western Atlatic continental shelf located between 4° N and 34°S—coastal segment (4°W)," in *The Seas*, eds A. R. Robinson and K. Brink (New York, NY: John Wiley and Sons), 209–251.

Castro-Filho, B. M., de Miranda, L. B., and Miyao, S. Y. (1987). Condições hidrográficas na plataforma continental ao largo de Ubatuba: variações sazonais e em média escala. *Bol. Inst. Ocean.* 35, 135–151. doi: 10.1590/s0373-55241987000200004

Chao, A. (1984). Nonparametric Estimation of the Scandinavian Journal of Statistics. *Scand. J. Stat.* 11, 265–270.

Chao, A., and Chiu, C.-H. (2016). *Species Richness: Estimation and Comparison.* Available online at: http://chao.stat.nthu.edu.tw/wordpress/paper/119.pdf (accessed August 10, 2021).

Chao, A., and Lee, S. M. (1992). Estimating the number of classes via sample coverage. *J. Am. Stat. Assoc.* 87, 210–217. doi: 10.1080/01621459.1992.10475194

Chao, A., Ma, K. H., Hsieh, T. C., and Chiu, C.-H. (2016). *SpadeR: Species-Richness Prediction and Diversity Estimation with R*. Available online at: https://rdrr.io/cran/SpadeR/man/SimilarityPair.html (accessed August 10, 2021).

Chapman, D. D., Pikitch, E. K., Babcock, E., and Shiyji, M. S. (2005). Marine reserve design and evaluation using automated acoustic telemetry: a case-study involving coral reef-associated sharks in the mesoamerican Caribbean. *Mar. Technol. Soc. J.* 39, 42–55. doi: 10.4031/002533205787521640

Chiu, C. H., Wang, Y. T., Walther, B. A., and Chao, A. (2014). An improved nonparametric lower bound of species richness via a modified good-turing frequency formula. *Biometrics* 70, 671–682. doi: 10.1111/biom.12200

Claudet, J., Osenberg, C. W., Domenici, P., Badalamenti, F., Milazzo, M., Falcón, J. M., et al. (2010). Marine reserves: fish life history and ecological traits matter. *Ecol. Appl.* 20, 830–839. doi: 10.1890/08-2131.1

Cochrane, K. L., and Garcia, S. M. (eds) (2009). *A Fishery Manager's Guidebook*, 2nd Edn. Rome: FAO. doi: 10.1002/9781444316315

Collins, A. B., Heupel, M. R., and Motta, P. J. (2007). Residence and movement patterns of cownose rays *Rhinoptera bonasus* within a south-west Florida estuary. *J. Fish Biol.* 71, 1159–1178. doi: 10.1111/j.1095-8649.2007.01590.x

Colonello, J. C., García, M. L., Lasta, C. A., and Menni, R. C. (2012). Reproductive biology of the spotback skate *Atlantoraja castelnaui* in the south-west Atlantic Ocean. *J. Fish Biol.* 80, 2405–2419. doi: 10.1111/j.1095-8649.2012.03288.x

Colonello, J. C., García, M. L., and Menni, R. C. (2011). Reproductive biology of the lesser guitarfish *Zapteryx brevirostris* from the south-western Atlantic Ocean. *J. Fish Biol.* 78, 287–302. doi: 10.1111/j.1095-8649.2010.02864.x

Contente, R. F., Mancini, P. L., Vaz-dos-Santos, A. M., Soares, L. S. H., Fischer, L. G., Silveira, L. F., et al. (2020). Spatial-seasonal variability of vertebrate assemblages in a Neotropical tidal flat: recommendations for monitoring the potential impacts of port expansion. *Reg. Stud. Mar. Sci.* 34, 101013. doi: 10.1016/j.rsma.2019.101013

D'Alberto, B. M., Carlson, J. K., Pardo, S. A., and Simpfendorfer, C. A. (2019). Population productivity of shovelnose rays: inferring the potential for recovery. *PLoS One* 14:e0225183. doi: 10.1371/journal.pone.0225183

De Léo, F. C., and Pires-Vanin, A. M. S. (2006). Benthic megafauna communities under the influence of the South Atlantic Central Water intrusion onto the Brazilian SE shelf: a comparison between an upwelling and a non-upwelling ecosystem. *J. Mar. Syst.* 60, 268–284. doi: 10.1016/j.jmarsys.2006.02.002

Dias, J. F., da Rocha, M. L. F., Schmidt, T. C., dos, S., Villamarin, B. C., and Morais, D. B. (2017). Ichthyofauna as an environmental quality indicator of the Bertioga channel, São Paulo (Brazil). *Braz. J. Oceanogr.* 65, 29–43. doi: 10.1590/S1679-87592017125206501

Domingos, J. F., dos, S., Paiva, B., Bruno, C. E. M., and de Amorim, A. F. (2021). Diet of elasmobranchs captured in the fishing of pink shrimp off souther of Brazil. *Braz. J. Anim. Environ. Res.* 4, 637–658. doi: 10.34188/bjaerv4n1-054

Edgar, G. J., Banks, S. A., Bessudo, S., Cortés, J., Guzmán, H. M., Henderson, S., et al. (2011). Variation in reef fish and invertebrate communities with level of protection from fishing across the Eastern Tropical Pacific seascape. *Glob. Ecol. Biogeogr.* 20, 730–743. doi: 10.1111/j.1466-8238.2010.00642.x

Edgar, G. J., Bustamante, R. H., Fariña, J. M., Calvopiña, M., Martínez, C., and Toral-Granda, M. V. (2004). Bias in evaluating the effects of marine protected areas: the importance of baseline data for the Galapagos Marine Reserve. *Environ. Conserv.* 31, 212–218. doi: 10.1017/S0376892904001584

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., et al. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature* 506, 216–220. doi: 10.1038/nature13022

Elliott, M., Whitfield, A. K., Potter, I. C., Blaber, S. J. M., Cyrus, D. P., Nordlie, F. G., et al. (2007). The guild approach to categorizing estuarine fish assemblages: a global review. *Fish Fish.* 8, 241–268. doi: 10.1111/j.1467-2679.2007.00253.x

Farrugia, T. J., Espinoza, M., and Lowe, C. G. (2011). Abundance, habitat use and movement patterns of the shovelnose guitarfish (*Rhinobatos productus*) in a restored southern California estuary. *Mar. Freshw. Res.* 62, 648–657. doi: 10.1071/MF10173

Fernandes, I. M., Bastos, Y. F., Barreto, D. S., Lourenço, L. S., and Penha, J. M. (2017). The efficacy of clove oil as an anaesthetic and in euthanasia procedure for small-sized tropical fishes. *Braz. J. Biol.* 77, 444–450. doi: 10.1590/1519-6984.15015

Figueiredo, J. L. (1977). *Manual de Peixes Marinhos do Sudeste do Brazil I. Introdução cações, Raias e Quimeras*. São Paulo: Museu de Zoologia da Universidade de São Paulo.

Folk, R. L., and Ward, W. C. (1957). Brazos River bar: a study in the significance of grain size parameters. *J. Sediment. Petrol.* 27, 3–26.

Forestry Foundation, S. P. S. (2019). *Plano de Manejo da Área de Proteção Ambiental Marina Litoral Centro. São Paulo*. Available online at: https://sigam.ambiente.sp.gov.br/sigam3/Repositorio/511/Documentos/APAM_LC/2019.02.26_Plano_Manejo_APAMLC.pdf (accessed August 10, 2021).

Forestry Foundation, S. P. S. (2020). *Plano de Manejo da Área de Proteção Ambiental Marinha do Litoral Norte. São Paulo*. Available online at: https://www.sigam.ambiente.sp.gov.br/sigam3/Repositorio/511/Documentos/APAM_LN/APAMLN_Plano_de_manejo_CTBio.pdf (accessed August 10, 2021).

Fox, H. E., Mascia, M. B., Basurto, X., Costa, A., Glew, L., Heinemann, D., et al. (2012). Reexamining the science of marine protected areas: linking knowledge to action. *Conserv. Lett.* 5, 1–10. doi: 10.1111/j.1755-263X.2011.00207.x

Freitas, R. H. A., Aguiar, A. A., Freitas, A. K. C. H. A., Lima, S. M. Q., and Valentin, J. L. (2019). Unravelling the foraging behavior of the southern stingray, *Hypanus americanus* (Myliobatiformes: Dasyatidae) in a southwestern atlantic MPA. *Neotrop. Ichthyol.* 17, 1–14. doi: 10.1590/1982-0224-20180131

Garman, S. (1913). The plagiostomia (Sharks and Rays). *Mem. Mus. Comp. ZooÏ. Harv. Coll.* 36, 1–528.

Genz, A., Bretz, F., Miwa, T., Mi, X., Leisch, F., Scheipl, F., et al. (2020). *mvtnorm: Multivariate Normal and t Distributions*. Available online at: https://cran.r-project.org/web/packages/mvtnorm/index.html (accessed August 10, 2021).

Giakoumi, S., McGowan, J., Mills, M., Beger, M., Bustamante, R. H., Charles, A., et al. (2018). Revisiting "success" and "failure" of marine protected areas: a conservation scientist perspective. *Front. Mar. Sci.* 5:223. doi: 10.3389/fmars.2018.00223

Gibran, F. Z., and de Moura, R. L. (2012). The structure of rocky reef fish assemblages across a nearshore to coastal islands' gradient in Southeastern Brazil. *Neotrop. Ichthyol.* 10, 369–382. doi: 10.1590/S1679-62252012005000013

Gill, D. A., Mascia, M. B., Ahmadia, G. N., Glew, L., Lester, S. E., Barnes, M., et al. (2017). Capacity shortfalls hinder the performance of marine protected areas globally. *Nature* 543, 665–669. doi: 10.1038/nature21708

Gomes, U. L., Santos, H. R., Gadig, O. B. F., Signori, C. N., and Vicente, M. M. (2019). Guia para identificação dos Tubarões, Raias e Quimeras do Rio de Janeiro. *Rev. Nord. Biol.* 27, 171–368. doi: 10.22478/ufpb.2236-1480.2019v27n1.47122

Goodyear, C. P. (1993). Spawning stock biomass per recruit in fisheries management: foundation and current use. *Can. Spec. Publ. Fish. Aquat. Sci.* 120, 67–81.

Grüss, A., Kaplan, D. M., Guénette, S., Roberts, C. M., and Botsford, L. W. (2011). Consequences of adult and juvenile movement for marine protected areas. *Biol. Conserv.* 144, 692–702. doi: 10.1016/j.biocon.2010.12.015

Halpern, B. S. (2003). The impact of marine reserves: Do reserves work and does reserve size matter? *Ecol. Appl.* 13, 117–137.

Hartig, F., and Lohse, L. (2020). *DHARMa: Residual Diagnostics for Hierarchical (Multi-Level/Mixed) Regression Models.* Available online at: http://florianhartig.github.io/DHARMa/ (accessed August 10, 2021).

Hilborn, R. (2016). Policy: marine biodiversity needs more than protection. *Nature* 535, 224–226. doi: 10.1038/535224a

Hildebrand, S. F., and W. C. Schroeder. (1928). Fishes of Chesapeake Bay. *Bulletin of the Bureau of Fisheries*, 43, 1–366.

Hilborn, R., and Walters, C. J. (1992). "Statistical catch-at-age methods," in *Quantitative Fisheries Stock Assessment,* eds R. Hilborn and C. J. Walters (Boston, MA: Springer), 369–390. doi: 10.1007/978-1-4615-3598-0_11

Hoff, N. T. (2015). *Integridade Biótica dos Ecossistemas na região do Arquipélago dos Alcatrazes, São Sebastião - SP*. Master's dissertation. São Paulo: Instituto Oceanográfico.

Hoff, N. T., Figueira, R. C. L., and Abessa, D. M. S. (2015). Levels of metals, arsenic and phosphorus in sediments from two sectors of a Brazilian Marine Protected Area (Tupinambás Ecological Station). *Mar. Pollut. Bull.* 91, 403–409. doi: 10.1016/j.marpolbul.2014.10.044

Hordyk, A. (2019). *LBSPR: Length-Based Spawning Potential Ratio*. Available online at: https://cran.r-project.org/web/packages/LBSPR/index.html (accessed August 10, 2021).

Hordyk, A., Ono, K., Valencia, S., Loneragan, N., and Prince, J. (2015). A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES J. Mar. Sci.* 72, 217–231. doi: 10.1093/icesjms/fsu004

IBAMA (2007). *Instrução Normativa IBAMA No 166 de 18 de JULHO de 2007*. Available online at: https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Instrucao_normativa/2007/in_ibama_166_2007_redeemalhe_suspensa_p_ibama_icmbio_7_2008_vigente.pdf (accessed August 10, 2021).

IBAMA (2008). *Instrução Normativa IBAMA No 189, de 23 de Setembro de 2008*. Available online at: https://www.gov.br/agricultura/pt-br/assuntos/aquicultura-e-pesca/legislacao/defesos/in-ibama-no-189_09_2008.pdf/view (accessed August 10, 2021).

ICMBio (2016a). *Avaliação do risco de extinção dos elasmobrânquios e quimeras no Brasil: 2010-2012*. Itajaí: ICMBio.

ICMBio (2016b). *Sumário Executivo do Plano de Ação Nacional para a conservação dos Tubarões e Raias Marinhos Ameaçados de Extinção*. Available online at: https://www.icmbio.gov.br/portal/faunabrasileira/plano-de-acao-nacional-lista/2839-plano-de-acao-nacional-para-a-conservacao-dos-tubaroes (accessed August 10, 2021).

ICMBio (2017). *Plano de Manejo da Estação Ecológica Tupinambás e Refúgio de Vida Silvestre do arquipélago de Alcatrazes.* Available online at: http://www.icmbio.gov.br/portal/images/stories/plano-de-manejo/plano_de_manejo_esec_tupinambas_revisarquipelogoalcatrazes_vol1.pdf (accessed August 10, 2021).

Imoto, R. D., Carneiro, M. H., and Ávila-da-Silva, A. O. (2016). Spatial patterns of fishing fleets on the Southeastern Brazilian Bight. *Lat. Am. J. Aquat. Res.* 44, 1005–1018. doi: 10.3856/vol44-issue5-fulltext-12

IUCN (2021). *The IUCN Red List of Threatened Species. 2020-3*. Available online at: https://www.iucnredlist.org (accessed March 14, 2021).

Kelley, D., Richards, C., and Layton, C. (2021). *oce: Analysis of Oceanographic Data package.* Available online at: https://cran.r-project.org/package=oce (accessed August 10, 2021).

Knip, D. M., Heupel, M. R., and Simpfendorfer, C. A. (2012). Evaluating marine protected areas for the conservation of tropical coastal sharks. *Biol. Conserv.* 148, 200–209. doi: 10.1016/j.biocon.2012.01.008

Larsonneur, C., Bouysse, P., and Auffret, J.-P. (1982). The superficial sediments of the English Channel and its Western Approaches. *Sedimentology* 29, 851–864.

Lessa, R. P., Vooren, C. M., and Lahaye, J. (1986). Desenvolvimento e ciclo sexual das fêmeas, migrações e fecundidade da viola, *Rhinobatos horkelii* (Müller & Henle, 1841) do Sul do Brasil. *Atlântica* 8, 5–34.

Lesueur, C. A. (1824). Description of several species of the Linnaean genus Raia, of North America. *J. Acad. Nat. Sci. Philadel.* 4, 100–121.

Lubchenco, J., and Grorud-Colvert, K. (2015). Making waves: the science and politics of ocean protection. *Science* 350, 382–383. doi: 10.1126/science.aad5443

Luiz-Silva, W., Matos, R. H. R., and Kristosch, G. C. (2002). Geoquímica e índice de geoacumulação de mercúrio em sedimentos de superfície do estuário de Santos - Cubatão (SP). *Quim. Nova* 25, 753–756. doi: 10.1590/s0100-40422002000500009

Magurran, A. E., and Henderson, P. A. (2003). Explaining the excess of rare species in natural species abundance distributions. *Nature* 422, 714–716. doi: 10.1038/nature01547

Mahiques, M. M., Mishima, Y., and Rodrigues, M. (1999). Characteristics of the sedimentary organic matter on the inner and middle continental shelf between Guanabara Bay and Sao Francisco do Sul, southeastern Brazilian margin. *Cont. Shelf Res.* 19, 775–798. doi: 10.1016/S0278-4343(98)00105-8

Mahiques, M. M., Sousa, S. H. M., Burone, L., Nagai, R. H., Silveira, I. C. A., Figueira, R. C. L., et al. (2011). Radiocarbon geochronology of the sediments of the São Paulo Bight (southern Brazilian upper margin). *An. Acad. Bras. Cienc.* 83, 817–834. doi: 10.1590/S0001-37652011005000028

Mahiques, M. M., Tessler, M. G., Maria Ciotti, A., Da Silveira, I. C. A., E Sousa, S. H. D. M., Figueira, R. C. L., et al. (2004). Hydrodynamically driven patterns of recent sedimentation in the shelf and upper slope off Southeast Brazil. *Cont. Shelf Res.* 24, 1685–1697. doi: 10.1016/j.csr.2004.05.013

Marini, T. L. (1936). Revisión de las especies de la familia Squatinidae en las aguas argentinas (*S. guggenheim n. sp.*). *Physis* 12, 19–30.

Marconi, M., Giglio, V. J., Pereira-Filho, G. H., and Motta, F. S. (2020). Does quality of scuba diving experience vary according to the context and management regime of marine protected areas? *Ocean Coast. Manag.* 194:105246. doi: 10.1016/j.ocecoaman.2020.105246

Marion, C., Vaske-Junior, T., Gadig, O., and Martins, I. (2011). Feeding habits of the shortnose guitarfish, *Zapteryx brevirostris* (Müller and Henle, 1841) (Elasmobranchii, Rhinobatidae) in southeastern Brazil. *Braz. J. Biol.* 71, 83–89. doi: 10.1590/s1519-69842011000100013

Martins, I. A., Martins, C. L., and Leme, M. H. D. A. (2005). Biological parameters and population structure of *Psammobatis extenta* in Ubatuba region, north coast of the State of São Paulo, Brazil. *J. Mar. Biol. Assoc. U.K.* 85, 1113–1118. doi: 10.1017/S0025315405012166

Mémery, L., Arhan, M., Alvarez-Salgado, X. A., Messias, M. J., Mercier, H., Castro, C. G., et al. (2000). The water masses along the western boundary of the south and equatorial Atlantic. *Prog. Oceanogr.* 47, 69–98.

Menni, R. C., Jaureguizar, A. J., Stehmann, M. F. W., and Lucifora, L. O. (2010). Marine biodiversity at the community level: zoogeography of sharks, skates, rays and chimaeras in the southwestern Atlantic. *Biodivers. Conserv.* 19, 775–796. doi: 10.1007/s10531-009-9734-z

Menni, R. C., and Stehmann, M. F. (2000). Distribution, environment and biology of batoid fishes off Argentina, Uruguay and Brazil. A review. *Rev. Mus. Argentino Cienc. Nat.* 2, 69–109.

Miranda Ribeiro, A. M. (1907). Fauna braziliense. Peixes (Desmobrânchios). *Arch. Museu Nactl.* 14, 137–171.

Mitchill, S. L. (1815). The fishes of New-York, described and arranged. *Transact. Liter. Philos. Soc. N. Y.* 1, 355–492.

MMA (2014). *Portaria No 445, de 17 de Dezembro de 2014. 11.* Available online at: https://www.icmbio.gov.br/portal/images/stories/docs-plano-de-acao-ARQUIVO/00-saiba-mais/05_-_PORTARIA_MMA_N%C2%BA_445_DE_17_DE_DEZ_DE_2014.pdf (accessed August 10, 2021).

Morais, R. A., Ferreira, C. E. L., and Floeter, S. R. (2017). Spatial patterns of fish standing biomass across Brazilian reefs. *J. Fish Biol.* 91, 1642–1667. doi: 10.1111/jfb.13482

Muto, E. Y., Soares, L. S., and Wongtschowski, C. (2000). Demersal fish assemblages off São Sebastião, southeastern Brazil: structure and environmental conditioning factors (summer 1994). *Rev. Bras. Oceanogr.* 48, 9–27.

Müller, J. (1836). *Vergleichende Anatomie der Myxinoiden, der Cyclostomen mit durchbohrtem Gaumen. Erster Theil. Osteologie und Myologie. Abhandlungen der Königlichen Akademie der Wissenschaften, Berlin,* 1834, 65–340.

Müller, J., and Henle, F. G. J. (1841). *Systematische Beschreibung der Plagiostomen.* Berlin: von Veit und Comp, 1–28.

Oddone, M. C., Amorim, A. F., Mancini, P. L., Norbis, W., and Velasco, G. (2007). The reproductive biology and cycle of Rioraja agassizi (Müller and Henle, 1841) (Chondrichthyes: Rajidae) in southeastern Brazil, SW Atlantic Ocean. *Sci. Mar.* 71, 593–604. doi: 10.3989/scimar.2007.71n3593

Oddone, M. C., and de Amorim, A. F. (2007). Length-weight relationships, condition and population structure of the genus Atlantoraja (Elasmobranchii, Rajidae, Arhynchobatinae) in Southeastern Brazilian waters, SW Atlantic Ocean. *J. Northwest Atl. Fish. Sci.* 38, 43–52. doi: 10.2960/J.v38.m599

Oddone, M. C., Norbis, W., Mancini, P. L., and Amorim, A. F. (2008). Sexual development and reproductive cycle of the Eyespot skate *Atlantoraja cyclophora* (Regan, 1903) (Chondrichthyes: Rajidae: Arhynchobatinae), in southeastern Brazil. *Acta Adriat.* 49, 73–87.

Oddone, M. C., and Vooren, C. M. (2004). Distribution, abundance and morphometry of *Atlantoraja cyclophora* (Regan, 1903) (Elasmobranchii: Rajidae) in southern Brazil, Southwestern Atlantic. *Neotrop. Ichthyol.* 2, 137–144. doi: 10.1590/S1679-62252004000300005

Oddone, M. C., and Vooren, C. M. (2005). Reproductive biology of *Atlantoraja cyclophora* (Regan 1903) (Elasmobranchii: Rajidae) off southern Brazil. *ICES J. Mar. Sci.* 62, 1095–1103. doi: 10.1016/j.icesjms.2005.05.002

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., et al. (2020). *Vegan: Community Ecology Package.* Available online at: https://cran.r-project.org/web/packages/vegan/index.html (accessed August 10, 2021).

Paijmans, K. C., Booth, D. J., and Wong, M. Y. L. (2019). Towards an ultimate explanation for mixed-species shoaling. *Fish Fish.* 20, 921–933. doi: 10.1111/faf.12384

Paiva-Filho, A. M., Schmiegelow, J. M. M., Giannini, R., and Ribeiro-Neto, F. B. (1989). Contribuição ao conhecimento da ictiofauna da região da Ilha de Alcatrazes (SP), Brasil. *Relat. Int. Inst. Ocean.* 25, 1–6.

Palmeira, A. R. O. (2012). *Biologia Reprodutiva da raia Dasyatis guttata (Bloch & Schneider, 1801) (Myliobatiformes: Dasyatidae) no litoral do Pará*. Master's thesis. João Pessoa: Universidade Federal da Paraíba.

Palóczy, A., Sartoretto, J. R., Hoff, N. T., Marques, O. B., Oliveira, R., and Biló, T. C. (2012). *ESEC Tupinambás: Relatório de Levantamento de Dados Primários – Meio Físico.* São Paulo.

Pincinato, R. B. M., and Gasalla, M. A. (2019). Exploring simple ecological indicators on landings and market trends in the South Brazil Shelf Large Marine Ecosystem. *Fish. Manag. Ecol.* 26, 200–210. doi: 10.1111/fme.12340

Pires-Vanin, A. M. S. (2008). "Megafauna e macrofauna," in *Oceanografia de um Ecossistema Subtropical: Plataforma de São Sebastião, SP*, eds S. Biral, M. Vizentin, and C. F. Fontana (São Paulo: EDUSP), 464.

Pires-Vanin, A. M. S., Rossi-Wongtschwski, C. L. D. B., Aidar, E., Mesquita, H. S. L., Soares, L. S. H., Katsuragawa, M., et al. (1993). *Estrutura e Função do Ecossistema de Platafoma Continental do Atlântico Sul Brasileiro: Síntese dos Resultados*. São Paulo: Universidade de São Paulo, 217–231.

Ponz-Louro, M. (1995). *Estratégias e Táticas Reprodutivas de Elasmobrânquios no Ecossistema de Ubatuba, SP, Brasil.* Master's thesis. São Paulo: Universidade de São Paulo.

Prado, H. M., Schlindwein, M. N., Murrieta, R. S. S., Nascimento, D. R., de Souza, E. P., Cunha Lignon, M., et al. (2019). The valo grande channel in the Cananéia-Iguape estuary-lagoon complex (SP, Brazil): environmental history, ecology, and future perspectives. *Ambient. Soc.* 22, 1–24. doi: 10.1590/1809-4422ASOC0182R2VU19L4TD

R Core Team (2020). *R: A Language and Environment for Statistical Computing.* Vienna: R Foundation for Statistical Computing.

Rangel, B. D. S., Hussey, N. E., Niella, Y., Martinelli, L. A., Gomes, A. D. O., and Moreira, R. G. (2020). Neonatal nutritional strategy of a viviparous elasmobranch with extremely low reproductive output. *Mar. Ecol. Prog. Ser.* 638, 107–121. doi: 10.3354/meps13261

Rangel, B. S., Hammerschlag, N., Sulikowski, J., and Guimarães Moreira, R. (2021). Foraging for nutrients? Dietary and reproductive biomarkers in a generalist apex predator reveal differences in nutritional ecology across life stages. *Mar. Ecol. Prog. Ser.* 664, 149–163. doi: 10.3354/meps13640

Rangel, B. S., Rodrigues, A., and Moreira, R. G. (2018). Use of a nursery area by cownose rays (Rhinopteridae) in southeastern Brazil. *Neotrop. Ichthyol.* 16, 1–8. doi: 10.1590/1982-0224-20170089

Regan, C. T. (1903). On a collection of fishes made by Dr. Goeldi at Rio Janeiro. *Proc. Zool. Soc. Lond.* 2, 59–68.

Ribeiro, V. V. (2020). Índice de Poluição por Pellets (IPP) na Baía de Santos (SP) no inverno de 2019. *Rev. Sítio Novo* 4:102. doi: 10.47236/2594-7036.2020.v4.i2.102-111p

Ripley, B., Venables, B., Bates, D. M., Hornik, K., Gebhardt, A., and Firth, D. (2021). *MASS: Support Functions and Datasets for Venables and Ripley's MASS.* Available online at: https://cran.r-project.org/web/packages/MASS/index.html

Rocha, F., and Gadig, O. B. F. (2013). Reproductive biology of the guitarfish *Rhinobatos percellens* (Chondrichthyes, Rhinobatidae) from the São Paulo Coast, Brazil, western South Atlantic Ocean. *J. Fish Biol.* 82, 306–317. doi: 10.1111/j.1095-8649.2012.03493.x

Rolim, F. A., Langlois, T., Rodrigues, P. F. C., Bond, T., Motta, F. S., Neves, L. M., et al. (2019). Network of small no-take marine reserves reveals greater abundance and body size of fisheries target species. *PLoS One* 14:e0204970. doi: 10.1371/journal.pone.0204970

Rossi-Wongtschowski, C. L. D. B., and Paes, E. T. (1993). *Padrões Espaciais e Temporais da Comunidade de Peixes Demersais do Litoral Norte do Estado de São Paulo-Ubatuba, Brasil.* (São Paulo: Universidade de São Paulo), 169–188.

São Paulo (2008). *Mosaico das Ilhas e Áreas Marinhas Protegidas do Litoral Paulista. Decreto No 53.528 8 Outubro 2008.* Available online at: https://www.al.sp.gov.br/repositorio/legislacao/decreto/2008/decreto-53528-08.10.2008.html (Accessed March 14, 2021).

São Paulo (2009). *Resolução SMA No 69 de 28 de Setembro de 2009*. Available online at: https://www.cetesb.sp.gov.br/licenciamento/documentos/2009_Res_SMA_69.pdf (accessed August 10, 2021).

São Paulo (2012). *Resolução SMA N° 51, de 28 de Junho de 2012*. Available online at: http://www.mpsp.mp.br/portal/page/portal/cao_urbanismo_e_meio_ambiente/legislacao/leg_estadual/leg_est_resolucoes/Resol-SMA-51-12-uso-rede-pesca-litoral-centro.pdf (accessed August 10, 2021).

Santos, H. R. S., and Carvalho, M. R. (2004). Description of a new species of whiptailed stingray from the southwestern Atlantic Ocean (Chondricthyes, Myliobatiformes, Dasyatidae). *Bol. Mus. N. S. Zool.* 516, 1–24.

Schlaff, A. M., Heupel, M. R., and Simpfendorfer, C. A. (2014). Influence of environmental factors on shark and ray movement, behaviour and habitat use: a review. *Rev. Fish Biol. Fish.* 24, 1089–1103. doi: 10.1007/s11160-014-9364-8

Shimabukuro, M., Bromberg, S., and Pires-Vanin, A. M. S. (2016). Polychaete distribution on the southwestern Atlantic continental shelf. *Mar. Biol. Res.* 12, 239–254. doi: 10.1080/17451000.2015.1131299

Siqueira, G. W., de Santis Braga, E., Pereira, S. F. P., and da Silva, E. (2005). Distribuição do mercúrio em sedimentos de fundo no Estuário de Santos SP/Brasil. *Rev. Esc. Minas* 58, 309–316. doi: 10.1590/s0370-44672005000400004

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., and Popper, A. N. (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. *Trends Ecol. Evol.* 25, 419–427. doi: 10.1016/j.tree.2010.04.005

Soares, L. S. H., Muto, E. Y., Gasparro, M. R., and Rossi-Wongtschwski, C. L. D. B. (2008). "Organização trófica dos peixes," in *Oceanografia de um Ecossistema Subtropical: Plataforma de São Sebastião, SP*, eds S. Biral, M. Vizentin, and C. F. Fontana (São Paulo: EDUSP), 464.

Soares, L. S. H., Rossi-Wongtschowski, C. L. D. B., Alvares, L. M. C., Muto, E. Y., and Gasalla, M. L. A. (1992). Grupos tróficos de peixes demersais da plataforma continental interna de Ubatuba, Brasil: I. Chondrichthyes. *Bol. Inst. Ocean.* 40, 79–85. doi: 10.1590/s0373-55241992000100006

Stramma, L., and England, M. (1999). On the water masses and mean circulation of the South Atlantic Ocean. *J. Geophys. Res.* 104, 20863–20883.

SUDEPE (1984). *Portaria SUDEPE N° 42 de 18 de Outubro de 1984*. Available online at: https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/1984/p_sudepe_42_n_1984_defesobagrerosado_rs_sc_pr_sp.pdf (accessed August 10, 2021).

Suguio, K. (1973). *Introdução à Sedimentologia*, ed. E. Blucher (São Paulo: EDUSP).

Takase, L. S., Stein, L. P., Hoff, N. T., and Siegle, E. (2021). Wave climate and power distribution around a rocky island: Alcatrazes, Brazil. *Ocean Coast. Res.* 69:14.

Tilley, A., López-Angarita, J., and Turner, J. R. (2013). Effects of scale and habitat distribution on the movement of the southern stingray *Dasyatis americana* on a Caribbean atoll. *Mar. Ecol. Prog. Ser.* 482, 169–179. doi: 10.3354/meps10285

Trevizani, T. H., Domit, C., Vedolin, M. C., Angeli, J. L. F., and Figueira, R. C. L. (2019). Assessment of metal contamination in fish from estuaries of southern and southeastern Brazil. *Environ. Monit. Assess.* 191:308. doi: 10.1007/s10661-019-7477-1

Viana, S. T. F., de Carvalho, M. R., and Gomes, U. L. (2016). Taxonomy and morphology of species of the genus Squalus Linnaeus, 1758 from the Southwestern Atlantic Ocean (Chondrichthyes: Squaliformes: Squalidae). *Zootaxa* 4133, 1–89. doi: 10.11646/zootaxa.4133.1.1

Villaseńor-Derbez, J. C., Faro, C., Wright, M., Martínez, J., Fitzgerald, S., Fulton, S., et al. (2018). A user-friendly tool to evaluate the effectiveness of no-take marine reserves. *PLoS One* 13:e0191821. doi: 10.1371/journal.pone.0191821

Vögler, R., Milessi, A. C., and Quiñones, R. A. (2003). Trophic ecology of *Squatina guggenheim* on the continental shelf off Uruguay and northern Argentina. *J. Fish Biol.* 62, 1254–1267. doi: 10.1046/j.1095-8649.2003.00105.x

Vögler, R., Milessi, A. C., and Quiñones, R. A. (2008). Influence of environmental variables on the distribution of *Squatina guggenheim* (Chondrichthyes, Squatinidae) in the Argentine-Uruguayan Common Fishing Zone. *Fish. Res.* 91, 212–221. doi: 10.1016/j.fishres.2007.11.028

Vooren, C. M., and Klippel, S. (2005). *Ações para a Conservação de Tubarões e Raias no Sul do Brasil*, 1st Edn, eds C. M. Vooren and S. Klippel Porto (Igaré: Alegre).

Vooren, C. M., and Silva, K. G. (1991). On the taxonomy of the angel sharks from southern Brazil, with the description of *Squatina occulta sp. n. Rev. Bras. Biol.* 51, 589–602.

Walbaum, J. J. (1792). *Petri Artedi Sueci Genera Piscium in Quibus Systema Totum Ichthyologiae Proponitur Cum Classibus, Ordinibus, Generum Characteribus, Specierum Diffentiis, Observationibus Plumiris. Ichthyologiae Pars III. Rose, Grypeswaldiae.* 723.

Wetherbee, B. M., Gruber, S. H., and Rosa, R. S. (2007). Movement patterns of juvenile lemon sharks Negaprion brevirostris within Atol das Rocas, Brazil: a nursery characterized by tidal extremes. *Mar. Ecol. Prog. Ser.* 343, 283–293. doi: 10.3354/meps06920

Wiegand, J., Hunter, E., and Dulvy, N. K. (2011). Are spatial closures better than size limits for halting the decline of the North Sea thornback ray, Raja clavata? *Mar. Freshw. Res.* 62, 722–733. doi: 10.1071/MF10141

Zar, J. H. (2009). *Biostatistical Analysis*, 5th Edn. Hoboken, NJ: Prentice Hall.

Zuur, A. F., Ieno, E. N., and Elphick, C. S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods Ecol. Evol.* 1, 3–14. doi: 10.1111/j.2041-210x.2009.00001.x

Zuur, A. F., Ieno, E. N., Walker, N., Saveliev, A. A., and Smith, G. M. (2009). *Mixed Effects Models and Extensions in Ecology with R*. New York, NY: Springer. doi: 10.1007/978-0-387-87458-6

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Identifying Pathways for Climate-Resilient Multispecies Fisheries

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Fish live in communities, and most fisheries catch multiple species, yet fishery management predominately focuses on single species. In many multispecies fisheries, a variety of species are generally caught together at similar rates. Failure to account for this adequately in management has resulted in serial depletion and alterations to the ecosystem. Ideally, multispecies fisheries management should strive to produce good yields from specific valuable stocks and avoid adverse impacts of fishing on marine ecosystems. Moreover, multispecies management should aim to build resilience to changes in stock productivity and distribution driven by climate change. Here, we present tools and pathways that seven fisheries are adopting to achieve these goals. These case studies – from Mexico, Cuba, and Chile – differ in data richness, governance structure, and management resources. The management systems are also in various stages of evolution from unmanaged to complete management of a single species but transitioning to multispecies management. While various analytical tools and decision-making processes are described in the case studies, a common feature is the use of participatory stakeholder processes to build capacity and socialize the importance of multispecies management. We use lessons from these cases to recommend a multispecies management approach to overcome the limitations of current practices (typically single-species catch limits or large spatial restrictions), using the participatory processes and data-limited assessments to create stock complexes that simplify multispecies management (i.e., the "fish baskets" approach). Indicator species for each fish basket are identified to support the development of fishery performance indicators, reference values, harvest control rules, and management measures to create an adaptive management cycle to enhance the fishery's resilience to impacts induced by climate change and other factors.

Keywords: fishery management, participatory, adaptive management, stakeholder driven, fish baskets

INTRODUCTION

Fisheries are critically important for the nutrition, food security, and livelihoods of hundreds of millions of people (Barange et al., 2018; FAO, 2020). Many of the world's fisheries catch multiple species or stocks (Pauly et al., 1998; Worm et al., 2009; Nakamura, 2015). The use of non-selective gears in many fisheries results in the application of the same fishing mortality rate to multiple species that differ in productivity. Creating a risk that lower productivity stocks will be depleted first, followed by the other stocks (serial depletion), reducing fishing opportunities (Jennings and Kaiser, 1998; Branch et al., 2010), and altering species interactions and entire ecosystems (Pauly et al., 2000; Chuenpagdee et al., 2003; Christensen and Pauly, 2004).

