# Enabling conditions for effective community-based marine reserves in small-scale fisheries

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## ABSTRACT

Coastal marine ecosystems provide livelihoods for small-scale fishers and coastal communities around the world. However, overfishing and unsustainable fishing practices threaten the marine environment and jeopardize the wellbeing of coastal communities. A common approach to protect the environment and recover overexploited stocks is to implement no-take marine reserves (areas where all extractive activities are off-limits). In small-scale fisheries, these are sometimes implemented as community-based reserves, where a group of fishers collectively agree to close an area to fishing. While we know that reductions in fishing effort are followed by a series of ecological benefits (increased biomass, abundance, and species diversity), we do not fully understand how environmental and governance dynamics influence the conservation and fisheries benefits of community-based marine reserves. In this work, we evaluate the ecological outcomes of four reserves established by three coastal communities in temperate and tropical ecosystems of Mexico. By combining causal inference techniques with an operationalization of the social-ecological systems framework, we identify the environmental and social conditions that enable reserve effectiveness. Our results show a strong interaction between environmental variation and community organization, which influences reserve effectiveness. For example, the most effective reserve had strong governance structures accompanied with low environmental variability. Thus, even when a community is well organized (and reserves are well enforced), environmental variation can hinder the benefits of a reserve, and vice versa. Our results are particularly relevant under present changing climate conditions, as they can better inform management and decision making.

**Keywords: Marine Protected Areas, Marine Conservation, Small-Scale Fisheries, Citizen Science, Mexico, Social-Ecological Systems**

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## 1 INTRODUCTION

Marine ecosystems around the world sustain significant impacts due to overfishing and unsustainable fishing practices (Halpern et al., 2008; Worm et al., 2006; Pauly et al., 2005). A common approach to manage the spatial distribution of fishing effort and recover stocks is through the implementation of marine reserves (*i.e.* areas where all fishing activities are off–limits; MRs) (Afflerbach et al., 2014; Krueck et al., 2017; Sala and Giakoumi, 2017).

Marine reserve science has largely focused on understanding the ecological effects of these areas, which include increased biomass, richness, and densities of organisms within the protected regions (Lester et al., 2009; Giakoumi et al., 2017; Sala and Giakoumi, 2017), climate change mitigation (Roberts et al., 2017), and protection from environmental variability (Micheli et al., 2012). However, there is considerably less literature focusing on the relationship between socioeconomic and governance structures and their relationship to ecological effectiveness (Halpern et al., 2013; López-Angarita et al., 2014; Mascia et al., 2017) or benefits to fisheries (Krueck et al., 2017); evaluations of marine reserves rarely provide a holistic view of the social-ecological system (López-Angarita et al., 2014).

While ecological factors (*e.g.* habitat representation, initial state of protection, connectivity to other protected areas) can determine the success of a MR, their effectiveness also depends on the socioeconomic and governance settings under which they are implemented and managed. Literature shows that many non-ecological characteristics can play an equally important role in the effectiveness of MRs. For example, age of a reserve (*i.e.* time since its implementation) and size were key to the effectiveness of MRs in Palau (Friedlander et al., 2017). In the Mediterranean, Di Franco et al. (2016) identify that surveillance and enforcement, presence of a management plan, and involvement of fishers in management and decision–making along with promotion of sustainable fishing practices were the key factors that increased stock health and income to fishers. At a global level, Edgar et al. (2014) indicate that enforcement, age, size, and isolation were important factors determining effectiveness of the reserves.

Marine Reserves in Mexico have been commonly implemented as "core zones" within Biosphere Reserves that are administered by the National Commission of Protected Areas (*Comisión Nacional de Áreas Marinas Protegidas*, CONANP). While CONANP has made efforts to have a participatory process, the implementation of these zones is still characterized by top–down approaches. This motivated Civil Society Organizations (CSOs) to work with coastal communities to implement community–based marine reserves (Uribe et al., 2010), which are usually established within a TURFs; thus making them TURF–reserves (Afflerbach et al., 2014). This bottom–up approach allows fishers to design their own reserves, which increases compliance and self–enforcement (Gelcich and Donlan, 2015; Espinosa-Romero et al., 2014; Beger et al., 2004). However, these reserves still lack legal recognition, making them vulnerable to poaching. In 2014, a new norm (NOM-049-SAG/PESC, 2014) allowed fishers to request the legal recognition of a community–based reserve under the name of "Fishing Refugia" (*Zona de Refugio Pesquero*, FR). Since then, **39** FR have been implemented along the Pacific, Gulf of California, and Mexican Caribbean coastlines, but no formal evaluation of their effectiveness has taken place.

