

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

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## 2 ABSTRACT

3 Abstract after comments from co-authors

4 **Keywords:** Marine Reserves, Marine Conservation, Small Scale Fisheries, Citizen Science, Mexico, Social–Ecological Systems

## 1 INTRODUCTION

5 Marine ecosystems around the world sustain significant impacts due to overfishing and unsustainable  
6 fishing practices (Halpern et al., 2008; Worm et al., 2006; Pauly et al., 2005). A common approach to  
7 manage the spatial distribution of fishing effort and recover stocks is through the implementation of marine  
8 reserves (*i.e.* areas where all fishing activities are off-limits; MRs) (Afflerbach et al., 2014; Krueck et al.,  
9 2017; Sala and Giakoumi, 2017).

10 Marine reserve science has largely focused on understanding the ecological effects of these areas, which  
11 include increased biomass, richness, and densities of organisms within the protected regions (Lester  
12 et al., 2009; Giakoumi et al., 2017; Sala and Giakoumi, 2017), climate change mitigation (Roberts et al.,  
13 2017), and protection from environmental variability (Micheli et al., 2012). However, there is considerably  
14 less literature focusing on the relationship between socioeconomic and governance structures and their  
15 relationship to ecological effectiveness (Halpern et al., 2013; López-Angarita et al., 2014; Mascia et al.,  
16 2017) or benefits to fisheries (Krueck et al., 2017); evaluations of marine reserves rarely provide a holistic  
17 view of the social-ecological system (López-Angarita et al., 2014). Here, we combine causal inference  
18 techniques (De Palma et al., 2018) and the social-ecological systems framework (Ostrom, 2009) to provide  
19 a comprehensive ecological and socioeconomic evaluation of four community-based marine reserves in  
20 three coastal communities in Mexico.

21 Marine Reserves in Mexico have been commonly implemented as “core zones” within Biosphere  
22 Reserves that are administered by the National Commission of Protected Areas (*Comisión Nacional de*  
23 *Áreas Marinas Protegidas*, CONANP). While CONANP has made efforts to have a participatory process,  
24 the implementation of these zones is still characterized by top-down approaches. This motivated Civil  
25 Society Organizations (CSOs) to work with coastal communities to implement community-based marine

26 reserves (Uribe et al., 2010), which are usually established within a Territorial Use Rights for Fisheries  
27 (TURFs); thus making them TURF-reserves (Afflerbach et al., 2014). This bottom-up approach allows  
28 fishers to design their own reserves, which increases compliance and self-enforcement (Gelcich and  
29 Donlan, 2015; Espinosa-Romero et al., 2014; Beger et al., 2004). However, these reserves still lack legal  
30 recognition, making them vulnerable to poaching. In 2014, a new norm (NOM-049-SAG/PESC, 2014)  
31 allowed fishers to request the legal recognition of a community-based reserve under the name of “Fishing  
32 Refugia” (*Zona de Refugio Pesquero*, FR). This new norm thus combines bottom-up approaches to design  
33 marine reserves, along with a legal recognition of the management intervention. Since then, 39 FR have  
34 been implemented along the Pacific, Gulf of California, and Mexican Caribbean coastlines, but no formal  
35 evaluation of their effectiveness has taken place.

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

46 The objective of this work is twofold: i) Provide the first evaluation of community-based marine reserves  
47 in Mexico, and ii) provide a comprehensive evaluation of the social-ecological system to identify how  
48 socioeconomic and governance characteristics relate to ecological effectiveness. With the purpose of  
49 providing a holistic evaluation, we combine ecological, socioeconomic, and governance indicators. We use  
50 causal inference techniques to provide a measurement of the effect of the management intervention, and  
51 combine it with the social-ecological systems framework (Ostrom, 2009).