Current Approaches to Multispecies Management

There are two main approaches currently in use that are aimed at reducing the risk of serial depletion for multispecies fisheries. One option is to set catch limits for each of the species that are caught by the fishery individually (Hilborn, 2017). This option entails stock assessments, monitoring, and enforcement programs capable of generating accountability to these limits for each species. Alternatively, multispecies fisheries can be managed with stock complexes, using a single annual catch limit, with the goal of removing stocks from this type of single-species treatment as data improves (e.g., Gulf of Mexico Reef Fish FMP, Farmer et al., 2016). Catch limits in multispecies fisheries can induce discards at sea (Branch, 2009; Essington et al., 2012; Grimm et al., 2012), strong accountability systems [e.g., New Zealand's Quota Management System (QMS); Lock and Leslie, 2007], and measures to avoid low productivity stocks [e.g., Fishpools to transfer quota in the British and Danish Catch Quota Management (CQM); Bonzon et al., 2013] are necessary to avoid fishery shutdowns. Fishers reduce discards of low productivity stocks by switching to more selective gear, using spatial data and communication at sea to avoid observed patches of low productivity stocks, and modifying gear to avoid low productivity stocks (examples summarized in Bonzon et al., 2013). Examples include the US Pacific groundfish trawl fishery (Warlick et al., 2018), the British Columbia groundfish trawl fishery (Turris, 2009), the Denmark Pelagic and Demersal fishery (Christensen, 2009), and the New Zealand groundfish fishery (Lock and Leslie, 2007). Most existing examples of multispecies fisheries that use a catch limit approach to prevent serial depletion appear to be highly regulated and are subject to high levels of accountability, requiring relatively large amounts of data, financial and human capital, and capacity (Bonzon et al., 2013).

An alternative approach to multispecies management is to restrict fishing in areas with the highest density of low productivity stocks to reduce the risk of serial depletion. The spatial restrictions must overlap with a large enough fraction of the stock's distribution to be effective. Overall fishing mortality on the entire stock is reduced sufficiently to achieve the goals of preventing serial depletion or allowing stock recovery to occur. While most Marine Protected Areas (MPAs) do not appear to displace much fishing effort (Hilborn et al., 2004), spatial restrictions designed to achieve multispecies fishery management goals would have to be quite large (Ovando et al., 2021) and sited within fishing grounds, resulting in the displacement of significant amounts of fishing effort. Resulting in significant losses of yield, income, and sometimes livelihoods. An example is the use of Rockfish Conservation Areas (RCAs) along the Pacific coast of the U.S. to help low productivity stocks that had been overfished, such as darkblotched rockfish (*Sebastes crameri*), canary rockfish (*Sebastes pinniger*), and bocaccio (*Sebastes paucispinis*). Ultimately, the fishery saw a shift in fishing dynamics, with loss of fishing effort relatively close to shore, impacting yields, income, and livelihoods along this coast (Mason et al., 2012).

Climate change significantly impacts marine and coastal ecosystems and fisheries, impacting existing fishing patterns (Gattuso et al., 2015; Barange et al., 2018) and threatening access to fish stocks in some areas that include some of the most vulnerable fishing communities (Ding et al., 2017). Indeed, climate impacts will continue to increase in severity over the coming decades and cascade ecologically, locking in significant adverse outcomes no matter what we do to further reduce emissions (IPCC, 2014; Pecl et al., 2017; Barange et al., 2018). Climate change impacts on fisheries require new solutions and ways of thinking (e.g., Free et al., 2019; García Molinos, 2020). Failure to plan for and adapt to these changes could result in crisis management – or simply in crisis. Free et al. (2020) found that despite the forecasted declines in productivity of global marine fisheries, implementing climate-adaptive fisheries management reforms could help protect yields and profits and ameliorate many of the adverse outcomes for livelihoods and food provisioning from climate change. Hence, it behooves fishery managers to attempt to anticipate climate-induced changes in individual stock distributions – and in the portfolio of stocks available at any given time in any given place – plan for those changes and take appropriate steps to mitigate impacts on fisheries.

Both conventional approaches to multispecies fishery management have limitations that may prevent their widespread use. Catch limits require extensive and expensive catch accounting, multiple stock assessments, and strong accountability measures and can induce bycatch levels that can be unacceptable. Spatial restrictions require data on the distribution of low and high productivity stocks and sufficient spatial separation. Moreover, to be effective for fishery management purposes, spatial restrictions must cover large areas and displace fishing effort, resulting in social and economic impacts. Neither approach is particularly suited to allow for adaptation to climate-induced change.

Worldwide, there is considerable interest in developing fishery management options that balance social, economic, and ecological objectives for multispecies fisheries (e.g., Möllmann et al., 2014; Voss et al., 2014) even in the face of climate change. Multispecies fisheries are quite common (May et al., 1979). They tend to be complex, as they may involve commercial, artisanal, and recreational sectors and can be large, medium, and small-scale, using multiple gear types with many disparate landing sites (Salas et al., 2007; Newman et al., 2018). We review seven case studies of data-limited multispecies fisheries in Latin America to describe the transition processes from single species to multispecies management strategies that consider climate change impacts. We examine (a) the general characteristics and status of the fisheries, (b) the suite of tools and pathways used by the fishery, and (c) plans to further enhance the sustainability and resiliency of fisheries.

CASE STUDY 1: COMMERCIAL FISHERIES OF THE YUCATAN PENINSULA, MEXICO

Fishery Characteristics

The Yucatan Peninsula (hereafter referred to as YP) is on the Atlantic coast of Mexico (**Figure 1**). In 2018, this region contributed about 10% of the total national volume and value of fisheries landings (CONAPESCA, 2018). The commercial fisheries include a semi-industrial fleet, with a vessel size between 15 and 25 m, and that operates fishing trips between 15 and 20 days; and a small-scale fleet, with vessels between 8 and 12 m, operating daily fishing trips and typically nearshore, 5–30 km from the coast (Fernández et al., 2011; DOF, 2018; Salas et al., 2019). From 2010 to 2018, both fleets employed about 25,000 fishers, and landings averaged 97,000 tons/year, generating a catch value of US$180 million/year. The small-scale fisheries comprised close to 90% of the fishers and contributed 65% of the volume and value of total landings (CONAPESCA, 2018; Coronado et al., 2020b).

In the YP, the most significant fishery by either volume or value over the last five decades has been the multispecies finfish fishery (which includes the red grouper *Epinephelus morio* and 99 other species), spiny lobster (*Panulirus argus*), red octopus (*Octopus Maya*), shrimp, and Atlantic seabob (*Xiphopenaeus kroyeri*) (Arreguín-Sánchez and Arcos-Huitrón, 2011; DOF, 2018; Salas et al., 2019). Between 2006 and 2014, landings from the small-scale fleet included 140 species (**Supplementary Table 1**).

In the YP, as in all of Mexico, fishery policies are regulated through a hierarchical scheme. The National Fisheries Commission (CONAPESCA) is responsible for integrating and maintaining a database with official statistics and implementing management strategies. Official Mexican Norms (NOMs) are regulations that also support the Mexican fisheries management system (Espinoza-Tenorio et al., 2011; Galindo-Cortes et al., 2019). Fisheries management includes fishing licenses or concessions granted to cooperatives and permit holders, fishing gear specifications, legal size, season closures, catch limits, and quotas (Espinoza-Tenorio et al., 2011; DOF, 2018). In some cases, the entire fishery and target groups are managed based on information available for only a single or few species (**Table 1**). For example, the finfish fishery includes around 99 species (**Supplementary Table 2**), but the main regulations are based exclusively on the red grouper (*Epinephelus morio*) (DOF, 2014; Coronado et al., 2020b). Traditionally, the fishery management plans have not considered the catch's multispecies nature, resulting in a standardized approach to regulations, not fully representing the heterogeneity of the fishery (Coronado et al., 2020b).

The YP fishery system has many challenges, including over-exploitation, which is linked to illegal fishing activities

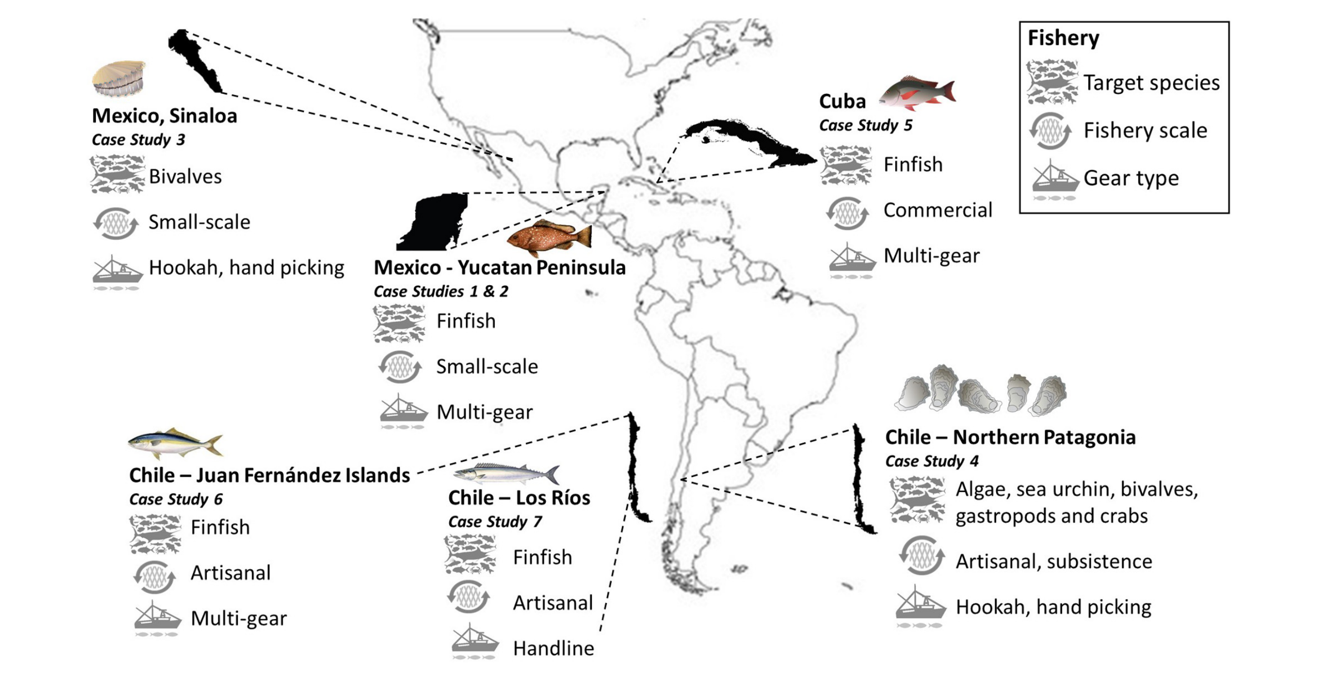

FIGURE 1 | Distribution of case studies, with description of each fishery, target species, type of fishery, and predominate gear types.

TABLE 1 | Fishery characterization of multispecies fisheries; commercial fisheries of the Yucatan Peninsula – Mexico, multispecies finfish fishery of the State of Yucatán – Mexico, multispecies Bivalve Fishery of Sinaloa – Mexico, Marine Coastal Areas of Indigenous People Caulín (MCAIP) Northern Patagonia – Chile, multispecies Finfish fishery of Cuba, the Forgotten Fish of Chile.

Fishery	Target (main)	Targets (others)	Season	Gear	# Fishers	# Vessels	Regulations
(1) Commercial fisheries of the Yucatan Peninsula, Mexico	Red grouper	140 species, including, spiny lobster, red octopus, shrimp, and Atlantic seabob fisheries	Closed season for finfish (45 days)	Handline, hookah/scuba, free diving, nets, jimbas, artificial shelters	∼25,000	11,000 vessels semi-industrial fleet (5 and 25 m); small-scale fleet (8 and 12 m)	Fishing licenses or concessions, fishing gear specifications, legal size, season closures, and quota limits.
(2) Multispecies finfish fishery of the State of Yucatan, Mexico	Red grouper	40 species of groupers and snappers	Closed season for finfish (59 days)	Longlines and hand lines	11,616	∼3,054 artisanal boats and 594 mid-range vessels	Fishing permits, Seasonal closures, gear restrictions, size limits for red grouper.
(3) Multispecies Bivalve Fishery of Sinaloa, Mexico	Bivalves (14 species)	24 species: sharks and rays, swimming crab, finfish and bivalves.	Closed season for targets: chocolate clam (2 years, May 2019–May, 2022), Oysters (July–November), Pata de Mula (July–September, others Bivalves (In process)	Semi-autonomous diving gear (hookah) and hand picking	1,600 permitted	37 bivalve permitted vessels	Closed season, no-take zones.
(4) Caulín Marine Coastal Area of Indigenous People (MCAIP) Northern Patagonia, Chile	Algae, sea urchin, bivalves, gastropods, and crabs	20 species	Year-around	Hookah diving, and hand picking.	58 divers, 41 fishermen, 301 shore harvesters	6 fishing vessels formally registered for fishing activities	Proposed: total allowable quota, reproductive bans, minimum catch sizes, closure of over-exploited stocks, fishing method and gear regulation, minimum resource density for harvest, and restricted fishing zones (no-take) with clear conservation goals.
(5) Multispecies Finfish Fisheries Management in Cuba	Finfish (e.g., finfish, sharks, and rays)	150 species; including lobster, shrimp, mollusks, sea cucumber, among other resources.	Year-around, except for spawning aggregation restriction for Lane Snapper in the Gulf of Batabanó	Purse seines, gillnets, pots, bottom and surface longline, and hook and line	∼20,000 fishers	9,500 vessels: state-owned fleet, 385 vessels (90% of the catch), private fleet comprises, 3,603 vessels.	Legal minimum sizes, seasonal closures during reproductive cycles, and fishing gear restrictions.
(6) Forgotten Fish of Chile	Finfish	>50 species					
Juan Fernández Archipelago and Desventuradas Islands	Finfish as bait for the lobster fishery	43 species	5/15 –9/30 to protect recruitment of lobster.	Handline, vertical longline and eel traps	272 fishers	42 vessels	Effort is related to the lobster season, use of Marcas; local property rights, and no gill nets. Currently, going through the process of developing a fishery management plan.
(7) Forgotten Fish of Chile – *Los Ríos*	Sierra	6 species	Year-around (weather dependent)	Handline	1,971	65	No regulations, in the process of developing a fishery management plan.

The name of each case study is in bold, as well as the attributes of each fishery summarized in the table.

(i.e., non-compliance with the catch limit, fishing activities during the closed season), unregulated fishing effort, low government capacity to coordinate surveillance and limited interaction between the government and fishing groups which is needed to maintain consensus around management strategies (Rosales-Raya and Fraga-Berdugo, 2018; Salas et al., 2019; Coronado et al., 2020b). In addition, the lack of socioeconomic data and concentration of biological monitoring and research on few species (i.e., red grouper, sea cucumber, red octopus, and Caribbean lobster) presents management challenges. Consequently, about 90% of the species landed in the region do not have sufficient information to inform regulations and management plans (Coronado et al., 2020b). Moreover, the Food and Agriculture Organization of the United Nations has identified climate impacts for the western Central Atlantic marine fisheries (Barange et al., 2018), and some research groups have started to assess those aspects (Arreguín-Sánchez, 2019; Cisneros-Mata et al., 2019).

Tools and Pathways for Climate-Resilient Multispecies Fishery Management

A diverse suite of fishery characteristics is now being monitored in the YP, including biological data, landings data, and socioeconomic information to address the complex problems that multispecies fisheries face at both the sub-regional and community levels. Coronado et al. (2020b) proposed a community typology built on landings and socioeconomic information to understand the local fisheries context and implement management tools according to the communities' context, following an adaptive approach. The typology classifies the small-scale multispecies fisheries from 22 communities into three clusters differentiated by fishing production, species composition, fishing effort, and economic characteristics. These results aid in understanding the fishery heterogeneity of the communities and their conditions, thus encouraging the explicit acknowledgment of these factors within policymaking and management. Typology analysis of multispecies fisheries can be helpful as an analytical instrument and as a planning tool, which is an essential component in building climate resilience in fisheries (Bahri et al., 2021).

The YP community typology reveals a disconnect between policymaking based on single-species management actions, the complexity of the multispecies fisheries, and the associated ecological and socioeconomic challenges (Salas et al., 2019; Coronado et al., 2020b). Some recommendations for fisheries management actions in the YP under the new typology include improving social cooperation, making plans more collaborative, and taking proactive, flexible, and innovative action to promote capacity-building efforts and interaction between the government and fishing groups to achieve healthy fisheries and sustainability. Understanding the characteristics of the multispecies fisheries within the communities and their socioeconomic contribution can help provide insights about the dynamics of fisheries and inform appropriate management strategies.

Next Steps for a More Climate-Resilient Multispecies Fishery

The transition toward a more participatory system that improves governance and accomplishes current management schemes is a challenge that requires trust among key stakeholders. It also demands access to and sharing reliable information for informed decision-making to enable implementation (Galindo-Cortes et al., 2019). With the establishment of an effective management system that is participatory, this fishery is moving toward climate-resilient practices (Bahri et al., 2021).

Given the identified data gaps in the YP (Coronado et al., 2020b), most of the efforts to improve the resilience of multispecies fisheries will be focused on building a rich database to comprehensively monitor information on productivity, landings, socioeconomic conditions, changes in fishers' population size, coastal infrastructure, and community vulnerability. Additionally, value chain analyses of multispecies fisheries are needed, with stakeholders and management institutions involved in a structural mapping approach (Coronado et al., 2020a). All these efforts together will provide the basis to understand the local fisheries context and implement proper management tools to support a sustainable pathway for multispecies fisheries in the region; while establishing a multistakeholder participatory process to implement effective fisheries management, both essential practices for building climate-create fisheries (Bahri et al., 2021).

CASE STUDY 2: MULTISPECIES FINFISH FISHERY OF THE STATE OF YUCATAN, MEXICO

Fishery Characteristics

Within the commercial fisheries of the Yucatan Peninsula, the main target species is the red grouper (*Epinephelus morio*). Red groupers are harvested under a finfish fishing permit, which applies to a multispecies fishery (a total of 100 species) including around 40 different species of groupers and snappers (Brulé et al., 2009; DOF, 2014; Coronado et al., 2020b). Catch occurs in the coastal waters of the Yucatan, in an area known as the Campeche Bank, an interconnected habitat of marshes, estuaries, lagoons, mangroves, and coral reefs. Campeche Bank is an important eco-region for Mexico, characterized as an ecotone between the Gulf of México and the Caribbean Sea (Aguilar-Medrano and Vega-Cendejas, 2019), representing approximately 116,257 km^2 of the continental shelf of Yucatan, Campeche, and Quintana Roo. Around 11,938 fishers operate a mid-range fleet and artisanal boats to fish red grouper in Yucatan (SEPASY, 2020) using longlines and hand lines. Hook size, fishing seasons, and allowable size are all regulated (DOF, 2015; **Table 1**).

The multispecies finfish fishery along Yucatan's state coasts is considered one of the most important in the region. Based on the national landings registry over 19 years (2000 – 2018) from CONAPESCA (INAI, 2020), yellowtail snapper (*Ocyurus chrysurus*), black grouper (*Mycteroperca bonaci*), and red snapper (*Lutjanus campechanus*), along with the red grouper, are the species with highest catches (**Supplementary Table 2**). In comparison, all other groupers and snappers caught in the red grouper fishery represent less than 15% of the total catch (Brulé et al., 2009; DOF, 2014).

The red grouper fishery is depleted according to the official status in the National Fisheries Act, which states that according to Mexican regulation, "*catches have decreased drastically hindering the population biomass recovery and risking sustainable harvest*" (DOF, 2018). Only the red grouper has been assessed using catch-based models (e.g., Gordon-Schaefer surplus production model; Gordon, 1954); there are currently no assessments for any of the other 99 finfish species caught together in the same fishery with red grouper. Catch records for red grouper go back as far as 1958, when the fishery implemented the initial regulations of mandatory finfish licenses and landing records. From 2003 forward, additional management measures were implemented, including closed seasons to restrict fishing during the spawning period for the red grouper along the adjacent waters of the Yucatan Peninsula and Tabasco. Most fishery regulations that focus on red grouper (closed season, management plan, and official norm) also pertain to other species of groupers fished in the multispecies fishery (DOF, 2014, 2015, 2017). Also, governance instruments for the fishery were formalized such as the red grouper management consulting committee and the grouper research network (i.e., el Comité Consultivo de Manejo de la Pesquería de Mero de Yucatán y Red de Investigadores de Mero, 2019).

One of the main challenges for Yucatan fisheries management is focusing only on one highly valued commercial species. All research, monitoring, and regulatory efforts focus on red grouper; however, fisheries that occur in the same area or are also associated species are seldom prioritized and lack strategies that promote fishery and livelihood sustainability. Based on Barange et al. (2018), the impacts of climate change on grouper and snapper populations in the Gulf of Mexico are considered low. However, the ecology and basic life histories, habitat, and food availability may be affected by increasing storms or hurricanes.

Tools and Pathways for Climate-Resilient Multispecies Fishery Management

Due to the Yucatan fishery sector's outstanding organizational capacity, NGOs and researchers often consult with the sector stakeholders on fisheries management and conduct joint studies. The sector also actively participates in the Federal Government's public consultations on fisheries regulations. Together, they have focused on a diagnosis of statewide fisheries and developing a master plan that identifies the main social, economic, and environmental guidelines for fisheries sustainability. At the same time, stakeholders from the Yucatan's fisheries also participated in workshops and processes led by the FAO (Flores-Nava et al., 2016a,b). In 2017, to gain more support, Yucatan fishers identified the need for representation within the Yucatan state government and the federal government in a Fisheries and Aquaculture State Ministry (DOEY, 2018). As a result, the governance system is being restructured and strengthened. For example, the State of Yucatan Fisheries and Aquaculture Council was reinstated, which is made up of representatives from the Government of Yucatan, CONAPESCA, INAPESCA, fishermen and other ordinance bodies such as the Nautical Committees and the newly created octopus and red grouper management consulting committee were established in the state council. The Nautical committees interact with municipal, state, and federal government concerning fisheries issues (Gaceta Municipal, 2015). The formal interaction of these committees at various levels of governance is a way to increase polycentricity, which is considered an effective way to achieve collective action around particular issues such as climate-ready fisheries management (Carlisle and Gruby, 2017).

Currently, fisheries sector participation and governance bodies are integrated mainly by governmental entities that allow NGOs to participate in the Consulting Committees and the Red Grouper Research Network. NGO participation has also been extended to technical workgroups that review compliance agreements and support and communicate the Consulting Committee's interests. NGO participation has enabled collaboration among academia and the fisheries sectors. For example, in early 2019, the Environmental Defense Fund de Mexico (EDF Mexico) organized a workshop in collaboration with all the stakeholders to identify research and management priorities for the red grouper fishery (Comité Consultivo de Manejo de la Pesquería de Mero de Yucatán y Red de Investigadores de Mero, 2019).

In 2019, 5 years after the initial publication of the red grouper fishery management plan (DOF, 2014), the master plan, and the fishery diagnosis (Flores-Nava et al., 2016a,b), the Consulting Committee's working group reviewed the proposed actions in each document. The Consulting Committee used a relative importance index to prioritize strategies and actions. Actions were classified by ordinance, social organization, bio-ecological, health and safety, and were validated through a participatory workshop held with the fisheries sector, researchers, NGOs, and government representatives (Comité Consultivo de Manejo de la Pesquería de Mero de Yucatán y Red de Investigadores de Mero, 2019).

To date, significant progress has been made in the implementation of the Consulting Committee's priority actions. Regarding ordinances, the priorities identified were fulfilled by a 2019–2020 SEPASY fisherman census (SEPASY, 2020) that monitored and summarized Yucatan fishing activity in detail, including the number of vessels and where each fisher operates. Also, since the formation of the red grouper consulting committee, 16 work sessions have been held over 3 years, making it the most active of the 10 consulting committees nationwide, inspiring the creation of other committees, including two committees for the octopus fishery in the same region. In terms of social organization, environmental education was one of the top priorities with capacity building for the sector. To advance these social organization priorities, in 2019, the Yucatan state government developed an environmental education program. It held associated events throughout the coastal communities to promote red grouper fishery management and the importance of the closed season to residents and tourists (*Festival de la veda del mero/Grouper Closed Season Festival*). EDF Mexico participated in these activities and organized two science outreach workshops with the Red Grouper Research Network, connecting these efforts to the fishing communities. Researchers presented relevant biological information on all grouper target species and snappers during the science outreach workshops, where attendees were fishers.

Next Steps for a More Climate-Resilient Multispecies Fishery

Ultimately, the efforts described above prioritized the urgent need for comprehensive monitoring and improved management of the other species caught in the fishery, moving beyond a single-species approach. Data collection is already occurring for a subset of targets, but increased data collection is planned for all the targets; new data will also support the interest in conducting more complex assessment methods. This prioritization is a critical step in planning for management that is adaptive and responsive to climate change and other impacts.

To further these prioritization efforts, a recent study identified knowledge gaps in the YP concerning sustainable fishing techniques, markets and business management, certifications, and exports, how to incorporate climate change impacts into fisheries decisions, connections between stakeholders, and population dynamics of all other species caught along with red grouper in the multispecies fishery (Pelcastre and García-Gutiérrez, 2021). The Consulting Committee and Research Network will connect members and fishery stakeholders to resources and create opportunities to fill these knowledge gaps. The stakeholder groups are currently working on a red grouper fishery rebuilding plan that aims to implement previously agreed upon management strategies to stop the further decline of the fishery. Fishery governance bodies (Comité Consultivo de Manejo de la Pesquería de Mero de Yucatán y Red de Investigadores de Mero) have committed to assess the stocks of all associated species and develop management strategies. These types of multistakeholder processes are essential in building climate resilience in fisheries (Bahri et al., 2021).

CASE STUDY 3: MULTISPECIES BIVALVE FISHERY OF SINALOA, MEXICO

Fishery Characteristics

Altata-Ensenada del Pabellón (AEP) is one of the most productive coastal lagoon systems in Sinaloa, Mexico. Sinaloa is also arguably the most politically and socially important fishing state in Mexico. It has both the country's largest small-scale and industrial fleets and the most significant volume landed. Sinaloa is also home to the headquarters of the Fisheries and Aquaculture National Commission (CONAPESCA). Government institutions, NGOs and fisher groups have been working together to develop a scalable model for ecosystem-based multispecies management in the AEP Lagoon System since 2012.

The AEP lagoon system is a designated Ramsar site of great importance (RAMSAR, 2008), and is central to the local economy where over 1,600 permitted fishers operate and many more fishers who lack permits. At least 24 species are harvested across four fisheries (bivalves, crustaceans, finfish, sharks and rays) in the AEP lagoon. Shrimp is the main fishery, based on the number of fishers and vessels, and the amount of revenue generated. Other significant fisheries are sharks and rays, swimming crab, finfish, and bivalves (i.e., clams and oysters). The multispecies bivalve fishery includes 14 species (**Supplementary Table 3**) and is an important subsistence and commercial fishery, as it is open during the closed seasons for shrimp and crab fisheries, providing critical job opportunities and a local food source (**Table 1**). Only the oyster (*Cassostrea corteziensis*) and chocolate clam (*M. squalida*) have closed fishing seasons, while the other shellfish species are accessible year-round (DOF, 2019). Among the permitted fishers in the AEP lagoon system, many participate in the multispecies bivalve fishery and, 37 boats have bivalve permits, but understanding the total fishing effort remains a challenge.

Fisheries in the AEP use different fishing gear depending on the target species, including traps, hook and line, cast nets, drift nets, and longlines onboard artisanal boats (>10 m length) (**Table 1**). The multispecies bivalve fishery operates from artisanal boats with three or four crew members. Bivalves are hand-collected at depths of less than 1 m. Fishers often carefully locate clams using their feet and then use a trench to remove the sand and a mesh bag ("jaba") to collect them. For oysters, fishers use gear called "gafa" or "rastrillo," which is made of two rakes operated like tweezers/pinchers in depths greater than 2 m. In deeper areas, fishers collect bivalves by freediving and using a steel rod to detach the rocks (DOF, 2019). Some bivalve species are managed at the taxon level. However, the lack of existing regulation and the deficient administration of some bivalve resources have caused the overexploitation of some species and the poor management of others. For example, the chocolate clam (*Megapitaria squalida*), an iconic species from Sinaloa, declined 92% from 2006 to 2014 (CONAPESCA, 2018).

Tools and Pathways for Climate-Resilient Multispecies Fishery Management

In 2011 fishing organizations, state and federal fisheries managers, academic institutions, and NGOs formed a working group. The working group began collaborating on fisheries management in the AEP lagoon system to improve the responsiveness of fisheries management to climate change and other impacts. Over time this group has included three Fishing Federations (two Women's Fishing Cooperatives, federal representatives from CONAPESCA and the National Fisheries Institute (INAPESCA), state-level fishery managers, and several academic institutions and NGOs (**Supplementary Table 4**).

At the start of the collaboration, the working group focused on the bivalve fishery and agreed that a multispecies approach to fisheries would help promote sustainability and potentially increase climate resilience. They proposed a bivalve sustainable management program, and in 2012, INAPESCA expanded efforts to develop an Ecosystem-based Fisheries Management (EBFM) Plan for the AEP lagoon, to manage all species harvested.

From 2012–2019, a working group facilitated by EDF Mexico collaborated on designing the Ecosystem-based Fisheries Management Plan (FMP) for the AEP lagoon, intending to establish an ecosystem-based vision and plan for sustainable climate-resilient fisheries management through a participatory process. This plan encompasses management for multiple fishing resources, among them shrimp, crab, bivalves, and finfish, to provide food and employment to thousands of families in the region, for whom fishing is not only an economic activity but also a part of their cultural heritage imbedded in their family traditions. Within the multispecies bivalve fishery, the plan identified the targeted chocolate clam (*Megapitaria squalida*) as a highly valuable species that had no harvesting regulations prior to 2018, stimulating focused efforts to transition to sustainable harvest (DOF, 2019).

In support of advancing co-management strategies, the participatory fisheries management program for bivalves has created: (1) a Consulting Committee for Fisheries Management and Administration of the Multistakeholder Lagoon System, (2) two women's fishing cooperatives that formed as a result of training activities on fishing organizations and permitting processes to become legal fishers, (3) the "Fortachones" Leadership Development Program for local fishing communities, and (4) co-managers, known as "Enlaces Comunitarios" who support community-based fisheries monitoring and surveillance activities (COBI, 2016; Tus Buenas Noticias, 2017; Gobierno de México, 2020).

The program also advanced efforts to create the scientific and economic basis for sustainable management, including (1) new scientific information on the main clam species harvested in the AEP lagoon system that will guide sustainable management decisions, (2) a biological-fishing monitoring program implemented with support from the bivalve fishers, (3) effective implementation of the Chocolate Clam Fisheries Improvement Project (FIP) in coordination with the PNO, to make these fisheries more competitive and responsible (Its currently a basic FIP with a rating of "B – Good Progress"), and (4) market analysis to identify added-value opportunities for bivalves (Fishery Progress, 2021).

The fishery management program also resulted in new fishing management regulations through participatory design and implementation in the AEP lagoon system. In coordination with the fishing sector and NGOs, fisheries authorities established a no-take zone in 2018 and a total 2-year harvest ban supporting the chocolate clam population (DOF, 2020).

Developing community-level leaders and strengthening social capital is a central focus of these activities and critical co-management attributes (Gutiérrez et al., 2011). The women's fishing cooperatives are the first in the country; members include harvesters and others involved in storing and selling bivalves who worked together to form legal entities and bring visibility to an often-ignored workforce. In the "Fortachones" program, community members participated in training on fisheries regulations, environmental sustainability, inspection and surveillance, markets and best fisheries management practices, communication, and public speaking. During workshops, participants in the program reported gaining knowledge, trust in the local fishing sector, and self-confidence, and as a result, participate more actively in fisheries decision making. These programs and the local leaders are building durable participatory processes.

After the publication of the FMP by INAPESCA in 2019 (DOF, 2019), the working group continued to advance the plan's goals through different implementation processes. Goals focused on improving the understanding of species status, development of management instruments appropriate to each species, and to the AEP lagoon system, and improving the conditions of fishing communities.

Next Steps for a More Climate-Resilient Multispecies Fishery

The AEP lagoon fishery has developed an effective fishery management system, supported by a diverse suite of stakeholders, which is one of the foundations of climate-resilient fisheries (Hilborn et al., 2020; Bahri et al., 2021). The next steps include the design of fisheries regulations for the chocolate clam and three associated bivalve species (*Chione californiensis, Atrina maura*, *Atrina tuberculosa*); a histological study of bivalves to determine fecundity and reproductive periods; genetic research to understand population structure, larval dispersal, and abundance trends; and implementing a community surveillance program to reduce illegal harvest. There are also plans to create a multispecies bivalve Fishery Improvement Program (FIP) to increase market access and value.

CASE STUDY 4: CAULÍN MARINE COASTAL AREA OF INDIGENOUS PEOPLE, NORTHERN PATAGONIA, CHILE

Fishery Characteristics

The Caulín Marine Coastal Area of Indigenous People (MCAIP or ECMPO in Spanish) is located north of Chiloé island in Northern Patagonia, Chile (**Figure 1**). The Caulín MCAIP covers an area of 27.29 km^2 and is managed by the "Asociación de Comunidades Williche ECMPO Caulín" (Association of Wiliche communities of the Caulín MCAIP), along with 12 other functional organizations within the territory (e.g., fishermen's unions, shore harvesting groups, divers, neighborhood boards, tourism groups, and other indigenous communities). In 2008, MCAIPs were initially established in Chile to protect and safeguard customary uses of coastal indigenous communities (Espinoza, 2016; Gissi et al., 2017; Hiriart-Bertrand et al., 2019). MCAIPs emerged as a complementary fisheries co-management system with broader objectives and scope than the Territorial Use Rights model. In addition to a focus on safeguarding customary uses, MCAIPs extend their scope to conservation and fisheries administration objectives (Hiriart-Bertrand et al., 2020). The MCAIP policy provides coastal communities the opportunity to hold legally recognized rights to local marine tenure to aid in the recuperation of rights and resources after being marginalized. These rights provide novel attributes to communities, allowing them to create local administration structures (through an

Administration/Management plan) and fisheries management plans, thus contributing to the overall sustainability of these natural resources.

The Caulín fishing community is comprised of 58 divers, 41 fishers, 301 shore harvesters, and six fishing vessels formally registered for fishing activities (SUBPESCA, 2021; **Table 1**). In the last 10 years, Caulín has reported landings for over 30 fishery resources from subsistence and commercial fisheries. Prior to the approval of the Caulín MCAIP in 2020, the fisheries had been exploited under an open-access regime. Only eight resources have commercial value in domestic and international markets from these fisheries, and the remaining are resources of local relevance for artisanal fisheries (SUBPESCA, 2021).

Among the commercial fisheries, the predominant landings are of *Agarophyton chilense* (Pelillo/red seaweed; >1,400 ton/year), *Loxechinus albus* (Erizo/Sea urchin; >120 ton/year), *Ameghinomya antiqua* (Almeja/clam; >70 ton/year), y *Sarcothalia crispata*20 (Luga negra/red seaweed; >30 ton/year). Despite being relevant for artisanal fisheries at the national level *Concholepas concholepas* (Loco/Chilean abalone), *Ostrea chilensis* (Ostra/Chilean oyster), *Metacarcynus edwarsii* (Jaiba marmola/Chilean rock crab), and *Gigartina skottsbergii* (Luga roja/red seaweed), have low landing volumes. Other resources that have reduced landing volumes (<500 kg/year; SERNAPESCA, 2019) and correspond to species with no commercial importance can therefore be considered as part of the subsistence fisheries (SUBPESCA, 2021). While most of the species that comprise Caulín's fisheries have an extensive geographic distribution within the Chilean coast, the effects of climate change and overexploitation threaten to cause local extinctions, profoundly compromising livelihoods, and traditions of indigenous and fishers' communities.

In Chile, as in much of the world, subsistence fisheries are not monitored or subject to fisheries management (Schumann and Macinko, 2007; Palomares and Pauly, 2019). Since MCAIP governance has an important cultural and traditional component, the development and implementation of its fisheries management plan should consider both commercial and subsistence fishing. Because fishery management in MCAIPs is based on some structural components of the TURF system, Chilean regulations require minimum standards for evaluating and managing each of the resources incorporated into the MCAIP fishery management plan. These minimum requirements are the direct evaluation, or stock assessment, of the resources to be exploited and the stock projection for quota allocation. These approaches have been widely applied to commercial fisheries administered under the Áreas de Manejo y Explotación de Recursos Bentónicos (AMERBs), where management costs are covered by profits received from the sale of resources. In subsistence fisheries, the destination of the catch varies from food, medicinal, or local agriculture fertilizer (Hiriart-Bertrand et al., 2020; SUBPESCA, 2021). These fisheries do not generate sufficient revenue to fund high-cost fisheries monitoring or management programs. These multispecies fisheries with a high diversity of non-commercial target resources are "data-poor fisheries" and lack processes for decision-making and implementation of management measures.

Tools and Pathways for Climate-Resilient Multispecies Fishery Management

During 2019-2020, MCAIP administrators with the technical support of Costa Humboldt (a Chilean based marine conservation organization) and funding support from the National Indigenous Corporation (CONADI), developed the MCAIP Caulín fishery management plan, based on the co-management of 19 fishing resources extracted with commercial and/or subsistence purposes (SUBPESCA, 2021). To fill data gaps, the fisheries management plan utilized a traditional ecological knowledge (TEK) based approach, including multiple bodies of knowledge accumulated through many generations of close interactions between people and the natural world (Berkes, 1999; Butler et al., 2012; Sánchez-Carnero et al., 2016; Berkström et al., 2019). The application of TEK potentially enhances the resilience of socioecological systems by providing a diversity of knowledge for problem-solving and related cross-scale and adaptive governance networks (Butler et al., 2012). TEK was gathered to complement scientific knowledge and more efficiently use limited financial resources (Berkström et al., 2019). The development of the plan required and achieved a high level of participation and incorporation of community-based knowledge to collect the TEK, which improved biological/fishing sampling efforts and the design and implementation of fisheries management measures.