We combine causal inference techniques (De Palma et al., 2018) and the social-ecological systems framework (Ostrom, 2009) to provide a comprehensive ecological and socioeconomic evaluation of community-based marine reserves in three coastal communities in Mexico. The objective of this work is twofold: i) Provide the first evaluation of community–based marine reserves in Mexico, and ii) provide a comprehensive evaluation of the social–ecological system to identify how socioeconomic and governance characteristics relate to ecological effectiveness.

# 2 MATERIALS AND METHODS

## 2.1 Study area

We focus our evaluation in three coastal communities from the Pacific coast of Baja California and the Mesoamerican Reef System (Fig 1). Fishing activities in all communities are assambled around fishing cooperatives that hold Territorial Use Rights for Fisheries (TURFs). Isla Natividad (IN) lies west of the Baja California Peninsula (Fig 1B), where kelp forests (*Macrocystis pyrifera*) and rocky reefs are the predominant habitats. The island is home to a the *Sociedad Cooperative de Producción Pesquera (SCPP) Buzos y Pescadores de la Baja California*, spiny lobster (*Panulirus interruptus*) represents an important fishery. However, other resources like finfish (yellow-tail jack, *Seriola lalandi*), sea cucumber (*Parastichopus parvimensis*), red sea urchin (*Mesocentrotus franciscanus*), snail (*Megastraea turbanica* y *M. undosa*), and abalone (*Haliotis spp*, until 2010) are also important sources of income. In 2006, the community decided to implement two community–based marine reserves within their fishing grounds, seeking to recover depleted stocks of invertebrate species (mainly lobster and abalone). Until today, these reserves are yet to be legally recognized as Fishing Refugia but count with full support from the community.

The other two communities are Maria Elena (ME) and Punta Herrero (PH; Fig 1C) in the Yucatan Peninsula, where coral reefs and mangroves are the representative coastal ecosystems. ME is a fishing camp –visited intermittently during the fishing season– belonging to the Cozumel fishing cooperative (*SCPP Cozumel*). PH is also home to a fishing cooperative (*SCPP José María Azcorra*). The main source of income to both communities is the Caribbean spiny lobster (*Panulirus argus*). These communities also target finfish in the off season, mainly snappers (Lutjanidae) and groupers (Serranidae). ME established eight marine reserves in 2012, and PH established four marine reserves in 2013 and an additional community-based (*i.e.* not legally recognized). All these reserves are legally recognized as Fishing Refugia.

## 2.2 Data collection

We use three main sources of information to evaluate these reserves. Ecological data come from the annual ecological monitoring of reserve and control areas, carried out by members from each community and personnel from the Mexican CSO "Comunidad y Biodiversidad" (COBI). These monitorings record richness and abundances of fish and invertebrate species in the reserves and control sites. Size structures are also collected in fish census. We define control sites as regions with habitat characteristics similar to the corresponding reserves, and that presumably had the same probability of being selected as reserves during the design phase. From all the reserves in these three communities, we use the ones that have data for reserve and control sites before and after the implementation of the reserve. This provides us with a Before-After-Control-Impact (*i.e.* BACI) sampling design that allows us to capture and control for temporal and spatial dynamics (De Palma et al., 2018; Ferraro and Pattanayak, 2006). BACI designs and causal inference techniques have proven effective to evaluate marine reserves, as they allow us to causally attribute observed changes to the intervention (Moland et al., 2013; Villaseñor-Derbez et al., 2018). All reserves were surveyed annually from at least one year before implementation until 2016. Table 1 shows a summary of sampling effort and year of implementation of the analyzed reserves.