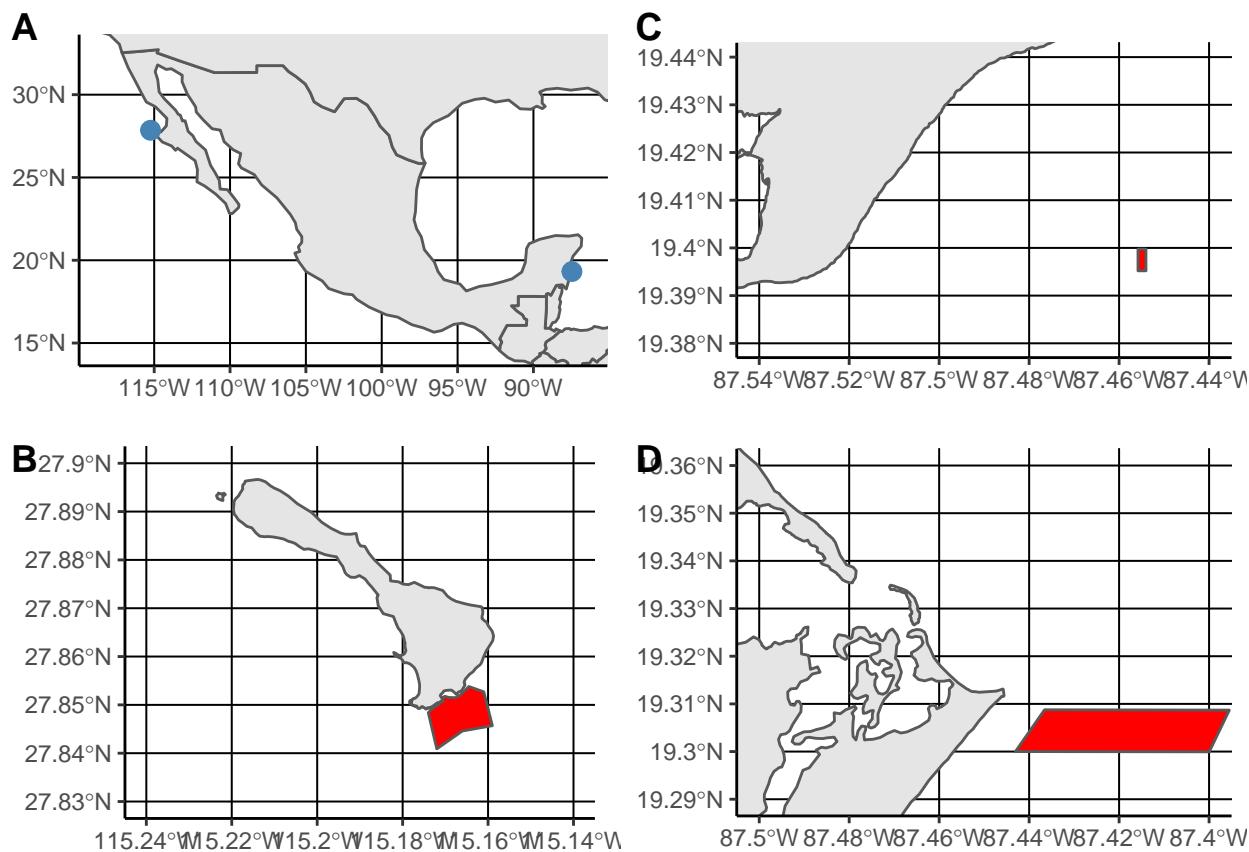
## 2 MATERIALS AND METHODS

### 52 2.1 Study area

53 We focus our evaluation in three coastal communities from the Pacific coast of Baja California ( $n = 1$ ) and  
54 the Mesoamerican Reef System ( $n = 2$ ; Fig 1). Isla Natividad (IN) lies west of the Baja California Peninsula  
55 (Fig 1B), where kelp forests (*Macrocystis pyrifera*) and rocky reefs are the predominant habitats. The  
56 island is home to a fishing cooperative (*Sociedad Cooperativa de Producción Pesquera Buzos y Pescadores*  
57 *de la Baja California SCL*), that holds a TURF for spiny lobster (*Panulirus interruptus*). However, other  
58 resources like finfish (yellow-tail jack, *Seriola lalandi*), sea cucumber (*Parastichopus parvimensis*), red sea  
59 urchin (*Mesocentrotus franciscanus*), snail (*Megastrea turbanica* y *M. undosa*), and abalone (*Haliotis*  
60 *spp*, until 2010) are also important sources of income. In 2006, the community decided to implement  
61 two community-based marine reserves within their fishing grounds, seeking to recover depleted stocks  
62 of invertebrate species (mainly lobster and abalone). Until today, these reserves are yet to be legally  
63 recognized as Fishing Refugia.