Using participatory mapping, semi-structured interviews and focus groups (**Supplementary Text 3**) directed to MCAIP users (e.g., indigenous groups, fisher unions, seaweed aquaculture groups, and other local organizations) Costa Humboldt collected relevant information on the spatial and temporal distribution of target species within the MCAIP Caulín. Additionally, Costa Humbolt gained access to historical data (e.g., stock variations, disappearance or expansion of natural banks, reproductive periods, and fishing effort) of underreported fisheries in the area. The information was assessed for accuracy by comparing the results with stock assessments conducted for target resources.

Participation of the Caulín community resulted in a fishery management plan adapted to the local context, incorporating 19 fishing resources relevant to commercial and subsistence fisheries of the MCAIP. The plan includes a series of fisheries administration measures. Some of these measures are part of the national fisheries regulations (Law 21.287 and bylaws), while the MCAIP administrators proposed others. These additional voluntary measures demonstrate the interest of MCAIP administrators (i.e., indigenous communities, fishers, and other stakeholders) in ensuring greater sustainability of their fishing activities. The measures included in the fisheries management plan are total allowable quota, seasonal restrictions, minimum catch sizes, closures to protect over-exploited stocks, fishing method and gear regulations, minimum resource densities that trigger harvest controls, and no-take zones (**Supplementary Table 5**). The creation of restricted or no-take areas managed by local communities is an innovative initiative at the national level. The MCAIP Caulín created four no-take zones (>1.5 km^2) that extend over 5.5% of the MCAIP. The objective of these areas is the protection of critical habitats considered fundamental for the conservation of local biodiversity and fish stocks identified by the TEK activities. Kelp forests and nursery habitats for sea urchins and clams are conservation targets that these no-take zones seek to protect.

Next Steps for a More Climate-Resilient Multispecies Fishery

Utilizing various tools provided by the fisheries administration, the MCAIP Caulín fisheries management plan simultaneously established single species and multispecies management measures. Due to the complexity involved in multispecies fishery management, the need for an intensive outreach program at the local scale is recognized to ensure and facilitate the implementation of the management measures. Some of this work was initiated through the participatory activities that shaped the fisheries management plan but continued technical support to the local community is needed during the following years of implementation to ensure its success. Likewise, the effectiveness of management measures must be constantly monitored and adapted according to the observed results. In turn, the fisheries management plan proposes performance indicators and reference points that facilitate the adaptive management of the MCAIP fisheries, like the FISHE process (**Supplementary Figure 1**). The MCAIP corresponds to a geographic area that did not have a detailed characterization of biodiversity or oceanographic conditions at the local scale prior to collaborating with Costa Humbolt. This multistakeholder collaboration and resulting fisheries management plan establish the baseline against which an adaptation program to climate change can be designed specifically for the sector. As a first step, the climate change adaptation strategy is based on (a) continuous monitoring (every 2 years) for adapting fishing regulations and (b) ensuring more resilient fisheries and socio-economic systems that can withstand the changes to come.

Coastal fisheries like those managed in the MCAIPs, are one of the most affected sectors by climate change (Palomares and Pauly, 2019). The MCAIP Caulín includes estuarine and fjord areas, expected to experience more extreme effects (Kennedy, 1990; Roessig et al., 2004). Co-management of multispecies fisheries should provide better adaptation and social resilience of the MCAIP fisheries system by reducing fishing pressure on the most affected resources while focusing on more resilient species.

CASE STUDY 5: MULTISPECIES FINFISH FISHERIES MANAGEMENT IN CUBA

Fishery Characteristics

Fisheries in Cuba are an important source of food, income, and livelihoods. Most fisheries occur in the coastal zone, within a mosaic of high biodiversity mangrove, seagrass, and coral reef habitats that provide numerous ecosystem services, including fisheries (Kritzer and Liu, 2014). The tropical waters around Cuba are very diverse, and fisheries exploit more than 150 different species (Valle et al., 2011). Landings can be divided fundamentally into fish (e.g., finfish, sharks, and rays), lobster, shrimp, mollusks, and sea cucumber, among other resources. Fish represent the largest volume of total landings (62%), but from an economic perspective, spiny lobster and shrimp are the most important (Claro et al., 2001). The Cuban fleet is very diverse and consists of approximately 9,500 vessels, divided into three categories: state-owned fleet, private fleet, and recreational vessels, but only the first two operate commercially. Within the state-owned fleet, 385 vessels are between 15 and 20 m in length and target the multispecies fish fisheries, accounting for approximately 90% of the total catch of these species (**Table 1**). The private fleet is comprised of 3603 smaller private vessels, most of them less than 15 m in length, with commercial access only to fish fisheries under a strict contract with state-owned companies. While most private vessels operate close to their home ports, this fishery has no territorial use rights (TURFs). The most typical fishing gears are purse seines, gillnets, pots, bottom and surface longlines, and hook and line. Fixed nets or trammel nets were banned in 2008 and trawls in 2012 (Puga et al., 2018; **Table 1**).

Many landing ports and the wide diversity of vessel types, fishing gear, and target species make it difficult to create and implement monitoring programs and estimate fishing effort, reference points, and resource status. Previous status estimates have been limited to descriptions of fisheries and catch series trends for all species together or of certain species or groups (Baisre, 2000, 2018; Claro et al., 2001, 2009; Valle et al., 2011). Consequently, only minimal management measures are implemented for the multispecies fishery, such as legal minimum sizes, seasonal closures during reproductive cycles, and fishing gear restrictions (Valle et al., 2011; Karr et al., 2017; Puga et al., 2018; **Table 1**). An exception is the Maximum Allowable Catch Quotas established for the lane snapper (*Lutjanus synagris)* during its spawning aggregation period in the Gulf of Batabanó. In addition, there is a National Action Plan to protect sharks and rays (PAN-Tiburones, 2015).

Cuba has taken necessary steps toward the implementation of ecosystem-based fisheries management (EBFM). Research (e.g., Centro de Investigaciones Pesquera, CIP) and management (e.g., Ministerio de la Industria Alimentaria, MINAL) institutions are embracing EBFM approaches through capacity building and the development of international projects. This work advances the evaluation of coastal socio-ecological systems subject to fishing and other forms of exploitation, helping inform the establishment of special management zones, primarily through the creation and management of an island-wide MPA network (Kritzer and Liu, 2014).

Unfortunately, finfish fisheries have declined over the last 30 years. In general, catch trends have experienced two phases, an upswing between the 1950s and 1980s, followed by a marked decline to the present (Valle et al., 2011; Baisre, 2018). Baisre (2000) showed that the average trophic level and average size of catches have declined in Cuban fisheries. One study estimates that 20% of the fishery resources are fully exploited, while 75% are overexploited, and 5% have collapsed (Baisre, 2018).

Although overfishing is one of the most important factors influencing low catch levels in Cuba, non-fishing impacts certainly also have an effect, and some of them are probably irreversible (Baisre, 2000). These include environmental changes caused by climatic phenomena (Claro et al., 2009) and activities such as damming of rivers (Baisre and Arboleya, 2006; Puga et al., 2018), changes in agricultural practices (Baisre, 2006), coastal development, and increased tourism (Claro et al., 2009). Puga et al. (2013) concluded that the degradation of coastal habitats in Cuba should be taken into account in stock assessments and the development of management strategies. The likelihood of overfishing and detrimental non-fishing impacts has led to a drastic reduction of fishing effort in Cuban fisheries. On the other hand, single-species fisheries management offers limited options for rebuilding overfished stocks given the multispecies nature of Cuban fish fisheries (Claro et al., 2001). Moreover, recent studies in Cuba (e.g., Gerhartz-Muro et al., 2018; Puga et al., 2018; Alzugaray et al., 2019) indicate issues with illegal fishing, which have been contributing to the decline of fish stocks and continued overfishing.

Tools and Pathways for Climate-Resilient Multispecies Fishery Management

Cuba published a new national Fisheries Law in 2020. The law recognizes the need to recover fish populations and calls for science-based management measures to guide these efforts. It mandates that fishery resources be managed using the principles of conservation, sustainable use, the precautionary approach, the implementation of scientific-technological criteria and the protection of ecosystems, in correspondence with national and international standards and the principles of food security and sovereignty of the nation ("Ley de Pesca." República de Cuba, 2019).

Many efforts have been taken to advance the science-based principles required by this new law. In 2015–2016, productivity-susceptibility analyses (PSA) were conducted to define priorities for research and management measures to improve the sustainability of finfish fisheries in Cuba. These analyses ranked species, in each of Cuba's four fishing zones, based on their relative vulnerability to overfishing, prioritizing the most vulnerable species for data collection, stock assessment, or conservation and management interventions (Puga et al., 2018; EDF, 2021a). A multi-institutional working group including the main scientific and administrative institutions of Cuba adapted the "Upside" bioeconomic model, developed by Costello et al. (2016). This approach provides a holistic view of the potential benefits obtained from sustainable fisheries based on biological and economic information and management questions. Preliminary results were obtained for a small group of nine priority species (**Supplementary Table 6**), showing that these populations were all depleted, and most of them were experiencing overfishing. The model projects increased profitability and biomass under sustainable management strategies (Alzugaray et al., 2019). This work considers the Cuban context, including estimated fishing mortality from the state-owned and private fleets, and illegal fishing.

Scientists are incorporating these initial results and currently working to implement climate-resilient and science-based management for 34 fish species that represent the highest percentages of total catches in the multispecies fisheries, vulnerable species and those of greatest economic importance (**Supplementary Table 6**). Additionally, these initial results are helping to inform the elaboration of stock complexes (fish baskets) with related groups of species formed according to different characteristics (biological and fishing operations) to avoid serial depletion and optimize yield. The working group also plans to include climate variability in the projections of biomass, catch, and economic benefits over time.

Another fundamental tool to achieve sustainable fisheries management is a learning network that serves as a platform for capacity building involving all key stakeholders and allows exchange and collaboration between different institutions and fishing communities during the different stages of fisheries management. Multispecies fishery management issues and solutions have been part of university courses and community workshops (Morón et al., 2019).

A "Sustainable Fisheries Management" university short course was offered in 2018 and 2019 for researchers, resource managers, conservation practitioners and fishing industry workers from almost all the provinces across the country (EDF, 2021b). This course equipped fisheries-related professionals with tools and models for fisheries assessment, shared successful examples of single-species management, highlighted the problems related to managing multi-species fisheries, reviewed main environmental problems, and emphasized the importance of EBM approaches. Participants conducted finfish stock assessments using real data during the course and practiced applying the fish baskets approach to multispecies fishery management. Participants also created a draft management plan for six species in the northeast fishing zone.

The 2018 "Encuentro Pesquero" (Fishers' Forum) and the "Taller de Escama" (Finfish Workshop) brought together representatives from 10 fishing communities who examined scientific results on the vulnerability and current status of different species involved in the multispecies fisheries (Morón et al., 2019). Together they discussed current management problems and possible solutions through dynamic activities such as "The Fishing Game," which also allows them to try out the construction of fish baskets (EDF, 2021c). These workshops allowed scientists, resource managers, and conservation specialists to discuss possible management strategies with the fishermen and gather their opinions and reactions.

Next Steps for a More Climate-Resilient Multispecies Fishery

Centro de Investigaciones Pesqueras (CIP) and the working group plan to incorporate climate change impacts into the fisheries bioeconomic model and discussions in future learning network activities. MINAL and CIP will continue to engage fishers and fishing communities in developing of multispecies fisheries management that will consider grouping species together according to their habitats and fishing gear, noting which species are caught together. Stakeholders and fishery managers will then select indicator species for each fish basket, considering their commercial and/or social importance to issue harvest control rules on these indicator species that can influence the rest of the species in the basket, facilitating management focused on one or more indicators but influencing all of them. This process requires high stakeholder participation and a vision for adaptive management as different species will respond to the impacts of climate change and harvest control measures in different ways. Adaptive management is another key foundation of climate-resilient fisheries (Bahri et al., 2021). The fish baskets approach recognizes, in the face of uncertainty, that it is impossible to determine the perfect management strategy. There is a great deal of uncertainty concerning climate change; therefore, adaptive management is an essential tool.

CASE STUDIES 6 AND 7: THE FORGOTTEN FISH OF THE JUAN FERNÁNDEZ ARCHIPELAGO AND DESVENTURADAS ISLANDS (6), AND LOS RÍOS REGION (7), CHILE

Fishery Characteristics

In 2013, Chile adopted the national fisheries law to include co-management as a key approach for sustainable fisheries management in open access areas (Orensanz and Seijo, 2013; Roa-Ureta et al., 2020). Under the updated fishery law, the management committee develops the management plan proposals and includes establishing localized forms of governance and exclusivity of access to delimited territories. Management committees are comprised of fishers and industry representatives, led by the Undersecretary of Fisheries and Aquaculture (SUBPESCA), and supported by the Fisheries Development Institute (IFOP) and the fisheries enforcement agency (SERNAPESCA). An additional scientific-technical committee is assigned to each fishery to analyze the performance and set the quota for each management plan.

In terms of global export from large-scale fisheries, Chile ranks 11th (FAO, 2020) globally, with targets such as anchovy, jack mackerel, and sardines, with annual landings volumes of 744,240 tons, 465,962 tons, and 320,147 tons (SERNAPESCA, 2019), respectively. Like other top producing fishing nations, these large-scale fisheries receive greater government attention through established annual research monitoring programs and management plans.

Data limitation is a critical obstacle for adaptive, sustainable management of fisheries, whether through top–down government stewardship or co-management by stakeholders. In Chile, data collection for the management of large-scale fisheries is supported by the government. Small-scale fisheries (SSFs), on the other hand, receive much less attention. Many lack data on resource abundance, catch and effort, and biological reference points, resulting in the absence of regulations and management plans. Chile's SSFs, located within 12 miles of the shore, produce annual landings between 30 and 3,000 tons. Each fishery serves as a subsistence food source, maintains cultural traditions, and catalyzes local economies centered on maintaining fishing livelihoods. In Chile, these fisheries are the "forgotten fish fisheries." Stakeholders in the Juan Fernández Archipelago (JFA) and Desventuradas Islands (DI), and the Los Ríos Region (**Figure 1**) are developing management plans for their forgotten fisheries to remedy this situation.

The JFA and DI is a unique ecosystem because of geographical isolation, which has contributed to several endemic marine and terrestrial species. Since being colonized in the 1890s, the local community inhabiting the islands have mostly been fishing families that traditionally rely on the spiny lobster fishery (*Jasus frontalis*) to support themselves financially throughout the year (Arana, 1987; Ahumada and Queirolo, 2014). The lobster fishery has been and still is the traditional fishery (Ernst-Elizalde et al., 2010) on the islands, even as species like the golden crab (*Chaceon chilensis*), morwong (*Nemadactylus gayi*) and yellowtail amberjack (*Seriola lalandi*) have recently become economically important (Ernst-Elizalde et al., 2020). The lobster fishery has high economic value in Chile and is sold primarily into export markets. Over time, the fishery has been managed with formal and informal regulations, including seasonal closures, sex and size limits, and a tenure system where each fisher or fisher's family member owns several fishing spots (Ernst-Elizalde et al., 2010). These regulations have resulted in 120 years of sustainable, profitable fishing, making the island community an example of sustainable fisheries management (Ernst-Elizalde et al., 2020). The fishing communities' bottom–up approach to development and management, including one of the world's largest multipurpose MPA (National Geographic, 2015; Mongabay, 2019; Ernst-Elizalde et al., 2020), is an international reference for management approaches.

The lobster fishery season starts October 1st and ends May 14th, with 272 fishers and 72 vessels. Since 2006 the artisanal fishery registry has been closed and no new fishers area allowed into the fishery. The lobster fishers use several local species as bait, such as Juan Fernández trevally (*Pseudocaranx chilensis*), several species of morays (*Gymnothorax* spp.), morwong (*Nemadactylus gayi*), englert's scorpionfish (*Scorpaenodes englerti*), pink maomao (*Caprodon longimanus*), jerguilla (*Girella albostriata*), Yellowtail amberjack (*Seriola lalandi*), Juan Fernández pampanito (*Scorpis chilensis*), and Juan Fernández corvina (*Umbreena reedi*). These are some species that are part of the JR and DI multispecies forgotten fish fishery; they are subject to limited to no monitoring and lack estimates of population status and management plans.

In the Los Ríos region, the sierra (*Thyrsites atun*) is a target species fished from the coastline of Coquimbo south to Los Lagos (i.e., management regions IV to X). *Sierra* is an important forgotten fish fishery regarding landings, reaching 1,805 tons in 2019 (SERNAPESCA, 2019). *Sierra* has traditionally been a vital subsistence fishery (Cariman and Reyes, 2019) with an artisanal fleet of boats less than 12 m long. Fishers use hand lines to fish for *sierra* and still maintain their traditional sailing boats. In the Los Ríos region, the *sierra* fishery involves 3,818 people, including ∼1,971 fishers and 657 total boats; however, in 2019, only 296 boats operated (Lobao-Tello et al., 2016; **Table 1**). The fishery lacks biological as well as fishery-dependent data. In 2018 the Chilean government formally recognized *sierra* as a fishery, initiating the formal fishery management framework process that involves stakeholders in developing a management plan and brings them into the management and regulatory process for *sierra*. Other forgotten fish species in Los Rios region are Patagonian blennie (*Eleginops maclovinus*), corvina drum (*Cilus gilberti*), Chilean silverside (*Odonthestes regia*), Chinook salmon (*Oncorhynchus tshawytscha*), slender tuna (*Allothunnus fallai*), and jack mackerel (*Trachurus murphyi*). Stakeholders support the goal of incorporating all these species into a multispecies management plan with *sierra*, as these species are fished with the same gear and in the same fishing grounds as the *sierra* fishery.

Tools and Pathways for Climate-Resilient Multispecies Fishery Management

In 2017, a collaboration involving fishers, government officials, academics, NGOs, and consultants launched the Chile learning network for small-scale fisheries. The development of the learning network arose after an analysis of Chile's SSF focused on the Territorial Use Rights for Fishing (TURFs), Marine and Coastal Areas for Indigenous Peoples (MCAIP), Open Access Management Plans, and the forgotten fish fisheries. The analysis assessed the main challenges and gaps these SSF face across the country, including information from a national stakeholder map, including interviews with fishers, government officials, academic researchers, NGO personnel, and consultants (Osman, 2016). As a result, the Chile SSF learning network co-developed with these stakeholders and adopted the goal to analyze problems related to near-shore artisanal fisheries collaboratively, find solutions to the problems, and build the fishers' capacity (RDA, 2021). The learning network aims to boost the collective action of communities by uniting them and encouraging collaboration between participants from different backgrounds who might not otherwise have the opportunity to work together.

Since 2017, multiple capacity-building trainings have been implemented through the learning network (RDA, 2021), covering diverse but interrelated themes such as co-management, illegal fishing, value chains, communication and leadership, monitoring and data analysis, and environmental impacts and resilience. In Chile, the learning network has created interactions and connections between stakeholders within and across fisheries and geographical scales, leading to new initiatives (e.g., regarding women's roles in artisanal fisheries, leadership, forgotten fish, and value chains, among others).

In the JFA and DI region, the Juan Fernández Fisher Association is creating the island's first climate-resilient multispecies fishery management plan for 43 forgotten fish species (**Supplementary Table 7**), including many endemic species that are critical for maintaining resilience in the face of climate change. The Juan Fernández fishing community recognized that the islands' forgotten fish used as lobster bait are a critical local food source and a vital attraction for national and international tourism. In 2019, the fishing community and the government, academics, and NGOs launched a multistakeholder, adaptive, science-based assessment process using the Framework for Integrated Stock and Habitat Evaluation (FISHE) (EDF, 2021a; **Supplementary Figure 1**). The working group is using FISHE to develop a multispecies climate-resilient fishery management plan for the forgotten fish. The multistakeholder FISHE working group identified 43 species (**Supplementary Table 7**), grouping these species into six fish baskets for management: commercial pelagic, commercial demersal, coastal commercial, bait, octopus, morwong, and other species (**Supplementary Figure 2**). To date, the working group also developed biological, social, and economic objectives for each basket and established a shared vision for the entire multispecies fishery for the JFA and DI.

In Los Ríos Region, the three main fisher federations (FIPASUR, FEPACOR Y FEPACOM), representing more than 1,500 fishers, have begun a collaborative development of a multispecies management plan for six species of forgotten fish (**Supplementary Table 7**). This multistakeholder group participated in workshops to understand the main challenges and gaps for the *sierra* fishery, establish a shared vision and objectives for the fishery, and initiate the development of the management plan. The multistakeholder group has primarily focused on *sierra* management as a single-species management plan to date. However, there is a common goal to include the other species caught with *sierra* and the future goal of building a multispecies management plan.

Next Steps for a More Climate-Resilient Multispecies Fishery

The precautionary approach is a part of the underlying basis for incorporating uncertainty into decision-making; accounting for uncertainty and unknowns is also a foundation of climate-resilient fisheries (Bahri et al., 2021). One precautionary activity is using ecosystem risk assessment methodologies in the initial phase of the management cycle to assess priority issues affecting the sustainability of a fishery, including external stressors and vulnerabilities related to climate change. In 2021, the JFA and DI stakeholder group plan to finalize efforts to understand the impact of climate change on the ecosystem and fishery to inform the multispecies fisheries management plan by conducting an ecosystem risk assessment, using the Comprehensive Assessment for Risk to Ecosystems (CARE) tool (Battista et al., 2017; EDF, 2021a). In the Los Ríos region, the stakeholders are starting to include the species that are fished together with *sierra* in the management plan process. Both forgotten fish fisheries are going through defining what climate-resilience implies for fishery data collection, new science, and management, including conducting risk assessments (e.g., CARE analysis) and developing monitoring and management goals that adapt uncertainty and unknowns over time.

LESSONS LEARNED

The case studies depict fisheries in various stages of transitioning to multispecies fisheries monitoring, management plan development, and implementation. Ranging from gap analysis, diagnosis of risks, and prioritization of management needs in

Mexico to a more comprehensive multispecies management design in Cuba and Chile. Several case studies (1, 2, and 5 -7) focus on more comprehensive monitoring and data collection (**Table 2**). Each fishery is adapting historical monitoring to a more comprehensive climate-resilient data collection scheme. For example, in case studies 1 and 2, the current biological tools only monitor a few species, e.g., red grouper, octopus, and lobster. The biological tools lack monitoring of biomass changes, and as much as 90% of the landing do not have sufficient information to inform regulations and management plans (**Table 2**). The next step will be to implement monitoring across the diverse suite of targets that informs the response of the targets to climate change. As each of these fisheries adapts and implements comprehensive monitoring programs to anticipate changes in fish stock distribution and productivity driven by climate change, the fishery can avoid crisis management and facilitate fishery planning (Fujita, 2021).

Almost all of case studies prioritize the polycentricity of governance and the building of better lines of communication, the participation between various stakeholders (case studies 2–7) or planning and participation (case studies 1–7; **Table 2**). The polycentricity of governance occurs through social tools, such as multistakeholder working groups and committees, cooperatives targeting underrepresented groups, and participatory monitoring. A common governance tool is co-management of the fisheries that are moving toward comprehensive monitoring and participation (**Table 2**).

While the case study fisheries employ various tools and pathways to avoid serial depletion while maintaining sustainable yields, they all rely on participatory processes to build awareness of the importance of multispecies management and approaches to overcome data limitations. Inclusive and participatory decision-making is key to moving forward a governance system that supports social equity in each of these fisheries (Bennett et al., 2021). In the case studies, other considerations align broadly with the ideals and principles of good governance (Borrini-Feyerabend and Hill, 2015). These include building local capacity in the decision-making process, transparency, and availability of information, decisions, and intentions to broaden stakeholder groups, and various accountability mechanisms (**Table 2**). Case studies 5 (Cuba), 6 (Juan Fernández Archipelago and Desventuradas Islands, Chile), and 7 (Los Ríos regions, Chile) illustrate a relatively new approach to multispecies management derived from the stock complex concept: fish baskets. Even though case studies 5, 6, and 7, are currently the only examples presented that utilize the fish baskets approach, many of the other case studies have interests in incorporating the fish baskets process in the next phase of transitioning from single species to multispecies management. The transition to the fish baskets approach can be relatively easy for these fisheries, as the most resource-intensive effort and the essential step of engaging stakeholders (via data collection, goal development, etc.) has already begun during the fishery management plan development.

The only case study that has transitioned from the management plan development phase to the implementation phase is the MCAIP Caulín case study (SUBPESCA, 2021). For many years, many fisheries have been working on the transition from a single species policy and management process to a multispecies process. Mechanisms that incentivize proactive planning, stakeholder communication, and engagement and provide appropriate data tools (for example, EDF, 2021b) are a welcomed resource to move forward fishery management plans from development to implementation. This process is supported by the knowledge that the plan, including the underlying monitoring and data collection that underpins the assessment process, will adapt over time, increasing capacity and certainty in implementation actions and management plans.

Certainty around how marine ecosystems and fisheries will respond to climate change is not guaranteed, by showcasing examples of fisheries that are using common tools and pathways for developing climate-adaptive fisheries management, for a variety of species, under different environmental and governance contexts can contribute to an increase in certainty for other fisheries that are transitioning to climate-resilient fishery management. Each of the case studies has either fully or begun to incorporate the foundations of climate-resilient fisheries into the process of fishery management plan development through the advancement of (1) effective fishery management systems, (2) instilling a participatory process, incorporating (3) precautionary actions in either the planning or implementation phase, and developing an (4) adaptive fishery management plan (Bahri et al., 2021). Likewise, the case studies are using similar tools and pathways to move toward climate resilience.

FISH BASKETS: AN ALTERNATIVE CLIMATE-RESILIENT MULTISPECIES MANAGEMENT APPROACH

Over the past decade, progress has been made for overcoming the critical scientific challenges of managing poorly understood multispecies fisheries systematically, beginning with the development and implementation of data-limited assessment and management approaches (e.g., FISHE, Fujita et al., 2013; EDF, 2021a; **Supplementary Figure 1**; AFM, McDonald et al., 2017; McDonald et al., 2018 and FishPath, Dowling et al., 2016). The use of indicator species, stock complexes, or métiers-based approaches for multispecies fisheries management also appears promising (Cope et al., 2011; Ulrich et al., 2012; Newman et al., 2018). Moreover, the concept of multispecies Pretty Good Yield provides a way of setting target biomass levels for various species with different productivity levels that can achieve a large percentage of maximum sustainable yield (Hilborn, 2010). But these approaches have not been widely adopted – especially in small-scale, data-, governance-, and resource-limited fisheries.

Stock complexes (e.g., Cope et al., 2011; NOAA Fisheries, 2019) and indicator species (Newman et al., 2018) are a way to manage multispecies fisheries, most often in data-rich, high-capacity governance systems. Similarly, the métier-based approach is helpful to create a typology for fishery management, from data collection to management tiers (e.g., Ulrich et al., 2012; Salas et al., 2019). Stock complexes and métiers are groups of species with similar geographic distributions, life histories, exploitation patterns,

TABLE 2 | Description of the fishery management challenges, and tools (e.g., biological, social, and governance) and science-based pathway utilized by each multispecies fishery.

		Tools			Pathway
Fishery	**Challenge**	**Biological**	**Social**	**Governance**	
(1) Commercial fisheries of the Yucatan Peninsula, Mexico	*YP fishery system is associated with over-exploitation that are linked to illegal fishing activities (non-compliance of the fishing quota, fishing activities during the closed season), rising unregulated fishing effort, poor government capacity to coordinate surveillance, and limited interaction between the government and fishing groups*	Monitoring, assessment, and management is focused on a few species (i.e., red grouper, octopus, and lobster); therefore 90% of the species landed in the region do not have sufficient information to inform regulations and management plans.	Fisheries management actions under the new typology include social arrangement and cooperation plan	Development of a community typology, small-scale multispecies fisheries from 22 communities are organized into three clusters differentiated by fishing production, species composition, fishing effort, and economic characteristics.	**Move toward a transdisciplinary approach:** multistakeholder investment in biological data, landings data, and socioeconomic information (per species), to address the complex problems that multispecies fisheries face at both the sub-regional and community level.
(2) Multispecies finfish fishery of the State of Yucatan, Mexico	*YP management system focuses only on the highly valued commercial species. All management, research, monitoring, and regulatory efforts focus on red grouper; however, fisheries that occur in the same area or are also associated species are seldom prioritized and lack strategies that promote fishery and livelihood sustainability.*	Monitoring, assessment, and management is focused only on red grouper.	Inclusion of key stakeholder groups, the academic partnerships, capacity building activities, and effective involvement of the fisheries sector.	Establishment of the Fisheries State Ministry, reinstatement of the State of Yucatan Fisheries and Aquaculture Council, and establishment of the Management Consulting and Nautical Committees.	**Collaborative, multistakeholder committees and management plan**; focused on the social, economic, and environmental guidelines for fisheries sustainability.
(3) Multispecies Bivalve Fishery of Sinaloa, Mexico	*Government institutions, NGOs and fisher groups have been working together to develop a scalable model for ecosystem-based multispecies management in the AEP Lagoon System, that increases fisheries regulations and reduces the administration deficient the bivalve resources.*	Community-based monitoring and surveillance -Enlaces Comunitarios, Market Analysis, Chocolate Clam Fisheries Improvement Project (FIP) in coordination the NGO Pronatura Noroeste (PNO), INAPESCA science.	Women's fishing cooperatives, Fortachones - Leadership Development Program for local fishing communities	Co-management-Consulting Committee for Fisheries Management and Administration of the Multistakeholder Lagoon System, established a no take zone/fishing refuge area and a two-year total ban on harvest for the target species.	A **multistakeholder** d**esigned and implemented ecosystem-based management** plan for all species and fishers involved in the AEP lagoon. Ultimately shifting from a single species FMP to holistic science-based and adaptive climate-resilient multispecies FMP.
(4) Caulín Marine Coastal Area of Indigenous People (MCAIP) Northern Patagonia, Chile	*Subsistence multispecies fisheries with a high diversity of non-commercial targets (therefore low to little money to monitor) that are "data-poor," making both decision-making and implementation of management measures under the government requirements difficult.*	Stock assessment complemented with traditional ecological knowledge (TEK) based approach to develop local models of species distribution; using participatory mapping and semi-structured interviews.	Use of focus groups, to validate and adjust the findings and results obtained through participatory mapping and interviews.	MACAIP protect and safeguard customary uses of coastal indigenous communities. MCAIPs bring together local stakeholders to develop a fisheries co-management system. MCAIPs recognize local governance systems in the development of fisheries management and conservation strategies.	**Participatory fishery monitoring and multispecies fishery management plan performance assessment requires outreach programs at local scale**. Periodic assessment requires technical support as well as local community participation for both, the correct implementation of management measures, and for the evaluation of performance indicators.

(Continued)

TABLE 2 | (Continued)

Fishery	Challenge	Tools			Pathway
		Biological	Social	Governance	
(5) Multispecies Finfish Fisheries Management in Cuba	*Establish the management of fishery resources under the principles of conservation, sustainable use, the precautionary approach, the implementation of scientific-technological criteria and the protection of ecosystems, in correspondence with national and international standards and the principles of food security and sovereignty of the nation.*	Data-limited assessment tools, e.g., PSA and upside models for target finfish species. Multistakeholder development and use of fish baskets for managing multispecies fisheries.	Multi-institutional working group (the main scientific and administrative institutions, and EDF), learning network among key stakeholders; including an Encuentro Pesquero" (Fishers' Forum) and the "Taller de Escama"(Finfish Workshop) that brought together representatives from 10 fishing communities, university short-course on fishery science and management.	Increased collaboration and engagement with fishers and fishing communities in the development of fish baskets and multispecies fisheries management.	**Multistakeholder (e.g., government, fishers, academia, and industry) designed and implemented multispecies management plan, using fish baskets**. Transitioning from monitoring and managing very few species, with single species FMP to a science-based and adaptive climate-resilient multispecies FMP.
(6 and 7) ***Forgotten Fish of Chile***	*In Chile's forgotten fisheries, communication is minimal among stakeholders, and both data and resources are not available for adaptive multispecies fisheries management, whether through top-down government stewardship or co-management by stakeholders.*	Data-limited assessment tools under FISHE, e.g., PSA, and CARE for target finfish species. Multistakeholder development and use of fish baskets for managing multispecies fisheries.	Multi-institutional working group (the main scientific and administrative institutions, fishing communities/fishing federations and EDF), learning network among key stakeholders, fisher request for support for FMP development.	Increased communication and engagement among fishing community, and the development of fish baskets and multispecies fisheries management.	**Fishing community designed climate-resilient fishery management plan, using fish baskets**. Increasing knowledge that monitoring and data collection is important and achievable, ultimately supporting the assessment and management of the fishery.

The name of each case study is in bold, as well at the challenges, types of tools and pathway used by each fishery.

and vulnerability to fisheries, managed as a single unit. Indicator species are selected 'indicators' of each group for assessing the risk to the sustainability of all similar species susceptible to capture within a fishery. The case studies suggest that participatory processes and data-limited assessment methods, driven by stakeholders' needs, can make multispecies fishery management more transparent and implementable in lower-resource governance contexts (EDF, 2021a; **Supplementary Text 1**).

Regardless of the multispecies management approach, a mechanism to convert scientific guidance to climate-resilient science-based management will be necessary given climate change's current and anticipated impacts on fisheries (Barange et al., 2018). Many fisheries have yet to carry out projections of fish stock distribution resulting from climate change that can provide such guidance. Here, we present a new approach for multispecies management that integrates the concepts of climate projection, stock complexes, indicator species, and participatory processes to create a framework, even in fisheries with insufficient data, resources, and governance (fish baskets approach).

As part of the Framework for Integrated Stock and Habitat Evaluation (FISHE) (EDF, 2021a), the fish baskets approach starts with a "climate profiling" step. Current projections of climate impacts (such as AquaMaps; Kaschner et al., 2010) along with scientific and expert knowledge of physiological tolerances, behavioral tendencies, and ecological requirements to anticipate future distribution and productivity of fishery target stocks to aid in planning. FISHE also includes data-limited tools for evaluating risks posed by climate change to ecosystems supporting fisheries (Battista et al., 2017) and assessing the climate vulnerability of target species (based on Hare et al., 2016). Outputs from these tools are included in the reference values, harvest control rules, and harvest control measures to account for climate impacts later in the FISHE process (EDF, 2021b, **Supplementary Text 2**).

The fish baskets approach also includes data-limited methods to rapidly estimate the vulnerability to overfishing

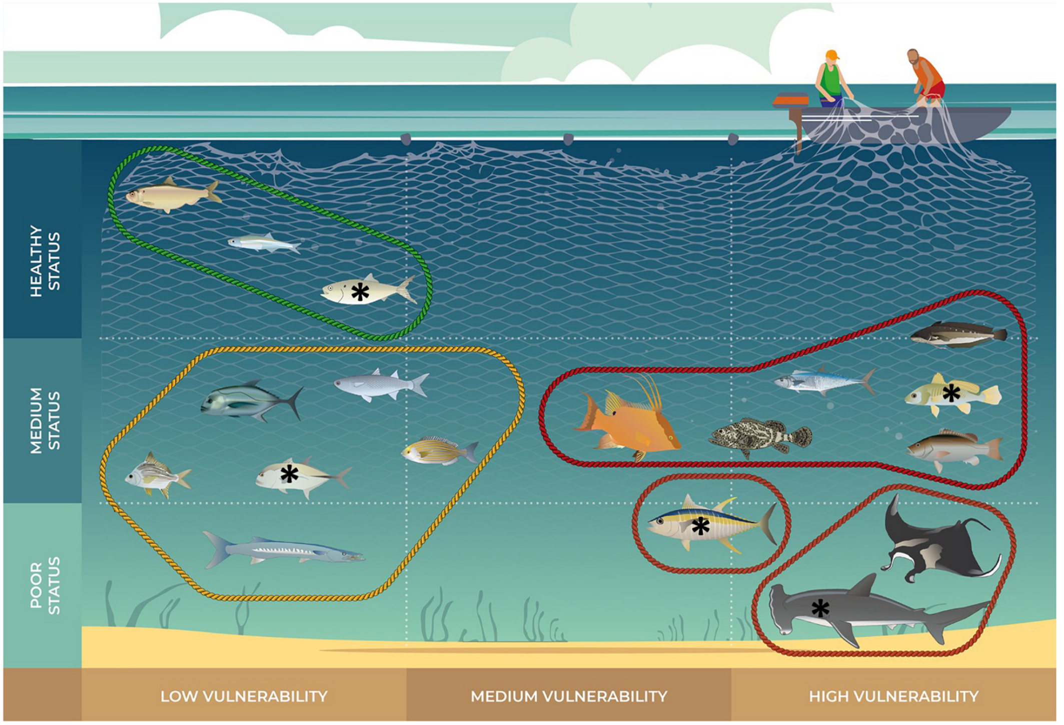

FIGURE 2 | Representative fish baskets, based on the relative estimates of vulnerability to overfishing (high, medium, low) and status (poor, moderate, and healthy) of each species. Each species is organized into a prioritization management basket; green for low, yellow for medium and red for high priority) for precautionary management. Each fish basket has an indicator species (*) to guide monitoring, assessment, and regulation implementation around © KualiComunicación, 2021.

and depletion/health status of all the stocks in a multispecies fishery (EDF, 2021a). These two measures initially sort species into groups with similar vulnerability, exploitation impacts, and stock status characteristics. Ultimately, stakeholders determine which species should be grouped based on social, economic, and ecological needs, a critical step to define stock complexes (fish baskets) for management. Indicator species that represent each basket or the lowest productivity species or highest climate change vulnerability (depending on risk tolerance and other considerations) within the basket are chosen and assessed more thoroughly using available data and expert knowledge (**Supplementary Text 2**). Reference points, harvest control rules, and harvest control measures for each indicator species can be made with a multi-indicator climate-ready adaptive management framework, such as FISHE (EDF, 2021a; **Figure 2**).