**Table 1.** Summary of commuity–based marine reserves by community.

| Community | TURF area ($km^2$) | Reserve area ($km^2$) | Percent as reserves | Year of implementation |
|---|---|---|---|---|
| Isla Natividad | 889.5 | 1.53 | 0.1720067 | 2006 |
| Maria Elena | 353.1 | 0.10 | 0.0283206 | 2012 |
| Punta Herrero | 299.7 | 0.43 | 0.1434768 | 2013 |

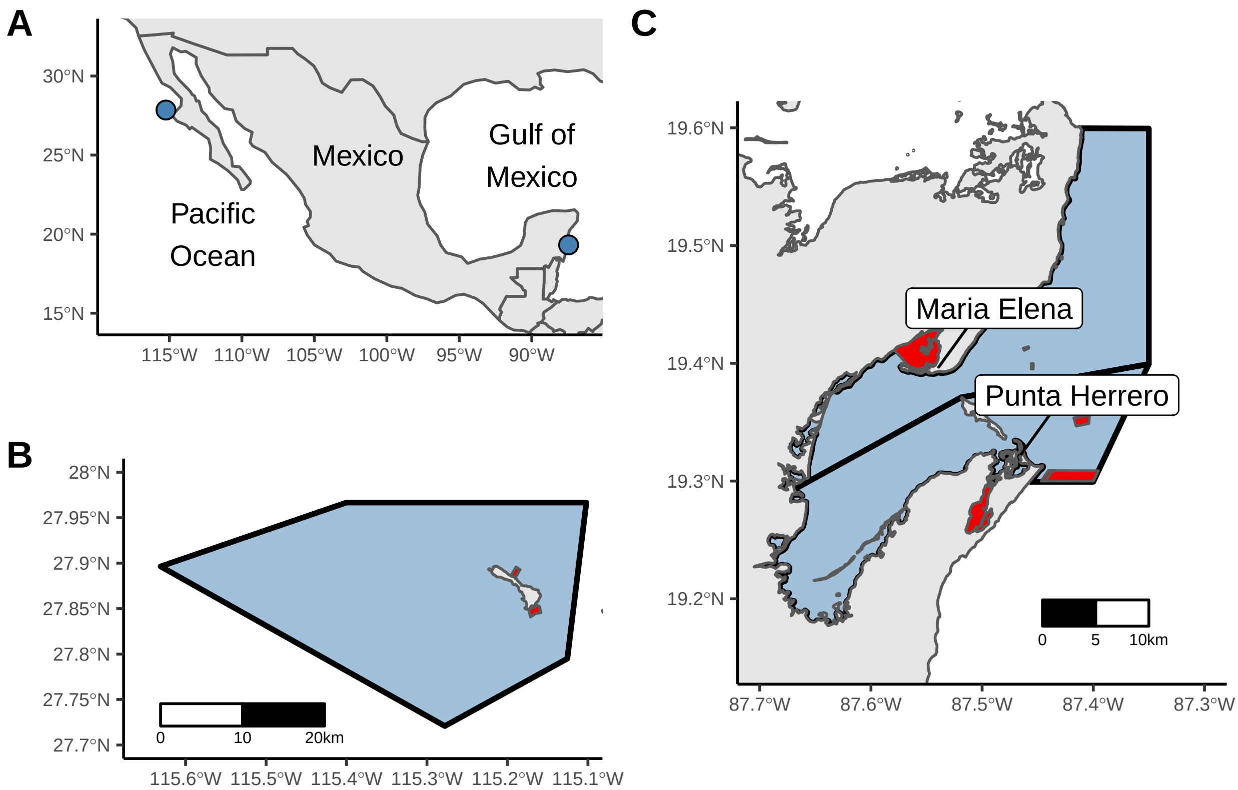


**Figure 1.** Location of the three coastal communities studied (A). Isla Natividad (B) is located off the Baja California Peninsula, Maria Elena (C) and Punta Herrero (D) are located in the Yucatan Peninsula.

Socioeconomic data come from landing receipts reported to the National Commission for Aquaculture and Fisheries (*Comisión Nacional de Acuacultura y Pesca*; CONAPESCA). Data contain monthly lobster landings (Kg) and value (MXP) from 2000 to 2014. This information was aggregated by year, and economic values were adjusted by the Consumer Price Index (OECD, 2017) via Eq 1.

$$I_t = RI_t \times \frac{CPI_t}{CPI_T} \tag{1}$$

Where $I_t$ represents the adjusted income for year $t$ as the product between the reported income for that year and the ratio between the consumer price index in that year ($CPI_t$) to the most recent year's consumer price index ($CPI_T$).