64 The other two communities are Maria Elena (ME; Fig 1C) and Punta Herrero (PH; Fig 1D) in the Yucatan  
65 Peninsula, where coral reefs and mangroves are the representative coastal ecosystems. ME is a fishing  
66 camp –visited intermittently during the fishing season– belonging to the Cozumel fishing cooperative. PH

67 is home to the “José María Azcorra” fishing cooperative. The main source of income to both communities  
 68 is the Caribbean spiny lobster fishery (*Panulirus argus*), which is carried out within their respective  
 69 TURFs. These communities also target finfish in the off season, mainly snappers (Lutjanidae) and groupers  
 70 (Serranidae). ME established eight marine reserves in 2012, and PH established four marine reserves in  
 71 2013. All these reserves are legally recognized as Fishing Refugia.



**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.

## 72 2.2 Data collection

73 To perform the evaluation of these reserves we use three sources of information. Ecological data come from  
 74 the annual ecological monitoring of reserve and control areas, carried out by members from each community  
 75 and personnel from the Mexican CSO “Comunidad y Biodiversidad” (COBI). These monitorings record  
 76 richness and abundances of fish and invertebrate species in the reserves and control sites. For fish census,  
 77 size structures are also collected to derive biomass. We define control sites as regions with habitat  
 78 characteristics similar to the corresponding reserves, and that presumably had the same probability of being  
 79 selected as reserves during the design phase. From all the reserves in these three communities, we use the  
 80 ones that have data for reserve and control sites before and after the implementation of the reserve. This  
 81 provides us with a Before-After-Control-Impact (*i.e.* BACI) design that allows us to capture and control for  
 82 temporal and spatial dynamics (De Palma et al., 2018; Ferraro and Pattanayak, 2006). BACI designs and  
 83 causal inference techniques have proven effective to evaluate marine reserves, as they allow us to causally  
 84 attribute observed changes to the intervention (Moland et al., 2013; Villaseñor-Derbez et al., 2018). All

**Table 1.** Summary of community-based marine reserves by community. Imp = Year of implementation, Start = Year of first sampling, number of fish transects in control (Cf) and reserve (Rf) sites, and number of invertebrate transects in Control (Ci) and Reserve (Ri) sites.

Community	Reserve - Control	Imp	Start	Cf	Rf	Ci	Ri
Isla Natividad	La Plana / Las Cuevas - La Dulce / Babencho	2006	2006	405	242	415	245
Maria Elena	Cabezo - Cabezo (Control)	2012	2012	44	45	27	21
Punta Herrero	El Faro - El Faro (Control)	2013	2013	39	40	24	32
Punta Herrero	Manchon - Manchon (Control)	2013	2012	43	45	27	42

85 reserves were surveyed annually from at least one year before implementation until 2016. Table 1 shows a  
 86 summary of the number of reserves, year of implementation, and number of transects for each reserve.

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

$$I_t = RI_t \times \frac{CPI_t}{CPI_T} \quad (1)$$

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

94 Governance data were collected at the community-level. The information was compiled by combining  
 95 key informants and the authors; experience and knowledge of the communities to collect the necessary  
 96 information. These data contain information on the ecological system where the fishing activities develop,  
 97 as well as the governance structures present in the cooperative. We also gathered information on the  
 98 resource unit (*i.e.* lobsters) and the relevant actors present in each community (Leslie et al., 2015).

## 99 2.3 Data analysis

100 Following a framework that relates reserve objectives to performance indicators (Villaseñor-Derbez et al.,  
 101 2018), we use five biological and two socioeconomic indicators to evaluate these marine reserves Table 2.  
 102 We also use a set of governance indicators to analyze the governance structures of each cooperative (Leslie  
 103 et al., 2015). The indicators (Table 3) focus on the resource system (four indicators), governance system  
 104 (seven indicators), resource units (three indicators) and actors (three indicators).