TRANSITIONING TO MULTISPECIES MANAGEMENT

How can small-scale multispecies fisheries transition to science-based, climate-resilient fishery management? Although the fisheries described in the case studies have not yet fully implemented multispecies fisheries management, they are each on a pathway toward that end. Several approaches are introduced in the case studies that are advancing multispecies management, including networks for communication and capacity building (e.g., learning networks, fisher exchanges; Jenkins et al., 2017), community-based fishery monitoring, bioeconomic modeling, leadership and women fisher development programs, recognition and use of traditional ecological knowledge, and the fish baskets approach (**Table 2**).

Fish baskets, an approach designed by local stakeholders to overcome challenges associated with conventional multispecies fisheries management approaches (i.e., lack of data and scientific capacity) by simplifying the assessment and management process and preventing serial depletion while moving toward sustainable fishery yields, profits, and livelihoods (EDF, 2021a), were also used in some of these case studies. The Fish baskets approach is a climate-resilient multispecies fishery management tool being applied in diverse fisheries worldwide, including those with different governance strategies and data availability (e.g., Belize, Cuba, and Chile).

Each case study utilizes a participatory process to motivate multispecies management, share knowledge, build capacity, create, and implement multispecies management plans (**Table 2**). Participatory processes are essential for supplementing scientific knowledge with traditional/local ecological knowledge and generating transparency and buy-in to the management process (Karr et al., 2017). Additionally, these case studies show how a participatory process combined with capacity building (i.e., technical knowledge, leadership development, and increased communication among stakeholders) leads to co-management, which in the case of these fisheries is key to durable and adaptive solutions for fishery management (d'Armengol et al., 2018; Wilson et al., 2018). Additionally, the case study fisheries all rely on co-management as a platform for anticipating climate impacts and adopting fishery indicators, reference values, harvest control rules, and harvest control measures that are sensitive to these impacts and adapt to changing conditions, promoting both ecological and social resilience.

Multispecies fisheries management shows great promise to reduce or prevent serial depletion and associated adverse impacts on social, economic, and ecological fishery performance goals by allowing for a more holistic understanding of the effects of fishing, climate, and other stressors on the ecosystem. Conventional approaches, such as setting catch limits for each stock or the use of spatial restrictions, can result in adverse impacts such as high discard rates and the dislocation of fishing effort. Moreover, they generally do not include ways to project the impacts of climate change as an aid to fishery planning. The fish baskets approach is a participatory framework for carrying out climate profiling and data-limited assessments and for articulating goals, indicators, reference values, harvest control rules, and harvest control measures that adapt to changes in stock status to expand the number of fisheries that can implement multispecies management to improve their performance.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

KK and VM conceived the symposium for IMCC 6: Resilient Multispecies Fisheries; in which each case study was initially presented, organized the case studies, processed the lessons learned and wrote the manuscript. DR and RF contributed to the organization of information and the manuscript. EC and NO-B contributed to both Yucatan Peninsula, Mexico case studies. MR contributed to the Sinaloa, Mexico case study. RA, RP, and SV contributed to the Cuba case study. JN, CV-F, and LH-B contributed to the Caulín MCAIP, Chile case study. LO, JS, and MM contributed to the Los Ríos and Juan Fernández Archipelago case studies. All authors wrote the manuscript and gave final approval of the version to be published and agree to be accountable for all aspects of the work.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.721883/full#supplementary-material

REFERENCES

Aguilar-Medrano, R., and Vega-Cendejas, M. E. (2019). Implications of the Environmental Heterogeneity on the Distribution of the Fish Functional Diversity of the Campeche Bank, Gulf of Mexico. *Mar. Biodivers.* 49, 1913–1929. doi: 10.1007/s12526-019-00954-y

Ahumada, M., and Queirolo, D. (2014). Fish Exploitation Associated to the Artisanal Fishing of Juan Fernández Lobster (*Jasus frontalis*). *Lat. Am. J. Aquat. Res.* 42, 213–223. doi: 10.3856/vol42-issue1-fulltext-18

Alzugaray, R., Puga, R., Valle, S., Morales, O., Grovas, A., López, L., et al. (2019). Un Enfoque Multiinstitutional para Modelar el Beneficio Bioeconómico de Perspectivas de Manejo Pesquero en Cuba. *Rev. Cub. Inv. Pesq.* 36, 52–61.

Arana, E. P. (1987). "Perspectivas Históricas y Proyecciones de la Actividad Pesquera Realizada en el Archipíelago de Juan Fernández, Chile," in *Islas Oceánicas Chilenas: Su Conocimiento Científicos y Necesidades de Investigaciones*, ed. J. C. Castilla (Santiago, CL: Ediciones Univ. Católica de Chile), 319–353.

Arreguín-Sánchez, F. (2019). Climate Change and the Rise of the Octopus Fishery in the Campeche Bank, México. *Reg. Stud. Mar. Sci.* 32:100852. doi: 10.1016/j.rsma.2019.100852

Arreguín-Sánchez, F., and Arcos-Huitrón, E. (2011). La Pesca en México: Estado de La Explotación y Uso de los Ecosistemas. *Hidrobiológica* 21, 431–462.

Bahri, T., Vasconcellos, M., Welch, D. J., Johnson, J., Perry, R. I., Ma, X., et al. (eds) (2021). "Adaptive management of fisheries in response to climate change," in *FAO Fisheries and Aquaculture Technical Paper No. 667*, (Rome: FAO).

Baisre, J. A. (2000). *Chronicle of Cuban Marine Fisheries, 1935-1995: Trend Analysis and Fisheries Potential.* Rome: FAO, 394.

Baisre, J. A. (2006). Assessment of Nitrogen Flows into the Cuban Landscape. *Biogeochemistry* 79, 91–108. doi: 10.1007/s10533-006-9004-z

Baisre, J. A. (2018). An Overview of Cuban Commercial Marine Fisheries: The Last 80 Years. *Bull. Mar. Sci.* 94, 359–375. doi: 10.5343/bms.2017.1015

Baisre, J. A., and Arboleya, Z. (2006). Going Against the Flow: Effects of River Damming in Cuban Fisheries. *Fish. Res.* 81, 283–292. doi: 10.1016/j.fishres.2006.04.019

Barange, M., Bahri, T., Beveridge, M. C. M., Chochrane, K. L., Funge-Smith, S., and Poulain, F. (2018). Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options. *FAO Fish. Tech. Pap.* 627, 1–628.

Battista, W., Karr, K., Sarto, N., and Fujita, R. (2017). Comprehensive Assessment of Risk to Ecosystems (CARE): A Cumulative Ecosystem Risk Assessment Tool. *Fish. Res.* 185, 115–129. doi: 10.1016/j.fishres.2016.09.017

Bennett, N. J., Katz, L., Yadao-Evans, W., Ahmadia, G. N., Atkinson, S., Ban, N. C., et al. (2021). Advancing Social Equity in and Through Marine Conservation. *Front. Mar. Sci.* 8:711538. doi: 10.3389/fmars.2021.711538

Berkes, F. (1999). *Sacred Ecology: Traditional .Ecological Knowledge and Resource Management*. Philadelphia: Taylor & Francis.

Berkström, C., Papadopoulos, M., Jiddawi, S., and Nordlund, M. (2019). Fishers' Local Ecological Knowledge (LEK) on Connectivity and Seascape Management. *Front. Mar. Sci.* 6:130. doi: 10.3389/fmars.2019.00130

Bonzon, K., McIlwain, K., Strauss, C. K., and Van Leuvan, T. (2013). Catch Share Design Manual: A Guide for Managers and Fishermen, 2nd Edition. *Environ. Defense Fund.* 1, 1–143.

Borrini-Feyerabend, G., and Hill, R. (2015). "Governance for the conservation of nature," in *Protected Area Governance and Management*, eds G. L. Worboys, M. Lockwood, A. Kothari, S. Feary, and I. Pulsford (Canberra, ACT: ANU Press), 169–206.

Branch, T. A. (2009). How Do Individual Transferable Quotas Affect Marine Ecosystems? *Fish. Fish.* 10, 39–57. doi: 10.1111/j.1467-2979.2008.00294.x

Branch, T. A., Watson, R., Fulton, E. A., Jennings, S., McGilliard, C. R., Pablico, G. T., et al. (2010). The Trophic Fingerprint of Marine Fisheries. *Nature* 468, 431–435. doi: 10.1038/nature09528

Brulé, T., Nóh-Quiñones, V., Sánchez-Crespo, M., Colás-Marrufo, T., and Pérez-Díaz, E. (2009). Commercial Catch Composition of the Grouper-Snapper Complex from the Southern Gulf of Mexico and Implications for the Management of its Fishery. *Proc. GCFI* 2008, 198–209.

Butler, J. R. A., Tawake, A., Skewes, T., Tawake, L., and McGrath, V. (2012). Integrating Traditional Ecological Knowledge and Fisheries Management in the Torres Strait, Australia: the Catalytic Role of Turtles and Dugong as Cultural Keystone Species. *Ecol. Soc.* 17, 1–19.

Cariman, P. J., and Reyes, P. R. (2019). Estado del Conocimiento Biológico y Pesquero de *Thyrsites atun* en el Hemisferio Sur. *Rev. Biol. Mar. Oceanogr.* 54, 11–20. doi: 10.22370/rbmo.2019.54.1.1434

Carlisle, K., and Gruby, R. L. (2017). Polycentric Systems of Governance: A Theoretical Model for the Commons. *Policy Stud. J.* 47, 927–951. doi: 10.1111/psj.12212

Christensen, A.-S. (2009). *Conflict and Complementarity – An Empirical Study of Conflicts Between Danish Fishermen and Fisheries Management Aiming to Develop an Interdisciplinary Framework to Understand and Mitigate Conflicts in Fisheries*. Ph. D. thesis. Aalborg, DK: Aalborg Universitet.

Christensen, V., and Pauly, D. (2004). Placing Fisheries in Their Ecosystem Context, An Introduction. *Ecol. Model.* 172, 103–107. doi: 10.1016/j.ecolmodel.2003.09.002

Chuenpagdee, R., Morgan, L. E., Maxwell, S. M., Norse, E. A., and Pauly, D. (2003). Shifting Gears: Assessing Collateral Impacts of Fishing Methods in US Waters. *Front. Ecol. Environ.* 1:517–524. doi: 10.1890/1540-92952003001[0517:SGACIO]2.0.CO;2

Cisneros-Mata, M. A., Mangin, T., Bone, J., Rodriguez, L., Smith, S. L., and Gaines, S. D. (2019). Fisheries Governance in the Face of Climate Change: Assessment of Policy Reform Implications for Mexican Fisheries. *PLoS One* 14:10. doi: 10.1371/journal.pone.0222317

Claro, R., Baisre, J. A., Lindeman, K. C., and García-Arteaga, J. P. (2001). Cuban fisheries: historical trends and current status. *Ecol. Mar. Fishes Cuba* 2001, 194–219.

Claro, R., de Mitcheson, Y. S., Lindeman, K. C., and García-Cagide, A. R. (2009). Historical Analysis of Cuban Commercial Fishing Effort and the Effects of Management Interventions on Important Reef Fishes from 1960–2005. *Fish. Res.* 99, 7–16. doi: 10.1016/j.fishres.2009.04.004

COBI (2016). *Fortalecimiento de Comunidades Pesqueras del Sistema Lagunar Altata-Ensenada del Pabelloìn, Sinaloa, Environmental Defense Fund de México*. Available online at: https://cobi.org.mx/wp-content/uploads/2016/10/Taller-de-Fortalecimiento-Comunitario_Sinaloa-EDF.pdf (accessed May 7, 2021).

Comité Consultivo de Manejo de la Pesquería de Mero de Yucatán y Red de Investigadores de Mero (2019). *Prioridades para el manejo y la investigación de la pesquería de mero. Mérida, Yucatán. June 2020*. Unpublished report.

CONAPESCA (2018). *Anuario Estadístico de Acuacultura y Pesca 2018. Comisioìn Nacional de Acuacultura y Pesca*. Mazatlán: National Commission of Fisheries and Aquaculture.

Cope, J. M., DeVore, J., Dick, E. J., Ames, K., Budrick, J., Erickson, D. L., et al. (2011). An Approach to Defining Stock Complexes for U.S. West Coast Groundfishes Using Vulnerabilities and Ecological Distributions. *N. Am. J. Fish. Manag.* 31, 589–604. doi: 10.1080/02755947.2011.591264

Coronado, E., Salas, S., Torres-Irineo, E., and Chuenpagdee, R. (2020b). Disentangling the Complexity of Small-Scale Fisheries in Coastal Communities Through a Typology Approach: The Case Study of the Yucatán Peninsula, Mexico. *Reg. Stud. Mar. Sci.* 36:101312. doi: 10.1016/j.rsma.2020.101312

Coronado, E., Salas, S., Cepeda-González, M. F., and Chuenpagdee, R. (2020a). Who's Who in the Value Chain For The Mexican Octopus Fishery: Mapping The Production Chain. *Mar. Policy* 118:104013. doi: 10.1016/j.marpol.2020.104013

Costello, C., Ovando, D., Clavelle, T., Strauss, C. K., Hilborn, R., Melnychuk, M. C., et al. (2016). Global Fishery Prospects Under Contrasting Management Regimes. *Proc. Natl. Acad. Sci.* 113, 5125–5129. doi: 10.1073/pnas.1520420113

d'Armengol, L., Prieto-Castillo, M., Ruiz-Mallén, I., and Corbera, E. (2018). A Systematic Review of Co-Managed Small-Scale Fisheries: Social Diversity and Adaptive Management Improve Outcomes. *Glob. Environs. Change* 52, 212–225. doi: 10.1016/j.gloenvcha.2018.07.009

DOF (2014). *ACUERDO por el que se da a conocer el plan de manejo Pesquero de Mero (Epinephelus morio) y especies asociadas en la península de Yucatán. SEGOB*. Mexico City: Diario Oficial de la Federación (DOF).

DOF (2015). *NORMA Oficial Mexicana NOM-065-SAG/PESC-2014, Para regular el aprovechamiento de las especies de mero y especies asociadas, en aguas de jurisdicción federal del litoral del Golfo de México y Mar Caribe*. Mexico City: Diario Oficial de la Federación (DOF).

DOF (2017). *Acuerdo por el que se modifica el similar por el que se establece veda para la captura de todas las especies de mero en las aguas de jurisdicción federal del Golfo de México correspondientes al litoral de los estados de Campeche, Yucatán y Quintana Roo, publicado el 14 de febrero de 2007. Primera seccion. 03-3-2017*. Mexico City: Diario Oficial de la Federación (DOF).

DOF (2018). *ACUERDO por el que se da a conocer la Carta Nacional Pesquera. Instituto Nacional de Pesca. Ciudad de México, México*. Mexico City: Diario Oficial de la Federación (DOF).

DOF (2019). *ACUERDO por el que se Da a Conocer el Plan de Manejo Ecosistémico del Sistema Lagunar Altata-Ensenada del Pabellón, Ubicado en los Municipios de Navolato y Culiacán, del Estado de Sinaloa. SEGOB*. Mexico City: Diario Oficial de la Federación (DOF).

DOF (2020). *ACUERDO por el que se establece veda temporal para la captura de almeja revénos (Megapitaria squalida) en el Sistema Lagunar Altata-Ensenada del Pabellón, en los Municipios de Navolato y Culiacán, Sinaloa. SEGOB*. Mexico City: Diario Oficial de la Federación (DOF).

DOEY (2018). ACUERDO por el que se modifica el Código de la Administración Pública de Yucatán, en materia de reestructuración de la Administración Pública Estatal. Ed. Vespertina. *Gobierno del Estado de Yucatán* 33, 1–15. doi: 10.30875/04343d54-es

Ding, Q., Chen, X., Hilborn, R., and Chen, Y. (2017). Vulnerability to impacts of climate change on marine fisheries and food security. *Mar. Policy* 83, 55–61. doi: 10.1016/j.marpol.2017.05.011

Dowling, N. A., Wilson, J. R., Rudd, M. B., Babcock, E. A., Caillaux, M., Cope, J., et al. (2016). "FishPath: a decision support system for assessing and managing data- and capacity-limited fisheries," in *Assessing and Managing Datalimited Fish Stocks*, eds T. J. Quinn, J. L. Armstrong, M. R. Baker, J. Heifetz, and D. Witherell (Alaska: University of Alaska), 59–95.

EDF (2021a). *FISHE: Framework for Integrated Stock and Habitat Evaluation*. New York, NY: Environmental Defense Fund (EDF).

EDF (2021b). *Engaging with Cuban fishing communities*. New York, NY: Environmental Defense Fund (EDF).

EDF (2021c). *"What's the Catch?" fishing game*. New York, NY: Environmental Defense Fund (EDF).

Ernst-Elizalde, B., Manríquez-Angulo, P., Orensanz, J. M., Roa, R., Chamorro-Solís, J., and Parada-Velíz, C. (2010). Strengthening of a Traditional Territorial Tenure System Through Protagonism in Monitoring Activities by Lobster Fishermen from the Juan Fernández Islands, Chile. *Bull. Mar. Sci.* 86, 315–338.

Ernst-Elizalde, B., Pino-Aguilera, J., Chamorro-Solís, J., Manríquez-Angulo, P., Rivara-Saacedra, P., Tapia-Álvarez, B., et al. (2020). Pesqueriía de crustaáceos del archipieìlago Juan Fernaìndez. *Boletín de Difusión* 2020, 1–28.

Espinoza, C. (2016). Ley del Borde Costero y Cuestión Étnica en Chile: Del Discurso a la Práctica Política. *Universum* 31, 123–139. doi: 10.4067/S0718-23762016000100008

Espinoza-Tenorio, A., Espejel, I., and Wolff, M. (2011). Capacity Building to Achieve Sustainable Fisheries Management in Mexico. *Ocean Coast. Manag.* 54, 731–741. doi: 10.1016/j.ocecoaman.2011.07.001

Essington, T. E., Melnychuk, M. C., Branch, T. A., Heppell, S. S., Jensen, O. P., Link, J. S., et al. (2012). Catch Shares, Fisheries, and Ecological Stewardship: A Comparative Analysis of Resource Responses to a Rights-Based Policy Instrument. *Conserv. Lett.* 5, 186–195. doi: 10.1111/j.1755-263X.2012.00226.x

FAO (2020). *The State of World Fisheries and Aquaculture 2020*. Rome: FOA, doi: 10.4060/ca9229en

Farmer, N. A., Malinowski, R. P., McGovern, M. F., and Rubec, P. J. (2016). Stock Complexes for Fisheries Management in the Gulf of Mexico. *Mar. Coastal Fisher.* 8, 177–201. doi: 10.1080/19425120.2015.1024359

Fernández, J. I., Álvarez-Torres, P., Arreguín-Sánchez, F., López-Lemus, L. G., Ponce, G., Díaz-de-León, A., et al. (2011). "Coastal Fisheries of Mexico," in *Coastal Fisheries of Latin America and the Caribbean*, eds S. Salas, R. Chuenpagdee, A. Charles, and J. C. Seijo (Rome: FAO), 231–284.

Fishery Progress (2021). *Mexico Gulf of California Sinaloa chocolate clam – Diving & Hand Gathered. Fisheries Improvement Project (FIP)*. Available online at: https://fisheryprogress.org/fip-profile/revén-gulf-california-sinaloa-chocolate-clam-diving-hand-gathered (accessed April 9, 2020).

Flores-Nava, A., Villanueva-García-Benítez, J., Vidal-Martínez, V. M., Olvera-Nóvoa, M. A., Alonzo Marrufo, E. R., Arreguín-Sánchez, F., et al. (2016a). *Diagnóstico de los sectores de la pesca y la acuacultura en el estado de Yucatán in FAO-SEDER*. Yucatán: Gobierno del Estado de Yucatán.

Flores-Nava, A., Villanueva-García-Benítez, J., Vidal-Martínez, V. M., Olvera-Nóvoa, M. A., Alonzo Marrufo, E. R., Arreguín-Sánchez, F., et al. (2016b). *Plan rector para el desarrollo de la pesca y la acuacultura Sostenibles de Yucatán in FAO-SEDER*. Yucatán: Gobierno del Estado de Yucatán.

Free, C. M., Mangin, T., Molinos, J. G., Ojea, E., Costello, C., and Gaines, S. D. (2020). Realistic Fisheries Management Reforms Could Mitigate the Impacts of Climate Change in Most Countries. *PLoS One* 15:e0224347. doi: 10.1371/journal.pone.0224347

Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., and Jensen, O. P. (2019). Impacts of Historical Warming on Marine Fisheries Production. *Science* 363, 979–983. doi: 10.1126/science.aau1758

Fujita, R. (2021). The assessment and management of data limited fisheries: Future directions. *Mar. Policy* 133:104730. doi: 10.1016/J.MARPOL.2021.104730

Fujita, R., Thornhill, D. J., Karr, K., Cooper, C. H., and Dee, L. E. (2013). Assessing and Managing Data-Limited Ornamental Fisheries in Coral Reefs. *Fish. Fish.* 15, 661–675. doi: 10.1111/faf.12040

Gaceta Municipal (2015). *Reglamentos internos del Comité Náutico y de ordenamiento pesquero local de Progreso, Chicxulub, Chelem y Chuburnápuerto. Municipio de Progreso, Yucatán. Año 1. Tomo 1., 229:1*. Available online at: http://ayuntamientodeprogreso.gob.mx/uthap/gaceta-municipal-229-h-ayuntamiento-2015-2018/ (accessed March 15, 2021).

Galindo-Cortes, G., Jiménez-Badillo, L., and Meiners, C. (2019). "Moving from Stock Assessment to Fisheries Management in Mexico: The Finfish Fisheries from the Southern Gulf of Mexico and Caribbean Sea," in *Viability and Sustainability of Small-Scale Fisheries in Latin America and the Caribbean*, Vol. 19, eds S. Salas, M. J. Barragán-Paladines, and R. Chuenpagdee (Cham: Springer), 243–263. doi: 10.1007/978-3-319-76078-0_11

García Molinos, J. (2020). Global Marine Warming in a New Dimension. *Nat. Ecol. Evol.* 4, 16–17. doi: 10.1038/s41559-019-1037-5

Gattuso, J. P., Magnan, A., Billé, R., Cheung, W. W., Howes, E. L., Joos, F., et al. (2015). Contrasting Futures for Ocean and Society from Different Anthropogenic CO2 Emissions Scenarios. *Science* 349:6243. doi: 10.1126/science.aac4722

Gerhartz-Muro, J. L., Kritzer, J. P., Gerhartz-Abraham, A., Miller, V., Pina-Amargós, F., and Whittle, D. (2018). An Evaluation of the Framework for National Marine Environmental Policies in Cuba. *Bull. Mar. Sci.* 94, 443–459. doi: 10.5343/bms.2017.1058

Gissi, N., Ibacache, D., Pardo, B., and y Ñancucheo, M. C. (2017). El Estado Chileno, Los Lafkenche y La Ley 20.249: ¿Indigenismo o Política del Reconocimiento? *Rev. Austral. Cienc. Soc.* 32, 5–21. doi: 10.4206/rev.austral.cienc.soc.2017.n32-01

Gobierno de México (2020). *Prevén aumento de aprovechamiento pesquero sustentable en el Sistema Lagunar Altata-Ensenada del Pabellón*. México: Gobierno de México.

Gordon, H. S. (1954). The economic theory of a common property resource. *J. Politic. Economy* 62:142.

Grimm, D., Barkhorn, I., Festa, D., Bonzon, K., Boomhower, J., Hovland, V., et al. (2012). Assessing Catch Shares' Effects: Evidence from Federal United States and Associated British Columbian Fisheries. *Mar. Pol.* 36, 644–657. doi: 10.1016/j.marpol.2011.10.014

Gutiérrez, N., Hilborn, R., and Defeo, O. (2011). Leadership, social capital and incentives promote successful fisheries. *Nature* 470, 386–389. doi: 10.1038/nature09689

Hare, J. A., Morrison, W. E., Nelson, M. W., Stachura, M. M., Teeters, E. J., Griffis, R. B., et al. (2016). A vulnerability assessment of fish and invertebrates to climate change on the Northeast U.S. continental shelf. *PLoS One* 11:e0146756. doi: 10.1371/journal.pone.0146756

Hilborn, R., Amoroso, R. O., Anderson, C. M., Baum, J.K., Branch, T. A., Costello, C., et al. (2020). Effective fisheries management instrumental in improving fish stock status. *Proc. Nat. Acad. Sci.* 117, 2218–2224. doi: 10.1073/pnas.1909726116

Hilborn, R. (2010). Pretty Good Yield and Exploited Fishes. *Mar. Policy* 34, 193–196. doi: 10.1016/j.marpol.2009.04.013

Hilborn, R. (2017). Traditional fisheries management is the best way to manage weak stocks. *Proc. Natl. Acad. Sci.* 114:E10610. doi: 10.1073/pnas.1715680114

Hilborn, R., Stokes, K., Maguire, J. J., Smith, T., Botsford, L. W., Mangel, M. et al. (2004). When can marine reserves improve fisheries management? *Ocean Coastal Manage.* 47, 197–205. doi: 10.1016/j.ocecoaman.2004.04.001

Hiriart-Bertrand, L., Silva, J. A., and Gelcich, S. (2020). Challenges and Opportunities of Implementing Marine and Coastal Areas for Indigenous Peoples Policy in Chile. *Ocean Coast. Manag.* 193:105233. doi: 10.1016/j.ocecoaman.2020.105233

Hiriart-Bertrand, L., Troncoso, J., Vargas, C., and Correa, A. (2019). "From Customary Law to the Implementation of Safeguard Measures: the Case of Marine and Coastal Areas for Indigenous People in Chile in Marine and Fisheries Policies," in *Latin America: A Comparison of Selected Countries*, eds M. Ruiz-Muller, R. Oyanedel, and B. Monteferri (New York, NY: Routledge), 137–146.

IPCC (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC.

Jenkins, L. D., Thompson, K. R., Bourillon, L., and Peckham, S. H. (2017). The Scope of Fisheries Learning Exchanges for Conservation. *Mar. Pol.* 77, 196–204. doi: 10.1016/j.marpol.2016.05.025

Jennings, S., and Kaiser, M. J. (1998). The Effects of Fishing on Marine Ecosystems. *Adv. Mar. Biol.* 34, 201–352. doi: 10.1016/S0065-2881(08)60212-6

Karr, K. A., Fujita, R., Carcamo, R., Epstein, L., Foley, J. R., Fraire-Cervantes, J. A., et al. (2017). Integrating Science-Based Co-Management, Partnerships, Participatory Processes and Stewardship Incentives to Improve the Performance of Small-Scale Fisheries. *Front. Mar. Sci.* 4:345. doi: 10.3389/fmars.2017.00345

Kaschner, K., Rius-Barile, J., Kesner-Reyes, K., Garilao, C., Kullander, S. O., Rees, T., et al. (2010). *AquaMaps: Predicted range maps for aquatic species*. Burlington, MA: World wide web electronic publication.

Kennedy, V. S. (1990). Anticipated Effects of Climate Change on Estuarine and Coastal Fisheries. *Fisheries* 15, 16–24. doi: 10.1577/1548-84461990015<0016:AEOCCO<2.0.CO;2

Kritzer, J. P., and Liu, O. R. (2014). "Fishery management strategies for Addressing Complex Spatial Structure in Marine Fish Stocks," in *In Stock Identification Methods*, eds S. X. Cadrin, L. A. Kerr, and S. Mariani (Boston: Academic Press), 29–57. doi: 10.1016/B978-0-12-397003-9.00003-5

Lobao-Tello, P. R. R., Hüne, M., and Soto, P. C. (2016). Technical Assistance for the Implementation of a Biological-Fishery Study of "Sierra" *Thyrsites atun* in the Los Ríos Region, South Chile. *Fundación Ictiológica, Fondo de Fomento para la Pesca Artesanal (FFPA)* 2016:03689. doi: 10.13140/RG.2.2.13961.03689

Lock, K., and Leslie, S. (2007). New Zealand's Quota Management System: A History of the First 20 Years. *Motu Econ. Pub. Pol. Res.* 2007:292825. doi: 10.22004/ag.econ.292825

Mason, J., Kosaka, R., Mamula, A., and Speir, C. (2012). Effort changes around a marine reserve: the case of the California Rockfish Conservation Area. *Mar. Policy* 36, 1054–1063. doi: 10.1016/j.marpol.2012.03.002

May, R. M., Beddington, J. R., Clark, C. W., Holt, S. J., and Laws, R. M. (1979). Management of multispecies fisheries. *Science* 205, 267–277.

McDonald, G., Campbell, S. J., Karr, K., Clemence, M., Granados-Dieseldorff, P., Jakub, R., et al. (2018). An Adaptive Assessment and Management Toolkit for Data-Limited Fisheries. *Ocean Coast. Manag.* 152, 100–119. doi: 10.1016/j.ocecoaman.2017.11.015

McDonald, G., Harford, B., Arrivillaga, A., Babcock, E. A., Carcamo, R., Foley, J., et al. (2017). An Indicator-Based Adaptive Management Framework and Its Development for Data-Limited Fisheries in Belize. *Mar. Policy* 76, 28–37. doi: 10.1016/j.marpol.2016.11.027

INAI (2020). *Plataforma Nacional de Transparencia Gobierno Federal*. Mexico: Mexico's National Transparency Platform (INAI).

"Ley de Pesca." República de Cuba (2019). *Ley 129 de 2019 de Asamblea Nacional del Poder Popular*. Cuba: "Ley de Pesca." República de Cuba.

Möllmann, C., Lindegren, M., Blenckner, T., Bergström, L., Casini, M., Diekmann, R., et al. (2014). Implementing Ecosystem-Based Fisheries Management: From Single-Species to Integrated Ecosystem Assessment and Advice for Baltic Sea Fish Stocks. *ICES J. Mar. Sci.* 71, 1187–1197. doi: 10.1093/icesjms/fst123

Mongabay (2019). *Chile: la ejemplar historia de los pescadores de Juan Fernández por la conservación de su mar*. Menlo Park, CA: Mongabay.

Morón, E. B., Vejarano, R. B., and Miller, V. (2019). Cuba: Netting Fishers. *Samudra Rep.* 81, 4–7.

Nakamura, K. (2015). *Multispecies Mixed Stock Fisheries Management –Review of Current& Best Practices for the Marine Stewardship Council, Technical Advisory Board November 2015*. London: Marine Stewardship Council.

National Geographic (2015). *Chile Creates Largest Marine Reserve in the Americas*. New York City: National Geographic.

Newman, S., Brown, J., Fairclough, D., Wise, B., Bellchambers, L., Molony, B., et al. (2018). A Risk Assessment and Prioritisation Approach to the Selection of Indicator Species for the Assessment of Multi-Species, Multi-Gear, Multi-Sector Fishery Resources. *Mar. Policy* 88, 11–22. doi: 10.1016/j.marpol.2017.10.028

NOAA Fisheries (2019). *Atlantic Highly Migratory Species: Stock Assessment and Fishery Evaluation Report*. Washington, D.C: NOAA.

Orensanz, J. M., and Seijo, J. C. (2013). "Rights-based Management in Latin American Fisheries," in *FAO Fish. Tech. Pap. No. 582*, (Rome: FAO).

Osman, L. P. (2016). "Pre-assessment landscape analysis and power map for Chilean near-shore small-scale fisheries," in *Environmental Defense fund Report*, (New York, NY: Environmental Defense Fund).

Ovando, D., Caselle, J. E., Costello, C., Deschenes, O., Gaines, S. D., Hilborn, R., et al. (2021). Assessing the population-level conservation effects of marine protected areas. *Conserv. Biol.* 2021:13782. doi: 10.1111/cobi.13782

Palomares, M. D., and Pauly, D. (2019). "Coastal Fisheries: The Past, Present, and Possible Futures," in *Coasts and Estuaries: The Future*, eds E. Wolanski, J. W. Day, M. Elliott, and R. Ramachandran (Amsterdam, NL: Elsevier), 569–576. doi: 10.1016/C2017-0-00731-0

PAN-Tiburones (2015). *Plan de Acción Nacional de Conservación y Manejo de Condrictios de la República de Cuba*. La Habana: Ministerio de la Industria Alimentaria.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. (1998). Fishing Down Marine Food Webs. *Science* 279, 860–863. doi: 10.1126/science.279.5352.860

Pauly, D., Christensen, V., Froese, R., and Palomares, M. L. (2000). Fishing Down Aquatic Food Webs. *Am. Sci.* 88, 46–51. doi: 10.1511/2000.1.46

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I. C., et al. (2017). Biodiversity Redistribution under Climate Change: Impacts on Ecosystems and Human Well-Being. *Science* 355:6332. doi: 10.1126/science.aai9214

Pelcastre, V., and García-Gutiérrez, I. (2021). *Evaluación rápida de las necesidades de conocimientos y habilidades para el sector pesquero de Yucatán*. Unpublished report.

Puga, R., Piñeiro, R., Alzugaray, R., Cobas, L. S., De León, M. E., and Morales, O. (2013). Integrating Anthropogenic and Climatic Factors in the Assessment of the Caribbean Spiny Lobster (*Panulirus argus*) in Cuba: implications for Fishery Management. *Int. J. Mar. Sci.* 3, 36–45. doi: 10.5376/ijms.2013.03.0006

Puga, R., Valle, S., Kritzer, J. P., Delgado, G., de León, M. E., Giménez, E., et al. (2018). Vulnerability of Nearshore Tropical Finfish in Cuba: Implications for Scientific and Management Planning. *Bull. Mar. Sci.* 94, 377–392. doi: 10.5343/bms.2016.1127

RAMSAR (2008). *Ensenada de Pabellones*. Gland: Ramsar Sites Information Service (RAMSAR).

RDA (2021). *Red de Aprendizaje: Pesca Artesanal – Chile*. New York, NY: Environmental Defense Fund.

Roa-Ureta, R. H., Henríquez, J., and Molinet, C. (2020). Achieving Sustainable Exploitation Through Co-Management in Three Chilean Small-Scale Fisheries. *Fish. Res.* 230:105674. doi: 10.1016/j.fishres.2020.105674

Roessig, J. M., Woodley, C. M., Cech, J. J., and Hansen, L. J. (2004). Effects of Global Climate Change on Marine and Estuarine Fishes and Fisheries. *Rev. Fish. Biol. Fish.* 14, 251–275. doi: 10.1007/s11160-004-6749-0

Rosales-Raya, M. L., and Fraga-Berdugo, J. E. (2018). Decision-Making in the Campeche Octopus Maya Fishery in Two Fishing Communities. *Marit. Stud.* 18, 91–101. doi: 10.1007/s40152-018-0127-3

Salas, S., Torres-Irineo, E., and Coronado, E. (2019). Towards a Métier-Based Assessment and Management Approach for Mixed Fisheries in Southeastern Mexico. *Mar. Policy* 103, 148–159. doi: 10.1016/j.marpol.2019.02.040

Salas, S., Chuenpagdee, R., Seijo, J. C., and Charles, A. (2007). Challenges in the Assessment and Management of Small-Scale Fisheries in Latin America and the Caribbean. *Fish. Res.* 87, 5–16. doi: 10.1016/j.fishres.2007.06.015

Sánchez-Carnero, N., Rodríguez-Pérez, D., Couñago, E., Le Barzik, F., and Freire, J. (2016). Species distribution models and local ecological knowledge in marine protected areas: the case of Os Miñarzos (Spain). *Ocean Coastal Manag.* 124, 66–77. doi: 10.1016/j.ocecoaman.2016.02.008

Schumann, S., and Macinko, S. (2007). Subsistence in coastal fisheries policy: what's in a word? *Mar. Pol.* 31, 706–718. doi: 10.1016/j.marpol.2006.12.010

SEPASY (2020). *Censo y reordenamiento pesquero 2019*. Yucatán: SEPASY.

SERNAPESCA (2019). *Anuarios Estadísticos de Pesca y Acuicultura*. Valparaíso: Servicio Nacional de Pesca y Acuicultura.

SUBPESCA (2021). *Aprueba planes de administración y de manejo y explotación para ECMPO que indica*. Valparaíso: Subsecretaría de Pesca y Acuicultura.

Turris, B. (2009). *Management of the British Columbia Groundfish Fisheries, Catch Shares Workshop [workshop]. October 20-21, 2009*. Bretton Woods: British Columbia Groundfish Fisheries.

Tus Buenas Noticias (2017). *De Altata la Primera Cooperative de Mujeres "Almejeras" de Sinaloa*. Culiacán: Tus Buenas Noticias.

Ulrich, C., Wilson, D. C., Nielsen, J. R., Bastardie, F., Reeves, S. A., Andersen, B. S., et al. (2012). Challenges and opportunities for fleet-and métier-based approaches for fisheries management under the European Common Fishery Policy. *Ocean Coastal Manage.* 70, 38–47. doi: 10.1016/j.ocecoaman.2012.06.002

Valle, S. V., Sosa, M., Puga, R., Font, L., and Duthit, R. (2011). "Coastal Fisheries of Cuba," in *Coastal Fisheries of Latin America and the Caribbean, FAO Fisheries and Aquaculture*, Vol. 544, eds S. Salas, R. Chuenpagdee, A. Charles, and J. C. Seijo (Rome: FAO), 155–174.