We use a set of governance indicators to analyze the governance structures of each cooperative (Leslie et al., 2015). The indicators (Table 3) focus on the resource system (four indicators), governance system (seven indicators), resource units (three indicators) and actors (three indicators). These were collected at the community–level from official documents used in the creation and designation of the marine reserves (DOF, 2012,?) and based on the authors' experience and knowledge of the communities.

### 2.3 Data analysis

We evaluate the effect thar marine reserves have had on four biological and two socioeconomic indicators (Table 2). Recall that reserves were implemented to protect lobster and other benthic invertebrates. However, we also contemplate fish species that are also targeted in the off-season and might receive collateral protection from the reserves.

**Table 2.** List of indicators used to evaluate the effectiveness of marine reserves, grouped by category.

| Category | Indicador | Units |
|---|---|---|
| Biological | Lobster density | org / $m^2$ |
| Biological | Invertebrate density | org / $m^2$ |
| Biological | Fish biomass | org / $m^2$ |
| Biological | Fish density | org / $m^2$ |
| Socioeconomic | Income from target species | M MXP |
| Socioeconomic | Landings from target species | Metric Tones |

**Table 3.** Indicators used for the operationalization of the SES framework (Leslie et al., 2015)

| Indicator | Isla Natividad | Maria Elena | Punta Herrero |
|---|---|---|---|
| **Resource systems (RS)** | | | |
| TURF presence | Yes | Yes | Yes |
| Type of ecosystem | Kelp Forest / Rocky Reefs | Coral Reef | Coral Reef |
| Intensity of environmental Disturbance | El nino event | Hurricanes | Hurricanes |
| Location | Island | Coastal | Coastal |
| **Governance systems (GS)** | | | |
| Fishing cooperative | Yes | Yes | Yes |
| Involved actors | COBI, Stanford, REBIVI | Alianza Kanan Kay, COBI, CONANP, Coop, CONAPESCA, Oceanus, FCyRH, FHMM, | Alianza Kanan Kay, COBI, CONANP, Coop, CONAPESCA, Oceanus, FCyRH, FHMM, |
| Presence of an inter-cooperative structure | Fedecoop | Non | Non |
| Fishing Regulations | Size limits, seasonal closures, quotas | Size limits, seasonal closures | Size limits, seasonal closures |
| Enforcement technology | Boats | Boats | Land enforcement |
| MR enforcement | | | |
| Cooperative regulations | | | |
| **Resource Units (RU)** | | | |
| Adult targeted species mobility | 1km | 30km | 30km |
| Targeted species longevity (years) | | | |
| Price of targeted species | | | |
| **Actors (A)** | | | |
| Leadership | | | |
| Level of illegal fishing | 1 | 1 | 3 |
| Presence of alternative livelihoods | | | |

Biological indicators are analyzed with a difference–in–differences analysis (Eq 2), which allows us to estimate the effect that the reserve has on the biological indicators by comparing trends across time and treatments (Moland et al., 2013; Villaseñor-Derbez et al., 2018). The analysis is performed with a multiple linear regression of the form:

$$I_{itj} = \alpha + \gamma_t Year_t + \beta Zone_i + \lambda_t Year_t \times Zone_i + \sigma_j Spp_j + \epsilon \quad (2)$$

Where year–fixed effects are represented by $\gamma_{it} Year_t$, and $\beta Zone_i$ captures the difference between reserve ($Zone = 1$) and control ($Zone = 0$) sites. The interaction term $\lambda_{it} Year_t \times Zone_i$ represents represent the mean change in the indicator inside the reserve, for year $t$, with respect to the first year of evaluation in the control site (See Table 1). When evaluating biomass and abundances, we include species–fixed effects ($\sigma_j$).

