



# Identifying Pathways for Climate-Resilient Multispecies Fisheries

Kendra A. Karr<sup>1\*</sup>, Valerie Miller<sup>2</sup>, Eva Coronado<sup>3</sup>, Nadia C. Olivares-Bañuelos<sup>4</sup>, Martha Rosales<sup>4</sup>, Javier Naretto<sup>5</sup>, Luciano Hiriart-Bertrand<sup>5</sup>, Camila Vargas-Fernández<sup>5</sup>, Romina Alzugaray<sup>6</sup>, Rafael Puga<sup>6</sup>, Servando Valle<sup>6</sup>, L. P. Osman<sup>7,8</sup>, Julio Chamorro Solís<sup>9</sup>, Marco Ide Mayorga<sup>10</sup>, Doug Rader<sup>11</sup> and Rod Fujita<sup>1</sup>

<sup>1</sup> Environmental Defense Fund, San Francisco, CA, United States, <sup>2</sup> Environmental Defense Fund, Austin, TX, United States, <sup>3</sup> Escuela Nacional de Estudios Superiores, Unidad Mérida, Universidad Nacional Autónoma de México, Ucu, Mexico, <sup>4</sup> Environmental Defense Fund de México, Mexico City, Mexico, <sup>5</sup> Costa Humboldt, Llanquihue, Chile, <sup>6</sup> Centro de Investigaciones Pesqueras del Ministerio de la Industria Alimentaria, Havana, Cuba, <sup>7</sup> Environmental Defense Fund, Valdivia, Chile, <sup>8</sup> CEAM, Universidad Austral de Chile, Valdivia, Chile, <sup>9</sup> Sindicato Trabajadores Independiente Pescadores Artesanales Juan Fernández, Universidad de Concepción, Valparaíso, Chile, <sup>10</sup> Federación Interregional de Pescadores Artesanales del Sur, Valdivia, Chile, <sup>11</sup> Environmental Defense Fund, Raleigh, NC, United States

## OPEN ACCESS

### Edited by:

Sophia N. Wassermann,  
University of Washington,  
United States

### Reviewed by:

Trevor Hutton,  
Commonwealth Scientific  
and Industrial Research Organisation  
(CSIRO), Australia  
Geret Sean DePiper,  
Social Sciences Branch, Northeast  
Fisheries Science Center (NOAA),  
United States

### \*Correspondence:

Kendra A. Karr  
kkarr@edf.org

### Specialty section:

This article was submitted to  
Marine Conservation  
and Sustainability,  
a section of the journal  
Frontiers in Marine Science

**Received:** 07 June 2021

**Accepted:** 22 September 2021

**Published:** 14 October 2021

### Citation:

Karr KA, Miller V, Coronado E, Olivares-Bañuelos NC, Rosales M, Naretto J, Hiriart-Bertrand L, Vargas-Fernández C, Alzugaray R, Puga R, Valle S, Osman LP, Solís JC, Mayorga MI, Rader D and Fujita R (2021) Identifying Pathways for Climate-Resilient Multispecies Fisheries. *Front. Mar. Sci.* 8:721883. doi: 10.3389/fmars.2021.721883