Voss, R., Quaas, M., Schmidt, J., and Hoffmann, J. (2014). Regional Trade-Offs from Multi-Species Maximum Sustainable Yield (MMSY) Management Options. *Mar. Ecol. Prog. Ser.* 498, 1–12. doi: 10.3354/meps10639

Warlick, A., Steiner, E., and Guldin, M. (2018). History of the West Coast Groundfish Trawl Fishery Tracking Socioeconomic Characteristics Across Different Management Policies in a Multispecies Fishery. *Mar. Pol.* 93, 9–21. doi: 10.1016/j.marpol.2018.03.014

Wilson, J. R., Lomonico, S., Bradley, D., Sievanen, L., Dempsey, T., Bell, M., et al. (2018). Adaptive Comanagement to Achieve Climate-Ready Fisheries. *Conserv. Lett.* 11:6. doi: 10.1111/conl.12452

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., et al. (2009). Rebuilding Global Fisheries. *Science* 325, 578–585. doi: 10.1126/science.1173146

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Public Perceptions of the Ocean: Lessons for Marine Conservation From a Global Research Review

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Insights into how public audiences perceive and relate to the ocean are pivotal to successful societal engagement and integration of human dimensions in marine conservation. Perceptions research explores how people understand, value or engage with an environment, issue or management response, and in the context of marine conservation, provides crucial insights for the development, delivery and evaluation of effective conservation interventions. This review of 349 peer reviewed studies explores the current state of research into public perceptions of the ocean. Using an extensive data extraction process, the review examined the geographical spread of ocean perceptions research, the topics of research focus, and the methods used. The review identifies gaps in current research activity, and opportunities for maximizing the impact of ocean perceptions research in current and future marine conservation. Key findings of the review include evidence that the rate of research is growing, with 59% of studies published between 2013–2017. However, a clear geographical skew is evident, with the majority of studies being undertaken in higher income countries. Furthermore, there has been a tendency to focus on charismatic species, or issues and spaces of clear human-ocean interaction (e.g., beaches), highlighting significant gaps in the topics and themes currently covered by ocean perceptions research. An additional gap identified is the underutilization of available methods to explore the complexity of marine perceptions. In a bid to address these gaps, the paper concludes with a series of recommendations designed to stimulate and support ocean perceptions research as being fundamental to the success of marine conservation efforts. While ocean perceptions research may be young, the growing research effort evidenced in this review gives optimism for realizing its potential and continuing to improve the integration of ocean perceptions research effectively into marine conservation.

Keywords: public perceptions, marine conservation, research, global review, policy, marine social sciences, society

INTRODUCTION

Ocean ecosystems are under intense and increasing pressure from human activities (O'Hara et al., 2021). Climate change, pollution and biodiversity loss undermine benefits to people which are essential for human survival (Worm et al., 2006; Pascual et al., 2017). Natural sciences have long provided the tools to assess and monitor ocean biodiversity and have been the dominant sciences applied to conservation (Mascia et al., 2003). However, there is now recognition that natural sciences alone are not sufficient to achieve marine conservation goals (Fletcher and Potts, 2007; Bennett, 2019). Marine conservation depends upon a clear understanding of the complex relationships between society and the ocean. The need to better understand these relationships has been recognized by both the marine research and policy communities (ISSC/UNESCO, 2013; Jefferson et al., 2015; Bennett, 2019; Bavinck and Verrips, 2020; McKinley et al., 2020a; Claudet, 2021). This shift has been echoed in the UN Decade of Ocean Science for Sustainable Development (2021–2031) which sets out the necessity of improved integration between natural and social sciences to tackle global ocean challenges (Ryabinin et al., 2019), and positions the Decade as a potential opportunity to forge a new and transformational relationship between society and the ocean.

Calls for a better understanding of the relationships between society and the ocean are not new. In the last two decades, various concepts have been proposed that envisage large scale societal changes to address the challenges facing the ocean, including, marine citizenship (Fletcher and Potts, 2007; McKinley and Fletcher, 2010, 2012), a focus on engagement with shallow seas and our "neighborhood ocean" (Vincent, 2011), and ocean literacy (Steel et al., 2005; Brennan et al., 2019; McKinley and Burdon, 2020; Kelly et al., 2021; Glithero and Zandvilet, 2021). While each of these comes with its own definitions, terminology, and frameworks, a common thread is the recognition that catalyzing a shift to an improved societal relationship with the ocean requires more than merely enhancing or improving society's knowledge of the ocean (Kollmuss and Agyeman, 2002; McKinley et al., 2020a). There has been a corresponding acknowledgment that social sciences, and more specifically, an understanding of public perceptions of the ocean (which, for the purposes of this study has been taken to mean seas, coasts, and the wider ocean) is essential to the success of pro-conservation actions within governments, industries and wider society (Schultz, 2011; Lotze et al., 2018; Stoll-Kleemann, 2019; McKinley and Burdon, 2020).

Perceptions are defined as "the way an individual observes, understands, interprets, and evaluates a referent object, action, experience, individual, policy, or outcome" (Bennett, 2016, p4). Perceptions research recognizes that society is not homogeneous and that perceptions of the ocean vary between individuals and groups. The variation in ocean perceptions within society is influenced by multiple contextual factors, including (but not limited to) socio-demographics, personality variables, access and experience of the ocean, coasts, or seas (Jefferson et al., 2015; Bennett, 2016). Historically, perceptions research has, to some extent, been dismissed as "anecdotal," and therefore, potentially "less reliable" than other forms of evidence [as discussed by Bennett (2016)]. However, it is now recognized that understanding how people perceive the ocean is fundamental to the design and implementation of marine conservation and other management interventions to maximize their impact (Gelcich et al., 2014; Jefferson et al., 2015; Potts et al., 2016; Bennett, 2019). This is confirmed by a growing literature illustrating the benefits of including public perceptions research in marine conservation practice (Jefferson et al., 2015; Bennett, 2016; Gelcich and O'Keeffe, 2016), including:

- Developing an understanding of the diverse societal attitudes, views and values held toward different components of the ocean and its management. This can provide crucial insights to support policy development, foster improved ocean literacy or marine citizenship, and catalyze behavior change (e.g., Potts et al., 2016);
- Supporting assessments of the social acceptability, effectiveness and impacts of conservation interventions, initiatives and policies [e.g., the introduction of a new marine protected area (MPA)] and developing insights into how these perceptions may influence their implementation (e.g., Lotze et al., 2018; Brueckner-Irwin et al., 2019; Rasheed, 2020);
- Informing the design of effective and meaningful mechanisms for stakeholder engagement, which can in turn support the legitimacy, equity and inclusivity of marine conservation activities and governance approaches (e.g., Burdon et al., 2019; Bennett et al., 2021);
- Fostering public sensitization to marine conservation activities through appropriate communication, awareness raising and engagement initiatives (e.g., Chambers et al., 2019; Kolandai-Matchett et al., 2021).
- In a policy context, public perceptions research provides valuable tools to monitor and measure success against a range of policy targets [e.g., Aichi Target 1; Sustainable Development Goal 14, see Haward and Haas (2021)].

Ocean perceptions research is currently fragmented and conducted across multiple disciplines and in a range of geographical and societal contexts (Jefferson et al., 2015). This results in the research being difficult to synthesize, challenging to interpret as a single body of work, and harder to access for practitioners or other researchers wishing to use the findings. To make a more impactful contribution to marine conservation outcomes, ocean perceptions research needs to be collated into a coherent body of literature. This will provide focus for those working in this field and establish a knowledge base for enhanced practice, to push forward the development of new ideas and insights, and to develop new methods and approaches (Jefferson et al., 2015).

Ocean perceptions research draws on the broad spectrum of marine social sciences approaches and methods to explore different research questions and evidence needs, using both qualitative and quantitative methods [See Newing (2011) and Bennett (2016) for more detail]. Quantitative methods are those which gather numerical data (e.g., often collected using questionnaires), whilst qualitative methods gather non-numerical data usually as text or images, such as that collected through interviews (Newing, 2011). While questionnaires and interviews are some of the more commonly used methods, social science approaches are diverse and include, for example; photostudies, in which photographs taken by respondents are used as interview prompts (e.g., Tonge et al., 2013); Q methodology, which is used to explore polarizing subjects and requires the respondent to sort a series of statements based on their agreement or disagreement (e.g., Gall and Rodwell, 2016); Community Voice Method which uses video interviews to explore a research question, then presents the findings of the research through a video report for further discussion by community and stakeholder groups (e.g., Ainsworth et al., 2019), while focus groups and community workshops allows the views of multiple participants to be collected (Newing, 2011). In addition, recent years have seen an emergence of methods which draw on arts and humanities disciplines to explore public perceptions of the ocean. These approaches provide a creative lens through which the complex connections between society and the sea can be explored (Bennett and Roth, 2019). Examples within the literature include the use of poetry to explore indigenous marine conservation knowledge (Kosgei, 2021) and Brennan's (2018) exploration of marine space through an arts/science collaboration.

An important consideration in any perceptions research is to explore the heterogeneity of perceptions within audiences as it is unlikely that all individuals within one audience will hold the same view of a particular issue. To assess heterogeneity of perceptions, researchers measure variables such as socio-demographics (e.g., age, gender) or engagement with a subject (e.g., visiting the coast). Further, a person's values are responsible for shaping intrinsic motivation and can influence perceptions and behaviors (Kollmuss and Agyeman, 2002; Manfredo et al., 2017). Social values are therefore a potentially powerful variable for exploring heterogeneity of perceptions. They can be measured through scales such as Schwartz Value Index (Schwartz, 2012), or integrating values typologies such as Kellert's typology of values (Kellert, 1997).

Given the complexity of relationships between society and the ocean it is reasonable to assume that there will be a corresponding diversity and variation in perceptions (Bennett, 2016). Therefore, adopting the full diversity of research methods is critical to enable a full exploration of public perceptions of the ocean.

Despite the increased recognition of the importance of public perceptions research in understanding human-ocean connections and the insight this provides to policy and management, challenges remain in translating these opportunities into meaningful action and impact. This paper presents an assessment of the existing ocean public perceptions research landscape, with a view to understanding knowledge gaps and identifying opportunities where this research can be better applied to marine conservation challenges. The paper delivers a "stock take" of ocean perceptions research, including the spatial and thematic focus of the research, the methods used to conduct the research, and the ways in which the research is funded. Furthermore, the paper presents a gap analysis that identifies research priorities to benefit marine conservation and public engagement with the ocean.

MATERIALS AND METHODS

To identify relevant studies for inclusion in this review, a suite of 126 search terms was used, divided into three categories of "public," "perceptions," and "marine" (**Table 1**). The review focused on peer-reviewed studies published in the English language, and therefore does not include studies published in the gray literature or those published in a language other than English. To maximize the opportunity to include relevant studies, two search engines were used: ScienceDirect and Google Scholar. Standard search protocols were used to conduct the searches, with each category of terms separated by "AND" and the individual terms within each category separated by "OR." In addition, the authors used their expert knowledge to include additional studies not identified through the searches.

Studies were only included in the review if they met three additional criteria: (1) the study had an ocean focus (in total or part); (2) it presented primary perceptions data (i.e., it was not a review); and (3) its survey population was the public. In this review, "public" is defined as those audiences not making an income from their engagement with the ocean. Thus, for example, studies of special interest groups such as recreational divers or anglers were included but studies with commercial divers and fishers were excluded. While ocean perceptions research with non-public audiences such as fishers, coastal managers and scientists is clearly an important part of responding to certain elements of marine conservation (Gall and Rodwell, 2016), these groups were beyond the scope of this review.

A total of 349 studies met all search criteria up to and including those published in May 2017 and were included in the review. Each study was reviewed by the author team to extract key data relating to a number of parameters (overview in **Table 2**, further details in SM1). The data extraction process was pilot tested in four iterations using a subset of 10–20 studies to ensure the extracted data met the research question requirements. Paper reviewing was carried out by all authors, with a subset of 5% of the studies re-reviewed by different authors to ensure inter-reviewer consistency.

The data extracted from each study is presented in **Table 2** (with further details about the extraction and analytical processes presented in **Supplementary Table 1**). Qualitative data was coded using a manual thematic coding and data reduction process (Bryman, 2016). Coding categories were defined through identification of the emergent themes and agreement of hierarchies of categories as required, with analysis and coding checked between the authors (see **Supplementary Table 1** for more).

RESULTS

This section describes the key research topics of the included studies, when and where the 349 studies were conducted, and the methods used (see **Supplementary Material 2** for a list of all 349 studies).

The Ocean Perceptions Research Landscape: When and Where Were the Studies Completed?

The review demonstrated the field of ocean perceptions research to be relatively nascent. The first study of public perceptions

TABLE 1 | Search terms used to identify research on public perceptions of the ocean.

Public terms	Perception terms	Marine terms		
Children	Attachment	Acidification	Fish farming	Pacific
Citizen	Attitude	Algae	Fisheries	Plankton
Communit*	Awareness	Antarctic	Fishing	Planning
Gender	Behavior	Aquaculture	Flooding	Plastic
International	Belief	Arctic	Gas	Pollution
National	Citizenship	Atlantic	Habitat	Reclamation
Public	Concern	Bathing	High seas	Recreation
Resident	Connection	Beach	Indian	Renewable energy
School	Emotion	Biodiversity	Invasive	Runoff
Senior citizen	Experience	Bycatch	Invertebrate	Saltmarsh
Society	Feeling	Cetacean	Litter	Sea
Student	Idea	Climate change	Littoral	Sea level rise
Tourist	Interest	Coast	Mangrove	Seabird
Visitor	Knowledge	Coastal management	Marine animal	Seafood
Young	Memory	Coastal protection	Marine environment	Seagrass
Youth	Opinion	Coral	Marine governance	Seascape
	Perceive	Crustacean	Marine industry	Seaside
	Perception	Deep sea	Marine life	Seaweed
	Perspective	Defense	Marine mammal	Sewage
	Relationship	Disease	Marine protected area	Shark
	Responsibility	Diving	Marine reptile	Shellfish
	Thought	Dredging	Marine reserve	Shipping
	Value	Echinoderm	Mining	Southern
	Viewpoint	Ecosystem services	Mollusk	Swimming
	Vision	Engineering	Ocean	Temperature
		Erosion	Ocean management	Tourism
		Estuary	Offshore	Water quality
		Eutrophication	Oil	Wetland
		Fish		

of the ocean was published in 1988 with 10 or fewer studies published per year until the late 2000s. 2009 marks the beginning of a considerable increase in the rate of publication to around 50 studies per year from 2015 onward (**Figure 1** and **Supplementary Table 3**). 59% of all the studies in this review were published between 2013–2017.

TABLE 2 | Research questions and details of extracted data (see SM1 for more information, codes link to relevant section of SM1).

Research question	Data extracted from papers
When and where were the studies conducted?	• Year of publication (Ai) • Journal (Aii) • Number of countries in which data was collected (Aiii) • List of countries in which data was collected (Aiv) • Scale of study (Av) • Funding source (Avi)
What did the study research?	• Target population (Bi) • Thematic focus (Bii_ • Non-marine element to study (Biii) • Public perceptions dimensions (see Jefferson et al., 2015) (Biv)
How was the study conducted?	• Method of data collection (Ci) • Model used (Cii) • Sample size (Ciii) • Socio-demographic variables measured (Civ) • Social values measured (Cv) • Ocean experience measured (Cvi)

The review found ocean perceptions research conducted on populations in Europe (31%), North America (27%), Oceania (17%), Asia (11%), Africa (6%), South America (4%), Caribbean (3%), and Central America (2%; **Figure 2**). The United States and Australia were the countries with the most studies with 24% (94) and 14% (56) studies, respectively. All other countries had 15 or fewer studies, with 57 countries having fewer than five studies (**Figure 2**; **Supplementary Table 4**). In terms of scale, the majority of studies (84%) assessed public perceptions at a sub-national scale (e.g., Piriyapada and Wang, 2014), with 12% at the national scale (e.g., Goldberg et al., 2016), and only 5% assessed perceptions in more than one country. The largest study assessed ocean perceptions in ten countries (Gelcich et al., 2014).

The 349 studies reviewed were published in 109 different journals (see **Supplementary Table 5** for detailed information). The journals Ocean and Coastal Management and Marine Policy together account for a third of the studies reviewed (19 and 13%, respectively). A further third of studies are shared across 16 titles with Tourism Management (4%), Ecological Economics (4%) and Environmental Management (3%) the next most common journals. The remaining studies are published across 91 titles.

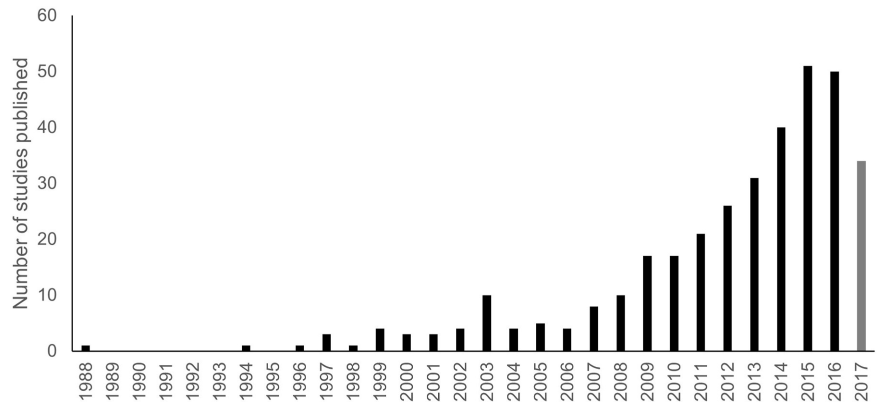

FIGURE 1 | Number of ocean perceptions studies published each year. Note 2017 count to May 2017 (*n* = 349).

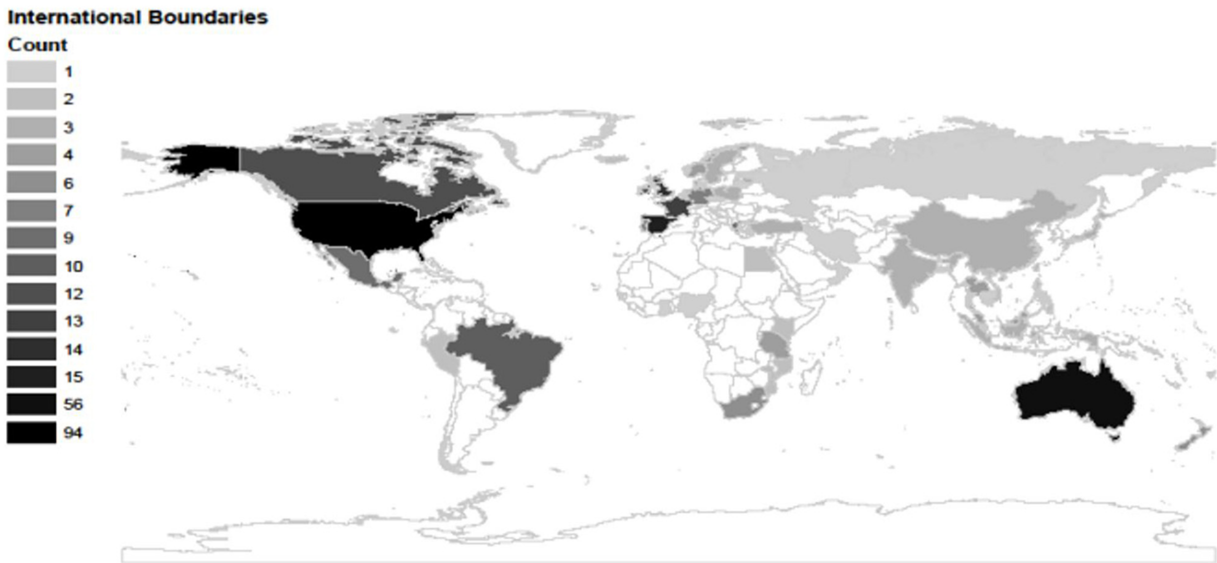

FIGURE 2 | Map showing number of ocean perceptions studies per country (*n* = 349).

While many of the journal titles have a marine or coastal focus, the range of disciplines represented by the journal titles is diverse, including conservation, tourism, recreation and sport, whole environment, social science, energy, geography, economics, health, agriculture, education, communication, psychology, sustainable development, amongst others. This suggests that researchers from a wide diversity of disciplines are contributing to ocean perceptions research.

Funding information was provided for only 250 (72%) of the 349 studies reviewed, with funding sources falling into seven categories (**Table 3**). National government bodies (including ministries, departments, and executive agencies) were the most common funders of ocean perceptions research, contributing to 60% of the 250 studies and being the sole funder of 86 studies. Universities, through bursaries, travel funds, and internal grants, contributed to 30% of the studies, although it is probable that the costs of many of the 99 studies with no funding information described may have been underwritten by universities. National research councils contributed to 19% of studies. The European Commission and philanthropic bodies each contributed to 11% of the studies (usually through funding of larger projects), while NGOs and commercial organizations each contributed to 4% of studies. Of the 250 studies with funding information, two thirds (67%) were supported by one category of funders, with the remaining third (33%) supported by two or more funder categories, usually including at least one university.

The Thematic Focus of Ocean Perceptions Research: What Did the Studies Research?

The target populations of the reviewed studies were most often residents or tourists/visitors (48 and 20%, respectively) (**Table 4**). A further 11 categories of "public" were identified, of which

TABLE 3 | Funders supporting marine public perceptions studies (*n* = 250).

Funding source	Number of studies	%
National government body	151	60
University	74	30
National Research Councils	48	19
European Commission	28	11
Philanthropic Foundations	28	11
NGOs	11	4
Commercial	10	4

Some studies were funded from more than one source.

TABLE 4 | Target population of studies (*n* = 349).

Target population	%
Residents	48
Tourists/visitors	20
Public	10
Beach/coastal users	10
Divers/snorkelers	7
Indigenous/traditional community residents	5
Recreational fishers	5
Students (any age) and teachers	3
Nature based tourism	3
Recreational boaters	3
Watersports (incl. surfers, kayak and kite surfers)	2
Marine/ocean users	1
Museum/aquarium visitors	1

Author definitions of their target population were used to categorize data.

eight were different types of recreational groups (**Table 4**). Most studies (84%) assessed perceptions of one population [e.g., residents; Perry et al. (2014)]; 14% of two [e.g., general public and tourists; Moscardo et al. (2001)], 1% of three [e.g., residents, tourists and indigenous/traditional communities; Brown et al. (2016)], and 0.6% of four (e.g., Strickland-Munro et al., 2016; Moore et al., 2017).

The most studied ocean topic was perceptions related to MPAs (15% of all studies; **Figure 3**) including for example, reactions of local communities to a no-take MPA in South Africa (Faasen and Watts, 2007), exploration of international tourists' willingness to pay to visit marine parks in the Seychelles (Mwebaze and MacLeod, 2013) and comparisons between public and expert views of threats to the ocean and proportion of New Zealand waters which are currently and should ideally be protected (Eddy, 2014). Studies exploring perceptions of biota included habitats (13%), single species or species groups (9%) and marine biodiversity (3%). Blue economy studies were dominated by research on perceptions of marine renewables, so this was split into two categories: blue economy (5%) including fisheries, aquaculture, desalination and mining; and marine renewables (7%). Threats explored through the studies include climate change (6%), pollution (5%), and environmental degradation (2%). 12% of studies explored perceptions of the marine environment or the coast without linking to a particular location or issue, categorized as broad scale marine and coastal. For example Chen and Tsai (2016) investigated ocean environmental awareness in Taiwanese students and Pakalniete et al. (2017) explored the preferences of Latvian citizens for improved marine waters.

Tourists and marine recreation populations were a large component of the target respondents (**Table 4**; 20%) and studies investigating public perceptions of tourism and recreation accounted for 11% of studies. 7% of studies focused on perceptions of management, including, for example, Alves et al. (2017) and de la Torre-Castro et al. (2017), while a further 2% of studies focused on understanding perceptions of marine cultural ecosystem services. Finally, studies included in the "other" category (4%) included perceptions of abiotic ocean features, citizen science and stewardship.

Perceptions of biotic components of the ocean environment accounted for 25% of all studies. 31 of the 86 biotic studies assessed perceptions of single species or species groups. **Table 5** presents a summary of the particular species and species groups explored, of which 90% studied perceptions of vertebrate species. Habitats were investigated in 45 studies including reefs (38% of habitat studies), beaches (31%), mangroves (13%), deep sea (9%), wetlands (7%), intertidal (2%), and seagrass (2%). One study investigated public perceptions of mangroves, reefs and seagrass meaning the total percent for habitat studies exceeds 100%.

It was also noted that 15% of studies included a non-marine component. These studies represent those spaces, issues or communities which span the land-sea boundary. For example, studies taking a geographically defined focus such as a National Park (e.g., De Lopez, 2003), exploring a ubiquitous issue such as climate change (McComas et al., 2015) or where the connection of the effects of land-based activities on marine environments is explored, e.g., Roca et al. (2009) who study perceptions of the impacts of run-off on beach quality. Relatively few studies explicitly compared marine and non-marine related perceptions, rather those including both took an integrated approach to their research.

Figure 4 shows the distribution of studies against dimensions of public perceptions research (Jefferson et al., 2015), which include dimensions of knowledge, values, and concern among others (for more information see **Supplementary Material 6**). We found that 84% of studies measured more than one component (e.g., Faasen and Watts (2007) who explore knowledge, human-ecosystem interactions, and behaviors). Knowledge was the most commonly measured dimension of perceptions (61%), while concern was found to be the second most frequently measured dimension (40%) of studies, with marine experiences, human-system interactions and economic values the next most frequently measured, found in over 30% of studies (see **Figure 4**). The least frequently measured dimensions were human health and wellbeing, and positive connections at 10 and 9%, respectively.

Research Methods Used: How Were the Studies Conducted?

The description of methods used are based on how methods were described by the author/s of the studies reviewed. The most

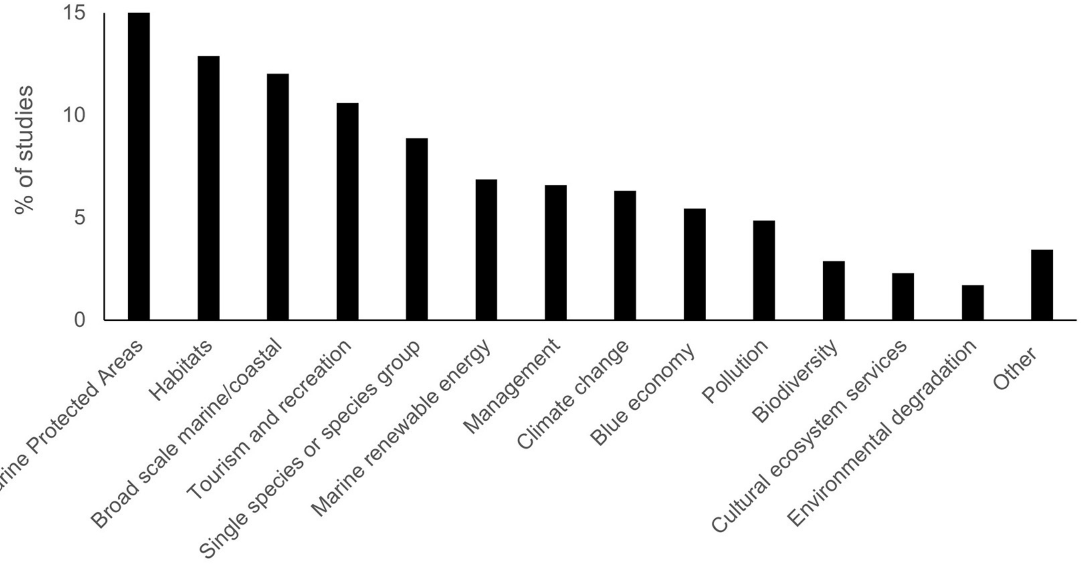

FIGURE 3 | Percentage of ocean perceptions studies investigating each theme; studies were allocated to a single category (*n* = 349).

commonly used method was questionnaires (70% of studies) followed by interviews (40%) and focus groups (9%). However, there was inconsistency in the use of the terms "questionnaire" and "interview" within some of the studies reviewed, leading to difficulties in clearly identifying the methods used. Multiple methods were used by 26% of studies and 12% used other methods, including participant observations, e.g., of diver's damaging behavior which was compared to self-reported damage (Hammerton, 2017), mapping such as participatory GIS mapping (Aswani et al., 2015), advanced interview techniques such as Q methodology (Brownlee and Verbos, 2015) or photo elicitation studies (Coleman and Kearns, 2015).

Around 30% of studies included economic assessment. This was usually to provide a metric of the scale, extent or direction of a perception, using a range of approaches, such as a contingent valuation method, or willingness to pay. For example, Barry et al. (2011) use willingness to pay to determine financial values to represent the scale of perception around the recreational value of Ireland's coastal resources, while Ariza et al. (2012) used travel cost methodologies to explore perceptions about the relationship between economic values and beach quality in Spain. 10% of studies used a psychology-based approach at some point in the study. These studies usually used a psychology-based approach to either classify the sample or to provide explanation of the observed perceptions. For example, Johnson et al. (2015) used the stakeholder characterization framework to classify perceptions of tidal energy, while Jefferson et al. (2014) used Maslow's Hierarchy of Needs to understand different values held by respondents about the marine environment in the United Kingdom.

TABLE 5 | Details of species studied (one study included two species).

Species group	Number of studies	Species if named
Fish	10	7 sharks, 2 salmon, 1 goliath grouper
Mammals	9	3 dolphins, 2 manatees, 1 monk seal, 1 gray seal
Reptiles	8	sea turtles (two of which loggerhead)
Inverts	3	2 jellyfish, 1 oyster
Birds	2	1 hooded plover

Sample sizes ranged from 8 to 23,788 respondents (**Figure 5**). Seven studies gave imprecise sample sizes (e.g., "approximately 550," "over 47" and were included as the given number (e.g., 550, 47), 12 studies did not report a sample size but an approximate result could be calculated from other details given in the paper (e.g., an n number given alongside presentation of results) and two studies did not report a sample size and were not included in this analysis. The remaining 328 studies gave precise sample sizes.

Many studies reported measuring socio-demographic variables but not all reported whether these variables explained any heterogeneity in the perceptions being measured. The studies were assessed for the inclusion of 12 commonly used socio-demographic variables (see **Supplementary Table 7** and **Figure 8**). An average of 4 socio-demographic variables were measured per study. 83% (290) of studies measured at least one socio-demographic variable (**Figure 6**; **Supplementary Figure 8**) with the most measured variables being age (88% of the 290 studies), gender (87%), education (59%) and place of residence (46%). 66% of studies which measured socio-demographic variables reported an influence of at least one variable on perceptions. However, this may be an underestimate as 32% of studies did not report at all whether the measured variables influenced perceptions, nor did they report whether they had tested and received a null result, adding to the ambiguity of this finding (**Figure 6**; **Supplementary Table 7** and **Figure 8**). It appears that many of those studies used their collected socio-demographic data only to describe the respondent profile, and not as a means of exploring heterogeneity of the perceptions

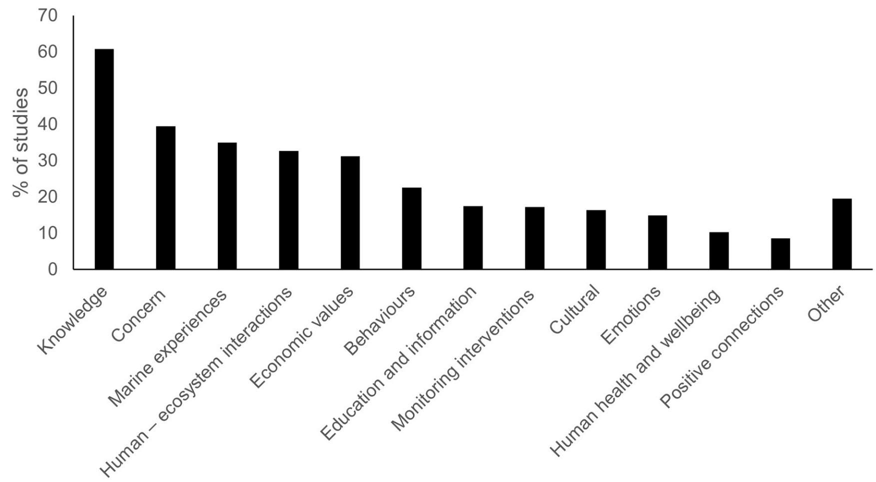

FIGURE 4 | Percentage of ocean perceptions studies measuring dimension of public perceptions research; studies could be in one or more categories (*n* = 349).

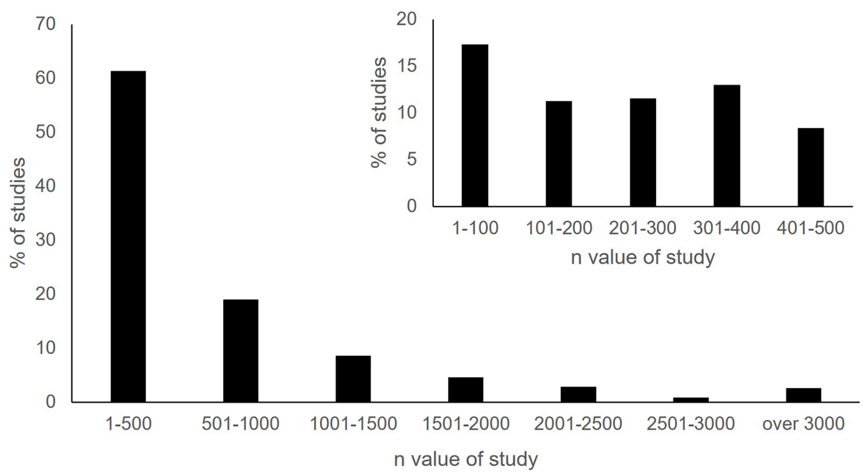

FIGURE 5 | Percent of ocean perceptions studies within each sample size category. Inset presents sample sizes for studies with fewer than 500 respondents (*n* = 347).

being measured. Around 10 studies did not clearly detail what variables they had measured, rather stating that they had collected "demographic characteristics."

Social values are the *trans*-situational goals and principles that guide human behavior (Manfredo et al., 2017). Analysis found that only 10% of studies measured social values. Of these 35 studies, 77% found an effect of social values on perceptions, 6% reported no effect of social values and 17% did not report their findings (**Figure 6**). A range of frameworks and models were used across these studies to measure social values, including established methods such as the New Environmental Paradigm or NEP (Alessa et al., 2003) or application of Kellert's typology of values, whilst other studies applied a bespoke set of questions on a narrower range of values, e.g., Grafeld et al. (2016) which used "a series of Likert questions to measure use, indirect use, bequest and existence values." Finally, 39% of all studies reviewed measured some element of interaction with the marine environment, of which 71% found an effect on perceptions, 4% reported no effect and 25% did not report on the analysis.

DISCUSSION

The aim of this review was to assess the existing ocean perceptions research landscape in order to identify gaps and set out recommendations to support improved contribution of public perceptions research to marine conservation. Through bringing attention to this subject area, and revealing current research gaps, the review aims to enhance the role of ocean perceptions research in marine conservation and cement its position within the UN Decade of Ocean Science for Sustainable Development 2021–2030, and beyond. The review found a growing rate of studies in ocean perceptions research which may infer increasing research effort, journals giving greater attention to conservation

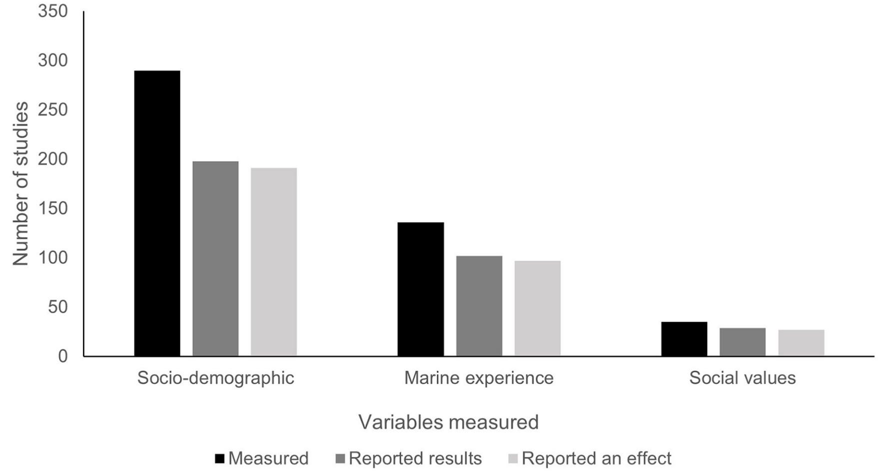

FIGURE 6 | Number of ocean perceptions studies which measured, reported results, and reported effects of socio-demographic variables, ocean experience and social values (*n* = 349).

social sciences, greater funding availability, or a combination of these. Despite this growth, the review highlighted a number of gaps including: (1) a skewed global distribution of studies; (2) a bias toward charismatic species and habitats, and a focus on spaces and issues where humans most obviously interact with the ocean (e.g., beaches) or are most contentious (e.g., MPAs); and (3) an apparent underutilization of available perceptions research methods. Each of these gaps will be explored in turn, followed by a discussion of how to strengthen the appreciation of ocean perceptions research to support marine conservation.

Gaps in Geographic Distribution of Ocean Perceptions Research

Recent decades have seen calls to increase the integration of social science research into all aspects of environmental conservation (e.g., Mascia et al., 2003; Bennett, 2019). The growth in publication rate of ocean perceptions research identified in this review fits the pattern of a response to these calls, and wider increases in publication rates in other subjects [e.g., spatial human dimensions research (Koehn et al., 2013); and qualitative conservation social science (Moon et al., 2016)]. However, this rate of publication is not equally distributed, with publications from the United States, Australia, and Europe dominating the research literature. This echoes the distribution of published research into public perceptions of climate change (Capstick et al., 2015), ecological biodiversity (Titley et al., 2017) and conservation (Di Marco et al., 2017). This could be influenced by our focus on English language publications. Despite the majority of scientific papers being published in English (Ramírez-Castañeda, 2020), it is recognized that whilst multilanguage research is challenging, it provides a richer insight for conservation action (Salager-Meyer, 2008; Angulo et al., 2021). This is an area which could be explored in future perceptions reviews. These findings suggest that benefits of ocean perceptions research are not yet being felt across all marine conservation efforts and, as a result, may in fact indirectly contribute to ongoing biodiversity loss and/or social inequity in under-represented study areas (Bennett et al., 2021).