Socioeconomic indicators are evaluated with a similar approach (Eq 3). Due to data constrains, only Isla Natividad and Maria Elena are evaluated in this case. We constructed panel-data information with yearly (2001 - 2014) lobster landings and income of the studied and neighbouring communities that have similar management strategies, and belong to larger Cooperative Federtations (McCay, 2017; Ayer et al., 2018). Neighbouring communities are used as counterfacutals that allow us to control for unobserved time-invariants. Each "treated" community (Isla Natividad and Maria Elena) has three counterfactual communities.

$$I_i = \alpha + \gamma_t Year_t + \beta Treated_i + \lambda_t Year_t \times Treated_i + \sigma_j Comm_j + \epsilon \tag{3}$$

The model interpretation remains as for Eq 2, but in this case the $Treated$ dummy variable indicates if the community has a reserve ($Treated = 1$) or not ($Treated = 0$) and $\sigma_j Comm$ captures community-level fixed-effects. This approach allows for a causal attribution of the observed changes to the reserve. All model coefficients were estimated via ordinary least–squares and heteroskedastic–robust standard errors (Zeileis, 2004).

These regressions allows us to make a causal link between the implementation of marine reserves and the observed trends by accounting for temporal and spatial dynamics (De Palma et al., 2018). The effect of the reserve is captured by the $\lambda_t$ coefficient, and represents the difference observed between the control site before the implementation of the reserve and the reserve site at time $t$ after controlling for other time and space variations (*i.e.* $\gamma_t$ and $\beta$ respectively).

## 3 RESULTS

The following sections present the effect that marine reserves had on each of the biological and socioeconomic indicators for each coastal community. Results are presented in terms of the difference through time and across sites, relative to the control site on the year of implementation (*i.e.* effect size). We also provide an overview of the governance settings of each community, and discuss how these dimensions might be related to the effectiveness of the reserves.

### 3.1 Biological

All indicators show idiosyncratic responses through time for each community. Figure 2A shows how lobster densities increase inside the reserve for Isla Natividad an Punta Herrero within the first years, but the effect is aroded through time. However, these effects are in the order of 0.2 extra organisms $m^{-2}$ and are not significantly different from zero ($p > 0.05$). The only case when lobster densities showed a significant positive effect ($p < 0.1$) was for Isla Natividad on the sixth year (*i.e.* 2012), a year after hypoxia events described in Micheli et al. (2012) caused mass mortality of organisms. Biomass was only evaluated for fish data (Fig 2B), and no changes were observed ($p > 0.1$), Punta Herrero even showed negative insignificant trends in the order of 0.01. Invertebrate and fish densities (2C-D) show similar patterns of lack of effectiveness with effect sizes oscillating around zero. Full tables with model coefficients are presented in the supplementary materials (**S1 Table**, **S2 Table**, **S3 Table**).

## 3.2 Socioeconomic

Lobster landings and revenue were only available for Isla Natividad and Maria Elena (Fig 3). For all years befor implementation, the effect sizes are close to zero, indicating that the control and treatment sites track each other well. However, effect sizes do not change after the implementation of the reserve. Again, the negative coeficient observed for Isla Natividad on year 5 correspond to the 2011 hypoxia events. The only positive change observed in lobster landings is for Isla Natividad in 2014 ($p < 0.1$). The trhee years of post-implementation data for Maria Elena do not show a significant effect of the reserve. Isla Natividad shows higher revenues after the iumplementation of the reserve, as compared to the control communities. However, these changes are also not ignificantly different and present an increased variation. All regression coefficients for each community and indicator are presented in **S4 Table**.

## 3.3 Governance

Although we have little information on the social dimension of these fisheries, using the SES framework indicators (Table 3), we can analyze the performance of each governance system (Table 4).

Our analysis shows that all of the systems analyzed share similarities in their Governance system which is based on cooperatives (GS5.2.3.2), with strong rules in use that include Operational rules (GS6.2), Collective-choice rules (GS6.3), Constitutional rules (GS6.3), and even Territorial use communal rights (GS6.1.4.3). However, we identified important differences in terms of the actors, resource systems and resource units. The value of lobster in isla natividad is higher than the lobster sold from Punta Herrero and Maria Elena (RU4), which can reduce the pressure on harvest. Lastly, in terms of actors, although all communities show a high level of leadership (A5), the level of trust (A6.1) is lower in Punta Herrero. In general, the presence and success of conservation initiatives depends on the incentives of local communities to maintain a healthy status of the resources they depend upon (Jupiter et al., 2017). The enabling conditions for conservation seem to be strongly present in all communities. Due to the clarity of access rights and isolation, the benefits of conservation directly benefit the members of the fishing cooperative. These conditions have favored the development of an efficient community-based enforcement systems.

