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Positive Social-Ecological Feedbacks in Community-Based Conservation

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Marine area-based conservation measures including no-take zones (areas with no fishing allowed) are often designed through lengthy processes that aim to optimize for ecological and social objectives. Their (semi) permanence generates high stakes in what seems like a one-shot game. In this paper, we theoretically and empirically explore a model of short-term area-based conservation that prioritizes adaptive co-management: temporary areas closed to fishing, designed by the fishers they affect, approved by the government, and adapted every 5 years. In this model, no-take zones are adapted through learning and trust-building between fishers and government fisheries scientists. We use integrated social-ecological theory and a case study of a network of such fisheries closures ("fishing refugia") in northwest Mexico to hypothesize a feedback loop between trust, design, and ecological outcomes. We argue that, with temporary and adaptive area-based management, social and ecological outcomes can be mutually reinforcing as long as initial designs are ecologically "good enough" and supported in the social-ecological context. This type of adaptive management also has the potential to adapt to climate change and other social-ecological changes. This feedback loop also predicts the dangerous possibility that low trust among stakeholders may lead to poor design, lack of ecological benefits, eroding confidence in the tool's capacity, shrinking size, and even lower likelihood of social-ecological benefits. In our case, however, this did not occur, despite poor ecological design of some areas, likely due to buffering by social network effects and alternative benefits. We discuss both the potential and the danger of temporary area-based conservation measures as a learning tool for adaptive co-management and commoning.

Keywords: commons, fisheries, no-take zones, Mexico, social-ecological systems, adaptive co-management, OECM, marine protected area

INTRODUCTION

Area-based fisheries closures, or "no-take" zones, constitute a cornerstone of twenty-first century marine conservation and management (Campbell and Gray, 2019; Cabral et al., 2020). The popularity of no-take zones largely stands on ecological evidence of increased biodiversity and biomass where fishing is banned or limited (Halpern et al., 2009, 2010; Gill et al., 2017; Jones et al., 2018). A key finding from this literature is that older, more permanent area-based fisheries closures have better ecological outcomes (Edgar et al., 2014). Because permanent areas are one-shot games, there is pressure to perfect their initial design (Margules and Pressey, 2000). However, competing social and ecological objectives and evidence complicate attempts to optimize initial design (De Santo, 2013). No-take marine protected areas (MPAs) in particular frequently focus on ecological objectives first and social considerations second (De Santo, 2013; Campbell and Gray, 2019; Visconti et al., 2019). As a result, MPAs on average have increased fish biomass within their boundaries (Gill et al., 2017) while simultaneously leading to negative human well-being outcomes a third of the time (Ban et al., 2019). The design of MPAs by experts prioritizing ecological criteria may be perceived as illegitimate by the stakeholders whose compliance is most critical to the MPA's success (Jentoft et al., 2012). That can lead to the alienation and marginalization of local resource users, low compliance rates, and ecological failure of the MPA in the long run (Fabinyi et al., 2015; Basurto et al., 2016). Alternate no-take management models, such as Other Effective Area-based Conservation Measures (OECMs) (Garcia et al., 2019), can offer less resistance from local communities while still potentially generating ecological benefits (Gell and Roberts, 2002). In either case, ecological success depends on initial design, creating high stakes when implementing no-take zones for conservation and management.

Tension between ecological and social objectives for no-take zones manifests as conflicts related to design characteristics such as the duration, location, and in particular the size, of no-take areas (Beattie et al., 2002; Ban et al., 2013; Gruby and Basurto, 2014; Krueck et al., 2018). Large size is associated with greater ecological benefits like high recovery rates of fish biomass, enhanced spillover of adults and larvae to adjacent areas, and protection of highly mobile species (Claudet et al., 2008; Vandeperre et al., 2011). However, large areas present governance challenges, being hard to establish when multiple actors operate within their border, and also hard to monitor and enforce (Gruby et al., 2017; Campbell and Gray, 2019). Additionally, large permanent areas may struggle to adapt in response to climate change (Mills et al., 2015; Hopkins et al., 2016), an urgent concern recently raised during the 1st Global Planning Meeting of the UN Decade of Ocean Sciences for Sustainable Development (UNESCO, 2019). Similarly, ecological evidence suggests that MPAs are most successful when distant from human impacts, for example when isolated by deep water or sand (Edgar et al., 2014) or distant from fishing communities (Advani et al., 2015). On the other hand, social scientists have questioned the long-term efficacy of remote MPAs (Jones and De Santo, 2016) with evidence that MPAs near fishing villages are easier to monitor, and can have higher compliance (Pollnac et al., 2001; McClanahan et al., 2006), highlighting the importance of local support for their long-term sustainability (Basurto et al., 2016).

Acknowledging that social and ecological objectives are not separable but are interlinked (Ostrom, 2009; Persha et al., 2011), an emerging approach is the implementation of adaptive area-based conservation tools (Quintana and Basurto, 2020), which apply key principles of adaptive management for social-ecological systems: monitoring, assessment, learning, and iterative re-design (Armitage et al., 2010). This approach to area-based conservation prioritizes the decision-making process with fishers at the center, building opportunities for collective action (Gruby and Basurto, 2014; Quintana and Basurto, 2020). As such, it is an approach that values the process as much as the outcome, challenging the need to achieve the "right" design before establishing MPAs or other spatial management tools (Possingham et al., 2006; Giakoumi et al., 2018; Jantke et al., 2018). Examples include voluntary, temporary fisheries closures such as those in the South Pacific, Indian Ocean, Latin America, and the Caribbean (Cohen et al., 2013; Jupiter et al., 2017; Moreno et al., 2017; Villaseñor-Derbez et al., 2019). These temporary closures are spatially-explicit areas agreed to by local fishers where fishing is limited or prohibited for a specified period of time, after which they must be re-negotiated (McClanahan et al., 2006; Daw et al., 2011). Being inherently temporary creates an iterative process of learning and trust-building, a key facet of adaptive co-management, which also makes these potential tools for adaptation to climate change (Armitage et al., 2008; Plummer et al., 2012). These temporary fishing closures can further serve as an opportunity for resource users and regional governments to practice making collective decisions about (co-)management of coastal resources more broadly (Gelcich et al., 2006; Lozano and Heinen, 2016) and become biosphere stewards (Plummer et al., 2020). Such areas respond to calls to reconceptualize area-based conservation and management tools as "policy experiments" with opportunities for adaptation (Fox et al., 2012). They also have the potential to broaden participation beyond traditional experts, support development objectives, and adapt to climate change (Karr et al., 2017; Bennett et al., 2018; Flannery et al., 2018).

Where they produce ecological benefits, temporary closures can build trust, strengthen collective action, and support long-term sustainable resource harvest (Govan, 2009; Turner et al., 2016), especially where cooperation among fishers is supported by non-governmental organizations (NGOs) (Eraso et al., 2010; Basurto et al., 2016). However, where ecological benefits do not materialize, due to poor placement, short duration, or widespread non-compliance, fisheries closures may instead erode trust (Giakoumi et al., 2018; Scyphers et al., 2019). The competing design recommendations (size, duration, etc.) discussed above generate trade-offs that stakeholders must navigate. Temporary fisheries closures may thus entail a risky learning process because of positive feedback loops in the social-ecological system between trust, governance, and ecological outcomes, amplifying success or failure (see **Box 1** and **Figure 1**). The success or failure of such closures has implications for global efforts to expand ocean protection to 30% of the ocean's surface (IUCN, 2016), as the failure of one no-take approach can lower confidence in another.

BOX 1 | Theoretical feedback loop for temporary no-take zones designed by fishers.

The conceptual model below integrates social and ecological theory about area-based conservation measures (Fox et al., 2012; Gill et al., 2017; Mascia et al., 2017) within the frameworks of collective action (Ostrom, 2009; Partelow, 2018) and adaptive co-management (Olsson et al., 2004; Armitage et al., 2010). Based on this scholarship, we propose a theoretical feedback loop for adaptable no-take zones (areas where fishing is banned) designed by the users they affect. This conceptual model is likely relevant to other sustainable management tools.