Gaps in the Ocean Themes Explored

Habitats and Species

The review found that existing ocean perceptions research is skewed toward charismatic species and habitats, echoing the documented bias in marine ecological research. For example, Duarte et al. (2008) describe a bias in ecological marine habitat research effort toward coral reefs over seagrass and mangroves (all threatened habitats). This pattern appears to be replicated in this review with coral reef perceptions studies dominating habitat-specific studies (15 coral reef studies, 6 studies on mangroves and 4 studies on the deep sea). Beaches are also frequently researched (10 studies), predominantly around themes of tourism, beach quality, use and management, while species-specific ocean perceptions research is dominated by vertebrates (90%; **Table 5**). Marine invertebrates are ecologically critical and can be an important part of the experience of marine biodiversity for many people, however, this review found that they appear to be relatively unexplored by ocean perceptions research. This under exploration of these species and spaces (and other similarly neglected topics) may limit our understanding about the connections people make with marine environments. Identifying these biases at this early stage of ocean perceptions research is perhaps not surprising, given similar trends identified in other fields. However, as we look to recommendations to improve the application of ocean perceptions research, addressing these biases will be important.

Human Activities and Management

The review found that the ocean perceptions studies with an emphasis on human activities tended to focus on MPAs, tourism and recreation, and renewable energy generation. It is possible that ocean perceptions research is being conducted on a greater diversity of activities but remains in the gray literature and was therefore not detected in this review. The topics highlighted in this review reflect important and often contentious interactions between people and the ocean. For example, the designation of an MPA can create tensions and competing narratives within and between affected communities. As such, understanding community-held perceptions of MPAs is potentially very useful when considering a designation or determining management measures. For instance, a public perceptions study would provide valuable insight to inform approaches that resolve matters of rivalry or disagreement (Voyer et al., 2015).

Although MPA focused perceptions studies were the greatest single group of studies (15%), this is a relatively small collection of 53 studies. Given that, at present, there are over 18,500 MPAs covering almost 28 million km^2 (UNEP-WCMC and IUCN, 2021), the ocean perceptions research literature is extremely limited. This reflects the assertion by Mascia et al. (2010) that there is a "scarcity of rigorous research on the social impacts of marine protected areas" (p.1428). The same observation can be made for ocean perceptions studies of marine renewable energy, in which the total number of studies (24) does not adequately reflect the scale of the offshore renewable energy sector, which in mid-2019 included 5,500 offshore wind turbines across 17 countries (International Energy Agency, 2019). This indicates that perceptions studies and the application of social sciences more generally does not currently reflect the role of society in developments of marine renewable energy or its potential impact on coastal communities (Kerr et al., 2014).

The limited focus on key ocean challenges has several possible explanations. It could be explained by a lack of recognition for the potential role of perceptions research in contributing to research into key global challenges. It could also reflect a legacy, or continuing, undervaluation of the "social voice" in ocean and coastal policy and management. For example, Gruby et al. (2016), in a perception study of large MPAs reported that a number of interviewees "were puzzled by our questions about the human dimensions of large MPAs. . . [and struggled] to recognize the relevance of social science concerning spaces where there are "no people." Regardless, it is clear that there is a major research opportunity *and* policy need to examine the public perceptions of key ocean crises, such as ocean climate impacts, plastic pollution, or how to transition to a circular ocean economy. Perhaps more fundamentally, the limited emphasis on understanding human attitudes toward key ocean challenges runs contrary to the core principle of the ecosystem approach that "management objectives are a matter of societal choice" (CBD, 2000), which is not being supported with the current level of ocean perceptions research effort.

The review confirms the veracity of calls from authors and practitioners that much greater emphasis is needed on understanding the social aspects of coastal and ocean systems. For example, Unsworth et al. (2019) describe one of the conservation challenges of seagrass conservation as a lack of societal awareness; Romañach et al. (2018) argue that mangrove conservation would benefit from understanding the complex interrelationships between social and natural systems; while McKinley et al. (2020b) assert the need for integrating social sciences into saltmarsh management. These testimonies illustrate the importance of ocean perceptions research (and marine social sciences more widely) in confronting conservation challenges, but that at present the research literature is inadequate to support these needs. Given the assertions that certain conservation outcomes are enhanced by the inclusion of ocean perceptions research, it may be appropriate to consider the development of a research agenda that enables the limited ocean perceptions capacity to be focused on the most urgent locations or topics.

Diversifying Marine Perceptions Research Methods

The ways in which ocean perceptions research can inform and support marine conservations are varied and rich (Jefferson et al., 2015; Bennett, 2016; Gelcich and O'Keeffe, 2016). The diversity of methods used to conduct perceptions studies are both qualitative and quantitative, from the familiar such as questionnaires, interviews and workshops to the less familiar such as digital storytelling, forum theater, and other creative and arts-based approaches (Bennett et al., 2017a). Despite this, our results indicate that current ocean perceptions research does not fully reflect the full range of methods and approaches available, with the majority of studies included in this review found to depend on the traditional social science methods of questionnaires and interviews. This review found there to be three main weaknesses of the current suite of methods used to undertake ocean perceptions studies including: (1) a focus on measuring societal knowledge and concern of marine topics, which is only one of many possible drivers shaping public ocean perceptions (**Figure 4**); (2) a lack of exploration of the heterogeneity of audience perceptions (**Figure 6**); and (3) the predominance of questionnaires and interviews as the dominant research methods employed.

Diversifying the Dimensions of Ocean Perceptions Research

Behavior change is at the heart of conservation (Schultz, 2011), with behavioral sciences such as environmental psychology exploring the complex process of catalyzing behavior changes. Behavior change is influenced by internal factors, such as an individual's emotions and values, and external factors such as the prevailing culture and social norms (Kollmuss and Agyeman, 2002). The idea that "people care about what they know" (Balmford et al., 2002) is persuasive, yet raising awareness or knowledge of marine conservation issues on its own rarely results in a behavior change (Stoll-Kleemann, 2019). Yet almost two-thirds of ocean perceptions research studies measured respondent knowledge (**Figure 4**). This suggests an underappreciation of factors such as emotions, culture, positive connections, or behaviors themselves in ocean perceptions research (Jefferson et al., 2015; McKinley and Burdon, 2020).

A high proportion of studies measure respondent worry or concern about specific ocean issues (40%) with only 9% of studies exploring positive connections with the ocean, which perhaps hints at a focus on the doom and gloom narrative frequently used to frame environmental issues (Vanderheiden, 2011) and feels disconnected from wider aspirations of social engagement for and with marine conservation. It is known that fear-based messaging can disengage, increasing feelings of apathy and disengagement (O'Neill and Nicholson-Cole, 2009; Gifford, 2011). Enhancing and understanding positive emotional connections, such as awe, wonder and fascination, with the ocean underpins the concepts of marine citizenship and ocean literacy and the wider connection to nature movement (McKinley and Burdon, 2020; McKinley et al., 2020a). These concepts aspire to use society-nature connections to encourage large scale societal shifts to protect and restore ocean health or biodiversity. Ocean perceptions research which explores a more diverse suite of connections between society and the sea is needed to provide the evidence base to underpin current ambitions to catalyze large scale societal change (Kearns and Collins, 2012; McKinley and Burdon, 2020).

The three dimensions least represented in the reviewed studies were emotions, human health and wellbeing and positive connections (**Figure 4**). Since the census end-date of this review in 2017, research related to these dimensions has continued to grow in prominence. "Blue health" (the connections between aquatic ecosystems and human wellbeing) has been the focus of major projects (e.g., the EU funded SOPHIE and Blue Health projects) and publications such as the Blue Health Agenda (Borja et al., 2020), the restorative value of blue spaces in response to the Covid-19 pandemic (Pouso et al., 2021) and the equigenic benefits of blue spaces (Fleming et al., 2019; Short et al., 2021). Eco-anxiety is gathering increasing attention as the scale of the biodiversity and climate crises appear to be more widely recognized by society (Cunsolo et al., 2020). The Blue Health Agenda (Borja et al., 2020) highlights the importance of "understanding the complex relationships existing between oceans and human health, in multiple knowledge areas and across sectors" and cite research gaps which would be filled through ocean perceptions research. Therefore, these dimensions of ocean perceptions research are likely to receive greater attention in the coming years as these issues gain further prominence.

The imbalances in the dimensions studied (**Figure 4**) may be due to a lack of awareness of methods for measuring dimensions, such as emotions, or may be due a lack of understanding of the importance of those dimensions within a conservation context. Ocean perceptions studies were found to rarely use psychology-based approaches as part of their methods, with economic valuation methods, or no existing approach used at all, more common. While it is difficult to interpret this pattern without knowing the disciplinary background of the lead researchers, Martin (2020) describes challenges which arise when social science research is conducted by those from non-social science disciplines. These challenges include (a) a lack of use of the literature to inform the development of social science research undertaken by natural scientists, and (b) the development of methods which do not build on the work of others indicating that perhaps some of the gaps in use of models arise from a lack of capacity for interdisciplinary working. Whilst knowledge and concern are not necessarily simple to measure [see for example Fischer and Young (2007) for a discussion of measuring knowledge of biodiversity], these lesser explored aspects of human relationships with the ocean require specialist disciplinary knowledge and method. Further work may be required to fully understand why this gap exists. Given the growing focus on emotional connection, wellbeing, and other topics, increased inclusion of conservation psychology methods and applications within ocean perceptions research is likely to be a positive trend.

Explore Heterogeneity of Audiences

In the context of ocean perceptions research, audience heterogeneity describes the variation in perceptions held within the target population. Understanding audience heterogeneity is fundamental to a thorough exploration of public perceptions of a subject (Kanagavel et al., 2014). As shown in **Figure 6**, ocean perceptions research to date has left this subject relatively unexplored, even when data on potential explanatory variables had been collected. The lack of effort to explore audience heterogeneity through socio-demographic variables, social values or marine interaction revealed in this review is concerning and shows a lack of appreciation for how these variables can influence perceptions. This perhaps fits with the pattern of considering "the public" as a single, homogenous audience (Kanagavel et al., 2014). Whilst it is certainly vital that variables are used to describe the respondent profile, the opportunity to fully explore perceptions were often not realized, even when data was available.

Socio-demographic variables were widely measured in the studies (particularly age and gender) with 83% of studies measuring at least one socio-demographic variable. This shows an awareness of the need to understand the sample being studied. However, 32% of these studies did not report whether they had tested for any influence of the socio-demographic variables measured on perceptions. Many studies appear to have used their socio-demographic data to describe the sample which engaged with the research, usually presented as a respondent profile. The high proportion of studies measuring these variables (83%) suggests researchers are familiar with the variables, and the need to understand who they are researching. However, there may also be a need to increase researcher awareness of the wider applicability of socio-demographic variables.

Engagement with the ocean was the primary focus of a number of studies, for example Ong and Musa (2012) explored the influence of experience and personality on diver behavior in Malaysia. However, engagement with the ocean stands alone as a potential explanatory variable, due to its influence on a person's perceptions, experiences and values of the ocean. Research into connection with nature, of which engagement with the ocean is an example, is increasingly showing the role it has with pro-environmental behaviors (Chawla, 2020). Despite this, 61% of studies did not include engagement with the ocean as a variable. There is real potential that greater assessment of engagement with the ocean could add considerable value to marine conservation through better understanding the impacts of visiting and experiencing marine spaces.

Social values are a complex but important subject which can inform innovative conversation strategies (Manfredo et al., 2017). However, only 10% of the reviewed studies measured social values, leaving this essential component of ocean perceptions research relatively unexplored. Their measurement requires an understanding of social sciences literature and methods which may be unexplored or unconsidered by many outside of environmental psychology disciplines. Where variables such as age or gender may be considered relatively simple to include in a questionnaire, researchers unfamiliar with social values methods may struggle to investigate their potential effects on ocean perceptions. Increasing the extent to which ocean perceptions research explores social values is an example of the recommendations by the World Social Sciences Review (ISSC/UNESCO, 2013) which calls for natural scientists to engage social scientists early in projects to identify the greatest impact of social science concept, such as the exploration of social values within projects. In parallel, the review also recommends social scientists take the lead in promoting the application of social sciences methods which can enhance the understanding of global environmental challenges (ISSC/UNESCO, 2013).

Ocean Perceptions Research Methods and Approaches

The findings of this review show a bias toward the use of questionnaire and interview methods in ocean perceptions research, and very limited application of more innovative methods, particularly of a qualitative nature (e.g., Community Voice Method). Given the complexities of the relationships between society and the sea, application of more diverse methods would be valuable to fully explore and expose the intricacies of this relationship (Bennett et al., 2017b; Bennett and Roth, 2019; Moon et al., 2019b). It is possible that this historical dependence on traditional methods and approaches reflects an existing trend in conservation social science, where researchers without a grounding in social sciences (e.g., natural or physical scientists) recognize the need for social evidence and therefore attempt research using unfamiliar methods (Martin, 2020). This is further explored by Martin (2020) who describes questionnaires as being perceived as "quick and easy" and often used by natural scientists to explore social components of otherwise familiar ecosystems. Understanding the source of the methods gaps, and the other gaps identified in the review, is important to identifying the best ways to diversify ocean perceptions research.

It is difficult to be sure how these disciplinary and methodology gaps in marine conservation developed. Marine conservation has historically been driven by natural sciences, and it is possible that training in conservation historically, and continues to, lack adequate social science content and the development of interdisciplinary skills and awareness needed to respond to the challenges facing the global ocean (Gardner, 2021). By continuing this trend, there is a risk that this disciplinary blind spot will continue, thus dramatically limiting the potential for effective marine conservation. Indeed, by the end of the UN Ocean Decade, if the patterns seen by Gardner (2021) continue, the conservation sector will continue to face a shortage of social science skills, and it is likely that these gaps will persist.

The growing recognition of the role of qualitative and creative methods is an opportunity to overcome some of the gaps to inform marine conservation by providing deeper insights into the connections between society and the ocean. Achieving this will require ocean perceptions research which: (1) integrates a greater extent and diversity of available models, concepts and approaches to deliver a broader suite of the types of ocean perceptions research through, for example, exploring behaviors, positive connections, cultural importance of the sea, human health and wellbeing; (2) appreciates that public perceptions of the ocean vary across populations, i.e., that there is more than one "public," and explores audience heterogeneity through the analysis of explanatory variables such as social values and socio-demographic characteristics; and (3) embraces a broader suite of methods and the opportunities this brings to be innovative about ways to engage different audiences and better understand the diversity of connections between society and the sea.

This review finds that overall, the ocean perceptions research community is currently not being adventurous or brave with the methods and analyses it uses, and as suggested by Overland and Sovacool (2020) needs to deliver more rigorous social science moving beyond the familiar methods and embracing the opportunities of a more diverse suite of social science methods. This call echoes those from other authors, including Moon et al. (2019a; p 427) state "by limiting how we see, experience or understand social sciences approaches, we limit the diversity of ways through which we can explore socio-ecological worlds. Furthermore, Bennett and Roth (2019) describe the need for exponential expansion of the topics examined by conservation social science, and the potential for social sciences, arts and the humanities to have a transformative effect on conservation paradigms, programs, policies and practices. Examples of where approaches like this are being adopted include the One Ocean Hub's innovative "Empatheatre" approach[1], as well as the recent work from the Wetland Life project[2], which used photonarratives and creative writing as a way to elucidate public perceptions of the benefits and disbenefits of wetland environments. Embracing the whole suite of approaches and interdisciplinary thinking in the formative development of ocean perceptions research would ensure diversification of the methods, dimensions and analyses it conducts.

CONCLUSIONS AND RECOMMENDATIONS

The paper presents the findings of an in-depth review of existing public perceptions research relating to the marine environment, cementing the field of ocean perceptions research as a growing discipline with increasing and valued applications to marine conservation. Understanding public perceptions of the ocean is critically important to ensuring that marine conservation efforts engage and resonate with target audiences, and that social impacts of conservation actions are captured. While ocean perceptions research is a relatively young field, it is clear that it is growing and is likely to continue to grow given increasing interest in marine social sciences (McKinley et al., 2020a). However, the review also highlights gaps in the current research which show it is not utilizing the full potential to

[1] www.empatheatre.com
[2] www.wetlandlife.org

impact marine conservation efforts. For example, even subjects which appear relatively well studied within ocean perceptions research, such as public perceptions of MPAs, are still calling out for social science evidence to support more equitable and socially sensitive interventions (Gruby et al., 2017). Despite the seemingly rapid growth in this field, gaps in knowledge and understanding remain. Addressing these and delivering ocean perceptions research in more countries, exploring more marine issues and exploiting a greater diversity of social sciences methods would deliver considerable insights into public perceptions of the ocean and therefore greater impact for marine conservation.

In order to achieve enhanced marine conservation impact, we recommend the following:

- Undertake a strategic transdisciplinary assessment to identify marine conservation priorities to which ocean perceptions research can leverage maximum impact;
- Expand the geographical reach of ocean perceptions research to reflect marine conservation efforts in a broader range of countries;
- Build global capacity to deliver, commission, interpret and apply ocean perceptions research;
- Inspire and enhance transdisciplinarity through the involvement of research, policy and practitioner actors in the development, delivery and application of ocean perceptions research;
- Promote ocean perceptions research and its value to those delivering, commissioning, interpreting and applying ocean perceptions research;
- Further investigate the gaps identified in this review in order to shape capacity building efforts, starting with exploration of the disciplines delivering ocean perceptions research;
- Undertake thematic meta-analyses of the ocean perceptions research literature to synthesize existing evidence for particular issues, including multi-language reviews and exploration of gray literature where possible;
- Incorporate social science content and specialist staff into undergraduate and postgraduate conservation training [for further details see Gardner (2021)];
- Ensure effective, two-way communication channels between researchers and marine conservation policy and practice for the development and application of ocean perceptions research;
- Intensify existing efforts to integrate social science and social scientists into marine conservation activities including network building, enhancing awareness of the diversity of social sciences methods and growth in interdisciplinary funding mechanisms (see McKinley et al., 2020a; Overland and Sovacool, 2020).

While some of the recommendations presented here are perhaps not novel or unexpected, they serve to further highlight the need for continued efforts to better integrate social sciences research, including ocean perceptions research, into the broader marine conservation landscape. Whilst it is encouraging to see the upward trajectory of ocean perceptions research, which can undoubtedly deliver impact for marine conservation, it is important that this is complemented by, and grounded in, appropriate training, capacity building and high-quality research. Given the urgency of the current challenges facing the ocean, all available methods to support effective and equitable responses to the biodiversity and climate crises should be used to their fullest capacity. We believe ocean perceptions research is an essential contribution to marine conservation and look forward to seeing the impacts this field will have in the coming decade and beyond.

AUTHOR CONTRIBUTIONS

RJ conceived the study, co-designed and contributed to data collection, undertook analysis, and led the drafting of the manuscript. EM co-designed and contributed to data collection, undertook analysis, and contributed to the drafting of the manuscript. HG and AN contributed to data collection. SF contributed to data collection, data analysis, and writing of the manuscript. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.711245/full#supplementary-material

REFERENCES

Ainsworth, G. B., Kenter, J. O., O'Connor, S., Daunt, F., and Young, J. C. (2019). A fulfilled human life: eliciting sense of place and cultural identity in two UK marine environments through the community voice method. *Ecosyst. Serv.* 39:100992. doi: 10.1016/j.ecoser.2019.100992

Alessa, L., Bennett, S. M., and Kliskey, A. D. (2003). Effects of knowledge, personal attribution and perception of ecosystem health on depreciative behaviors in the intertidal zone of pacific rim national park and reserve. *J. Environ. Manag.* 68, 207–218. doi: 10.1016/S0301-4797(03)00068-9

Alves, B., Ballester, R., Rigall-I-Torrent, R., Ferreira, Ó, and Benavente, J. (2017). How feasible is coastal management? A social benefit analysis of a coastal destination in SW Spain. *Tour. Manag.* 60, 188–200. doi: 10.1016/j.tourman.2016.12.004

Angulo, E., Diagne, C., Ballesteros-Mejia, L., Adamjy, T., Ahmed, D. A., Akulov, E., et al. (2021). Non-English languages enrich scientific knowledge: the example of economic costs of biological invasions. *Sci. Total Environ.* 775:144441. doi: 10.1016/j.scitotenv.2020.144441

Ariza, E., Ballester, R., Rigall-I-Torrent, R., Saló, A., Roca, E., Villares, M., et al. (2012). On the relationship between quality, users' perception and economic valuation in NW Mediterranean beaches. *Ocean Coast. Manag.* 63, 55–66. doi: 10.1016/j.ocecoaman.2012.04.002

Aswani, S., Diedrich, A., and Currier, K. (2015). Planning for the future: mapping anticipated environmental and social impacts in a nascent tourism destination. *Soc. Nat. Resour.* 28, 703–719. doi: 10.1080/08941920.2015.1020582

Balmford, A., Clegg, L., Coulson, T., and Taylor, J. (2002). Why conservationists should heed pokémon. *Science* 295, 2367–2367. doi: 10.1126/science.295.5564.2367b

Barry, L., van Rensburg, T. M., and Hynes, S. (2011). Improving the recreational value of Ireland's coastal resources: a contingent behavioural application. *Mar. Policy* 35, 764–771. doi: 10.1016/j.marpol.2011.01.009

Bavinck, M., and Verrips, J. (2020). Manifesto for the marine social sciences. *Marit. Stud.* 19, 121–123. doi: 10.1007/s40152-020-00179-x

Bennett, N. J. (2016). Using perceptions as evidence to improve conservation and environmental management. *Conserv. Biol.* 30, 582–592. doi: 10.1111/cobi.12681

Bennett, N. J. (2019). Marine social science for the peopled seas. *Coast. Manag.* 47, 244–252. doi: 10.1080/08920753.2019.1564958

Bennett, N. J., and Roth, R. (2019). Realizing the transformative potential of conservation through the social sciences, arts and humanities. *Biol. Conserv.* 229, A6–A8. doi: 10.1016/j.biocon.2018.07.023

Bennett, N. J., Katz, L., Yadao-Evans, W., Ahmadia, G. N., Atkinson, S., Ban, N. C., et al. (2021). Advancing social equity in and through marine conservation. *Front. Mar. Sci.* 8:994. doi: 10.3389/fmars.2021.711538

Bennett, N. J., Roth, R., Klain, S. C., Chan, K., Christie, P., Clark, D. A., et al. (2017a). Conservation social science: understanding and integrating human dimensions to improve conservation. *Biol. Conserv.* 205, 93–108. doi: 10.1016/j.biocon.2016.10.006

Bennett, N. J., Roth, R., Klain, S. C., Chan, K. M. A., Clark, D. A., Cullman, G., et al. (2017b). Mainstreaming the social sciences in conservation. *Conserv. Biol.* 31, 56–66. doi: 10.1111/cobi.12788

Borja, A., White, M., Berdalet, E., Bock, N., Eatock, C., Kristensen, P., et al. (2020). Moving toward an agenda on ocean health and human health in Europe. *Front. Mar. Sci.* 7:37. doi: 10.3389/fmars.2020.00037

Brennan, C., Ashley, M., and Molloy, O. (2019). A system dynamics approach to increasing ocean literacy. *Front. Mar. Sci.* 6:360. doi: 10.3389/fmars.2019.00360

Brennan, R. E. (2018). Re-storying marine conservation: integrating art and science to explore and articulate ideas, visions and expressions of marine space. *Ocean Coast. Manag.* 162, 110–126. doi: 10.1016/j.ocecoaman.2018.01.036

Brown, G., Strickland-Munro, J., Kobryn, H., and Moore, S. A. (2016). Stakeholder analysis for marine conservation planning using public participation GIS. *Appl. Geogr.* 67, 77–93. doi: 10.1016/j.apgeog.2015.12.004

Brownlee, M. T. J., and Verbos, R. I. (2015). Measuring outdoor recreationists' beliefs in climate change: testing the Occurrence and Anthropogenic Causation Scale (OC-AN). *J. Outdoor Recreat. Tour.* 11, 1–12. doi: 10.1016/j.jort.2015.06.003

Brueckner-Irwin, I., Armitage, D., and Courtenay, S. (2019). Applying a social-ecological well-being approach to enhance opportunities for marine protected area governance. *Ecol. Soc.* 24:3.

Bryman, A. (2016). *Social Research Methods*, 5th Edn. Oxford: Oxford University Press.

Burdon, D., Potts, T., McKinley, E., Lew, S., Shilland, R., Gormley, K., et al. (2019). Expanding the role of participatory mapping to assess ecosystem service provision in local coastal environments. *Ecosyst. Serv.* 39:101009. doi: 10.1016/j.ecoser.2019.101009

Capstick, S., Whitmarsh, L., Poortinga, W., Pidgeon, N., and Upham, P. (2015). International trends in public perceptions of climate change over the past quarter century. *WIREs Clim. Change* 6, 35–61. doi: 10.1002/wcc.321

CBD (2000). "COP 5 decision V/6," in *Conference of the Parties to the Convention on Biological Diversity, 15-26 May 2000* - Nairobi, Kenya.

Chambers, R., Hart, N., Ranger, S., Birney, A., Angheloiu, C., Loring, J., et al. (2019). The Marine CoLAB: taking a CoLABorative, values based approach to connect people to the Ocean. *Front. Mar. Sci.* 6:619. doi: 10.3389/fmars.2019.00619

Chawla, L. (2020). Childhood nature connection and constructive hope: a review of research on connecting with nature and coping with environmental loss. *People Nat.* 2, 619–642. doi: 10.1002/pan3.10128

Chen, C.-L., and Tsai, C.-H. (2016). Marine environmental awareness among university students in Taiwan: a potential signal for sustainability of the oceans. *Environ. Educ. Res.* 22, 958–977. doi: 10.1080/13504622.2015.1054266

Claudet, J. (2021). The seven domains of action for a sustainable ocean. *Cell* 184, 1426–1429. doi: 10.1016/j.cell.2021.01.055

Coleman, T., and Kearns, R. (2015). The role of bluespaces in experiencing place, aging and wellbeing: insights from Waiheke Island, New Zealand. *Health Place* 35, 206–217. doi: 10.1016/j.healthplace.2014.09.016

Cunsolo, A., Harper, S., Minor, K., Hayes, K., Williams, K., and Howard, C. (2020). Ecological grief and anxiety: the start of a healthy response to climate change? *Lancet* 4, 261–263.

de la Torre-Castro, M., Fröcklin, S., Börjesson, S., Okupnik, J., and Jiddawi, N. S. (2017). Gender analysis for better coastal management-Increasing our understanding of social-ecological seascapes. *Mar. Policy* 83, 62–74. doi: 10.1016/j.marpol.2017.05.015

De Lopez, T. T. (2003). Economics and stakeholders of Ream National Park, Cambodia. *Ecol. Econ.* 46, 269–282. doi: 10.1016/S0921-8009(03)00142-3

Di Marco, M., Chapman, S., Althor, G., Kearney, S., Besancon, C., Butt, N., et al. (2017). Changing trends and persisting biases in three decades of conservation science. *Glob. Ecol. Conserv.* 10, 32–42. doi: 10.1016/j.gecco.2017.01.008

Duarte, C. M., Dennison, W. C., Orth, R. J. W., and Carruthers, T. J. B. (2008). The charisma of coastal ecosystems: addressing the imbalance. *Estuar. Coasts* 31, 233–238. doi: 10.1007/s12237-008-9038-7

Eddy, T. D. (2014). One hundred-fold difference between perceived and actual levels of marine protection in New Zealand. *Mar. Policy* 46, 61–67. doi: 10.1016/j.marpol.2014.01.004

Faasen, H., and Watts, S. (2007). Local community reaction to the 'no-take' policy on fishing in the Tsitsikamma National Park, South Africa. *Ecol. Econ.* 64, 36–46. doi: 10.1016/j.ecolecon.2007.06.026

Fischer, A., and Young, J. C. (2007). Understanding mental constructs of biodiversity: implications for biodiversity management and conservation. *Biol. Conserv.* 136, 271–282. doi: 10.1016/j.biocon.2006.11.024

Fleming, L., Maycock, B., White, M., and Depledge, M. (2019). Fostering human health through ocean sustainability in the 21st century. *People Nat.* 1, 276–283.

Fletcher, S., and Potts, J. (2007). Ocean citizenship: an emergent geographical concept. *Coast. Manag.* 35, 511–524. doi: 10.1080/08920750701525818

Gall, S. C., and Rodwell, L. D. (2016). Evaluating the social acceptability of marine protected areas. *Mar. Policy* 65, 30–38. doi: 10.1016/j.marpol.2015.12.004

Gardner, C. J. (2021). Not teaching what we practice: undergraduate conservation training at UK universities lacks interdisciplinarity. *Environ. Conserv.* 48, 65–70. doi: 10.1017/S0376892920000442

Gelcich, S., and O'Keeffe, J. (2016). Emerging frontiers in perceptions research for aquatic conservation. *Aquat. Conserv.* 26, 986–994. doi: 10.1002/aqc.2714

Gelcich, S., Buckley, P., Pinnegar, J. K., Chilvers, J., Lorenzoni, I., Terry, G., et al. (2014). Public awareness, concerns, and priorities about anthropogenic impacts on marine environments. *Proc. Natl. Acad. Sci.* 111, 15042–15047. doi: 10.1073/pnas.1417344111

Gifford, R. (2011). The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation. *Am. Psychol.* 66, 290–302. doi: 10.1037/a0023566

Glithero, L., and Zandvilet, D. (2021). *Evaluating Ocean Perceptions and Ocean Values: The Canadian Ocean Literacy Survey*.

Goldberg, J., Marshall, N., Birtles, A., Case, P., Bohensky, E., Curnock, M., et al. (2016). Climate change, the great barrier reef and the response of Australians. *Palgrave Commun.* 2:15046. doi: 10.1057/palcomms.2015.46

Grafeld, S., Oleson, K., Barnes, M., Peng, M., Chan, C., and Weijerman, M. (2016). Divers' willingness to pay for improved coral reef conditions in Guam: an untapped source of funding for management and conservation? *Ecol. Econ.* 128, 202–213. doi: 10.1016/j.ecolecon.2016.05.005

Gruby, R. L., Fairbanks, L., Acton, L., Artis, E., Campbell, L. M., Gray, N. J., et al. (2017). Conceptualizing social outcomes of large marine protected areas. *Coast. Manag.* 45, 416–435. doi: 10.1080/08920753.2017.1373449

Gruby, R. L., Gray, N. J., Campbell, L. M., and Acton, L. (2016). Toward a social science research agenda for large marine protected areas. *Conserv. Lett.* 9, 153–163. doi: 10.1111/conl.12194

Hammerton, Z. (2017). Determining the variables that influence SCUBA diving impacts in eastern Australian marine parks. *Ocean Coast. Manag.* 142, 209–217. doi: 10.1016/j.ocecoaman.2017.03.030

Haward, M., and Haas, B. (2021). The need for social considerations in SDG 14. *Front. Mar. Sci* 8:632282. doi: 10.3389/fmars.2021.632282

International Energy Agency (2019). *Offshore Wind Outlook 2019.* World Energy Outlook Special Report. Available online at: https://www.iea.org/reports/offshore-wind-outlook-2019 (accessed May 15, 2021).

ISSC/UNESCO (2013). *World Social Science Report 2013: Changing Global Environments*. Paris: OECD.

Jefferson, R. L., Bailey, I., Laffoley, D. d'A, Richards, J. P., and Attrill, M. J. (2014). Public perceptions of the UK marine environment. *Mar. Policy* 43, 327–337. doi: 10.1016/j.marpol.2013.07.004

Jefferson, R., McKinley, E., Capstick, S., Fletcher, S., Griffin, H., and Milanese, M. (2015). Understanding audiences: making public perceptions research matter to marine conservation. *Ocean Coast. Manag.* 115, 61–70. doi: 10.1016/j.ocecoaman.2015.06.014

Johnson, T. R., Jansujwicz, J. S., and Zydlewski, G. (2015). Tidal power development in maine: stakeholder identification and perceptions of engagement. *Estuar. Coasts* 38, 266–278. doi: 10.1007/s12237-013-9703-3

Kanagavel, A., Raghavan, R., and Veríssimo, D. (2014). Beyond the "general public": implications of audience characteristics for promoting species conservation in the western ghats hotspot, India. *Ambio* 43, 138–148. doi: 10.1007/s13280-013-0434-2

Kearns, R., and Collins, D. (2012). Feeling for the coast: the place of emotion in resistance to residential development. *Soc. Cult. Geogr.* 13, 937–955. doi: 10.1080/14649365.2012.730150

Kellert, S. R. (1997). *The Value of Life: Biological Diversity And Human Society*. Washington, DC: Island Press.

Kelly, R., Evans, K., Alexander, K., Bettiol, S., Corney, S., Cullen-Knox, C., et al. (2021). Connecting to the oceans: supporting ocean literacy and public engagement. *Rev. Fish Biol. Fish.* 1–12.doi: 10.1007/s11160-020-09625-9

Kerr, S., Watts, L., Colton, J., Conway, F., Hull, A., Johnson, K., et al. (2014). Establishing an agenda for social studies research in marine renewable energy. *Energy Policy* 67, 694–702. doi: 10.1016/j.enpol.2013.11.063

Koehn, J. Z., Reineman, D. R., and Kittinger, J. N. (2013). Progress and promise in spatial human dimensions research for ecosystem-based ocean planning. *Mar. Policy* 42, 31–38. doi: 10.1016/j.marpol.2013.01.015

Kolandai-Matchett, K., Armoudian, M., Thrush, S., Hillman, J., Schwendenmann, L., Jakobsson, J., et al. (2021). Marine ecosystem science and the media: exploring ways to improve news coverage through journalist–scientist working relations. *Aquat. Conserv.* doi: 10.1002/aqc.3708

Kollmuss, A., and Agyeman, J. (2002). Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environ. Educ. Res.* 8, 239–260. doi: 10.1080/13504620220145401

Kosgei, J. (2021). Indigenous knowledge and marine conservation in oral poems from the Kenyan Coast. *Wasafiri* 36, 71–78. doi: 10.1080/02690055.2021.1879498

Lotze, H. K., Guest, H., O'Leary, J., Tuda, A., and Wallace, D. (2018). Public perceptions of marine threats and protection from around the world. *Ocean Coast. Manag.* 152, 14–22. doi: 10.1016/j.ocecoaman.2017.11.004

Manfredo, M. J., Bruskotter, J. T., Teel, T. L., Fulton, D., Schwartz, S. H., Arlinghaus, R., et al. (2017). Why social values cannot be changed for the sake of conservation. *Conserv. Biol.* 31, 772–780. doi: 10.1111/cobi.12855

Martin, V. Y. (2020). Four common problems in environmental social research undertaken by natural scientists. *Bioscience* 70, 13–16. doi: 10.1093/biosci/biz128

Mascia, M. B., Brosius, J. P., Dobson, T. A., Forbes, B. C., Horowitz, L., McKean, M. A., et al. (2003). Conservation and the social sciences. *Conserv. Biol.* 17, 649–650. doi: 10.1046/j.1523-1739.2003.01738.x

Mascia, M. B., Claus, C. A., and Naidoo, R. (2010). Impacts of marine protected areas on fishing communities. *Conserv. Biol.* 24, 1424–1429. doi: 10.1111/j.1523-1739.2010.01523.x

McComas, K. A., Schuldt, J. P., Burge, C. A., and Roh, S. (2015). Communicating about marine disease: the effects of message frames on policy support. *Mar. Policy* 57, 45–52. doi: 10.1016/j.marpol.2015.02.012

McKinley, E., Acott, T., and Yates, K. L. (2020a). Marine social sciences: looking towards a sustainable future. *Environ. Sci. Policy* 108, 85–92. doi: 10.1016/j.envsci.2020.03.015

McKinley, E., Pagès, J. F., Alexander, M., Burdon, D., and Martino, S. (2020b). Uses and management of saltmarshes: a global survey. *Estuar. Coast. Shelf Sci.* 243:106840. doi: 10.1016/j.ecss.2020.106840

McKinley, E., and Burdon, D. (2020). Understanding Ocean Literacy And Ocean Climate-Related Behaviour Change In The UK: An Evidence Synthesis. Final report produced for the Ocean Conservation Trust and Defra. Willerby: Daryl Burdon.