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

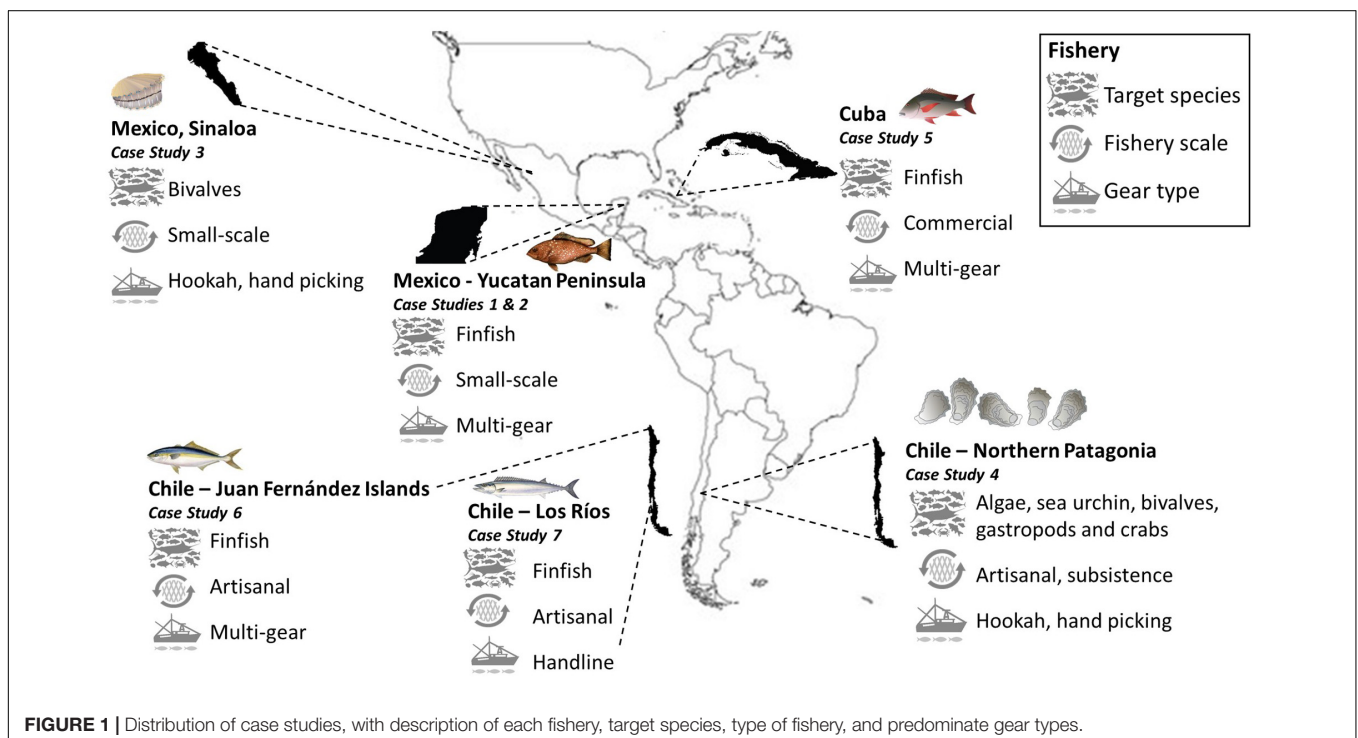
### Fishery Characteristics

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.

<b>Fishery</b>	<b>Target (main)</b>	<b>Targets (others)</b>	<b>Season</b>	<b>Gear</b>	<b># Fishers</b>	<b># Vessels</b>	<b>Regulations</b>
<b>(1) Commercial fisheries of the Yucatan Peninsula, Mexico</b>	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.
<b>(2) Multispecies finfish fishery of the State of Yucatan, Mexico</b>	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.
<b>(3) Multispecies Bivalve Fishery of Sinaloa, Mexico</b>	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.
<b>(4) Caulín Marine Coastal Area of Indigenous People (MCAIP) Northern Patagonia, Chile</b>	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.
<b>(5) Multispecies Finfish Fisheries Management in Cuba</b>	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.
<b>(6) Forgotten Fish of Chile</b> <i>Juan Fernández Archipelago and Desventuradas Islands</i>	Finfish	>50 species					
	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.
<b>(7) Forgotten Fish of Chile – Los Ríos</b>	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-resilient 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<sup>2</sup> 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<sup>2</sup> and is managed by the “Asociación de Comunidades Williche ECMPO Caulín” (Association of Williche 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), and *Sarcothalia crispata* (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 edwardsii* (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 Humboldt 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 ( $> 1.5 \text{ km}^2$ ) 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*), engler's scorpionfish (*Scorpaenodes engleri*), pink maomao (*Caprodon longimanus*), jerguilla (*Girella albostrigata*), Yellowtail amberjack (*Seriola lalandi*), Juan Fernández pampanito (*Scorpius 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 (*Thyrssites 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 Ríos region are Patagonian blennie (*Eleginops maclovinus*), corvina drum (*Cilus gilberti*), Chilean silverside (*Odonthestes regia*), Chinook salmon (*Oncorhynchus tshawytscha*), slender tuna (*Allothenus 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.