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

Indicator	Isla Natividad	Maria Elena	Punta Herrero
<b>Resource systems (RS)</b>			
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
<b>Governance systems (GS)</b>			
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			
<b>Resource Units (RU)</b>			
Adult targeted species mobility	1km	30km	30km
Targeted species longevity (years)			
Price of targeted species			
<b>Actors (A)</b>			
Leadership			
Level of illegal fishing	1	1	3
Presence of alternative livelihoods			

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

Category	Indicador
Biological	Abundance
	Richness
	Shannon's diversity index
	Biomass
	Abundance of target species (lobsters)
Socioeconomic	Income from target species
	Landings from target species

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

$$I_i = \alpha_i + \gamma_{it}Year_t + \beta Zone_i + \lambda_{it}Year_t \times Zone_i + \sigma_j Spp_j + \epsilon \quad (2)$$

109 Where year-fixed effects are represented by  $\gamma_{it}Year_t$ , and  $\beta Zone_i$  captures the difference between  
 110 reserve ( $Zone = 1$ ) and control ( $Zone = 0$ ) sites. The interaction term  $\lambda_{it}Year_t \times Zone_i$  represents  
 111 represent the mean change in the indicator inside the reserve, for year  $t$ , with respect to the first year  
 112 of evaluation in the control site (See Table 1). When evaluating biomass and abundances, we include  
 113 species-fixed effects ( $\sigma_j$ ). For abundances and richness (*i.e.* count data) the model is estimated with a  
 114 quasipoisson error distribution.

115 Socioeconomic indicators are evaluated with a similar approach (Eq 3), where landings and income  
 116 before and after the implementation of the reserve are compared:

$$I_i = \beta_0 + \beta_1 Post \quad (3)$$

117 This approach does not allow for a causal attribution of the observed changes to the reserve, but still  
 118 allows us to draw important information that can inform our conclusions. For both approaches, model  
 119 coefficients are estimated via ordinary least-squares and heteroskedastic-robust standard errors (Zeileis,  
 120 2004).

### 3 RESULTS

Our methodological approach with biological indicators 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). Here we present the effect that marine reserves had on each of the biological indicators for each coastal community, along with the trends in socioeconomic indicators of lobster catches and revenues. We also provide an overview of the state of the socioeconomic and governance settings of each community, and discuss how these dimensions might be intertwined with each other.