In this simplified model, the level of initial *trust* in the no-take zone's potential (defined as confidence that it will have positive outcomes) determines initial *design* (number, location, size, etc.) (Charles and Wilson, 2009; del Mar Mancha-Cisneros et al., 2018). Empirically, this initial trust often depends on factors like historical relationship with government, non-governmental organizations (NGOs) and/or scientists (Kusumawati and Huang, 2015; Basurto et al., 2016; Ordoñez-Gauger et al., 2018), predicted compliance rates (i.e., reputational history of fishers affecting their likelihood of mutual restraint) (Ostrom and Ahn, 2009), and expected or potential ecological benefits (Bennett and Dearden, 2014; Hargreaves-Allen et al., 2017; McNeill et al., 2018). Depending on initial design (Halpern, 2003; Lester et al., 2009), and mediated by socio-ecological factors like habitat quality and compliance (Marin-Monroy et al., 2020), the no-take zone may (or may not) lead to ecological changes like increased biomass of target species (Edgar et al., 2014; Gill et al., 2017). This in turn may or may not be perceived by the fishers (Bergseth et al., 2015). The fishers then evaluate these perceived results to update their trust in the no-take zone, which starts the next iterative cycle with a collective action process and new area design (McNeill et al., 2018).

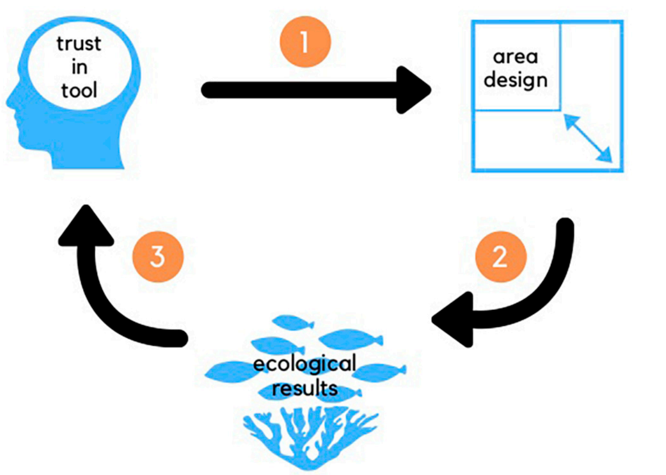


Diagram of simplified feedback loop between individual fishers' trust in the probable efficacy of a no-take area tool, the design they collectively agree upon, and the resultant ecological changes. Arrows generally represent positive feedbacks, but are mediated by numbered processes on the right, which affect the strength and direction of the feedback. Numbers above match processes on the right.

Link 1: Decision-making processes involving collective action such as leadership, social organization, and previous experience in collective action mediate how individual trust is reflected in collectively agreed-upon no-take zone design (Ostrom et al., 1994; Osmond et al., 2010).

Link 2: Social-ecological processes like compliance, species mobility, and spillover mediate the effect of design on ecological outcomes of the no-take zone (Fox et al., 2012; Edgar et al., 2014; Gill et al., 2017; Mizrahi et al., 2019).

Link 3: Assessment, perception, and valuation processes like fishing in adjacent areas, observing changes inside the no-take zone (e.g., underwater surveys), and perceived monitoring and enforcement mediate how ecological results are detected and evaluated to update individual trust in the next timestep (McClanahan et al., 2005).

FIGURE 1 | A diagram of the simplified feedback loop and the three Links that make up the conceptual model.

Model predictions: This simple model provides a potential mechanism for both an "upwards spiral" of increasing trust, improving design, and increasing ecological benefits, as well as a "downwards spiral" of evaporating trust, deteriorating design, and negligible ecological benefits. For example, the model predicts that when the system starts with low initial trust in the no-take zone's potential, it leads to a low-risk design (e.g., small size or protection of unproductive sites) and thus insignificant ecological results. The lack of results further reduces trust in the no-take zone's likely efficacy, which reduces fishers' willingness to close productive areas, and further decreases the likelihood of ecological benefits ("downwards spiral"). Conversely, high initial trust leads to a better no-take zone design that produces significant and detectable ecological results, leading to greater trust in the no-take zone's future potential. This leads to improving no-take zone design until the perceived costs (e.g., loss of fishing area) outweigh the benefits ("upwards spiral"). If such a feedback loop were to be widespread in adaptive no-take zones, the thresholds between these two outcomes in any particular context, as well as the mechanisms to reinforce or break out of the feedback loops, would be of great interest to conservation practitioners as well as scholars.

In this paper, we explore feedback loops for area-based no-take zones that prioritize adaptation and learning rather than optimized initial design. We first describe a conceptual model and discuss its utility in explaining empirical outcomes from temporary no-take zones aimed at rebuilding fisheries called fishing refugia (in Spanish, Zonas de Refugio Pesquero) in the Gulf of California, Mexico. In this region, a network of fishing refugia was established in 2012 with a 5-year duration, with the legal goal of rebuilding fisheries (DOF, 2012). When these expired in 2017, local fishers redesigned and renewed them, resulting in an increase in the number (+1) and size of the largest fishing refugia (550% growth) while the smaller areas were unchanged (DOF, 2017). We chose this case because of the authors' long-term experience (5–20 + years) in the study region and access to fine-scale and temporally overlapping social and ecological data (2009–2017). We examine the following research questions:

> *Can social-ecological feedback loops explain diverging outcomes in adaptive, temporary no-take zones designed by fishers? Is there empirical support for these feedback loops?*

We depart from a theoretical conceptualization of how these dynamics would work, explained in detail in **Box 1**. We present the conceptual model first for logical flow of the paper, but note that this model emerged both deductively and inductively, through iterative conversations about theory and this case. Since the model emerged (in part) from the case, we do not use the case to "test" the model's validity; instead we use the model to explore and critically evaluate possible mechanisms explaining patterns we found empirically. Specifically, we discuss the social and ecological feedback loops that may have caused a divergent pattern wherein the largest area was expanded and smaller areas were unchanged. We contribute to a growing body of work that combines models and empirical evidence to understand social-ecological dynamics within small-scale fisheries and marine conservation governance (Lindkvist et al., 2017; Okamoto et al., 2020; Wijermans et al., 2020).

MATERIALS AND METHODS

Case Study: Fishing Refugia of the Corredor, Baja California Sur, Mexico

Mexico's fishing refugia are area-based tools—either limited take or no-take zones—intended to protect or rebuild fisheries (DOF, 2014). Most are temporary (CONAPESCA, 2019). Unlike traditional protected areas governed by Mexico's Ministry of the Environment (SEMARNAT), which many fishers—for example in the northwest of Mexico—mistrust, fishing refugia are governed by Mexico's Fisheries Commission (Comisión Nacional de Acuacultura y Pesca, hereafter "CONAPESCA") which provides subsidies and fishing permits to fishers. CONAPESCA has implemented area-based fisheries closures like fishing refugia since 1975 (De Anda-Montañez et al., 2013), but fishing refugia were not established as an official fisheries management tool until 2007, when they were included in the General Law of Sustainable Fishing and Aquaculture with "the primary purpose of conserving and contributing, natural or artificially, to the development of fishing resources by protecting their reproduction, growth or recruitment areas, as well as preserving and protecting the environment that surrounds them" (DOF, 2007).

In 2010, after a series of meetings convened by civil society organizations and academic scientists, CONAPESCA opened an invitation to Mexico's fishers to initiate a process of fisheries management that included proposals to establish fishing refugia completely closed to fishing. The first effort to attend this call happened in the San Cosme to Punta Coyote Corredor region (the "Corredor") in the state of Baja California Sur, with technical support from the Sociedad de Historia Natural Niparajá (hereafter Niparajá), a civil society organization dedicated to regional conservation (Niparajá is led by one of the coauthors of this paper, AHW). After a process spanning several years, on November 16, 2012, Mexico's first network of no-take fishing refugia was established in the Corredor (DOF, 2012). Since 2012, 41 fishing refugia have been established across Mexico, covering 20,185 km^2 in the coastal waters of four states (CONAPESCA, 2017). Most to date have been designed and proposed by small-scale fishers, who decide on the location, size, and duration (typically 5 years at a time with the option of renewal). Almost all fishing refugia are strict no-take (including the first ones, established in the Corredor, which this paper discusses), although some of the refugia allow for limited take. Refugia are poorly enforced by CONAPESCA in practice, leaving much of the monitoring and enforcement to vigilantes, fisher organizations (e.g., cooperatives), or their civil society partners.