McKinley, E., and Fletcher, S. (2010). Individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. *Ocean Coast. Manag.* 53, 379–384. doi: 10.1016/j.ocecoaman.2010.04.012

McKinley, E., and Fletcher, S. (2012). Improving marine environmental health through marine citizenship: a call for debate. *Mar. Policy* 36, 839–843. doi: 10.1016/j.marpol.2011.11.001

Moon, K., Adams, V. M., and Cooke, B. (2019a). Shared personal reflections on the need to broaden the scope of conservation social science. *People Nat.* 1, 426–434. doi: 10.1002/pan3.10043

Moon, K., Blackman, D. A., Adams, V. M., Colvin, R. M., Davila, F., Evans, M. C., et al. (2019b). Expanding the role of social science in conservation through an engagement with philosophy, methodology, and methods. *Methods Ecol. Evol.* 10, 294–302. doi: 10.1111/2041-210X.13126

Moon, K., Brewer, T., Januchowski-Hartley, S., Adams, V., and Blackman, D. (2016). A guideline to improve qualitative social science publishing in ecology and conservation journals. *Ecol. Soc.* 21:17. doi: 10.5751/ES-08663-210317

Moore, S. A., Brown, G., Kobryn, H., and Strickland-Munro, J. (2017). Identifying conflict potential in a coastal and marine environment using participatory mapping. *J. Environ. Manag.* 197, 706–718. doi: 10.1016/j.jenvman.2016.12.026

Moscardo, G., Green, D., and Greenwood, T. (2001). How great is the great barrier reef! tourists' knowledge and understanding of the world heritage status of the great barrier reef. *Tour. Recreat. Res.* 26, 19–25. doi: 10.1080/02508281.2001.11081173

Mwebaze, P., and MacLeod, A. (2013). Valuing marine parks in a small island developing state: a travel cost analysis in Seychelles. *Environ. Dev. Econ.* 18, 405–426. doi: 10.1017/S1355770X12000538

Newing, H. (2011). *Conducting Research in Conservation: Social Science Methods and Practice*. London: Routledge. doi: 10.4324/9780203846452

O'Hara, C. C., Frazier, M., and Halpern, B. S. (2021). At-risk marine biodiversity faces extensive, expanding, and intensifying human impacts. *Science* 372, 84–87. doi: 10.1126/science.abe6731

O'Neill, S., and Nicholson-Cole, S. (2009). "Fear won't do it": promoting positive engagement with climate change through visual and iconic representations. *Sci. Commun.* 30, 355–379. doi: 10.1177/1075547008329201

Ong, T. F., and Musa, G. (2012). Examining the influences of experience, personality and attitude on SCUBA divers' underwater behaviour: a structural equation model. *Tour. Manag.* 33, 1521–1534. doi: 10.1016/j.tourman.2012.02.007

Overland, I., and Sovacool, B. K. (2020). The misallocation of climate research funding. *Energy Res. Soc. Sci.* 62:101349. doi: 10.1016/j.erss.2019.101349

Pakalniete, K., Aigars, J., Czajkowski, M., Strake, S., Zawojska, E., and Hanley, N. (2017). Understanding the distribution of economic benefits from improving coastal and marine ecosystems. *Sci. Total Environ.* 58, 29–40. doi: 10.1016/j.scitotenv.2017.01.097

Pascual, U., Balavnera, P., Diaz, S., Pataki, G., Roth, E., Stenseke, M., et al. (2017). Valuing nature's contributions to people: the IPBES approach. *Curr. Opin. Environ. Sustain.* 2, 7–16. doi: 10.1016/j.cosust.2016.12.006

Perry, E. E., Needham, M. D., Cramer, L. A., and Rosenberger, R. S. (2014). Coastal resident knowledge of new marine reserves in Oregon: the impact of proximity and attachment. *Ocean Coast. Manag.* 95, 107–116. doi: 10.1016/j.ocecoaman.2014.04.011

Piriyapada, S., and Wang, E. (2014). Quantifying the costs and benefits of coastal water quality improvements in the ko chang marine national park, Thailand. *Environ. Processes* 1, 149–169. doi: 10.1007/s40710-014-0013-y

Potts, T., Pita, C., O'Higgins, T., and Mee, L. (2016). Who cares? European attitudes towards marine and coastal environments. *Mar. Policy* 72, 59–66. doi: 10.1016/j.marpol.2016.06.012

Pouso, S., Borja, A., Fleming, L., Gomez-Baggethun, E., White, M., and Uyarra , M. C. (2021). Contact with blue-green spaces during the COVID-19 pandemic lockdown beneficial for mental health. *Sci. Total Environ.* 756:143984. doi: 10.1016/j.scitotenv.2020.143984

Ramírez-Castañeda, V. (2020). Disadvantages in preparing and publishing scientific papers caused by the dominance of the english language in science: the case of Colombian researchers in biological sciences. *PLoS One* 15:e0238372. doi: 10.1371/journal.pone.0238372

Rasheed, A. R. (2020). Marine protected areas and human well-being-A systematic review and recommendations. *Ecosyst. Serv.* 41:101048. doi: 10.1016/j.ecoser.2019.101048

Roca, E., Villares, M., and Ortego, M. I. (2009). Assessing public perceptions on beach quality according to beach users' profile: a case study in the Costa Brava (Spain). *Tour. Manag.* 30, 598–607. doi: 10.1016/j.tourman.2008.10.015

Romañach, S. S., DeAngelis, D. L., Koh, H. L., Li, Y., Teh, S. Y., Raja Barizan, R. S., et al. (2018). Conservation and restoration of mangroves: global status, perspectives, and prognosis. *Ocean Coast. Manag.* 154, 72–82. doi: 10.1016/j.ocecoaman.2018.01.009

Ryabinin, V., Barbière, J., Haugan, P., Kullenberg, G., Smith, N., McLean, C., et al. (2019). The UN decade of ocean science for sustainable development. *Front. Mar. Sci.* 6:470. doi: 10.3389/fmars.2019.00470

Salager-Meyer, F. (2008). Scientific publishing in developing countries: challenges for the future. *J. English Acad. Purp.* 7, 121–132. doi: 10.1016/j.jeap.2008.03.009

Schultz, P. W. (2011). Conservation means behavior. *Conserv. Biol.* 25, 1080–1083. doi: 10.1111/j.1523-1739.2011.01766.x

Schwartz, S. H. (2012). An overview of the schwartz theory of basic values. *Online Read. Psychol. Cult.* 2:1116. doi: 10.9707/2307-0919.1116

Short, R., Cox, D., Tan, Y., Bethel, A., Eales, J., and Garside , R. (2021). Review of the evidence for oceans and human health relationships in Europe: a systematic map. *Environ. Int.* 146:106275. doi: 10.1016/j.envint.2020.106275

Steel, B. S., Smith, C., Opsommer, L., Curiel, S., and Warner-Steel, R. (2005). Public ocean literacy in the United States. *Ocean Coast. Manag.* 48, 97–114. doi: 10.1016/j.ocecoaman.2005.01.002

Stoll-Kleemann, S. (2019). Feasible options for behavior change toward more effective ocean literacy: a systematic review. *Front. Mar. Sci.* 6:273.doi: 10.3389/fmars.2019.00273

Strickland-Munro, J., Kobryn, H., Brown, G., and Moore, S. A. (2016). Marine spatial planning for the future: using Public Participation GIS (PPGIS) to inform the human dimension for large marine parks. *Mar. Policy* 73, 15–26. doi: 10.1016/j.marpol.2016.07.011

Titley, M. A., Snaddon, J. L., and Turner, E. C. (2017). Scientific research on animal biodiversity is systematically biased towards vertebrates and temperate regions. *PLoS One* 12:e0189577. doi: 10.1371/journal.pone.0189577

Tonge, J., Moore, S. A., Ryan, M. M., and Beckley, L. E. (2013). A photo-elicitation approach to exploring the place meanings ascribed by campers to the ningaloo coastline, North-western Australia. *Aust. Geogr.* 44, 143–160. doi: 10.1080/00049182.2013.789591

UNEP-WCMC, and IUCN (2021). *Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM) [Online], May 2021*. Cambridge: UNEP-WCMC and IUCN.

Unsworth, R. K. F., McKenzie, L. J., Collier, C. J., Cullen-Unsworth, L. C., Duarte, C. M., Eklöf, J. S., et al. (2019). Global challenges for seagrass conservation. *Ambio* 48, 801–815. doi: 10.1007/s13280-018-1115-y

Vanderheiden, S. (2011). Rethinking Environmentalism: beyond doom and gloom. *Glob. Environ. Politics* 11, 108–113. doi: 10.1162/GLEP_r_00045

Vincent, A. C. J. (2011). Saving the shallows: focusing marine conservation where people might care. *Aquat. Conserv.* 21, 495–499. doi: 10.1002/aqc.1226

Voyer, M., Gollan, N., Barclay, K., and Gladstone, W. (2015). 'It×s part of me'; understanding the values, images and principles of coastal users and their influence on the social acceptability of MPAs. *Mar. Policy* 52, 93–102. doi: 10.1016/j.marpol.2014.10.027

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., et al. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science* 314, 787–790. doi: 10.1126/science.1132294

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Pathways to Justice, Equity, Diversity, and Inclusion in Marine Science and Conservation

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Marine conservation sciences have traditionally been, and remain, non-diverse work environments with many barriers to justice, equity, diversity, and inclusion (JEDI). These barriers disproportionately affect entry of early career scientists and practitioners and limit the success of marine conservation professionals from under-represented, marginalized, and overburdened groups. These groups specifically include women, LGBTQ+, Black, Indigenous, and people of color (BIPOC). However, the issues also arise from the global North/South and East/West divide with under-representation of scientists from the South and East in the global marine conservation and science arena. Persisting inequities in conservation, along with a lack of inclusiveness and diversity, also limit opportunities for innovation, cross-cultural knowledge exchange, and effective implementation of conservation and management policies. As part of its mandate to increase diversity and promote inclusion of underrepresented groups, the Diversity and Inclusion committee of the Society for Conservation Biology-Marine Section (SCB Marine) organized a JEDI focus group at the Sixth International Marine Conservation Congress (IMCC6) which was held virtually. The focus group included a portion of the global cohort of IMCC6 attendees who identified issues affecting JEDI in marine conservation and explored pathways to address those issues. Therefore, the barriers and pathways identified here focus on issues pertinent to participants' global regions and experiences. Several barriers to just, equitable, diverse, and inclusive conservation science and practice were identified. Examples included limited participation of under-represented minorities (URM) in research networks, editorial biases against URM, limited professional development and engagement opportunities for URM and non-English speakers, barriers to inclusion of women, LGBTQ+, and sensory impaired individuals, and financial barriers to inclusion of URM in all aspects of marine conservation and research. In the current policy brief, we explore these barriers, assess how they limit progress in marine conservation research and practice, and seek to identify initiatives for improvements. We expect the initiatives discussed here to advances practices rooted in principles of JEDI, within SCB Marine and, the broader conservation community. The recommendations and perspectives herein broadly apply to conservation science and practice, and are critical to effective and sustainable conservation and management outcomes.

Keywords: equity, diversity, inclusion, conferences, peer-review, bias, marine, conservation

INTRODUCTION

The lack of diversity in marine sciences and conservation has existed for a while, however its extent, specific causes and impacts are being characterized more recently by scholars and practitioners globally. Overcoming this lack of diversity triggered by systemic inequities and exclusion remains complex and overdue, and can only be achieved by first identifying causative factors and potential pathways to resolution of each. Some efforts to improve equity, diversity, and inclusion are underway, especially within the last decade (Tulloch, 2020). While the overall representation of individuals from marginalized, overburdened, and underrepresented minorities (URM) has seen a modest increase, ethnic, and racial diversity within the marine or ocean sciences has stagnated (Bernard and Cooperdock, 2018). Some of the identified challenges in marine sciences, and more generally in the biophysical sciences, include lack of leadership roles for under-represented groups, access to academic conferences, representation across all communities, and organizational-level changes. To develop the initiatives and support systems that foster diversity and inclusion in STEM, diversity and inclusion in leadership roles are required (Robinson et al., 2013; Abdul-Raheem, 2016). A lack of diversity at the leadership level is often due to an absence of support systems for URM individuals, leading to systemic effects of a non-inclusive and unempathetic environment. There is ample evidence that minority groups in science face multiple barriers that span across the processes of publishing and funding to being hired and tenured. So URMs largely remain URMs with no upward mobility over time.

One barrier is ecology conferences; most do not ensure diversity of plenary speakers or provide support services to include parents with childcare needs and LGBTQ+ individuals (Tulloch, 2020). Many ecology conferences also have high registration fees and travel costs which can exclude many ethnic minorities and early career researchers due to a lack of funding resulting in financial barriers to developing professional connections and collaborations (Niner et al., 2020; Niner and Wassermann, 2021). Another barrier is publication in scientific journals, editors and reviewers are primarily from North America and Europe and identify as male (Preston, 2018). Gender-related barriers also exist. A recent report by Women in Ocean Sciences suggests that 78% of women engaged in marine sciences have experienced sexual harassment in their workplace or learning environment (Sexual Harassment in Marine Science, n.d.). Only 39% of the respondents who experienced sexual harassment reported it, and only one-third had institutional policies in place to tackle sexual harassment (Sexual Harassment in Marine Science, n.d.). Last, compared to majority groups, gender and racial minorities' novel contributions are recognized at lower rates by other scholars and equally impactful contributions are less likely to result in successful scientific careers (Hofstra et al., 2020).

Equity, diversity, and inclusion in marine sciences are required to ensure representation across all communities in the marine conservation space. This representation ensures the prioritization of justice, stakeholder and rightsholder supportive outcomes, effective communication, and sustainability in conservation measures. Further, diversity is known to foster innovation (Phillips, 2014). Research has demonstrated that groups of people working together who are diverse in terms of race, ethnicity, social status, and gender are more innovative than homogeneous groups; typically generate more productive and innovative solutions to problems; and demonstrate greater critical thinking and analytical skills (Phillips, 2014). Marine conservation has one of the highest complexity indices (Dulvy et al., 2017) due to the inherently complex nature of the issues it encompasses, including the numerous stakeholders and diverse interests involved. Those complexities include, for example, the design and management of conservation for marine organisms and ecosystems, which may often span multiple countries' exclusive economic zones and jurisdictions as well as affect fisheries dependent livelihoods. Marine conservation requires innovative ideas to solve such complex issues, ensure sustainable, and effectively protect marine biodiversity. Marine conservation, therefore, needs to invest and engage in improving diversity and inclusion in the field.

Current efforts to increase diversity of URM students in STEM tend to focus on improving students' academic capabilities and psychological perceptions of STEM. However, a sustained improvement in justice, equity, diversity, and inclusion (JEDI) issues in conservation requires the comprehensive engagement of the marine science community and institutions to identify and address inadequacies hindering JEDI at the organizational level (Grogan, 2019). Transparency on JEDI objectives can help focus the community's efforts, promote relevant initiatives, and allow for accountability in those cases where biases and inequities persist. For instance, in recognition of this challenge more resources have been dedicated to JEDI in marine conservation in the context of the United Nations Decade of Ocean Science for Sustainable Development (Singh et al., 2018).

As part of its mandate to increase diversity and promote inclusion, the Diversity and Inclusion committee of the Society for Conservation Biology-Marine Section (SCB Marine) organized two JEDI focus groups at the virtually held Sixth

International Marine Conservation Congress (IMCC6), August 2020. IMCC6 had an unusually high number of URM participants (Niner and Wassermann, 2021) due to its virtual nature, inclusive environment, and support services, which increased ease of access and reduced the conference's financial burden (Niner and Wassermann, 2021). The diverse backgrounds of a large number of participants enabled us to tap into this group to identify barriers to diversity and inclusion and solutions to improve on these challenges.

In the current policy brief, we discuss barriers to JEDI in marine conservation identified during the focus groups, in particular the systemic barriers and their implications for URM, assess how they limit progress in marine science and conservation, and seek to identify initiatives for improvements. We expect the avenues for improvements discussed in this article to advance policies and initiatives rooted in justice, equity, diversity and inclusion, within the conservation science and practice communities.

METHODS

We held two focus groups, for 3 hours and 1 hour, respectively, and invited IMCC6 attendees to identify issues affecting JEDI in marine conservation and to explore pathways to addressing the identified issues. Approximately 20 participants attended the first focus group (FG1) and as such the discussions occurred for the entire session in one place instead of dividing participants into breakout groups to discuss different issues. The first part of FG1 included introductions from all participants and enabled a discussion of barriers to JEDI in marine conservation experienced by participants and anyone willing to share their experiences could contribute. The second part of FG1 focused on a group discussion of pathways to addressing barriers to JEDI in marine conservation. FG2 lasted 1 h, was a continuation of FG1, included some new participants and some from FG1, and involved a detailed discussion of pathways to JEDI in response to a subset of key barriers identified in FG1. All points made during both focus groups were recorded as written meeting minutes by the 3 organizers of the focus group. The session was not recorded given the sensitive nature of the topics discussed and to respect the privacy of the participants. The participants' residences and nationalities included locations in North America, Europe, Asia, Africa, Australia, and island regions. The participants identified several barriers to just, equitable, diverse, and inclusive conservation science and practice pertinent to participants' global regions and experiences. Examples of barriers raised during the focus groups included limited participation of URM in research networks, editorial biases against URM, limited professional development and engagement opportunities for URM and non-English speakers, barriers to inclusion of women, LGBTQ+, and sensory impaired individuals, and financial barriers to inclusion of URM in all aspects of marine conservation and research. The issues identified and solutions suggested by participants were submitted to the Society for Conservation Biology marine section as a statement of requests (**Supplementary Figure 1**) via electronic communication. The statement was supported by 110 signatories from broad geographic and institutional affiliations (**Figure 1**). In the current manuscript, we have expanded upon each of the barriers to JEDI identified in the focus groups and included in the Statement of Requests. Each of the themes, including barriers and pathways to improving the respective challenges discussed here, was identified in the focus group and documented in the Statement of Requests.

We acknowledge that the term URM is likely unwieldy and undesirable to some, as has been discussed extensively by Dr. Tiffani Williams[1] and others. However, our use of this term is due to a lack of an all-encompassing term to enable inclusion of all minorities and issues concerning them at a global level, discussed in this piece. Our attempt is not to label minorities as a permanently underrepresented group, but rather to include and recognize all minority groups and define the issues serving as barriers to their inclusion in marine conservation and pathways to remove these barriers, such that there are no URM groups in the future realm of marine conservation.

JUSTICE, EQUITY, DIVERSITY, AND INCLUSION ISSUES, LESSONS LEARNED, BARRIERS, AND SOLUTIONS

The following sections provide a description of challenges and barriers to JEDI in marine conservation under three main categories: STEMming the leaky pipeline, equity in editorial matters, and support services during events and meetings. These challenges were identified by participants from two JEDI focus group sessions during IMCC6. We also describe potential solutions to address these challenges and barriers in each of the three sections.

Theme 1: STEMming the Leaky Pipeline

Barriers to Retention and Impact on the Field

Barriers to participation in STEM for women, LGBTQ+, and Black, Indigenous, and people of color (BIPOC) students and professionals exist at every stage of learning and career development. This is even more true in marine conservation science, which is white and male-dominated, particularly in leadership and decision making positions. This imbalance is self-perpetuating, as non-white, non-male students and researchers do not feel welcome in the field (or are sometimes intentionally or unintentionally excluded), whether because of active, overt discrimination and sexism; unaddressed microaggressions; lack of recognition and rewards; and/or absence of models of success for URM in the field.

In addition, science and scholarship from Europe and North America dominate conservation science, with the academic reward system creating yet more barriers for academics from non-English speaking countries through publication and citation indices. Similarly, historically, academic conferences,

[1] "Underrepresented Minority" Considered Harmful, Racist Language- a thought-piece by Dr. Tiffani Williams on "Communications of the ACM Blog." https://cacm.acm.org/blogs/blog-cacm/245710-underrepresented-minority-considered-harmful-racist-language/fulltext.

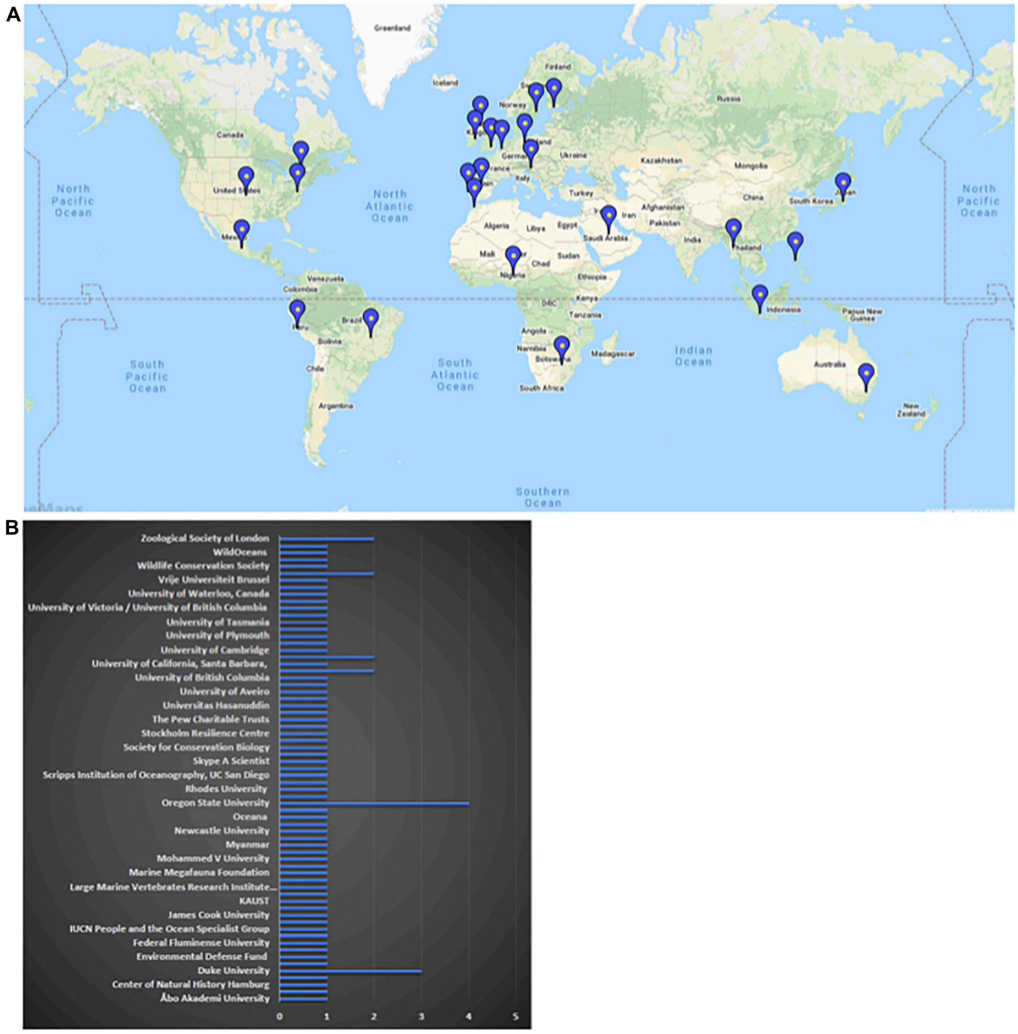

FIGURE 1 | Country of work or nationality **(A)** and affiliation **(B)** of those who signed the Statement of Requests to SCB Marine Section and chose to share the information.

and opportunities to present research have been hosted in the global North, making attendance difficult for participants from the global South, including students and researchers with limited funding. Breaking down these barriers will take concerted action at every stage of education and professional development. Shifting institutional lock-in and changing power dynamics requires deliberate, reflexive work by those who are currently active in professional and academic networks, including academic societies like SCB (Nocco et al., 2021).

Over the last year, questions of privilege and oppression have come to the fore, with global protests against entrenched racism leading to established organizations like universities, businesses, governments, and NGOs questioning their historical roles in oppression and exclusion of BIPOC students, scholars, and professionals. SCB expressed solidarity with the Black Lives Matter movement (SCB Pledges Solidarity with BLM protests, 2020), with SCB North America section noting, "We cannot ignore our own part in acquiescing to broad scale anti-Black racism. The historic and continuing research and practice of conservation has consistently contributed to the marginalization of Black people" (Society for Conservation Biology North America (SCBAM), 2020). Moving towards justice and equity will therefore require an "active dismantling" of racist systems, including in conservation.

How to Address Barriers to Retention and Advancement

Given that barriers exist at every stage of academic and professional training and development, there are several points of entry for addressing these barriers, including for a professional society like SCB. Stemming (or STEMming) the "leaky pipeline", in particular, is an area where SCB can help. Students and early career professionals require equitable, consistent access to mentorship, educational networking and, opportunities, career development, and advancement. Both participation and career advancement in marine conservation depend on forming connections and networks that can open doors, support research, and create opportunities for underrepresented and historically marginalized students and professionals.

The recent focus on racial justice has largely coincided with the COVID-19 pandemic, which provides useful lessons and opportunities for advancing new ways of doing more inclusive marine conservation. This includes expanded access to meetings, capacity building, training, mentorship, and professional development opportunities via online meetings and teaching tools (see section three for other suggestions on improving meetings).

Increasing Access

While there are still challenges with connectivity, online tools can increase access, as the pandemic has made clear. Two years ago, during the UNFCCC COP25,[2] a group of early career researchers developed an online learning series about ocean and climate with speakers from around the world for people who were unable to travel to the COP (#virtualblueCOP, now #VirtualBlueDecade). At the time, focusing on broadening access and limiting carbon emissions by turning to virtual meetings was still a novel idea (Thomsen and Creelman, 2021). Today, it is common enough that we talk about "Zoom fatigue" (e.g., Bailenson, 2021) and people are exploring alternatives and ways to improve online connections (e.g., Wiederhold, 2020). The online format of IMCC6 allowed for the participation of those who would otherwise not have had the chance to meet and develop connections (e.g., Sarabipour, 2020).

Given that in-person networking and dissemination events such as conferences, workshops, and other meetings are key to professional development (Favaro et al., 2016; Oester et al., 2017; Timperley et al., 2020), these changes are welcome. The costs associated with in-person events are often prohibitively high, despite the presence of tiered registration fees that account for one's career stage or country of origin; for instance, reduced fees or financial support for early career scientists and/or participants from low-income countries. The rotation of the country or region where the conference is hosted, as in the case of the IMCC conference, often helps alleviate some of the financial burden, but does not eliminate the problem.

Additionally, while some institutions financially support students' participation in such events, students engaged in programs with limited institutional funding are less likely to have access to financial support. They also may not be able to pay up-front costs while waiting to be reimbursed by their institutions. Early career scientists and professionals typically also have limited access to funds and may be engaged in projects that hinder their participation in conferences and meetings. Conditions in academic institutions such as a higher teaching burden compared to senior colleagues and the need to invest time in raising grant funding and pursuing tenure also likely result in limited time for research dissemination and networking that requires travel (Timperley et al., 2020; Niner and Wassermann, 2021).

[2]UNFCCC COP25-25th Conference of the Parties to the United Nations Framework Convention on Climate Change.

Increasing Recognition of Under-Represented Minorities Scholars and Professionals

Adding to these barriers, gender, race, and ethnicity factors limit opportunities for professional development, as reflected in URM professionals' participation in conferences and their role therein. For example, they are invited less often for prominent roles such as keynote or plenary speakers (Sardelis and Drew, 2016; King et al., 2018; Timperley et al., 2020; Niner and Wassermann, 2021); their publication record is affected by biases in the editorial and review process (see section two); and their promotion and professional development are limited by other structural equity imbalances (Ginther and Kahn, 2004; Hengel, 2017; Mengel et al., 2019; Doleac et al., 2021; Sarsons et al., 2021). Virtual meetings, because of the lower barriers to participation, may offer opportunities to remedy some of these inequities.

Alternatives to in-person meetings can be used beyond scientific conferences, and scientific societies can take advantage of them to support students and early career professionals, encouraging them to remain in the field. For example, one of the calls developed by the JEDI committee in its regular meetings in advance of the workshop was to create a "marine diversity network," a global online platform to allow widespread communication, promote transparency, and develop positive collaborations. This is a role for which SCB Marine is well-suited, and that can carry the mission of SCB Marine beyond biennial meetings and publications and into practical engagements and collaborations among members.

In recognition of the multiple issues hindering JEDI, and specifically the barriers to participation in the IMCC conference, SCB Marine introduced a code of conduct in 2016 to promote diversity and inclusion, limit inequity of access to conferences related to one's personal safety, and avoid possible harassment (Favaro et al., 2016). SCB Marine has also worked to incentivize female leadership, offering preferential fees as a means of attracting increased participation from women (Niner and Wassermann, 2021), and it is likely that the SCB Marine community will continue to support online and hybrid conferences. Nonetheless, structural injustices persist with technological barriers to access affecting primarily professionals from the global South (Niner et al., 2020; Niner and Wassermann, 2021).

Accounting for Unequal Barriers to and Opportunities for Advancement

Recognizing that underrepresented groups face barriers to reaching senior leadership roles is fundamental in initiatives for professional development. In addition to having to face the "leaky pipeline," it continues to be difficult for members of underrepresented groups to advance in conservation science. For example, women continue to leave the field more often and have lower promotion rates than men (McGuire et al., 2012). Professional development and support are critical to addressing this imbalance. Professional societies are designed to provide these through activities like conferences, publications, and the recognition and promotion of excellence in research (e.g., National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2005). However, there are still barriers that need to be addressed to ensure that underrepresented members are able to take advantage of these activities.

Structural inequities, such as biases in credit attribution and opportunities for dissemination in academic work and promotion, may hinder the professional development of URMs. There is evidence, for example, from the field of economics that co-authorship matters differently for tenure for men and women (Sarsons et al., 2021), that women are less likely to be invited to present their work in seminars (Doleac et al., 2021), that their work tends to spend longer in the peer-review process compared to men's work (Hengel, 2017), that it is less likely for them to get tenure and takes more time to do so (Ginther and Kahn, 2004), and that they tend to receive systematically lower teaching evaluations compared to their male colleagues, which is driven by the input of male students (Mengel et al., 2019).

Professional societies like SCB can continue to take steps to reduce these barriers. For example, regular, year-round seminar series and workshop opportunities would support ongoing career development, community building, and networking. These activities should specifically ensure the inclusion of early career conservationists from diverse cultural and geographic backgrounds. Addressing systemic discrimination requires a sustained commitment from all facets of society membership. For instance, the labor of leading JEDI initiatives tends to be taken on by URMs, and the long-held, institutionalized nature of discrimination means that it often goes unseen and unacknowledged by unaffected members (Crandall et al., 2021). Leadership and members can take action by recognizing these ongoing inequalities, engaging in education and organizational stock-taking, and by acting as proactive allies (Crandall et al., 2021).

Providing Mentorship and Sponsoring Opportunities

SCB Marine is also well positioned to provide mentorship opportunities that can help students and early career professionals find community, learn skills, navigate obstacles, and build networks. Given the importance of networks in career success (e.g., Suedkamp Wells et al., 2005), linking students and early career researchers and professionals to mentors who actively open up opportunities for the students and early career professionals they are working with is an opportunity for professional societies like SCB Marine to make a lasting difference for its members.

Having access to a diverse pool of mentors at every learning and career transition is also important for career development and support (Nocco et al., 2021). Further, serving as mentors can itself promote growth and learning, especially at early career stages (Reddick et al., 2012). A good example of matching early career professionals to a range of mentors and mentorship opportunities is the Roger Arliner Young (RAY) Diversity Fellowship Program, a two-year paid fellowship placing recent graduates in marine conservation or energy efficiency and renewable energy positions with NGO and government partners as part of a cohort of fellows.[3] The RAY Fellowship matches fellows with multiple mentors. Host organizations are encouraged to provide a mentor to each incoming fellow in addition to the fellow's supervisors. Environmental Leadership Program (ELP), which runs the RAY fellowship, matches fellows to past RAY alumni (who benefit by being able to serve as mentors themselves). ELP also matches fellows to mentors from its own network of past ELP fellows. Thus incoming fellows have several mentors, and can also draw on experiences of other fellows in their cohort.

SCB Marine can facilitate these kinds of mentorship matches through creating fellowship and/or mentorship programs. It could establish a (or join an existing) program to create transition fellowships to broaden participation in marine conservation at each level of advancement (e.g., between undergraduate and graduate programs, or between graduate school and professional/academic positions). These could include a peer mentoring component in which the previous year's mentees and fellows return as peer mentors or advisors. It could also set up mentor/mentee programs. A key element would be training mentors and fellowship hosts to ensure they have the skills and tools necessary to be successful. In taking these steps, SCB Marine would help establish a "marine diversity network," as discussed above through a global online platform that allows widespread communication, promotes transparency, creates peer-to-peer networking opportunities, and develops positive collaborations.

Field Research/Practice. In addition to barriers to participation in conferences, underrepresented groups can face challenges in conducting fieldwork. These include the aforementioned lack of access to funding, as well as home care responsibilities, which fall more often on women, and a valorization of in-person fieldwork which can affect disabled researchers if accommodations are not made (Moon et al., 2012). Fieldwork can also present challenges such as harassment of underrepresented researchers, including, for example, female scientists on research vessels and in other field settings (Orcutt et al., 2014).

Concerns for LGBTQ+ Success. The barriers faced by members of LGBTQ+ communities have received limited attention. Only recently have works begun to bring to light the many concerns of LGBTQ+ scientists with respect to their performance evaluations and, ultimately, their academic careers. While evidence from marine conservation and sciences is largely missing, instances of discrimination, bullying, and harassment all lead to a higher likelihood of LGBTQ+ scientists leaving academia (Taylor, 2021).

Parachute Science. Notable as an important additional JEDI consideration in the marine conservation field is addressing the practice of parachute science. Asha de Vos, in Scientific American,[4] explains the term "*parachute science*" as "the conservation model where researchers from the developed world

[3]See https://rayfellowship.org/program-overview. Note that Anna Zivian, one of the authors, helped establish the RAY program through work at Ocean Conservancy.

[4]Scientific American. (2020). The Problem of "Colonial Science": Conservation projects in the developing world should invest in local scientific talent and infrastructure. https://www.scientificamerican.com/article/the-problem-of-colonial-science [Accessed April 7, 2021].

come to countries like mine, do research and leave without any investment in human capacity or infrastructure. It creates a dependency on external expertise and cripples local conservation efforts. The work is driven by the outsiders' assumptions, motives, and personal needs, leading to an unfavorable power imbalance between those from outside and those on the ground." The same phenomenon is seen in developed countries, when a researcher or organization conducts a project in vulnerable areas (e.g., inner-city) or Indigenous communities, often benefitting from the knowledge held by local peoples, then leaves without any reciprocal investment. The work is done on or in the community, rather than *for, with* or *by* the community.

Colonial research practices have previously led to exclusion, marginalization, and disempowerment of Indigenous communities, including in marine research (Zurba et al., 2019; Kourantidou et al., 2020). Despite progress in the development of participatory and community-based research methodologies that allow for meaningful engagement of local resource users, such as those from Indigenous communities, these challenges persist and harm effective and inclusive marine conservation.

An additional concern is that inclusive and locally focused research can take longer and potentially cost more than research not co-designed nor conducted with communities, which creates additional barriers for researchers. If time to publication is extended [not to mention the ongoing issues with recognition of researchers without formal Ph.D. backgrounds (see, for example, the story of peer-review in Liboiron, 2021, p. 55)[5]], it can result in impacts on job security and advancement, with the pressure to "publish or perish" causing tension with taking the needed time to conduct research in an equitable, inclusive, and participatory way. Greater flexibility in research funding, as well as recognition from professional societies and other research institutions for co-produced research, could help provide support for this kind of research[6].

Although there is no silver-bullet solution to these challenges, measures such as requirements from research institutions for the means of engagement with local marine resource users/communities as well as for compliance with research ethics and standards (including those set by the communities) can help alleviate some of these challenges in the short term. Adopting measures to mitigate parachute science in marine research can improve outcomes from an equity and conservation perspective (Stefanoudis et al., 2021). For instance:

- Actively engaging with local early career marine professionals, particularly in those places where conservation practices take place. Engagement may happen through internships, exchange programs, and co-supervision of students and/or early career professionals.
- Increasing involvement of societal collaborators such as stakeholders and rights-holders who are often excluded from the research and decision-making process.
- Meaningful engagement to help strengthen research capacity locally, empower local actors, and enrich perspectives valuable to marine conservation through local knowledge and long-term practical experiences (Kourantidou et al., 2020).
- Supporting, partnering with, and replicating when possible, long-term models of investment that support local capacity building in concert with empowered local decision making. e.g., NOAA's Capacity Building Partnership in Fisheries for the U.S. Territories in the Western Pacific[7] (**Supplementary Figure 1**).
- Reducing harm. Marine science and conservation projects often appear to implicate only non-human species; however, following the human-subjects research model of risk assessment, harm reduction, and transparency and accountability at the institutional level could prevent or mitigate instances of parachute science (John et al., 2016) and yield more comprehensive results and tangible outcomes (Quigley et al., 2019).
- Using the platform of scientific societies to serve as a model of leadership in this space through their own actions and/or amplifying the JEDI priority approaches by organizations across their field.
    - They may choose to adopt, as a society of professionals, formal policies on discrimination, including hiring a diversity ombudsperson and/or other society staff or members specifically designated to address JEDI concerns or complaints.
    - SCB has many sections poised to partner and support sections focused on promoting the work of early career professionals, which may include nominations for awards, memberships on boards, and key committee memberships.
    - Lastly, they are also well suited to support the field, centrally addressing some of the leaky pipeline issues described in this brief.

Theme 2: Equity in Editorial Matters

Impact of Editorial Inequity on Marine Conservation and Communities

Issues associated with race, geography, gender identity, sexual orientation, and disabilities should by no means affect scientists' professional opportunities to navigate editorial and peer review processes and their scholarly success. However, the lack of diversity in marine conservation is reflected in the editorial process leading to scientific publications and the resulting body of publications, whether these be papers presented at conferences or in science journals (see text footnote 2). Similar to other disciplines, the presence of structural inequality with in the marine conservation and science's academic architechture affects certain individuals' ability to conduct science and communicate their work (Taylor, 2021). In fact, this issue is potentially more pervasive in the marine sciences, with it and other

[5]Thank you, Max Liboiron, for your remarkable book, as well as your discussion on good relations in reading and citing texts.

[6]Thank you to our reviewer for raising this additional issue.

[7]NOAA's Capacity Building Partnership for the U.S. Territories in the Western Pacific. http://www.wpcouncil.org/2019-2020-us-pacific-territories-fishery-capacity-building-scholarship-announcement-applications-due-mar-1st/.

geosicences being some of the least diverse STEM fields (Bernard and Cooperdock, 2018) having achieved negligible progress to increase diversity over the last four decades (Bernard and Cooperdock, 2018). Similar trends are also found in the social sciences, with economics and policymaking, in particular, suffering a significant lack of racial, gender, and ethnic diversity (Ginther and Kahn, 2004; Bayer and Rouse, 2016; Lundberg, 2018; Wu, 2018; Doleac et al., 2021; Dupas et al., 2021; Sarsons et al., 2021).