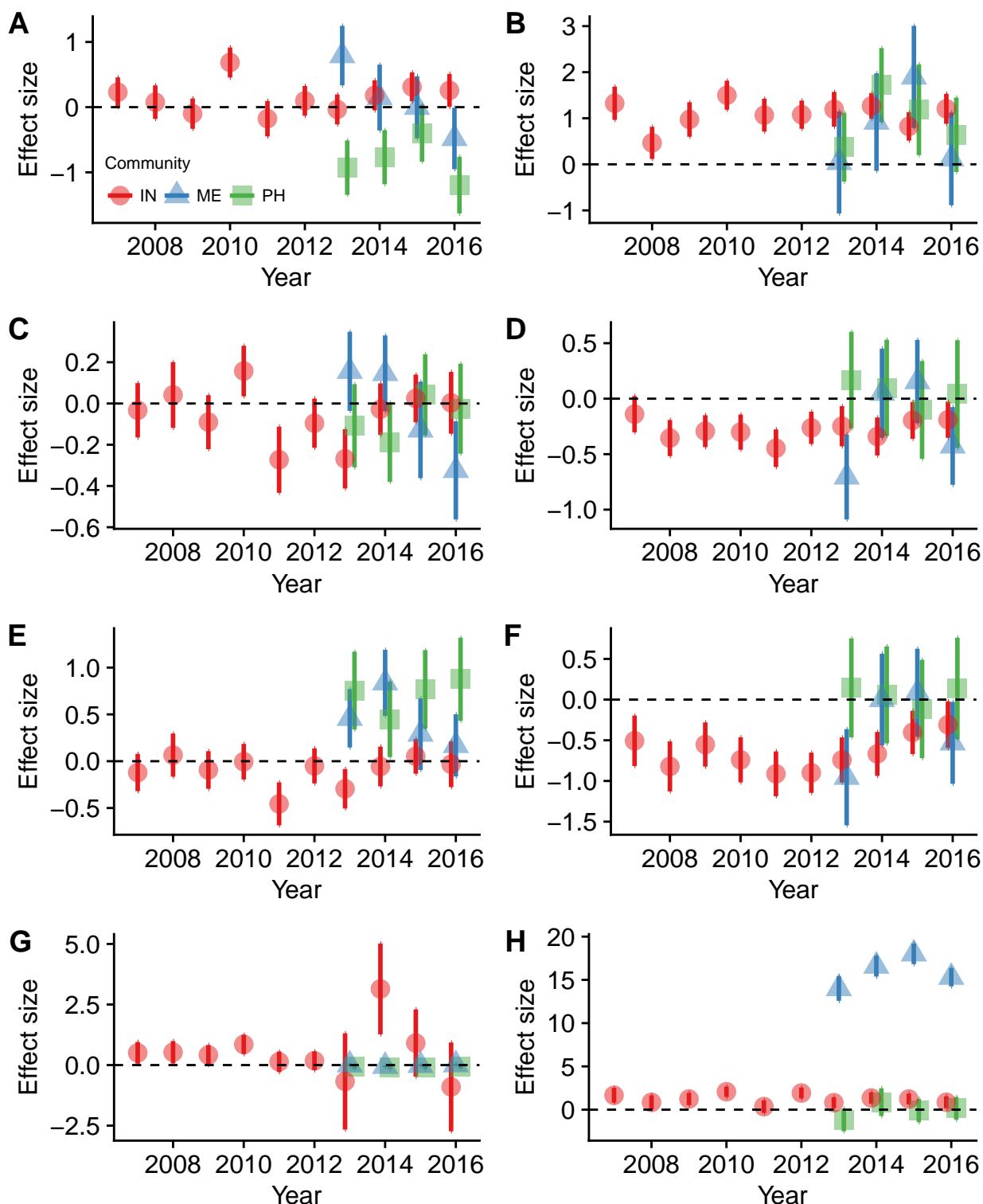
#### 3.1 Biological

Effect sizes for biological indicators are shown in Figure 2, and Figure 3 shows the summarized biological effects by community. Isla Natividad shows inconsistent effects across data sources (*i.e.* fish vs. invertebrates). For example, the reserve had a small effect on fish abundances (Fig 2A), where only year 2010 showed significant effect sizes in fish abundances ( $p < 0.05$ ) and all other years oscillated above and under zero ( $p > 0.05$ ). However, invertebrate abundances (Fig 2B) presented a positive trend relative to the control site before implementation ( $p < 0.05$ ) for all but 1 year (2008). Maria Elena and Punta Herrero showed no significant increase in fish and invertebrate abundances ( $p < 0.05$ ), except for invertebrates in Punta Herrero for 2014 –right after the implementation of the reserves– which showed a significant increase (*i.e.*  $\lambda_{2014} = 2.5, p < 0.05$ ). Full tables with model coefficients are presented in the supplementary materials (**S1 Table**, **S2 Table**, **S3 Table**).

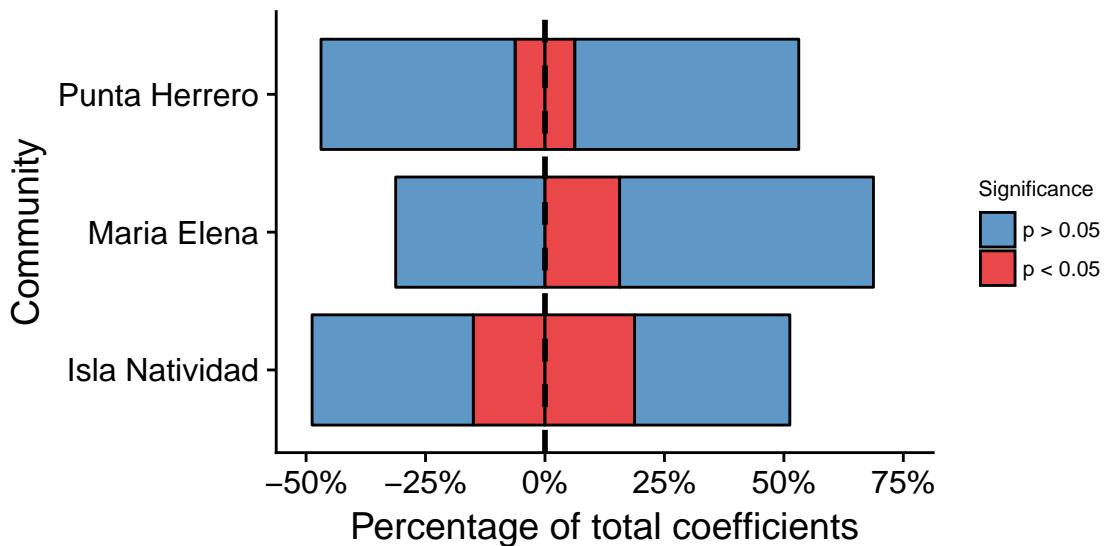
While the number of fish species oscillated above and below zero through time for all reserves, none of these changes were statistically significant ( $p > 0.05$ ) indicating that the reserves had no effect on fish species richness (Fig 2C). For invertebrate species in Isla Natividad, all effect sizes were negative, but only significant for 2008, 2009, 2011, and 2014 ( $p < 0.05$ ; Fig 2D). For Maria Elena and Punta Herrero, the data do not show significant changes in invertebrate species richness ( $p > 0.05$ ).