Mexico's first fishing refugia were established in the Corredor because of the confluence of declining fisheries and support from Niparajá. The Corredor is on the coast of the Gulf of California, which produces up to 71% of Mexico's total fisheries by volume (OECD, 2006). There is evidence of decline in the health of exploited ecosystems and the status of fish populations throughout the Gulf of California (Sala et al., 2004; Saenz-Arroyo et al., 2005; Giron-Nava et al., 2019), including the Corredor region, which has 13 permanent fishing towns, 659 residents, and 104 fishing vessels (Niparajá, 2016). Most livelihoods in the Corredor depend on fishing, with some ranching and tourism. Fishers in the region fish from 6 to 8-m "pangas" (fiberglass boats with an outboard motor) typically on day-trips although some set up fishing camps on nearby islands. Fishers have multispecies finfish permits, and primarily target snappers (especially red snapper, *Lutjanus peru*), groupers, jacks, and triggerfish; they are relatively homogeneous in terms of gear, with 93% of fishers using hook and line, although some (30%) also use targeted gillnets, especially for sharks and rays (Niparajá et al., 2009). Since 2009, Niparajá has led data collection efforts in the Corredor, including socioeconomic surveys in 2009 and 2016, annual underwater ecological monitoring data from 2012 to present, and fish catch monitoring data from 2012 to present, which we use in this paper.

Ecological Data

From 2012 to 2017, Niparajá implemented an ecological monitoring plan to track the ecosystem changes within and outside the network of fishing refugia established in 2012, partly with the involvement of fishers from the Corredor. For this monitoring, Niparajá trained nine fishers from the Corredor who joined their scientific team as "Buzos Monitores" (monitoring divers) in annual expeditions (mostly in October) to at least one site inside each fishing refugia and one comparable control site outside the refugia (Quintana et al., 2020). To perform the surveys, divers deployed a 30 m transect and registered all fish and invertebrates encountered in a 2 × 2-m box (4 m^2) over 20–30 min following the transect tape. Divers recorded the species, size and number of individuals observed. Given the fisheries objectives of the fishing refugia, we focused our analysis on the eight species of primary commercial importance that include: leopard grouper (*Mycteroperca rosacea*), creole fish (*Paranthias colonus*), trigger fish (*Balistes polylepis*), yellow snapper (*Lutjanus argentiventris*), cenizo snapper (*Lutjanus novemfasciatus*), mulato snapper (*Hoplopagrus guentherii*), jacks (*Caranx* sp.), and parrotfish (*Scarus* sp.). The selection of these eight primary commercial species provided one line of evidence to evaluate the refugia's progress toward its legal goal of curbing fisheries decline.

For each of the fishing refugia within rocky reefs (excluding the ones in estuaries given their role as nursery grounds), we estimated the total density in number of individuals per square meter and the total biomass in tons per hectare, from 2012 to 2017. We calculated biomass from length estimates recorded during monitoring, scaled by species-specific length-weight ratios. These values were estimated for both the protected area and their respective control areas. We also estimated the average rate of change in biomass for each fishing refugia as the slope of a linear model between the year and the average annual biomass. These results were then compared to the total area of each fishing refugia to test the relationship between size and rate of recovery.

Social Data

The social outcomes discussed below are primarily based on a survey of 95 fishers that Niparajá and Duke University conducted in 2016, comprising over half of all 173 active commercial fishers in the Corredor (Niparajá, 2016). The surveys typically lasted from 1 to 3 h and covered diverse topics related to socioeconomics and fishing, including household economy, fishing behavior, and attitudes toward the fishing refugia. The survey questions used in this paper are extracted and listed in **Supplementary Material 4**. A team of trained enumerators conducted this survey through interviews using pen and paper in every town in the Corredor from June to December 2016. Participation was voluntary with no financial incentive. Spatial distribution of respondents is tabulated in **Supplementary Material 3**. Given the constraints of surveying fishers in rural towns, sampling was a mix of purposive, random, and opportunistic to achieve a minimum sample size of at least 50% of active fishers from each town. Half of respondents for the 2016 survey were selected purposively based on their participation in a 2009 survey (n = 86) also conducted by Niparajá, which aimed to survey 1/3 of boat captains about fishing behavior and socioeconomic status. This survey preceded the fishing refugia and aimed to assess interest in the tool, as well as general attitudes about fishing. The rest of the respondents for the 2016 survey were randomly selected from a list of names. However, since only active fishers were surveyed, and fishers frequently spend time away from their communities (either in nearby cities or at fishing camps), response rates are hard to estimate. No fishers declined to be interviewed, although some stalled and then could not be found later. When targeted fishers could not be found or were no longer active fishers, fishers from their nearest kin or fishing crew were interviewed. Ultimately, about half of active fishers were interviewed.

These outcomes are analyzed and contextualized using qualitative data about perceptions of the fishing refugia from 6 months of in-depth fieldwork including observation, journaling, and informal and semi-structured interviews (n = 68) with stakeholders involved in implementing and evaluating them, as well as document analysis of legal documents and white papers. Interviews sought to understand how fishers perceived the fishing refugia, covering topics such as fishers' knowledge; the Buzos Monitores fisher-monitoring program; adaptive management and evaluation; property rights and responsibilities; and fisheries change. For interviews, following IRB approval (Duke University permit 2018-0130) AQ spent approximately 180 days from 2016 to 2018 in the field, recording and transcribing 54 semi-structured interviews with fishers, their families, government fisheries agency staff, university scientists, and Niparajá staff. A further 14 interviews were not audio-recorded but information was recorded in detailed notes. A.Q. coded transcriptions and conducted thematic analysis iterative with writing. The quotations presented below were selected from the 68 interviews because they most succinctly and articulately represented the variation of attitudes and perceptions that emerged in these interviews. These quotations were translated from Spanish, with minor edits to maintain original sentiment and intent, and for clarity. Respondents' names are hidden to protect anonymity.

RESULTS

> *"For the past 20 years, fishing has been disappearing. So Niparajá came and invited us to make fishing refugia. The people [here] did not really agree, because we did not know how the refugia would function. We did not know how the refugia would end up. And so we in the community started to talk, amongst ourselves, about whether it would be good. Some said yes, some said no. Well, you don't lose anything by trying it for 5 years, by testing to see if it would work. So we agreed and signed the paperwork with Niparajá. And so we didn't fish there that year, and the second year. By the third year, we went to see: and there were many fish. Many, many, many fish. It was working."*
>
> (Interview with fisher from Agua Verde, 11/13/17)

Link 1: Effect of Initial Trust on MPA Size Mediated by Collective Decision Process

The fishers of the 13 towns of El Corredor ultimately designed 11 fishing refugia of highly variable size, the most salient design characteristic, ranging from 0.4 to 5.9 km^2 (DOF, 2012; **Table 1**). Individually, El Corredor fishers had variable trust in the probable efficacy of the fishing refugia. When Niparajá first presented the idea of fishing refugia to the fishers of El Corredor, they had mixed reactions. For example, an early supporter from the largest town of Agua Verde described the initial reaction to fishing refugia as follows: "To us in the community, it was like a light bulb: this is good, [the fishing refugia] will be like a natural nursery for fish reproduction" (interview with fisher, 11/14/17). A more skeptical fisher, also from Agua Verde, told us, "I don't see [the fishing refugia] as a place to discharge fish to the whole area where we fish; it is impossible" (interview with fisher, 12/8/17). Nothing like a fishing refugia (i.e., a legal area-based fisheries closure) had ever been established in the Corredor, where illegal fishing was already widespread in various forms. Technically, about half of the Corredor fishers lacked permits and thus operated outside the margins of legal fishing despite generations of fishing in the area (Niparajá et al., 2009). Far more problematic from the perspective of El Corredor fishers were illegal and semi-legal fishers from "outside" (especially, the town of Ensenada Blanca to the north, the city of La Paz to the south, and the states of Sonora and Sinaloa across the Gulf of California), who were perceived as responsible for fisheries decline through the use of "damaging" gear like spearfishing, gillnets, and shrimp trawling. Finally, as a largely inaccessible region with low population density, no paved roads, and little coverage by cellular phone service, El Corredor was largely ignored by government officials, including fisheries officers. As such, there was also little trust in the official fisheries agency or its ability to enforce regulations.

While there was variation in individual fishers' trust in the fishing refugia's potential overall, focus groups conducted by Niparajá in 2009 revealed collective patterns among the 13 towns, published in a report called "Conociendo El Corredor" (Niparajá et al., 2009). Fishers from about half the towns (Agua Verde, Los Dolores, Ensenada de Cortes, San Evaristo, and El Pardito) proposed the solution of temporary area closures (such as refugia) (**Table 1**). Only fishers from Agua Verde proposed solutions like "establish well-defined catch sizes and limits" and "fishers should only catch species that their permits allow" indicating support for and trust in official regulations.