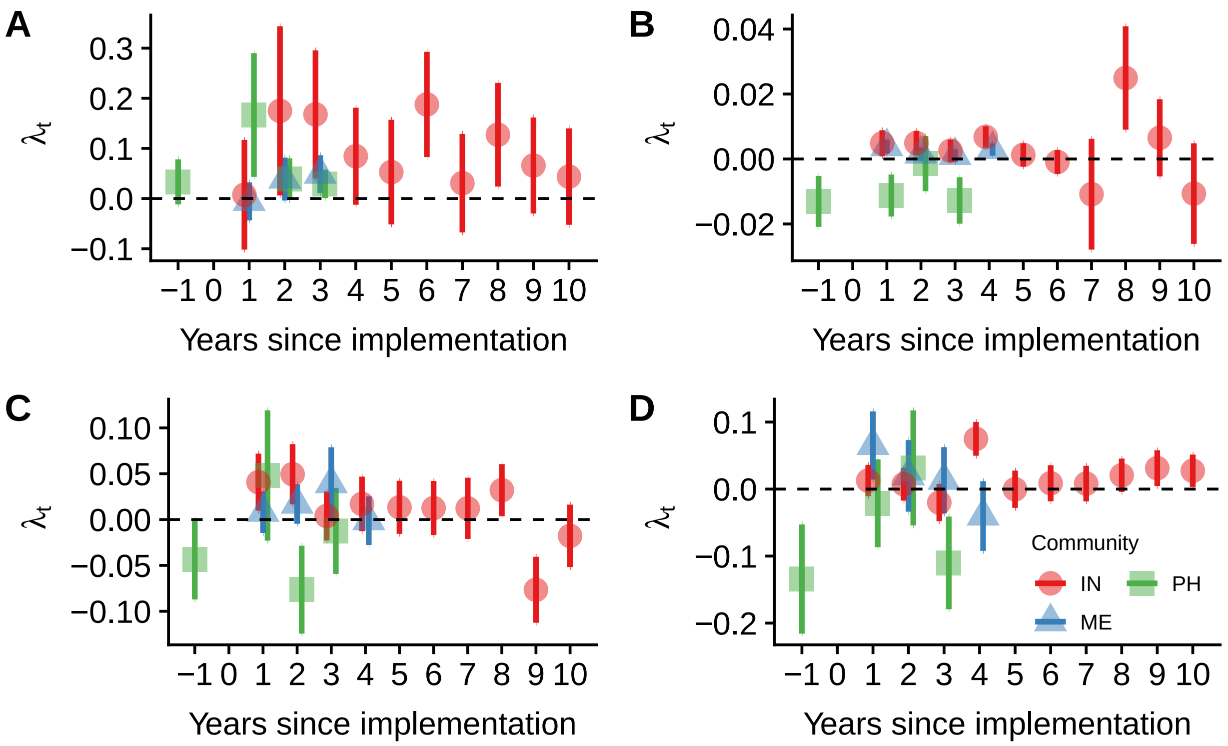


**Figure 2.** Effect sizes for marine reserves from Isla Natividad (IN; red cirlcles), Maria Elena (ME; blue triangles), and Punta Herrero (PH; green squares) for lobster densities (*Panulirus spp*; A), fish biomass (B), invertebrate densities (C), and fish densities (D). Plots are ordered by survey type (left column: invertebrates; right column: fish). Points are jittered hotizontally to avoid overplotting. Points indicate the effect size, and errorbars standard errors. Years have been centered to year of implementation.