Fishery	Challenge	Tools			Pathway
		Biological	Social	Governance	
<b>(1)</b> <b>Commercial fisheries of the Yucatan Peninsula, Mexico</b>	<i>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</i>	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.	<b>Move toward a transdisciplinary approach:</b> 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.
<b>(2)</b> <b>Multispecies finfish fishery of the State of Yucatan, Mexico</b>	<i>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.</i>	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.	<b>Collaborative, multistakeholder committees and management plan;</b> focused on the social, economic, and environmental guidelines for fisheries sustainability.
<b>(3)</b> <b>Multispecies Bivalve Fishery of Sinaloa, Mexico</b>	<i>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.</i>	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.	<b>A multistakeholder designed and implemented ecosystem-based management plan</b> 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.
<b>(4)</b> <b>Caulín Marine Coastal Area of Indigenous People (MCAIP) Northern Patagonia, Chile</b>	<i>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.</i>	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.	<b>Participatory fishery monitoring and multispecies fishery management plan performance assessment requires outreach programs at local scale.</b> 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	
<b>(5) Multispecies Finfish Fisheries Management in Cuba</b>	<i>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.</i>	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.	<b>Multistakeholder (e.g., government, fishers, academia, and industry) designed and implemented multispecies management plan, using fish baskets.</b> Transitioning from monitoring and managing very few species, with single species FMP to a science-based and adaptive climate-resilient multispecies FMP.
<b>(6 and 7) Forgotten Fish of Chile</b>	<i>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.</i>	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.	<b>Fishing community designed climate-resilient fishery management plan, using fish baskets.</b> 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 as 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**).

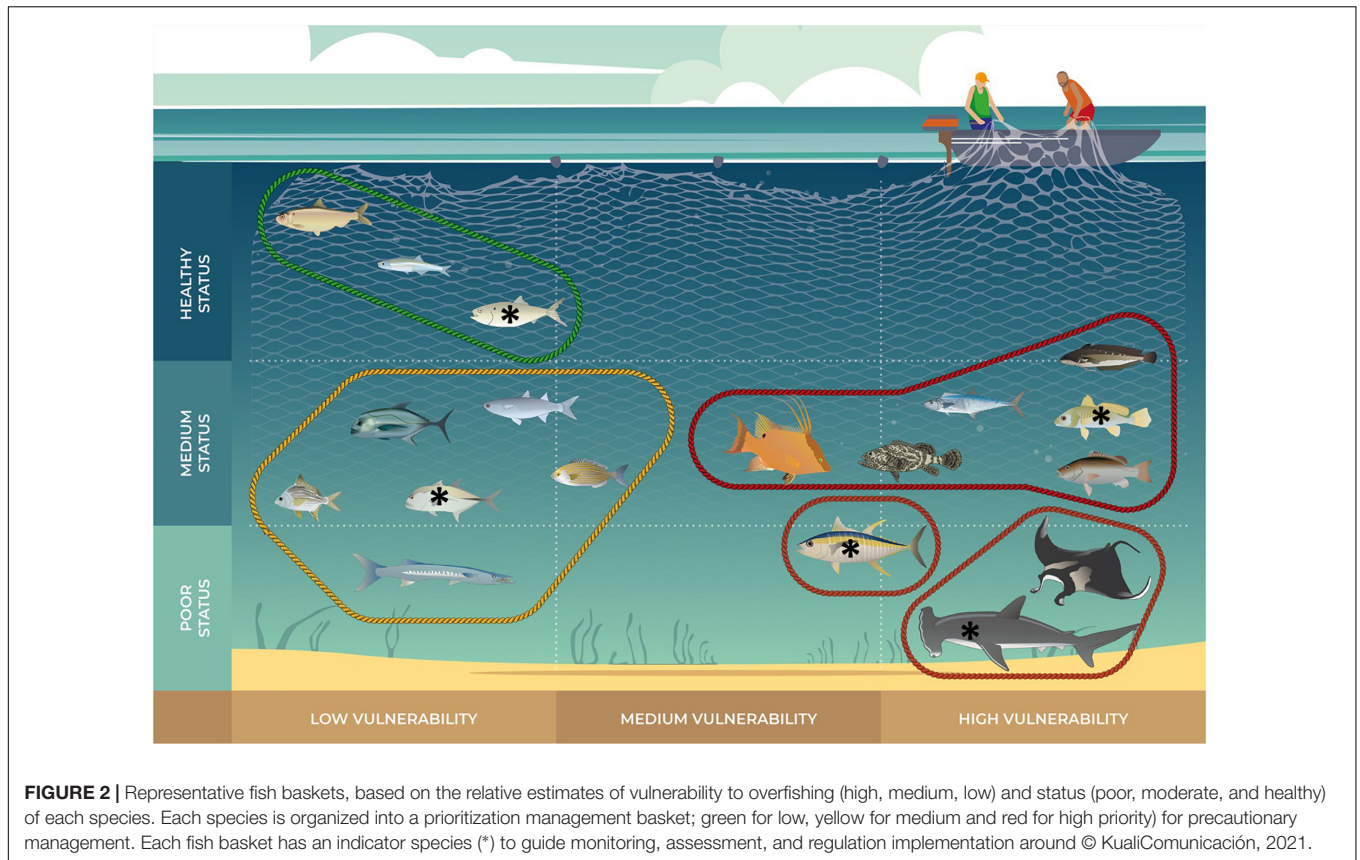
Regardless of the multispecies management approach, a mechanism to convert scientific guidance to climate-resilient science-based management will be necessary given climate change’s current and anticipated impacts on fisheries (Barange et al., 2018). Many fisheries have yet to carry out projections of 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