The reasons for town-level differences in initial trust in the fishing refugia was likely influenced by a number of endogenous variables like historical relationship to government, relationship to Niparajá, and road accessibility (**Table 1**). For example, in Agua Verde prior to 2009, a Niparajá staff member had built a permanent house and resided there for over a year, and government presence included a permanent paid government representative and government-funded schooling from pre-kindergarten through middle school.

The decision-making process mediated how initial individual trust level translated into the design of the fishing refugia in 2012. Because refugia are voluntary, they were negotiated and debated amongst the fishers between November 2009 and May 2010. In the northern Corredor (Agua Verde and Tembabiche), where towns are large and spread apart, there is very little overlap of fishing areas (**Table 1**; **Supplementary Material 1**), and towns decided individually on which areas to establish as fishing refugia. These towns are also characterized by the presence of fishing cooperatives, which establish a formal mechanism for leadership to reach consensus. On the other hand, in the southern Corredor (all other towns), fishing zones overlap substantially and respondents from many towns reported a lack of incentives to care for fisheries resources in 2009 (Niparajá et al., 2009) (**Table 1**), as such, proposals from one town were often rejected by another. Ultimately, refugia were only established when a majority of fishers from each affected town agreed. **Supplementary Table 3** lists all fishing refugia established in 2012, and which towns negotiated and agreed to each one's establishment.

The outcome given heterogeneous individual trust and a heterogeneous decision-making process, with greater presence of

TABLE 1 | Comparison of fishing towns in El Corredor in terms of total population, number of commercial fishers, relationship to government prior to 2009, relationship with Niparajá prior to 2009, accessibility through roads, lack of incentives to take care of fishing areas, conflicts with other fishers due to fishing areas overlap, and whether or not they proposed an area closure.

Town (population)	# Fishers	Relationship to government pre-2009	Relationship to Niparajá pre-2009	In focus groups in 2009, fishers identified the following issues:		
				Lack of incentives to protect resources*	Overlap of fishing areas*	Interest in establishing closures*
Agua Verde (278)	60	Paid government representative and multiple funded schools	Niparajá built a house for staff member, who lived there for 1.5 years. Also is a common place for fishers meetings.			×
Tembabiche (80)	18	Paid government representative				
Los Dolores (6)	3			×	×	×
Ensenada de Cortés (61)	15			×	×	×
Punta Alta (36)	14			×	×	
La Cueva (19)	7			×	×	
Nopoló (4)	1			×	×	
Palma Sola (12)	5			×		
San Evaristo (90)	24	Paid government representative			×	×
El Pardito (16)	12		Niparajá staff member partly resided here for 1.5 years	×	×	×
El Portugués (3)	3		Resentment about previous Niparajá project			
Punta Coyote (35)	11			×	×	

*All towns except El Portugués are resident communities where fishers live with their families; El Portugués is a fishing camp. The population and number of fishers reflect census data collected in 2016 by Niparajá. For columns with *, × marks town where fishers discussed the respective issue in focus groups conducted in 2009 by Niparaja.*

FIGURE 2 | Divergent pattern of fishing refugia adaptation after first 5 years. Original map is shown in light purple (established 2012 for 5 years). Note largest area in the north, San Marcial, created by fishers in the town of Agua Verde. In 2017, all fishing refugia were renewed for another 5 years with no changes, except San Marcial, which was expanded (shown in dark purple hatching). Map designed and created by Erin Ristig based on legal maps (DOF, 2012, 2017).

cooperatives and leadership in the north, was that the towns in the north proposed a greater area of fishing refugia (on average, 4.16 km^2 per town) compared to the south (on average, 0.46 km^2 hectares per town). The largest area by far was the "San Marcial" fishing refugia created by Agua Verde, at 5.92 km^2, compared to the median size of 0.64 km^2. **Figure 2** shows the location and extent of each fishing refugia in 2012 and the updated map from 2017.

Link 2: Ecological Effects of MPAs Mediated by Size and Socio-Ecological Factors

We found that on average, both the fishing refugia and their respective control areas had similar values for density and biomass in 2012 (**Figure 3**), when the network was first established. The fishing refugia presented clear signs of recovery

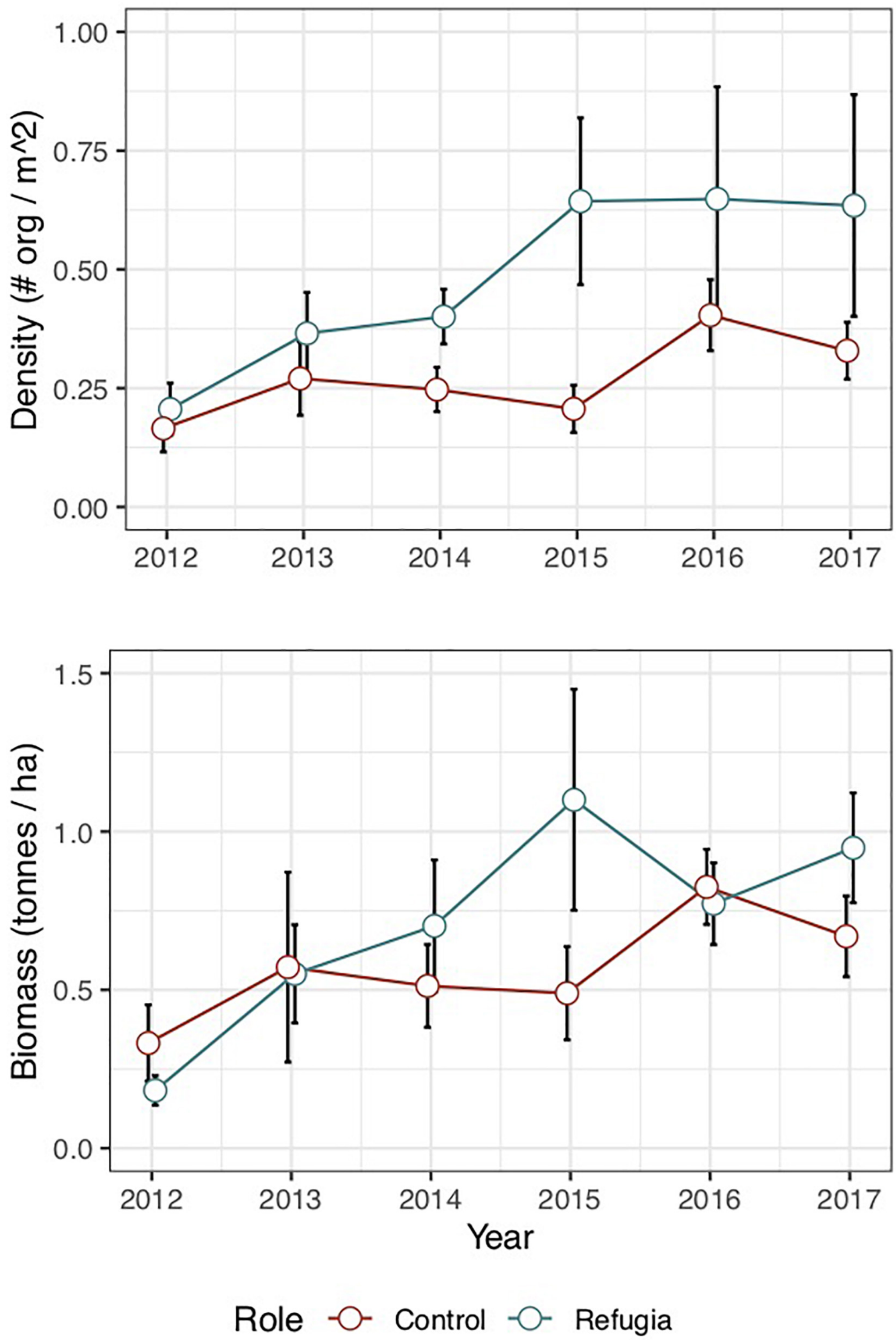


FIGURE 3 | Comparison of ecological parameters (biomass and density) between fishing refugia (blue) and control sites (red) from 2012 to 2017, from transect monitoring data. Trends show increase in both biomass and density over time, with significantly greater increases in fishing refugia.