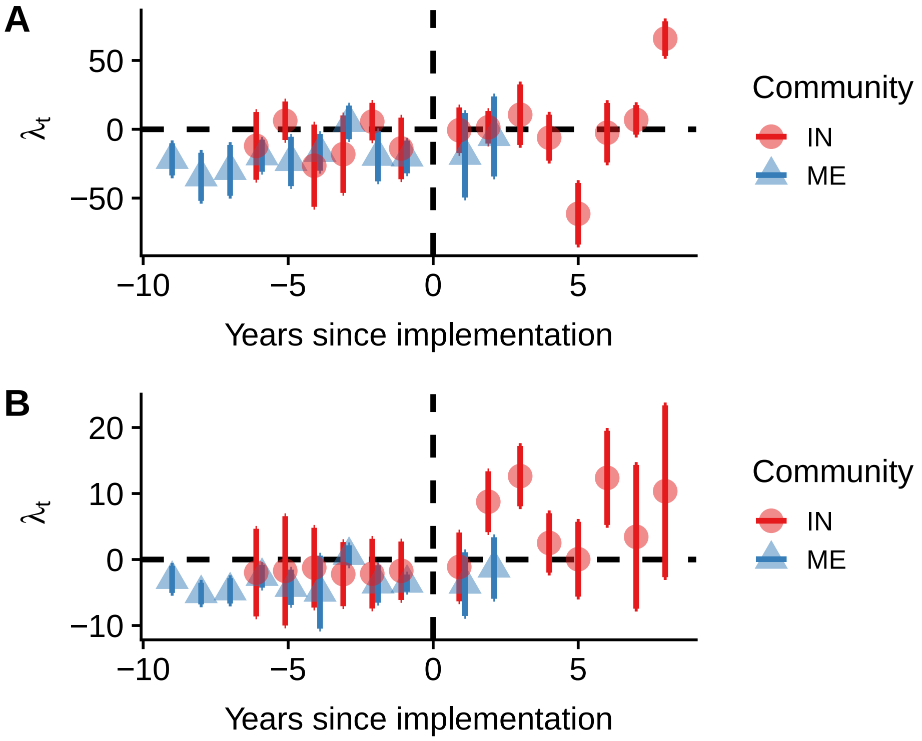


**Figure 3.** Effect sizes for lobster catches (A) and revenues (B) in at Isla Natividad (IN; red circles) and Maria Elena (ME; blue triangles)

**Table 4.** Analysis of the fishing cooperatives based on the Social-Ecological systems framework (McGinnis and Ostrom, 2014).

| | Indicator | Isla Natividad | Maria Elena | Punta Herrero |
|---|---|---|---|---|
| **Resource systems (RS)** | | | | |
| RS2 – Clarity of system boundaries | TURF presence | High | High | High |
| RS3 – Size of resource system | | | | |
| RS5 – Productivity of system | Type of ecosystem | High | High | High |
| RS7 – Predictability of system dynamics | Intensity of environmental disturbance | Low (ENSO) | High | High |
| RS9 – Location | Proximity to other communities/cities | Isolated | Not Isolated | Not Isolated |
| **Governance systems (GS)** | | | | |
| GS1 – Government organizations | Presence of fishing cooperatives | Yes | Yes | Yes |
| GS2 – Nongovernment organizations | Involved actors | Yes | Yes | Yes |
| GS3 – Network structure | Presence of an inter-cooperative structure | Yes | No | No |
| GS4 – Property-rights systems | TURF presence | Yes | Yes | Yes |
| GS5 – Operational-choice rules | Fishing Regulations / MPA enforcement / Enforcement technolofy | Yes | Yes | Yes |
| GS6 – Collective-choice rules | Cooperative regulations | Yes | Yes | Yes |
| GS7 – Constitutional-choice rules | | | | |
| **Resource units (RU)** | | | | |
| RU1 – Resource unit mobility | Targeted species home range | Low | Medium | Medium |
| RU2 – Growth or replacement rate | Max age of targeted species | Low | Medium | Medium |
| RU4 – Economic value | Price of targeted species | high | High | high |
| **Actors (A)** | | | | |
| A1 – Number of relevant actors | | 98 | | |
| A2 – Socioeconomic attributes | | | | |
| A5 – Leadership/entrepreneurship | Leadership | High | High | High |
| A6 – Norms (trust-reciprocity)/social capital— (Based on illegal fishing) | Level of illegal fishing | High | High | Low |
| A8 – Importance of resource (dependence) | Presence of alternative livelihoods | High | High | High |

# 4 DISCUSSION

theory tells us more than 5 years are needed, so it;s not surprise for PH and ME. But IN didnt make it either.