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.

## 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 Multiinstitucional 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 Archipiélago de Juan Fernández, Chile," in *Islas Oceánicas Chilenas: Su Conocimiento Científico y Necesidades de Investigaciones*, ed. J. C. Castilla (Santiago, CL: Ediciones Univ. Católica de Chile), 319–353.

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.

## ACKNOWLEDGMENTS

KK and VM would like to thank Nicholas Fairbairn for his support in reviewing and editing all the literature cited for the manuscript. We especially thank Kristin Kleisner and two outside reviewers, GD and TH, for helpful comments. EC would like to acknowledge CONPAESCA and fisher groups for the contribution of data and information. NO-B would like to acknowledge the contributions of Federaciones Regionales de Sociedades Cooperativas de la Industria Pesquera del Centro y Oriente del Estado de Yucatán, Armadores Pesqueros y la Secretaria de Pesca y Acuicultura Sustentable de Yucatán, regional delegation CONAPESCA and INAPESCA CRIAP-Yucalpeten to the management of multispecies in the Yucatan. JN, CV-F, and LH-B would like to thank Asociación de Comunidades Indígenas del ECMPO Williche Caulín for the trust and work carried out related to the administration of the MCAIP. RA, RP, and SV would like to thank Eduardo Boné-Morón for all logistical support and Grupo Empresarial de la Industria Alimentaria (GEIA) for both support and information provided for the Cuba case study. LO, JS, and MM would like to thank Erica Cunningham for the constant support, and Daniela Cajas and Guisella Muñoz for the continual commitment to manage the forgotten fish fisheries.

## 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>

- 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.rsm.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., Choichrane, 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., Ahmadi, 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, 2<sup>nd</sup> 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., Noh-Quinones, 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 Pabellón, 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](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 Acuicultura y Pesca 2018. Comisión Nacional de Acuicultura 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. Environ. 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-Solis, 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-Solis, J., Manríquez-Angulo, P., Rivara-Saaccedra, P., Tapia-Álvarez, B., et al. (2020). Pesquería de crustáceos del archipiélago Juan Fernández. *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 acuicultura 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 acuicultura 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 CO<sub>2</sub> 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 Ñancuqueo, 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. Monteferrri (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” *Thyrstites 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-Irriego, 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 Cooperativa 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

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Publisher's Note:** All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Copyright © 2021 Karr, Miller, Coronado, Olivares-Bañuelos, Rosales, Naretto, Hiriart-Bertrand, Vargas-Fernández, Alzugaray, Puga, Valle, Osman, Solís, Mayorga, Rader and Fujita. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.