between 2012 and 2017, with the average numerical density of fishes inside the fishing refugia going from 0.21 ± 0.05 fish/m^2 in 2012 to 0.63 ± 0.23 fish/m^2 in 2017. Conversely, the control areas went from an average density of 0.16 ± 0.05 fish/m^2 in 2012 to 0.33 ± 0.06 fish/m^2 in 2017. Additionally, the average biomass inside the fishing refugia went from 0.18 ± 0.05 tons/ha in 2012 to 0.95 ± 0.17 tons/ha in 2017; a greater recovery than the control areas that went from 0.33 ± 0.12 tons/ha

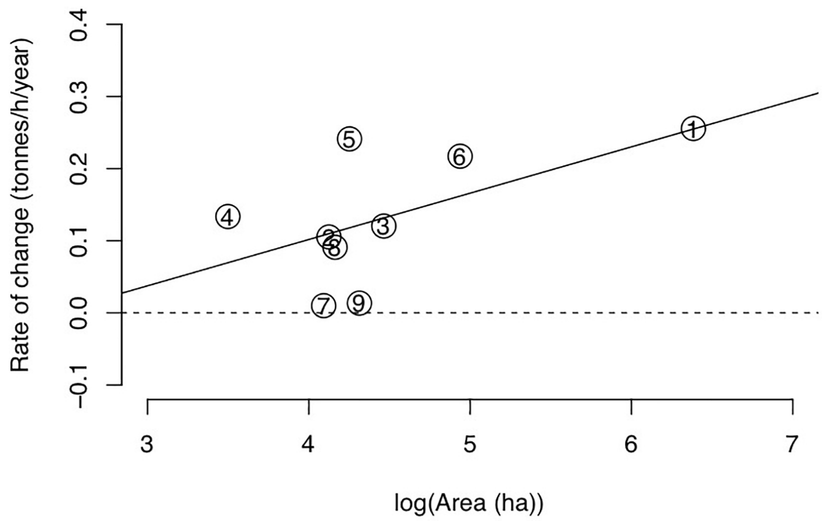


FIGURE 4 | Differential rates of biomass recovery based on total area for each fishing refugia. Each refugia is indicated by a number as follows: (1) San Marcial, (2) San Mateo, (3) Punta Botella, (4) La Morena, (5) La Habana, (6) San Diego, (7) El Pardito, (8) San Francisquito, and (9) Punta Coyote. La Brecha and Estero Tembabiche were excluded from this analysis given that those sites were established primarily to protect juveniles of important commercial in the coastal lagoons, thus no comparable metric of biomass recovery was available.

in 2012 to 0.67 ± 0.13 tons/ha in 2017 (**Figure 3**). These results highlight that even though adjacent areas are subject to similar environmental conditions and variability, the impact of protection was detectable.

We also found a marginally significant relationship between the logarithm of the total protected area and the average rate of change in biomass (**Figure 4**). Larger fishing refugia showed a faster biomass recovery ($R^2 = 0.33$, $P = 0.1$).

Link 3: Effect of Perception of Ecological Effects on Individual-Level Trust in Fishing Refugia

Based on the survey of El Corredor fishers conducted in 2016, about two-thirds of fishers reported that they perceived positive ecological results from the refugia 4 years after their establishment. Fishers who perceived positive effects were significantly more likely to propose the expansion of their fishing refugia and the creation of new ones than fishers who did not perceive positive ecological results (**Figure 5**). In contrast, fishers who perceived no ecological change resulting from the fishing refugia were more likely to propose eliminating the refugia (**Figure 5**).

Our interviews conducted in 2017 suggested that the Corredor fishers primarily drew on three sources of information to assess whether the fishing refugia were producing ecological benefits: (1) fisheries—whether there were detectable changes in catch or income; (2) underwater monitoring by "Buzos Monitores"; and (3) direct sampling by chumming the waters with bait, throwing a hook or fishing inside the fishing refugia. The fishers evaluated these perceptions differently, according to their own value systems and cost-benefit analyses: some fishers argued that the refugia were working on the basis of detectable differences with the promise of future potential, while others wanted to see more substantial results (e.g., "getting rich") in accordance to time sunk in meetings and loss of fishing area. Fishers thus combined perceptions with their value systems to arrive at a decision of whether the refugia were "working."

In the 2016 survey, El Corredor fishers were asked: "Let's suppose that the fishing refugia had never been established. How do you think the resources would be in this area?" In other words, "What was the effect of the fishing refugia on the resources?" Almost two-thirds (63%) said that the Fishing refugia had a positive impact in the resources. A third (31%) reported that there was no impact. A few (6%) said that the impacts were negative (**Figure 5**).

The same survey asked fishers several questions to propose modifications for the fishing refugia, which were going to expire in 2017. Fishers were asked whether they wanted to propose one or more sites for new fishing refugia, and then what action they would like to take regarding the 11 existing ones: keep as is, modify, or eliminate. If they said they wanted to modify the refugia, they were asked to describe how. In almost all cases of "modify," fishers then stated that they wanted to expand the respective area (**Supplementary Figure 1**). Compared to fishers who perceived no fishery changes resulting from the refugia, fishers who perceived that the refugia had benefited their fisheries were more likely to propose new sites for fishing refugia, were more likely to modify (expand) their existing refugia, and less likely to eliminate them. These two groups did not significantly differ in whether they decided to keep their refugia; overall (t-test, $P > 0.05$), most fishers proposed keeping the existing refugia. Evidence from El Corredor thus suggests that, for individual fishers, perception of ecological

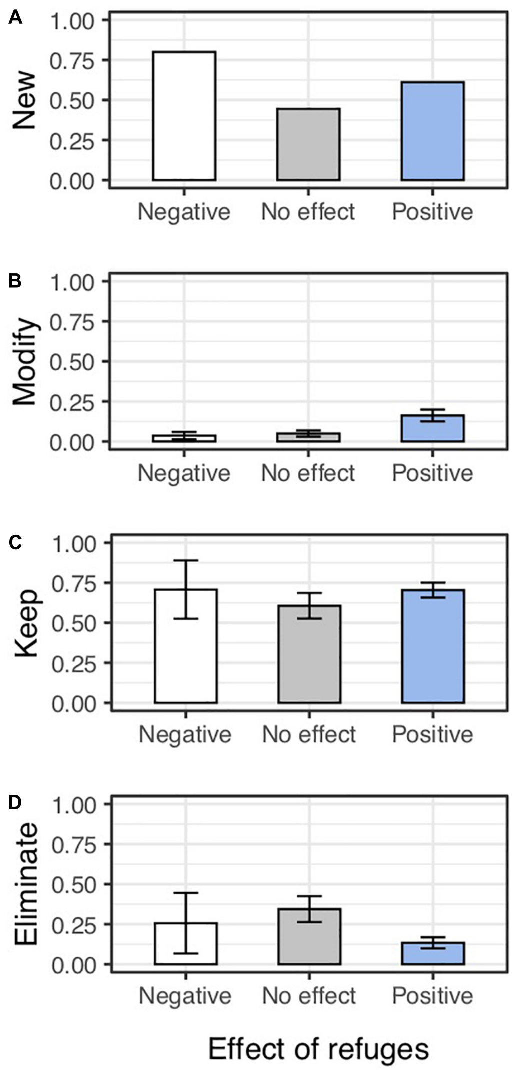


FIGURE 5 | Breakdown of respondents' management proposals by whether they perceived positive ($N = 54$, 63%), null ($N = 27$, 31%), or negative ($N = 5$, 6%) fishery results from the existence of fishing refugia. The y-axis represents the proportion of respondents from each group that proposed **(A)** a site for a new refugia, **(B)** the modification (in almost all cases, expansion) of existing refugia, **(C)** to keep their refugia as is, and **(D)** to eliminate refugia.

benefits from the refugia was associated with trust both in the particular refugia in specific locations ("modify") and trust in the broader tool of the refugia ("new") in the context of the Corredor.

Link 1, Again: Effect of Established Trust and Collective Action on Modified No-Take Zone Size

Given the variation in individual fishers' trust in the refugia reflected in the 2016 surveys (**Figure 5**), a second decision-making process mediated how individual trust in the MPAs was reflected in the ultimate re-design of the fishing refugia in 2017.