Effect sizes for Shannon's diversity index for fish (Fig 2E) in Isla Natividad oscillated between  $\lambda_{2011} = -0.45$  and  $\lambda_{2010} = -0.005$ , but were not significantly different from null hypotheses of no change (*i.e.*  $\lambda_t = 0; p > 0.05$ ). For invertebrates in that same community (Fig 2F), Shannon's diversity index showed a significant decrease between 2008 and 2014, with largest decrease observed for 2011 ( $\lambda_{2011} = -0.91; p < 0.05$ ). In the case of Maria Elena and Punta Herrero, Shannon's diversity index for fish showed increases in the order of  $\lambda_t = 1$ . For Maria Elena and Punta Herrero, these effects were only statistically significant for 2014, and 2014 and 2015 ( $p < 0.05$ ).

Biomass was only evaluated for fish data (Fig 2G). In Isla Natividad, fish biomass presented a steady but small increase ( $p > 0.05$ ), and exhibited an increased variability in biomass between 2013 and 2016. Maria Elena and Punta Herrero also showed small, non-statistically significant increases in fish biomass ( $p > 0.05$ ). The last biological indicator is abundance of target species, *Panulirus interruptus* and *P. argus*, for the Pacific and Caribbean, respectively (Fig 2H). Isla Natividad presented small constantly-positive effects but were not significantly different from the reference point of control site before the implementation of the reserve ( $p > 0.05$ ). Maria Elena showed significant increases in lobster densities in the order of  $\lambda_t = 10$  ( $p < 0.05$ ). Finally, Punta Herrero presented alternating negative and positive effects, but these were not different from the baseline case ( $p > 0.05$ ).



**Figure 2.** Effect sizes for marine reserves from Isla Natividad (IN; red circles), Maria Elena (ME; blue triangles), and Punta Herrero (PH; green squares) for community-level indicators. Plots are ordered by survey type (left: fish; right: invertebrates) and indicators: Abundance (A, B), Richness (C, D), Shannon's diversity index (E, F), fish biomass (G), and lobster (*Panulirus spp*) abundances (H). Points are jittered horizontally to avoid overplotting. Points indicate the effect size, and errorbars are heteroskedastic-robust standard errors.



**Figure 3.** Summarized effects of the marine reserves by direction (positive - negative) and significance.

## 162 3.2 Socioeconomic

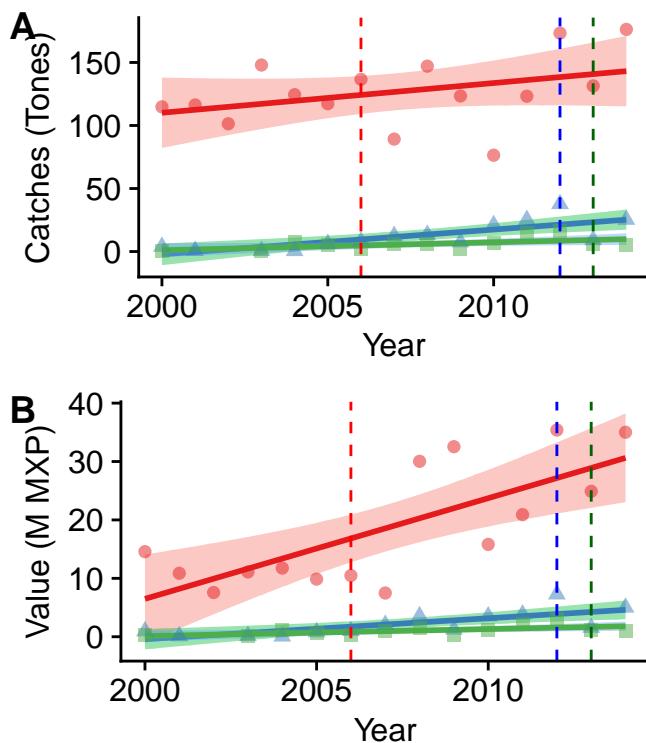
163 Lobster catches and income showed a increase after the implementation of the reserves for Isla Natividad  
 164 and Maria Elena, but not for Punta Herrero (Fig 4). However, the differences in catches and and revenue  
 165 were not different in the periods before and after the implementation ( $p > 0.05$ ) except for revenues in Isla  
 166 Natividad, which presented a significant increase of 14.37 (M MXP;  $p < 0.05$ ). Table 4 presents all the  
 167 regression coefficients.