Our results indicated idiosyncratic biological effects of the reserves across communities and indicators, with a combination of positive and negative effects. However, many of these effects were not statistically significant, indicating no effect of the reserve. The socioeconomic indicators pertaining to landings and revenues showed little or no change after reserve implementation. While lobster densities represent an indicator directly tied to reserve objectives, we also evaluate other biological indicators to test for additional effects and as a double-check. ll indicators presented a similar pattern. The lack of expected effectiveness poses the question, why do these communities continue to support the reserves? While not in the main scope of this paper, understanding the social-ecological context in which these communities and their reserves might provide insight to answer this question. Here, we discuss plausible explanations to lack of effectiveness observed based on literature and our social-ecological system analysis. We also discuss potential shortcomings in our analysis, and provide management recommendations to improve reserve effectiveness.

Our approach to evaluate the temporal and spatial changes of each indicator provides a more robust measure of reserve effectiveness. Some works have solely focused on an inside-outside comparison of indicators (Guidetti et al., 2014; Friedlander et al., 2017; Rodriguez and Fanning, 2017), which do not address temporal variability (De Palma et al., 2018). Other works have compared the trend observed within a reserve through time (Betti et al., 2017), which cannot distinguish between the temporal trends in a reserve and the entire system (De Palma et al., 2018). By accounting for trends between sites and through time, we can control for time and space dynamics, and provide a better identification of the effect

Age, isolation, and enforcement are important factors influencing effectiveness of a marine reserve (Edgar et al., 2014). Isla Natividad has the oldest reserve, is fairly isolated, and has a well-established community-based enforcement system. Neighbouring fishing communities are known to be well organized with successful resource management of their resources (McCay, 2017; McCay et al., 2014). Maria Elena and Punta Herrero are relatively young reserves (Table 1). With the age, relative isolation, and enforcement level of these reserves, one would expect to observe effectiveness. However, another key feature of effective MRs is size (Edgar et al., 2014); the lack of effectiveness is perhaps attributed to the reserves being too small 1. Furthermore, perturbations that do not distinguish reserve boundaries, such as the environmental variability observed in Isla Natividad can also hinder effectiveness. The possibility of increasing reserve size or merging existing networks into a larger reserve should be evaluated.

Our analysis of landings and revenues does not identify detectable changes in these indicators. However, previous research has shown that reserves in Isla Natividad yield fishery benefits for the abalone fishery (Rossetto et al., 2015). Abalone are sesile invertebrates with less mobility (compared to lobsters), and thus current reserve size might not be enough for lobster's range of mobility even when accounting for reserve age in Isla Natividad. Other community-based marine reserves in tropical ecosystems have taken up to six years to show a spillover effect (da Silva et al., 2015). Reserves in Maria Elena and Punta Herrero are relatively small and young, and may need more time for abundances to increase enough to export larvae or adult organisms.

A second explanation lies on the the mismatch of objectives during the design process. The Project description (*Estudios Técnicos Justificativos*) of each MR provides little information about the followed design guidelines. However, all reserves had to be approved by the community members. Depending on the communities' capacity to look for longterm benefits, many communities may favor implementation of reserves on sites that represent a low fishing cost. As a consequence, the marine reserve have low impacts in reducng the fishing effort. Having small reserves in areas that do not compromise fishing profits might explain why this communities still support their reserves.

Although our case studies fulfilled the social requirements for effective marine reserves ("high enforcement, presence of a management plan, fisher engagement in management, and promotion of sustainable fishing"; Di Franco et al. (2016)), our results show that proper reserve design is crucial for effective marine reserves. The social-ecological systems framework allowed a systematic diganosis and compare all the different case studies, allowing us to identify and tease appart possible explanations (Basurto et al., 2013).

## CONFLICT OF INTEREST STATEMENT

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.

## AUTHOR CONTRIBUTIONS

JC and EA analyzed and interpreted data, discussed the results, and wrote the manuscript. AS, SF and JT edited the manuscript and discussed the results.

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## SUPPLEMENTAL DATA

Supplementary Material should be uploaded separately on submission, if there are Supplementary Figures, please include the caption in the same file as the figure. LaTeX Supplementary Material templates can be found in the Frontiers LaTeX folder

### *S1 Figure*

Timeseries of indicators for IN

### *S2 Figure*

Timeseries of indicators for ME

### *S3 Figure*

Timeseries of indicators for PH

### *S1 Table*

Coefficient estimates for Isla Natividad

### *S2 Table*

Coefficient estimates for Maria Elena

### *S3 Table*

Coefficient estimates for Punta Herrero

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## FIGURE CAPTIONS