As discussed above in Link 1, in the northern Corredor (Agua Verde and Tembabiche), decisions were made at the town level. In Agua Verde, which had the largest refugia and the largest ecological benefits measured in underwater surveys (**Figure 4**), fishers overwhelmingly reported that the refugia had benefited their fishery (**Figure 6A**) in the 2016 survey. Fishers from Agua Verde were also the most likely to propose new sites and to modify (expand) their existing site. In Tembabiche, which had proposed four smaller refugia, and where there were variable ecological benefits measured in underwater surveys, fishers were less likely to propose new refugia or to expand their refugia. In the southern Corredor, refugia had to be negotiated among multiple towns because of overlapping fishing areas. Towns in the south are also (in most cases) much smaller than the north, and because of these two factors we combined the responses of fishers on the 2016 surveys below in **Figure 6**. Compared to Agua Verde and Tembabiche, in the southern Corredor, fishers were less likely to report positive fishery outcomes from the refugia, less likely to propose new sites, and less likely to expand their existing sites. They were more likely to propose eliminating their existing refugia. Summing individual responses across the Corredor about the 11 existing refugia, the average fisher wanted to maintain the majority (64%) of refugia as is, eliminate 21%, and modify (expand) 14% of the refugia. Additionally, a slight majority of fishers overall (55%), including fishers from the southern Corredor, proposed new sites for refugia.

The individual fishers' opinions aggregated by town or region (**Figure 6**) in 2016 were the starting point for negotiations, which took place over 2017, largely facilitated by Niparajá. In February 2017, Niparajá hosted a 2-day meeting in the capital city of La Paz to kick-start negotiations, disseminate results from the 2016 survey and ecological monitoring from 2012 to 2016, and suggest recommendations. Government officials, university partners, Niparajá staff, and fishers themselves gave presentations to 173 attendees representing every town in El Corredor. One of the most salient design recommendations from ecologists at two local universities was to increase the size of all the refugia to improve ecological performance.

Community discussions and negotiations ensued. In almost every community, at least one fisher proposed a large fishing refugia, either at a new site or as a dramatic expansion of an existing one. However, the refugia were ultimately only expanded where a majority of fishers perceived that they had produced positive results and where there was leadership to generate a unified vision among the various individual perspectives. Each town and each refugia had its own path-dependent process through which a final decision was made, but three cases (Agua Verde, San Diego, and Portugues) illustrate the diversity of decision-making processes and the factors that influenced them; we describe these below.

Aqua Verde—Large Ecological Benefits, Strong Leadership, Expanded Refugia

Agua Verde was the town that, in the original design approved in 2012, proposed the largest fishing refugia (San Marcial). In the renewal process in 2017, strong leadership from the presidents

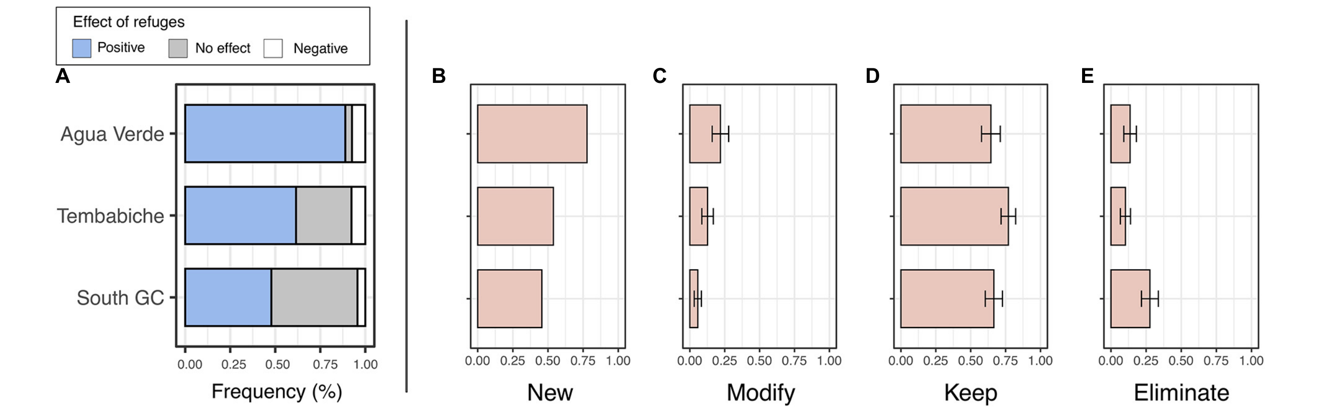


FIGURE 6 | Effect of perception of positive ecological changes on likelihood of proposing new refugia and expanding existing ones, based on 2016 social science survey. Individual survey responses are aggregated by community in the north (Agua Verde, Tembabiche) and together in the south, where fishing zones overlap, and multiple communities had to negotiate each refugia (see **Table 2**). **(A)** shows proportion of individuals who reported perceiving positive, neutral, and negative ecological effects of the refugia on fisheries. **(B–E)** show proportion of fishers who: proposed new refugia **(B)**, proposed to modify (mostly expand, see **Supplementary Material 1**) existing refugia **(C)**, proposed to keep existing refugia **(D)**, and proposed to eliminate existing refugia **(E)**.

of the two oldest cooperatives facilitated a unified vision ("go big"), ultimately resulting in a dramatic expansion of the fishing refugia. Both cooperative presidents were highly respected and able to engage their fishers, and they agreed that, if Agua Verde was going to keep having refugia, they would do it in earnest and make an even larger area. Fishers in Agua Verde had seen fishing improve over the previous 5 years since the refugia were established. The reason was unclear: whether there were fewer nets being used, or the water had coincidentally gotten more productive, among other reasons. However, there were stories of fishers coming back from San Marcial having seen positive results of fish recuperation inside the refugia. On this basis, the cooperative presidents were able to get strong support from their members for the idea of a single large refugia, leaving the precise details (e.g., which reefs or rocky areas to include) to the fishers who knew the area best and were most invested in the process. Ultimately, they dramatically expanded the fishing refugia of San Marcial and added another one nearly as large, connected on one side, where most fishing was banned although bait fishing would continue to be permitted. Both areas left a 50-m strip along the coastline where fishing was allowed, so as not to affect people fishing non-commercially with hook and line from the shore, primarily women and children (**Figure 2**).

San Diego Island—High Ecological Potential, Poaching, and Fractured Leadership, No Change in Refugia

In comparison, the fishing refugia at San Diego Island was a case of high hopes and ultimate disappointment. The refugia at San Diego possesses many of the characteristics that ecologists have associated with good MPA design, including a diversity of habitats and having once been extremely productive. Fishers from El Corredor who agreed to establish the refugia, and thus give up fishing there, had high hopes for strong recovery of fish. However, fishers from six different towns participated in designing the San Diego fishing refugia, leading to a lack of a sense of ownership or responsibility to monitor and enforce it. Unlike San Marcial, which is near the town and which most Agua Verde fishers pass by to go fishing, San Diego is out of the way of most fishers' daily fishing trips. As a result, monitoring is time-consuming and expensive for fishers. Lack of compliance from external fishers eventually led to decreasing compliance from fishers within El Corredor, who felt it unfair to give up their fishing grounds only to be raided by outsiders. By 2017, fishers from the six towns who originally agreed to San Diego still agreed that the site had great potential. One fisher, arguing that larger size would lead to better enforcement from authorities and monitoring by fishers from El Corredor, proposed a large and ambitious extension of San Diego, including the entire island extending all the way to the reef it currently encompasses. However, lacking a clear leadership among all communities, and after years of poor compliance, the ecologically ambitious proposal to expand San Diego did not gather enough support. Ultimately San Diego was renewed with no changes.

El Portugués—No Ecological Benefit, Strong Ringleader, No Change in Refugia

A third case of the decision-making process took place in El Portugues, a fishing camp in the southern Corredor which transitioned from apathetic/oppositional to oppositional from 2012 to 2017. In 2012, fishers from El Portugues declined to participate in the process of designing the original fishing refugia. Opposition partly stemmed from a fisher who had moved to Portugues after losing his previous fishing ground to an MPA established in 2007 that was supported by a different branch of Niparajá. The refugia closest to the camp is Punta Coyote, generally considered by El Corredor fishers to be the poorest in ecological design, and which had no demonstrable ecological benefits by 2016 in transect or fishing data. By 2017, fishers from El Portugues decided to participate in the renewal process. Fishers from Punta Coyote proposed a new fishing refugia in a shared fishing ground with El Portugues, but fishers from El Portugues opposed the area. While Punta Coyote agreed and was willing to sacrifice the fishing area, Portugues was not. Their opposition prevented the area's establishment in 2017. In the proposal that ultimately resulted from the intra- and inter-town negotiations through the collective action process, almost all the fishing refugia were renewed with no changes (**Figure 2**). While new potential sites or expansion of existing sites were proposed in many towns, all but one (San Marcial) of these proposals got bogged down in conflict and uncertainty and were ultimately rejected by the majority of relevant fishers.