**Table 4.** Regression coefficients for lobster catches and revenues for Isla Natividad (1, 4), Maria Elena (2, 5), and Punta Herrero (3, 6).

	Dependent variable:					
	Catches (tones)			Revenue(M MXP)		
	(1)	(2)	(3)	(4)	(5)	(6)
Post	7.37	5.83	-1.26	14.37***	1.24	-0.06
Constant	122.68***	11.41***	6.06***	10.89***	2.04***	1.06***
Observations	15	14	13	15	14	13
R <sup>2</sup>	0.02	0.04	0.01	0.52	0.04	0.0004

*Note:*

\* $p < 0.1$ ; \*\* $p < 0.05$ ; \*\*\* $p < 0.01$



**Figure 4.** Time series of lobster catches (A) and revenues (B) in at Isla Natividad (IN; red circles), Maria Elena (ME; blue triangles), and Punta Herrero (PH; green squares).

### 168 3.3 Governance

169 Although we have little information on the social dimension of these fisheries, using the SES framework  
 170 indicators (Table 3), we can analyze the performance of each governance system with respect to MR  
 171 enforcement (Table 5). In general, the presence and success of conservation initiatives depends on the  
 172 incentives of local communities to maintain a healthy status of the resources they depend upon (Jupiter  
 173 et al., 2017). The enabling conditions for conservation seem to be strongly present in Isla Natividad. Due  
 174 to the clarity of access rights and isolation, the benefits of conservation directly benefit the members of  
 175 the fishing cooperative. These conditions have favored the development of an efficient community based  
 176 enforcement system. In contrast, the communities of Maria Elena and Punta Herrero are located near  
 177 other fishing communities and cities. In Maria Elena, the fishing pressure caused by outsiders can be  
 178 reduced by implementing a strong enforcement system (in water and land) supported by CSOs and the  
 179 local government (CONANP). Lastly, the community of Punta Herrero shows the highest levels of illegal  
 180 activities which can be attributed to its connectedness to other communities and the lack of appropriate  
 181 technologies for enforcement.

**Table 5.** Analysis of the fishing cooperatives based on the Social-Ecological systems framework (McGinnis and Ostrom, 2014).

	Indicator	Isla Natividad	Maria Elena	Punta Herrero
<b>Resource systems (RS)</b>				
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
<b>Governance systems (GS)</b>				
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 technology	Yes	Yes	Yes
GS6 – Collective-choice rules	Cooperative regulations	Yes	Yes	Yes
GS7 – Constitutional-choice rules				
<b>Resource units (RU)</b>				
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
<b>Actors (A)</b>				
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

182 Our results indicated idiosyncratic biological effects of the reserves across communities and indicators,  
183 with a combination of positive and negative effects. However, many of these effects were not statistically  
184 significant, indicating no effect of the reserve 3. The socioeconomic indicators pertaining to landings and  
185 revenues associated to those landings showed little or no temporal change before and after reserve imple-  
186 mentation. These contrasting effects, however, might be clarified when understanding the social-ecological  
187 context in which these communities and their reserves sit. In this section, we discuss potential shortcomings  
188 in our analysis, and provide plausible explanations to the observed biological and socioeconomic basing on  
189 previous literature and our analysis of the social-ecological system.