Publication records are vital to professional growth, upward mobility, and ultimately to researchers' employment and professional success. Therefore if the editorial processes and publication pipelines are skewed such that they disfavor URM in marine sciences, they will result in lower success rates of URM individuals and fewer URM individuals in leadership positions in science and conservation practice. In fact, there is evidence that URM individuals are rewarded to a lesser extent in STEM fields even when they produce research products that are more innovative and more impactful compared to their non-URM peers (Hofstra et al., 2020). In addition to these impacts at the individual's professional success, inherent bias in the publication record has the ability to skew conservation and management decisions reliant on best available science.

Why Does Editorial Inequity Exist?

In order to improve equity and inclusion in editorial and publication processes, we first need to identify the key issues contributing to inequities in these processes. We describe several key contributors in the following section.

Lack of Reviewer Diversity. Individuals participating as peer reviewers are more frequently from North America and Europe and identify as male (Preston, 2018). Further, first-time reviewers are usually approached to review manuscripts due to professional relationships with the editor either directly or through their principal investigators (Preston, 2018). Therefore, the system ensures continued dominance of reviewers who are or are associated with white, male and non-minority individuals in the editorial process[8].

Geographic Bias. Reviewers tend to favor publication of manuscripts authored by people of the same country; this geographic bias has proven to be a large disadvantage for scientists from non-western countries (i.e., outside North America and Europe) (Grogan, 2019). For western reviewers, a lack of knowledge in conservation research and practice in parts of the world outside their region of familiarity may lead to a lack of understanding of pressing conservation issues and of research infrastructure available to scientists and practitioners. For example, in developing countries where state of the art infrastructure may not be available, researchers and practitioners could be using "perceived" out of date and 'inadequate methods or equipment'. We argue that this work should not be dismissed due to lack of novelty in methodological approaches or other methodological drawbacks, as it may still hold the potential to produce vital data to meet conservation needs in the region which a foreign reviewer may not necessarily be aware of. Instead, efforts should be focused on recruiting editors and reviewers who can appreciate the nuances of research, conservation and related technological advances from diverse geographic regions. The perceived lack of comprehensive and novel research methods typically leads to a publication in a lower ranking journal or rejection of publications all together. Work from geographically or culturally unfamiliar places is also perceived as less important or less representative of global issues, even though such scientific knowledge often provides crucial lessons at global, regional, and local scales (unpublished from IMCC4 plenary speeches by Max Liboiron and Asha de Vos).

Professional Network Bias. Researchers and practitioners from emerging regions are often not in the professional networks of decision making groups such as reviewers and editors. Thus URM individuals and their work are not known and thus not acknowledged nor validated in the same way as the work of their peers in developed countries. As a result, research and practice by URMs are perceived less favorably in journal and conference publications. Lack of oral and written scholarly publications also leads to lower success of URM grant applications which are again often reviewed by the same professional networks which URM individuals are typically not associated with.

URMs outside western reviewer circles may not use the same means or extent of social media communications and, hence, may not be as familiar with the social practices and culture of western professional networks (see for example Shiffman, 2018). Thus, again, the issue of low familiarity with URMs' body of work, its validation and acknowledgement combined with the limited knowledge of the regional work culture among reviewers results in lower success at peer-reviewed publications, and resultantly at obtaining research funding by URMs. The cycle of biased peer review thus perpetuates and severely restricts scholarly success and career advancement for URMs.

Gender Bias. There is evidence that reviewers tend to favor publications authored by people of the same gender or country as themselves, which has proven to be a large disadvantage for women and scientists from non-Western countries (Grogan, 2019; Murray et al., 2019). Additionally, Murray et al., 2019 find that papers with a male last or corresponding author are more likely to be accepted compared to their female counterparts. Bendels et al. (2018) provide evidence that as the impact factor of a journal increases, the likelihood of a woman as the first, last, or corresponding author in the journals' publications decreases significantly. Women and other minority groups are significantly underrepresented in editorial boards and reviewer pools (Grogan, 2019), further propagating reviewer biases against minorities.

Even though such trends are contentious and divisive across different fields of research (Fox and Timothy Paine, 2019; Squazzoni et al., 2021), there is a general consensus that more

[8]The London School of Economics and Political Science. (2020). Read and Publish Open Access Deals Are Heightening Global Inequalities in Access to Publication. https://blogs.lse.ac.uk/impactofsocialsciences/2020/02/21/read-and-publish-open-access-deals-are-heightening-global-inequalities-in-access-to-publication/[Accessed April 7, 2021].
Forbes. (2020). How Prestige Journals Remain Elite, Exclusive and Exclusionary. https://www.forbes.com/sites/madhukarpai/2020/11/30/how-prestige-journals-remain-elite-exclusive-and-exclusionary/?sh=3a3dc0ac4d48 [Accessed April 7, 2021].

effort is needed to increase diversity in scientific peer-review and editorial processes. Even though the biases described above have not been thoroughly examined for marine sciences specifically, there is an imperative to address them given that these biases likely exist, and may even be stronger in some cases, due to the significantly low diversity in marine sciences compared to other STEM fields (Bernard and Cooperdock, 2018).

Language. The vast majority of scientific publications and conferences require English language proficiency and use. The work of those not so proficient or used to a different style of English (e.g., British vs. Indian vs. American English) are perceived unfavorably during the review process and may end up having less impact and citations (Meneghini et al., 2008; González-Alcaide et al., 2012). This problem is exacerbated by the large load of requests for reviews of applications, presentations, and publications often experienced by reviewers; these make reviewers more inclined to make a first pass rejection or acceptance decision based on quality of language and linguistic clarity after a cursory review.

For many researchers and practitioners, especially those from developing countries, it can be cost prohibitive to use professional editing services before, or even during, the review process, and they may not be able to meet reviewer requests or suggestions. This often leads to a higher rate of rejection for publications from URM individuals.

Financial Burden on Authors and Reviewers. As discussed by the focus group, most open access scientific publication avenues entail high article publication charges (APC). These are often unaffordable by URM professionals and academics; hence open access publications remain limited and therefore their work remains inaccessible to URM communities in the developed and developing world alike. A few publication houses (e.g., Frontiers, SpringerNature, Biomedcentral) use World Bank criteria to allow individuals from these countries or regions to apply for APC waivers; however, these criteria often do not cover all those who are unable to afford APC. Further, large APCs could act as deterrents even to application for APC waiver due to the low prospects of success, and thus continue to act as barriers to publication success.

Further, early career URM researchers not only need to meet the ongoing challenges of doing science in the less-resourced settings that exist in many low to middle income countries, but also need to be able to pay high APCs (which can approximate to a years' salary or more)—to showcase their research.

Reviewers from URM communities may be unable to spend as much time as their peers on the review process given disproportional financial hardships and overburdened schedules. This further reduces reviewer diversity and likely leads to a failure in providing necessary support from reviewers/editors to URM authors.

Needless to say, those unable to publish are unable to validate their work in the broader conservation community and, as such, remain disadvantaged in the grant making process and in terms of securing jobs. Financial burden is another significant barrier that can restrict URMs from achieving upward mobility over time.

Life Events Leading to Name Changes. LGBTQ+ and women scientists who change their names after gender reassignment or after marriage, experience a negative impact to their publication record and thus their careers. Typically, they are "outed" by their publication history with hardly any options to update their names on publications (Taylor, 2021).

How to Address Discrepancies in Editorial and Review Processes to Improve Publication Success Among URM Communities in Marine Sciences?

Biases in the editorial and review processes are pervasive and multifactorial as has been outlined in earlier sections. However, publication success is one of the most important metrics for evaluation and validation of one's scientific progress and is crucial for upward mobility and occupation in leadership positions. As such the JEDI focus group organized at the IMCC6 conference and workshop organized among SCB marine members identified the following ways to address and correct inequities in editorial and peer-review processes:

1. Encourage training of editorial boards and staff in matters related to diversity to ensure they are adequately equipped to handle both explicit and implicit biases. The latter can be particularly hard to identify and therefore experts on bias in science evaluation may be particularly useful in helping avoid direct and indirect biases toward minority groups and designing suitable responses (Eisen, 2020).
2. Support and publish papers and projects which are works led by or in partnership with locals in the area where work is being done. Apply Best Practices to decision making models that afford different forms of knowledge, representing known gaps in the publication record, a place in the decision making process (NOAA, 2019). Efforts and publications which contribute to supporting research capacity and educational capacity in non-western countries through collaboration and training initiatives (e.g., DOCKSIDE, 2019) should be recognized.
3. Promote commitments on behalf of journals to increase equity, diversity, and inclusion with respect to gender, geography, and ethnicity in the review and editorial processes and encourage frequent reporting on progress or efforts in these aspects:

    a. Reporting of data on the demographic composition of editorial groups and staff throughout time, or other efforts, and new targets toward a balanced representation of different groups and/or increased representation of underrepresented minority groups.
    b. Implement metrics that show how potential biases in the reviewer/editorial process can be avoided, e.g.:

        i. monitor review panel composition of gender and other demographic characteristics such as ethnicity or country of origin/residence. Examine and analyze these trends over time in peer-reviewed published research.

ii. monitor composition of reviewer databases of journals to ensure they are diverse. This will in turn facilitate increased diversity in the selection of reviewers on behalf of the editors.

c. Identify pathways, jointly with publishers, through which LGBTQ+ and women scientists can avoid a negative impact to their publication record and careers when changing names.

4. Ensure diversity in editorial (scientific advisory) boards and editorial staff, e.g.,:

   a. promote participation of marine scholars from URM groups,
   b. open up opportunities for new recruits of editors (e.g., through open calls) in line with the journal's commitments to increase equity, diversity, and inclusion (see point 2 above).

5. Provide English language editing support at no extra cost to authors through the journal's editorial services or through volunteer editors with English proficiency who might then have a chance to learn about research from diverse geographic and topic areas. This will improve dialogue across URM and non-URM communities and will encourage meaningful collaborations.
6. English language journals should be able to accommodate at a minimum abstracts or blurbs in the preferred language of the authors. This can enable a) reaching a wider audience, particular those for whom the research is of direct relevance and b) URM communities to express themselves to their peers, serve as role models to individuals in their communities, and provide a chance for dialogue and encouragement within URM conservation communities.
7. Implement measures to avoid "parachute" and "colonial" science in marine research.

   a. requirements to provide to the journal the research permit and research ethics permit numbers along with justification in those cases where the permits do not exist.

In order for conservation of biodiversity and to ensure justice, equity, diversity, and inclusion for all communities and individuals impacted by or participating in conservation science and practice, it is important to change editorial practices in the context of JEDI. The marine conservation community needs to ensure that editorial practices address inequities of opportunity for researchers independent of their race, gender, geography, or other characteristics.

Theme 3: Support Services During Events and Meetings

Differences in gender, race, culture, and socio-economic status are perhaps most intense when a diverse group of people meets to make decisions about a society or topic to which all participants feel a sense of ownership or connection; for example, in board meetings to direct the work of a society, or a work group to tackle an important question or issue. In addition, the typical in-person conference format is in itself all consuming, with every minute of the day and evening scheduled with information dissemination and a multitude of workshops, events, and activities. Despite the exhaustion that many participants experience, often due both to the meeting schedule and fatigue from travel and operating in another time zone, there are advantages to having in-person meetings, e.g., a better collective understanding of an issue or problem, progress in the workings of a society, or increased collaborative work and general progress in the particular field the meeting is focused upon. For some, it is also an opportunity to better understand the working practices of another culture and, perhaps, gain a deeper understanding of the many challenges the whole planet faces.

Many societies provide a code of conduct or a diversity and inclusion document for such meetings, with an investigation or disciplinary procedure outlined if these codes are not adhered to (see Sardelis et al., 2017 for proposed intervention strategies promoting equity and diversity in conferences that arose through the IMCC4 congress). Sadly, there is rarely a bridge between this dry list of what is and is not acceptable behavior and the consequences of not following the one- or two- page document that is supposed to encompass a myriad of behaviors from a diverse background of participants and channel them onto one path. This section explores the challenges presented when holding meetings, either in-person, virtually, or in a hybrid format, and suggests some mechanisms which diminish barriers and create a more inclusive environment for all participants. We focus on the meetings typical of SCB however, we hope that some of the suggestions herein inspire a change in practices within other societies.

Language

No matter what type of meeting is being convened, from board meetings and working groups to webinars and conferences, expanding support facilities and services will help ensure that the event is more inclusive and accessible to all participants. Several international institutions or conventions, e.g., the International Whaling Commission, the IUCN, and various U.N. Conventions, have three or more operating languages into which all official correspondence is translated and which are offered as standard translation options during meetings. This is not so for many global societies that often have single or bi-lingual operating languages that govern meetings and correspondence however, these societies often have a mandate to recruit and maintain international participation. As global travel and meeting restrictions have created a dramatic upsurge in online meetings, the technology to support online meetings has also improved exponentially. Translation services, once expensive, have become increasingly easier to implement in these online environments and both closed captioning and simultaneous translation can be easily incorporated into most platforms. Recognizing that it is still challenging to incorporate all languages, prior to any meeting or event, understanding the demographics of the desired audience and the most common languages spoken should be a primary action of the meeting organizer or chair. Developing a translation strategy allows meeting materials to be provided in the most relevant languages, and bespoke translation services can be incorporated from the outset. Inviting participants to present in their native language also helps remove barriers caused by language and with translation services in place, communication can be considerably improved between participants who do not share a common language. Although perhaps easier to implement in virtual meetings, conveners of in-person meetings should strive to develop a multilingual announcement and registration process and include language specific queries as part of this process to assess needs for presenting and communicating in various languages.

An Inclusive Online Convening Space

Organizers must consider how to create convening spaces that are accessible and welcoming to all participants therefore, an understanding of both timing and technology is critical. For those who will be convening meetings, abundant resources exist for facilitating online gatherings that are accessible, inclusive, welcoming, and avoid common barriers to participation[9]. Facilitation is a vital component of inclusive conversations, panel discussions, and Q&A sessions; conveners should take care to ensure, for example, that session moderators and organizers are equipped with the tools and training necessary to facilitate inclusively, equitably, and in an anti-oppressive manner. A key part of inclusiveness is understanding time zones and which working days different cultures use; for example, in Middle Eastern countries, the workweek is Sunday to Thursday. If meetings are held across more than eight time zones, it is inevitable that some attendees will be requested to work outside normal working hours. While this is unavoidable with global groups, the conveners of the meeting should first assess what time zone participants are attending from and strive to offer multiple meeting choices that include typical working hours for all participants, not just those in the extreme east or west time zones. If there are simply too many time zones to accommodate easily, a second meeting can be convened at a different time so that meeting minutes or recordings can be shared. This is already practiced by the SCB Conference Committee to accommodate members from more than eight different time zones. This allows all committee members to share and discuss information and assists in breaking down global participation barriers. Recording meetings also allows participants who communicate in a different language to have more time to understand the discussion. Most online platforms also provide an encryption service to secure recordings for sharing.

There are also special considerations for virtual convenings, such as recognizing that technology access and literacy are not equitable. Inequities in technology access and literacy are not new, but received added attention in 2020 due to the increase in virtual healthcare and remote learning (e.g., Becker et al., 2020). These inequities are even evident in which conferences shifted from in-person to virtual in 2020 due to the COVID-19 pandemic. Falk and Hagsten (2021) demonstrated this shift

[9]AORTA (Anti-Oppression Resource and Training Alliance). (2017). Anti-oppressive facilitation for democratic process: making meetings awesome for everyone. http://aorta.coop/portfolio_page/anti-oppressive-facilitation [Accessed March 15, 2021].

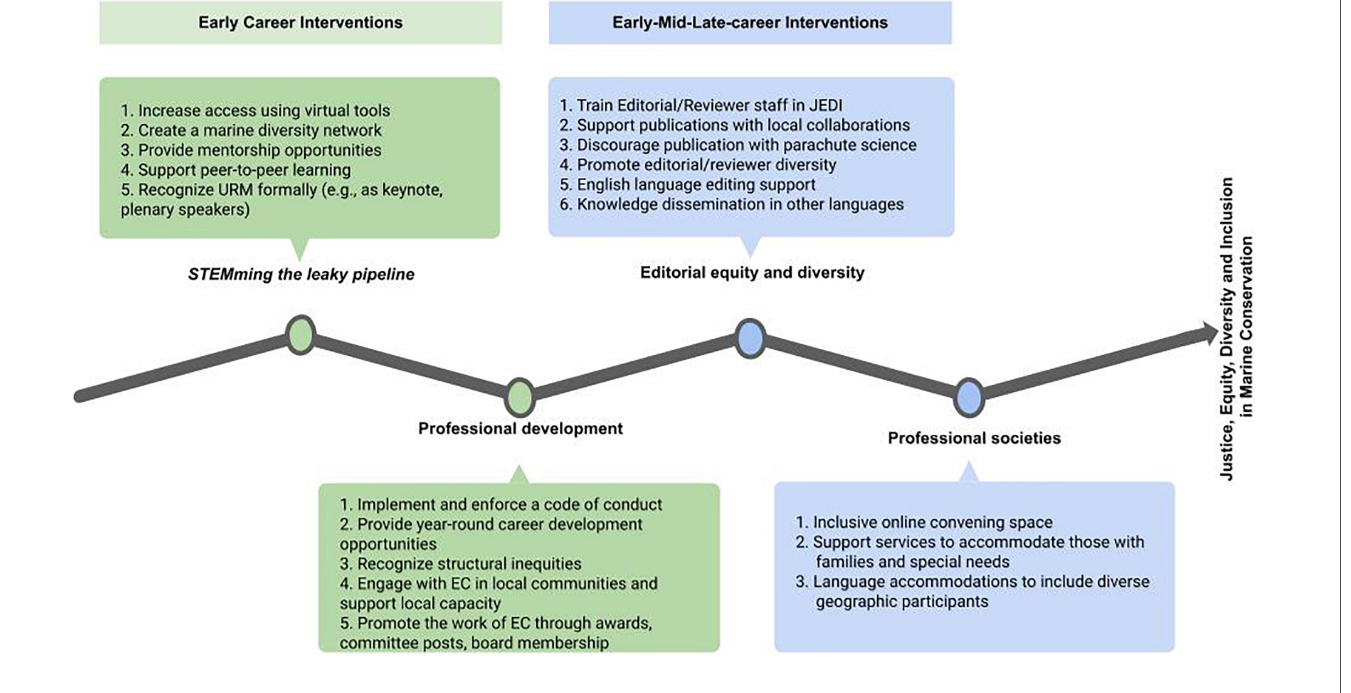

FIGURE 2 | Summary of actionable recommendations to remove barriers to equity, diversity, and inclusion at different career stages in the marine conservation space.

depended on, in part, the conveners' home country and access to high-speed internet. While conveners cannot be expected to solve access issues, they can provide information, guidance documents, and training for the technology tools that will be used, such as document-sharing and video conference platforms. For those without a reliable or fast internet connection, offering the option to pre-record the presentation, followed by live Q&A, can ensure that the presentation can occur and keep the agenda on schedule.

There are strengths and challenges to both in-person and virtual conferences; neither provide a panacea for JEDI concerns. In-person academic conferences provide a myriad of benefits, some of which are difficult to replicate in a virtual setting even with online tools like spatial.chat etc., such as feedback on active research and face-to-face networking with colleagues. There is a long list of important support services needed to ensure that in-person conferences, meetings, and other convenings provide pathways for overcoming common barriers to participation. One of these is financial support. Many academic societies provide scholarships and free or reduced registration for those who volunteer during the event (e g., IMCC conferences). However, conference fees still pose a barrier for some (Tsang, 2019) and travel costs will inevitably be inequitable when organizing international conferences (Arend and Bruijns, 2019; Niner and Wassermann, 2021). Providing support and, particularly, understanding travel visa constraints should be a consideration during early planning of any in-person meeting.

Another key area of consideration is family support. There is increasing recognition that we need to normalize parenthood in academia, including services at conferences such as: breast feeding and childcare (Calisi, 2018) and discounted registration rates for childcare providers. These services should be an integral part of all conference communications and be options within the registration system. And finally, most in-person conferences come with a suite of pre-, during, and post-conference events, workshops, field trips, and evening events. Those engaged in organizing these events should consider the cultural context of the surrounding area and participants (e.g., not all centered around alcohol), event accessibility for those with different abilities and those who may require translation services, and cost (e.g., providing scholarships to participate in these events) (Morris and Washington, 2017; Sarabipour, 2020).

DISCUSSION

Marine conservation is an interdisciplinary field that requires diverse communities and experts to work together through cross-sectional science and practice. It requires innovative interdisciplinary approaches, representation from diverse stakeholders, and communication across these sectors. Systematic barriers and unjust pathways perpetuate the opposite. Marine conservation science and practice need, to be rooted in justice, equity, and inclusion of diverse communities, particularly those who are impacted either by the lack of or alternatively, by the existence of conservation initiatives. Consideration of interests of a diverse set of stakeholders is key to an equitable, just, and sustainable conservation movement.

For instance, the absence of editorial and publication equity will likely result in a failure to recruit a diverse community of conservation scientists and practitioners, leading to under-representation of diverse voices in key places of conservation impact and lack of communication among interdisciplinary groups. Ultimately this is expected to lead to failures in effective conservation for marine resource users. With fewer URM individuals in leadership and decision-making positions, it is unlikely that a diverse set of employees will be hired or supported at conservation-focused institutions and this cycle will continue, translating into lower recruitment of URM students and early career professionals. Fewer URM individuals in top positions also mean fewer role models; this also leads to far lower recruitment of URM students and early career professionals.

Further, lack of diversity deprives marine sciences and conservation from serving the interests of the general public in an effective enough manner and limits improvement to human, social, and economic wellbeing expected through marine resource and conservation management. A marine conservation profession and an associated academic space that is limited to a narrow set of perspectives, experiences, and expertise is likely to miss opportunities to illuminate critical questions, leading to poorly informed decisions and policy-making. The questions then are: How different would marine conservation be if the work of URMs received more recognition and URMs were offered systematically more opportunities for inclusion in research and conservation circles? What would policy and conservation look like if the experiences and knowledge of URMs were better reflected in marine sciences and practice?

We have summarized the barriers and pathways to removing these barriers as discussed in the current manuscript in **Figure 2**. We envision that these specific interventions at respective career stages will enable equity, diversity, inclusion, and through these, a just marine conservation space.

CONCLUSION

We expect that the issues highlighted in the current manuscript will help the field of conservation continue to identify barriers to JEDI and more purposefully address these in all aspects of conservation science and practice. Specifically, we envision a future wherein the field standardizes and places value on not just who is doing conservation work, but the what, where, and how the work is done and with whom the results are shared. We hope to have laid key markers for improvement that can be more broadly institutionalized across the myriad of organizations and sectors that contribute to the field of marine conservation (**Figure 2**). Furthermore, we each individually hold agency in addressing barriers to JEDI within our own spheres of influence (current networks, organizations, etc.) and can activate a web of social capital that transcends organizational silos. Even still, institutionalization of the road map initially discussed in our global dialog and specified here will require a continuous open mind and investments of time and expertise in the process and integration of JEDI in every aspect of conservation research and practice.

AUTHOR CONTRIBUTIONS

SJ conceptualized, led and organized the JEDI workshop at IMCC6 and contributed to writing the manuscript. MC, LP, and AZ organized the workshop, manuscript and contributed to writing the manuscript. MK and ELM participated in the workshop and organized and wrote the manuscript. JS participated in the workshop and managed the team to facilitated completion of the manuscript. RAS participated in the workshop and contributed to writing the manuscript. All authors contributed to editing the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.696180/full#supplementary-material

REFERENCES

Abdul-Raheem, J. (2016). Faculty diversity and tenure in higher education. *J. Cult. Div.* 23, 53–56.

Arend, M. E., and Bruijns, S. R. (2019). Disparity in Conference Registration Cost for Delegates from Low- and Middle-Income Backgrounds. *Afr. J. Emerg. Med.* 9, 156–161. doi: 10.1016/j.afjem.2019.01.016

Bailenson, J. N. (2021). Nonverbal overload: a theoretical argument for the causes of Zoom fatigue. *Technol. Mind Behav.* 2:1. doi: 10.1037/tmb0000030

Bayer, A., and Rouse, C. E. (2016). Diversity in the economics profession: a new attack on an old problem. *J. Econ. Perspect.* 30, 221–242. doi: 10.1257/jep.30.4.221

Becker, J., Washington, J., Naff, D., Woodard, A., and Rhodes, J. (2020). *Digital equity in the time of COVID-19: the access issue*. Richmond, VA: Metropolitan Educational Research Consortium.

Bendels, M. H. K., Müller, R., Brueggmann, D., and Groneberg, D. A. (2018). Gender disparities in high-quality research revealed by Nature Index journals. *PLoS ONE* 13:e0189136. doi: 10.1371/journal.pone.0189136

Bernard, R. E., and Cooperdock, E. H. G. (2018). No progress on diversity in 40 years. *Nat. Geosci.* 11, 292–295. doi: 10.1038/s41561-018-0116-6

Calisi, R. M. (2018). Opinion: how to tackle the childcare–conference conundrum. *Proc. Natl. Acad. Sci. U S A* 115, 2845–2849. doi: 10.1073/pnas.1803153115

Crandall, C., Baumann, J., Cooney, P., Croteau, A., Croxton, A., Flaherty-Walia, K., et al. (2021). How to be an ally to women in fisheries science. *Fisheries* 46, 140–144. doi: 10.1002/fsh.10565

DOCKSIDE (2019). *DOCtoral Program in Khmer Universities Strengthening the International Development of Environmental and Maritime Research*. Available online at: http://www.dockside-kh.eu/the-project/

Doleac, J., Hengel, E., and Pancotti, E. (2021). Diversity in economics seminars: who gives invited talks? *AEA Papers Proc.* 111, 55–59.

Dulvy, N. K., Simpfendorfer, C. A., Davidson, L. N. K., Fordham, S. V., Bräutigam, A., Sant, G., et al. (2017). Challenges and priorities in shark and ray conservation. *Curr. Biol.* 27, R565–R572. doi: 10.1016/j.cub.2017.04.038

Dupas, P., Sasser Modestino, A., Niederle, M., Wolfers, J., and The Seminar Dynamics Collective. (2021). *Gender and the dynamics of economics seminars. w28494*. Cambridge, MA: National Bureau of Economic Research, doi: 10.3386/w28494

Eisen, M. B. (2020). We need to act now. *ELife* 9:e59636. doi: 10.7554/eLife.59636

Falk, M. T., and Hagsten, E. (2021). When international academic conferences go virtual. *Scientometrics* 126, 707–724.

Favaro, B., Oester, S., Cigliano, J. A., Cornick, L. A., Hind, E. J., Parsons, E. C. M., et al. (2016). Your science conference should have a code of conduct. *Front. Mar. Sci.* 3:103. doi: 10.3389/fmars.2016.00103

Fox, C. W., and Timothy Paine, C. E. (2019). Gender differences in peer review outcomes and manuscript impact at six journals of Ecology and Evolution. *Ecol. Evol.* 9, 3599–3619. doi: 10.1002/ece3.4993

Ginther, D., and Kahn, S. (2004). Women in economics: moving up or falling off the academic career ladder? *J. Econ. Perspect.* 18, 193–214. doi: 10.1257/0895330042162386

González-Alcaide, G., Valderrama-Zurián, J. C., and Aleixandre-Benavent, R. (2012). The impact factor in non-English-speaking countries. *Scientometrics* 92, 297–311.

Grogan, K. E. (2019). How the entire scientific community can confront gender bias in the workplace. *Nat. Ecol. Evol.* 3, 3–6. doi: 10.1038/s41559-018-0747-4

Hengel, E. (2017). *Publishing while female. Are women held to higher standards? Evidence from peer review. Cambridge Working Papers in Economics, 1753, Faculty of Economics*. Cambridge: University of Cambridge.

Hofstra, B., Kulkarni, V. V., Munoz-Najar Galvez, S., He, B., Jurafsky, D., and McFarland, D. A. (2020). The diversity-innovation paradox in science. *Proc. Natl. Acad. Sci.* 117, 9284–9291. doi: 10.1073/pnas.1915378117

John, F., Brockington, D., Bunnefeld, N., Duffy, R., Homewood, K., Jones, J. P. G., et al. (2016). Research ethics: assuring anonymity at the individual level may not be sufficient to protect research participants from harm. *Biolog. Conserv.* 196, 208–209. doi: 10.1016/j.biocon.2016.01.025

King, L., MacKenzie, L., Tadaki, M., Cannon, S., McFarlane, K., Reid, D., et al. (2018). Diversity in geoscience: participation, behaviour, and the division of scientific labour at a Canadian Geoscience Conference. *Facets* 2018:111. doi: 10.1139/facets-2017-0111

Kourantidou, M., Hoover, C., and Bailey, M. (2020). Conceptualizing indicators as boundary objects in integrating Inuit Knowledge and Western Science for marine resource management. *Arctic Sci.* 2020:13. doi: 10.1139/as-2019-0013

Liboiron, M. (2021). *Pollution is Colonialism*. Durham: Duke University Press.

Lundberg, S. (2018). Report: committee on the status of women in the economics profession (CSWEP). *AEA Papers Proc.* 108, 704–721. doi: 10.1257/pandp.108.704

McGuire, K. L., Primack, R. B., and Losos, E. C. (2012). Dramatic improvements and persistent challenges for women ecologists. *BioScience* 62, 189–196. doi: 10.1525/bio.2012.62.2.12

Meneghini, R., Packer, A. L., and Nassi-Calo, L. (2008). Articles by Latin American authors in prestigious journals have fewer citations. *PLoS One* 3:e3804.

Mengel, F., Sauermann, J., and Zölitz, U. (2019). Gender bias in teaching evaluations. *J. Eur. Econ. Assoc.* 17, 535–566. doi: 10.1093/jeea/jvx057

Moon, N. W., Todd, R. L., Morton, D. L., and Ivey, E. (2012). *Accommodating students with disabilities in science, technology, engineering, and mathematics (STEM)*. Atlanta, GA: Center for Assistive Technology and Environmental Access, Georgia Institute of Technology, 8–21.

Morris, V., and Washington, T. (2017). *The role of professional societies in STEM diversity*, Vol. 65. Providence: American Mathematical Society, doi: 10.1090/noti1642

Murray, D., Siler, K., Larivière, V., Chan, W. M., Collings, A. M., Raymond, J., et al. (2019). Gender and international diversity improves equity in peer review. *BioRxiv* 2019:400515. doi: 10.1101/400515

National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2005). *Facilitating Interdisciplinary Research*. Washington, DC: The National Academies Press, doi: 10.17226/11153

Niner, H. J., Johri, S., Meyer, J., and Wassermann, S. N. (2020). The pandemic push: can COVID-19 reinvent conferences to models rooted in sustainability, equitability and inclusion? *Socio-Ecol. Pract. Res.* 2020, 1–4. doi: 10.1007/s42532-020-00059-y

Niner, H. J., and Wassermann, S. N. (2021). Better for whom? Leveling the injustices of international conferences by moving online. *Front. Mar. Sci.* 8:638025. doi: 10.3389/fmars.2021.638025

NOAA (2019). Available online at: https://www.legislative.noaa.gov/docs/19-065933-Traditional-Knowledge-in-Decision-Making-Document-Signed.pdf (accessed February 28, 2021).

Nocco, M. A., McGill, B. M., McDonough, MacKenzie, C., Tonietto, R. K., Dudney, J., et al. (2021). Mentorship, equity, and research productivity: lessons from a pandemic. *Biolog. Conserv.* 255:108966. doi: 10.1016/j.biocon.2021.108966

Oester, S., Cigliano, J. A., Hind-Ozan, E. J., and Parsons, E. C. M. (2017). Why conferences matter—an illustration from the International Marine Conservation Congress. *Front. Mar. Sci.* 4:257. doi: 10.3389/fmars.2017.00257

Orcutt, B., Cetinic, I., and Bigelow Laboratory for Ocean Sciences (2014). Women in oceanography: continuing challenges. *Oceanography* 27, 5–13. doi: 10.5670/oceanog.2014.106

Phillips, K. W. (2014). How diversity makes us smarter. *Sci. Am.* 2014:42. doi: 10.1038/scientificamerican1014-42

Preston, A. (2018). *GSPR — Publons. 2018*. Available online at: https://publons.com/community/gspr (accessed July 2021).

Quigley, D., Levine, A., Sonnenfeld, D. A., Brown, P., Tian, Q., and Wei, X. (2019). Survey on using ethical principles in environmental field research with place-based communities. *Sci. Eng. Ethics* 25, 477–517. doi: 10.1007/s11948-017-9981-4

Reddick, R. J., Griffin, K. A., Cherwitz, R. A., Cerda-Prazak, A. A., and Bunch, N. (2012). What you get when you give: how graduate students benefit from serving as mentors. *J. Facult. Dev.* 26, 37–49.

Robinson, P. A., Byrd, D., Louis, D. A., and Bonner, F. A. (2013). Enhancing faculty diversity at community colleges: a practical solution for advancing the completion agenda. *FOCUS Coll. Univ. Sch.* 7:1.

Sarabipour, S. (2020). Virtual conferences raise standards for accessibility and interactions. *ELife* 9:e62668. doi: 10.7554/eLife.62668

Sardelis, S., and Drew, J. A. (2016). Not 'pulling up the ladder': women who organize conference symposia provide greater opportunities for women to speak at conservation conferences. *PLoS One* 11:e0160015. doi: 10.1371/journal.pone.0160015

Sardelis, S., Oester, S., and Liboiron, M. (2017). Ten strategies to reduce gender inequality at scientific conferences. *Front. Mar. Sci.* 4:231.

Sarsons, H., Gërxhani, K., Reuben, E., and Schram, A. (2021). Gender differences in recognition for group work. *J. Polit. Econ.* 129, 101–147. doi: 10.1086/711401

SCB Pledges Solidarity with BLM protests (2020). *Society for Conservation Biology (SCB)*. Availble online at: https://conbio.org/publications/scb-news-blog/scb-pledges-solidarity-with-blm-protests [Accessed April 6, 2021].

Sexual Harassment in Marine Science (n.d.). *WOMEN IN OCEAN SCIENCE*. Available online at: https://www.womeninoceanscience.com/sexual-harassment [Accessed April 6, 2021]

Shiffman, D. S. (2018). Social media for fisheries science and management professionals: how to use it and why you should. *Fisheries* 43, 123–129.

Singh, G. G., Cisneros-Montemayor, A. M., Swartz, W., Cheung, W., Guy, J. A., Kenny, T.-A., et al. (2018). A Rapid assessment of co-benefits and trade-offs among sustainable development goals. *Mar. Policy* 93, 223–231. doi: 10.1016/j.marpol.2017.05.030

Society for Conservation Biology North America (SCBAM) (2020). *Statement from the Society for Conservation Biology North America condemning anti-Black racism and police violence*. Available online at: https://scbnorthamerica.org/index.php/general/statement-from-the-society-for-conservation-biology-north-america-condemning-anti-black-racism-and-police-violence [Accessed April 6, 2021].

Squazzoni, F., Bravo, G., Farjam, M., Marusic, A., Mehmani, B., Willis, M., et al. (2021). Peer review and gender bias: a study on 145 scholarly journals. *Sci. Adv.* 7:eabd0299. doi: 10.1126/sciadv.abd0299

Stefanoudis, P. V., Licuanan, W. Y., Morrison, T. H., Talma, S., Veitayaki, J., and Woodall, L. C. (2021). Turning the tide of parachute science. *Curr. Biol.* 31, R184–R185. doi: 10.1016/j.cub.2021.01.029

Suedkamp Wells, K. M., Ryan, M. R., Campa, H., and Smith, K. A. (2005). Mentoring guidelines for wildlife professionals. *Wildlife Soc. Bull.* 33, 565–573. doi: 10.2193/0091-7648200533[565:MGFWP]2.0.CO;2

Taylor, K. A. (2021). EDI(Torial): Equality, diversity, and inclusion and platelets - 2021. *Platelets* 32, 3–4. doi: 10.1080/09537104.2020.1854542

Thomsen, M., and Creelman, A. (2021). *From exclusive conferencing to community building – facing the challenge of the climate crisis. The Post-Pandemic University (blog)*. Available online at: https://postpandemicuniversity.net/2021/03/07/from-exclusive-conferencing-to-community-building-facing-the-challenge-of-the-climate-crisis/ [Accessed March 7, 2021].

Timperley, C., Sutherland, K. A., Wilson, M., and Hall, M. (2020). He Moana Pukepuke: navigating tender and ethnic inequality in early career academics' conference attendance. *Gender Educ.* 32, 11–26. doi: 10.1080/09540253.2019.1633464

Tsang, J. (2019). Rent or Conference — Early-career researchers shouldn't have to choose. *Nature* 2019:979. doi: 10.1038/d41586-019-00979-0

Tulloch, A. I. T. (2020). Improving sex and gender identity equity and inclusion at conservation and ecology conferences. *Nat. Ecol. Evol.* 4, 1311–1320. doi: 10.1038/s41559-020-1255-x

Wiederhold, B. K. (2020). Connecting through technology during the coronavirus disease 2019 pandemic: avoiding 'Zoom fatigue'. *Cyberpsychol. Behav. Soc. Netw.* 23, 437–438. doi: 10.1089/cyber.2020.29188.bkw

Wu, A. H. (2018). Gendered language on the economics job market rumors forum. *AEA Papers Proc.* 108, 175–179. doi: 10.1257/pandp.20181101

Zurba, M., Maclean, K., Woodward, E., and Islam, D. (2019). Amplifying indigenous community participation in place-based research through boundary work. *Prog. Hum. Geogr.* 43, 1020–1043. doi: 10.1177/0309132518807758

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