DISCUSSION

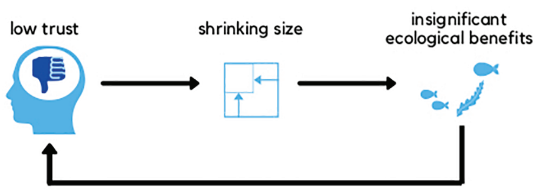
Managing Expectations of No-Take Zones

Our results and the conceptual model they support (**Box 1**) suggest that the success of community-based no-take zones depends on stakeholders' expectations. When users have the power to design temporary no-take zones, "good enough" ecological design, leadership, and collective action can result in growing trust and improving ecological benefits, while "not good enough" areas can result in loss of trust and poor ecological outcomes. Stakeholders, themselves, decide what is "good enough," and this is likely to depend on whether outcomes align with their expectations, including non-ecological outcomes such as attention from the government and compliance. Whether the game is "win-win" or "lose-lose" thus depends on expectations. If, as has been documented (Christie, 2004; Bennett and Dearden, 2014), scientists promise strong ecological benefits from no-take zones that do not materialize, resource users' trust in the no-take zones' future success is likely to deteriorate, and they are likely to remove it. In the case of the Corredor, while NGO staff at Niparajá point to significant increases of biomass within the fishing refugia as a "win," fishers from the Corredor have reported feeling disenchanted by ongoing poaching by outsiders, lack of enforcement by the fisheries agency, and less economic recovery than they had expected. As the wife of a fisher told us, "We work more and more with Niparajá on the refugia, and who here has become rich? Nobody. Nobody has become rich" (interview 11/18/17). This pathway of stakeholder disenchantment could be one reason for the downgrading, downsizing, and degazettement of protected areas ("PADDD"), increasingly recognized as a widespread phenomenon and threat to biodiversity (Shrinking loop, **Figure 7**) (Mascia and Pailler, 2011; Symes et al., 2016; Golden Kroner et al., 2019).

At the same time, our model also implies that adaptive no-take zones do not have to be optimally designed at the outset, so long as they align sufficiently with users' expectations to build trust. In the case of the Corredor, the refugia were initially much smaller than most MPAs globally, with a median size of 0.64 km^2 and mean size of 1.2 km^2, compared to global MPA median size of 4.6 km^2 and global mean size of 544 km^2 (Wood et al., 2008). They were also much smaller than the suggested minimum size of MPAs in a network, of 4–6 km^2 (Shanks et al., 2003) or 10–100 km^2 (Halpern and Warner, 2003). However, when the refugia were adapted and renewed after the first 5 years, the town where a majority of fishers perceived that there were ecological benefits from the refugia (Agua Verde) had established two refugia within or above recommended size ranges for MPAs, 33 km^2 and 27 km^2 (see **Supplementary Material 3**; Growth

Shrinking loop

In this idealized scenario, low initial confidence in the no-take zone's potential leads to poor initial design (in this example, small initial size) and thus insignificant ecological results. This further reduces trust in the no-take zone's potential, leading to shrinking size and continued lack of ecological results. Trust deteriorates and area size ultimately reaches 0.



Growth loop

In the alternative idealized scenario, high initial confidence leads to large enough initial no-take zone size to produce significant and detectable ecological results, leading in turn to greater trust in the no-take zone's likelihood of success. This leads to increasing area size until costs (e.g. loss of fishing area) outweigh benefits.

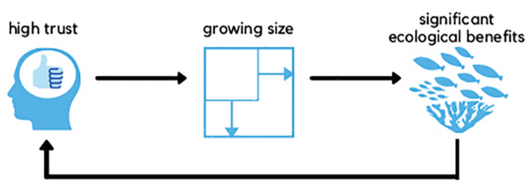


FIGURE 7 | Two predictions of the feedback loop described in **Box 1**: shrinking loop and growth loop.

loop, **Figure 7**). No-take zones that were sufficiently effective in the initial design grew dramatically in the second, at least where the design and decision process supported a collective vision. An implication of this conceptual model is that networks of fisher-designed no-take zones with variable ecological success are predicted to become more successful over time, at least from the perspective of resource users, who in theory improve and grow effective zones and reduce or eliminate the ineffective ones.

Contrary to predictions from our conceptual model (**Figure 7**), fishers did not reduce or eliminate low-performing refugia, but instead re-instated them all. During the process of adaptation and renewal (2017), not a single fishing refugia was eliminated despite low ecological performance by some, and widespread perception in the southern towns that their refugia did not produce ecological benefits. One explanation is that a network of no-take zones increases the likelihood of a "win-win" game even if initial design includes some poor-performing areas. Information and people flow between communities of the Corredor, which could allow the ecological success of the largest area (San Marcial) to build trust in the likely efficacy of refugia in other towns. Another possible reason is inertia and conflict avoidance, especially in the southern Corredor where towns disagreed about how and where to change the refugia, and where it may have been politically easier to simply keep things the same for another 5 years. A well-documented behavior given uncertainty about preferences is to defer to the default (Davidai et al., 2012). Inertia could lead to continued protection of ecologically pointless sites, such as one refugia that is generally agreed-upon by Corredor fishers as a site unlikely to benefit their fisheries, and thus reinforce cynical predictions about the uselessness of no-take zones. On the other hand, decision inertia could be beneficial, if biomass recovery was not yet detectable within 5 years in the smaller refugia and only requires more time. Inertia could thus buy time for fishing communities to organize better, reduce fishing by outsiders, increase monitoring, and increase the efficacy of their refugia over time. Decision inertia and information flow can also support the creation of networks of community-based no-take zones, of which the Corredor refugia are an example. Some heterogeneity is expected, and some elements of the network will be more biologically successful than others. However, if enough trust is built through engagement with external actors or fishers in other areas where ecological performance is better, the local population will likely be willing to continue to support and allow longer-term effects to become visible.

Another reason that none of the fishing refugia in the Corredor were eliminated, despite some being ecological failures, might be because of benefits independent from ecological outcomes. These alternative benefits include building a relationship with Niparajá, which assists with fisheries paperwork and legal issues; building a relationship with the fisheries agency in charge of enforcement and fishing permits; and increased subsidies, including in some towns the ability to enter a lottery for MX$8000 (approximately US$360) intended to compensate lost fishing grounds from the refugia. In the 2016 survey, 48% of fishers reported an increase in government attention (40% reported no change) and 68% reported an increase in government subsidies (20% reported no change). Relationships with Niparajá and the government have led to tangible benefits in the Corredor, such as a doubling in the number of fishing permits in the Corredor (Quintana and Basurto, 2020). In an interview, a professor from a local university told us, "One of the advantages of the refugia is not just fishing: there is a massive broader benefit, that there is regulation, that there are permits for people, that people organize themselves, that the [shrimp] trawlers don't enter. The social impacts of the refugia are much greater than the economic benefits of the refugia in 5 years" (interview 11/29/17). These benefits are effectively independent of the quality of the refugia's design, but could provide a strong incentive to keep refugia even if they are not producing ecological benefits, particularly if the opportunity cost is small in terms of lost fishing area.

"Means Are After All Everything": No-Take Zone Design as a Means Not an End of Adaptive Management

In a global push to protect the oceans, international bodies have agreed to protect 30% of the global oceans by 2030 (IUCN, 2016). This has generated a rapid expansion of area-based conservation tools and increased ambitious commitments by political leaders to establish MPAs and other no-take zones. Riding this political momentum, scientists have tried to come up with models and strategies to design no-take zones that will attend ecological, economic and societal goals. Perceiving that the establishment of these zones is a one-shot game, these models consider as much information as possible to come up with the optimal design (Sala et al., 2002; Possingham et al., 2006). However, optimizing initial design of a permanent area concentrates power in those who are at the table from the beginning. This process excludes and alienates stakeholders who are initially mistrustful or skeptical of the area design process, as is the case in many fishing communities (Holm and Soma, 2016; del Mar Mancha-Cisneros et al., 2018). Ultimately, "optimal" ecological design that generates social conflicts often leads to long-term problems for no-take zones (Christie, 2004; Gray and Campbell, 2009; Mascia et al., 2017).