190 The contrasting biological effectiveness observed is perhaps explained by our approach to evaluate the  
191 temporal and spatial changes of each indicator. Some works have solely focused on an inside-outside  
192 comparison of indicators (Guidetti et al., 2014; Friedlander et al., 2017; Rodriguez and Fanning, 2017),  
193 which do not address temporal variability (De Palma et al., 2018). Other works have compared the trend  
194 observed within a reserve through time (Betti et al., 2017), which cannot distinguish between the temporal  
195 trends in a reserve and the entire system (De Palma et al., 2018). By accounting for trends between sites  
196 and through times, we can control for time and space dynamics, and provide a better identification of the  
197 effect. However, it is worth looking deeper into each case, and identifying other plausible explanations.

198 Age, isolation, and enforcement are important factors influencing effectiveness of a marine reserve  
199 (Edgar et al., 2014). Isla Natividad has the oldest reserve, is fairly isolated, and has a well-established  
200 community-based enforcement system. While other communities are certainly within reach, these are  
201 known to be well organized fishing communities with successful resource management (McCay, 2017;  
202 McCay et al., 2014). The reserve at Isla Natividad presented the largest percentage of significantly positive  
203 changes in biological indicators (19%), but an important portion of was also negative (15%). With the  
204 age, relative isolation, and enforcement level of this reserve, it would be expected for it to be considerably  
205 effective. The potential gap in performance can be attributed to perturbations that do not distinguish reserve  
206 boundaries, such as environmental variability (**no recuerdo esta cita**). The region is known to be under  
207 the influence of recurrent hypoxia and high-temperature events known to cause massive adult mortalities  
208 (Micheli et al., 2012).

209 Maria Elena and Punta Herrero are relatively young reserves (See Table 1). From these, the Maria Elena  
210 exhibited the highest performance in terms of biological indicators (15% significantly positive). In contrast,  
211 Punta Herrero had a similar proportion of positive and negative effects.

212 The way in which we measure changes in catches and revenues can not identify whether the observed  
213 differences are simply caused by pre-existing temporal trends or by the implementation of the reserve. Yet,  
214 there were no detectable changes in these indicators, except for landings in Isla Natividad. Other research  
215 has shown that reserves in Isla Natividad yield fishery benefits for the abalone fishery (Rossetto et al.,  
216 2015). Since the trend was not detected in catches –directly related to abundance and fishing effort– it is  
217 plausible that these differences are purely explained by an increase in market-level prices.

218 The fact that there was no detectable change in catches for Maria Elena and Punta Herrero can be explained  
219 by a combination of factors related to the design, management, age, or ecological factors. Reserves in these  
220 communities are relatively small and young, and may need more time for lobster abundances to increase  
221 enough to export larvae or adult organisms. Other community-based marine reserves in tropical ecosystems  
222 have taken up to six years to show a spillover effect (da Silva et al., 2015). A complimentary explanation

223 lies in the results observed for the governance system. The lack of enforcement in Punta Herrero, for  
224 example, could explain the lack of effectiveness observed in their reserves.

225 Our results show that community-based marine reserves can be effective if the environmental and social  
226 settings allow it. By studying the social-ecological system as a whole, we can provide a wider range of  
227 explanations to the patterns observed. It is interesting that even under the best enabling social conditions,  
228 climate variability can hinder the effect of a reserve –Although it is interesting to imagine what the state  
229 of that fishery had been if the reserve and organized cooperative were not present–. On the contrary, we  
230 show how under low climate variability, absence of proper governance structures can limit the effectiveness  
231 and benefits of a reserve. Whether the combination of a stable environment and governance structures are  
232 additive or multiplicative represents an interesting area for future research, especially under a changing  
233 climate.

## CONFLICT OF INTEREST STATEMENT

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

## AUTHOR CONTRIBUTIONS

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

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238 JCVD CONACyT + LAFF ASC SF JT

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241 by members of the communities here mentioned, who collected the biological data.

## SUPPLEMENTAL DATA

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

245 **S1 Figure**

246 Timeseries of indicators for IN

247 **S2 Figure**

248 Timeseries of indicators for ME

249 **S3 Figure**

250 Timeseries of indicators for PH

251 **S1 Table**

252 Coefficient estimates for Isla Natividad

253 **S2 Table**

254 Coefficient estimates for Maria Elena

255 **S3 Table**

256 Coefficient estimates for Punta Herrero

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## FIGURE CAPTIONS