Building from our results, we propose that instead of trying to get the perfect socio-ecological design in one try, the process of getting there is even more important and offers a sensible way to adapt to changing social and environmental conditions. In particular, the model of co-managed temporary fisheries closures (such as the fishing refugia of the Corredor) represents an opportunity to practice collective action, foster collaborations with universities, NGOs and other communities, and engage fishers in curbing marine resource decline. While this approach to area-based conservation may not initially be as attractive to political leaders aiming to meet international agreements, since the areas may start out quite small, our theoretical model (**Box 1**) and empirical data suggest that successful sites are likely to grow in size when they build collective trust, in our case, by a factor of five within 5 years. The establishment of this kind of management tool can still take advantage of political support generated by international commitments for area protection, as was the case for Mexico's fishing refugia (Quintana and Basurto, 2020). This model may also be attractive to governments as a tool to adapt to climate change and other emergent local pressures, as the iterative process provides a continued opportunity to adapt the design to current environmental variability as well as to social dynamics within and between communities.

This alternative model of no-take zone design as a means, rather than an end, of adaptive co-management reflects the idea of collective action around conservation and environmental management as a practice ("practicing the commons") rather than an outcome of resource and property rights allocation (Müller, 2020). This process-oriented approach aligns with emerging research on the "commons," which we define as social-ecological systems governed by collective tenure and management institutions (Dietz et al., 2002; Velicu and García-López, 2018), and which frequently characterizes fisheries and marine ecosystems (Partelow et al., 2018). Because of the centrality of the process of ongoing negotiation, some have argued for the noun "commons" to be replaced with the verb "commoning" to emphasize the practice and role of ongoing collective use and management (Linebaugh, 2008; Bresnihan, 2015; Basurto and Garcia Lozano, 2021). The opportunity to practice commoning allows resource user communities to develop affective relationships like care toward the commons and to develop identities as "commoners" (Singh, 2017). It also allows resource users to test whether they can trust each other, governments, and non-governmental collaborators. This is particularly important where initial trust between fishers and government agencies is low, for example from widespread enclosure and neoliberal reform (Nayak and Berkes, 2011; Bresnihan, 2016). In Mexican fisheries, for example, neoliberal reforms in the 1990s eroded collective management institutions and trust in centralized management (Young, 2001). In such places, practicing the commons allows for "re-commonization" of resource systems (Basurto and Garcia Lozano, 2021). Re-commoning can be seen in the Corredor via the fishing refugia. Initially "the people here did not really agree, because we did not know how a refugia would function" (longer quotation above; interview 11/13/17). However, through the process of working together within and between the Corredor communities, with the organization Niparajá, and with government scientists and bureaucrats, fishers have developed trust and confidence in the process, as well as a greater sense of responsibility and power over their coastal resources (Quintana and Basurto, 2020).

Based on our results, we argue that it may be productive for international bodies to consider no-take zones as a means, not an end, of marine conservation and resource sustainability. No-take zones like fishing refugia have the potential to unite the fishery sector under the common principle that protecting an area for a specified period of time can provide benefits on various levels, from providing food for local people, to restoring species populations, to developing a tourism industry. Such tools can complement other management instruments, with the advantage of centralizing participation of fishers and working through institutions that they may trust more. Being temporary gives stakeholders a chance to negotiate their adaptation in response to learning, social-ecological changes, and evolving objectives.

In such cases, benefits to biodiversity conservation seem most likely where trust increases, compliance is high, and fishers are engaged in the process (see **Box 1**). If fishers can identify alternative benefits of no-take zones unrelated to ecological performance, iterative design can allow for re-commoning, becoming a tool to practice fisheries co-management with governmental agencies. However, this requires fishers to conceptualize and imagine no-take zones beyond their typical selling points (i.e., fisheries and biodiversity benefits), such as in Mexico where they are legally defined as a tool for rebuilding fisheries. Such alternative benefits could provide an incentive for resource users, governments, or non-governmental partners to practice commoning even without rapid ecological improvements. Trust among fishers and their allies for marine management could grow if ecological benefits later materialize—or trust could grow for another reason, like improved collaborative relationship or seeing benefits in other areas especially if part of a network (e.g., in the case of El Corredor, fishers in the south could look north to Agua Verde). Thus it is not about the no-take zone itself but about the process that it creates for fishers' ability to adaptively co-manage by learning to common and do commoning. This ability then can prepare them to address future conservation challenges in the region.

CONCLUSION

We argue that the optimal size of community-based no-take zones could be much smaller than sizes recommended by ecologists—at least when we consider initial size, for areas that can later be expanded. Rather than adhere to minimum size recommendations based on ecological objectives (such as 4–6 km^2 or 10–100 km^2, depending on target species; Halpern and Warner, 2003; Shanks et al., 2003), the minimum size suggested by our model is primarily determined by fishers' willingness and perceptions, though mediated by ecological processes. When we reconceptualize temporary no-take zones as opportunities for "commoning" in an iterative, multi-step game of adaptive management, the minimum initial size is simply the sufficient size to produce ecological benefits, as perceived by stakeholders. In this case, 11 no-take zones with a mean size of 1.2 km^2 were able to build trust, with the largest (initially 5.9 km^2) expanded to 33 km^2 after 5 years. In this model, fishers' perceptions are critical; for this, informal information-gathering pathways (e.g., chumming the water; sample fishing in the reserve; participation in a monitoring program) may be more important than data produced through the familiar methods favored by ecologists, such as transects or statistical analyses (Quintana et al., 2020). Notably, multiple no-take zones arranged in a network may lead to greater opportunities for fishers to play with size and design, so that trust is built even if some areas fail. Ultimately, we challenge assumptions about no-take area size and design, arguing that possibilities for more just governance may be found in temporary, adaptive areas that do not optimize initial design.

Based on this case and conceptual model, our recommendation for policy makers and scientists is to facilitate processes where fishers and other stakeholders can design temporary no-take zones that are likely to produce visible ecological benefits. Policy-makers could support community monitoring programs and enact policies that give fishers the power to design temporary no-take zones. Multiple zones assembled in a network of areas may provide opportunities for learning across areas, even if some end up as failures. However, no-take zone design can be a dangerous game, if areas fail to result in benefits or trust is eroded. For example, where compliance is low (e.g., if outsiders cannot be prevented from fishing in the areas), trust can erode in the general tool and process. We call for a research agenda to explore the positive potential of temporary fisher-designed no-take zones, in order to identify the characteristics of places where growth feedback loops exist vs. where trust is eroded ("shrinking loop")—as well as how these positive feedbacks are disrupted. With a diagnostic understanding of positive feedbacks in community-based conservation, policy-makers and civil society organization staff could find ways to tap into community potential, foster win-win outcomes, and avoid spiraling into social-ecological failure.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: the quantitative datasets analyzed in this study are proprietary information owned by the NGO, Niparajá, and the Coasts and Commons Co-Laboratory at Duke University (contact: XB, xavier.basurto@duke.edu) and thus are not publically available. For inquiries about the ecological monitoring data from 2012 to present and the 2009 social science survey of the Corredor fishers, please contact SR-VD, Director of the Sustainable Fisheries Program at Niparajá, SR-VD at vandyck@niparaja.org. For inquiries about the social science survey data from the survey of Corredor fishers conducted in 2016, please contact XB at xavier.basurto@duke.edu. For inquiries about the in-depth qualitative data (interviews and observation) used to contextualize the study, please contact AQ at anastasiaquintana@ucsb.edu. Requests to access these datasets should be directed to AQ, anastasiaquintana@ucsb.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Duke University IRB. All participants gave oral informed consent to participate in research. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

AQ AG-N, SU, and AC conceived the initial idea for this manuscript at the Eco-DAS conference in Oahu, HI in 2018. AW, XB, and SR-VD designed and collected the social science surveys. AQ collected the qualitative social science data. AG-N, AW, and SR-VD collected the ecological data. AQ, AG-N, SDS, and OAO conducted the analysis. All authors developed the concepts and contributed to the writing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2021.652318/full#supplementary-material

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Conflict of Interest: SR-VD and AW work for the organization, Sociedad de Historia Natural Niparajá, which facilitated the implementation of the fishing refugia in the Corredor. To reduce the potential for conflict of interest, Niparajá colleagues did not participate in data analysis or interpretation used for this manuscript, although they provided contextualizing information and feedback on patterns that other authors identified. Data was analyzed skeptically and patterns were only identified using multiple lines of evidence, including in-depth qualitative data collected separately from Niparjá by AQ over 6 months living in the study region.

The remaining 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.

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