

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

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2 ABSTRACT

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

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

1 INTRODUCTION

24 Marine ecosystems around the world sustain significant impacts due to overfishing and unsustainable
25 fishing practices (Halpern et al., 2008; Worm et al., 2006; Pauly et al., 2005). A common approach to
26 manage the spatial distribution of fishing effort and recover stocks is through the implementation of marine
27 reserves (*i.e.* areas where all fishing activities are off-limits; MRs) (Afflerbach et al., 2014; Krueck et al.,
28 2017; Sala and Giakoumi, 2017).

29 Marine reserve science has largely focused on understanding the ecological effects of these areas, which
30 include increased biomass, richness, and densities of organisms within the protected regions (Lester
31 et al., 2009; Giakoumi et al., 2017; Sala and Giakoumi, 2017), climate change mitigation (Roberts et al.,
32 2017), and protection from environmental variability (Micheli et al., 2012). However, there is considerably
33 less literature focusing on the relationship between socioeconomic and governance structures and their
34 relationship to ecological effectiveness (Halpern et al., 2013; López-Angarita et al., 2014; Mascia et al.,
35 2017) or benefits to fisheries (Krueck et al., 2017); evaluations of marine reserves rarely provide a holistic
36 view of the social-ecological system (López-Angarita et al., 2014). Here, we combine causal inference
37 techniques (De Palma et al., 2018) and the social-ecological systems framework (Ostrom, 2009) to provide
38 a comprehensive ecological and socioeconomic evaluation of four community-based marine reserves in
39 three coastal communities in Mexico.

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

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

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

2 MATERIALS AND METHODS

71 2.1 Study area

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

83 The other two communities are Maria Elena (ME; Fig 1C) and Punta Herrero (PH; Fig 1D) in the Yucatan
84 Peninsula, where coral reefs and mangroves are the representative coastal ecosystems. ME is a fishing
85 camp –visited intermittently during the fishing season– belonging to the Cozumel fishing cooperative. PH
86 is home to the “José María Azcorra” fishing cooperative. The main source of income to both communities
87 is the Caribbean spiny lobster fishery (*Panulirus argus*), which is carried out within their respective
88 TURFs. These communities also target finfish in the off season, mainly snappers (Lutjanidae) and groupers
89 (Serranidae). ME established eight marine reserves in 2012, and PH established four marine reserves in
90 2013. All these reserves are legally recognized as Fishing Refugia.

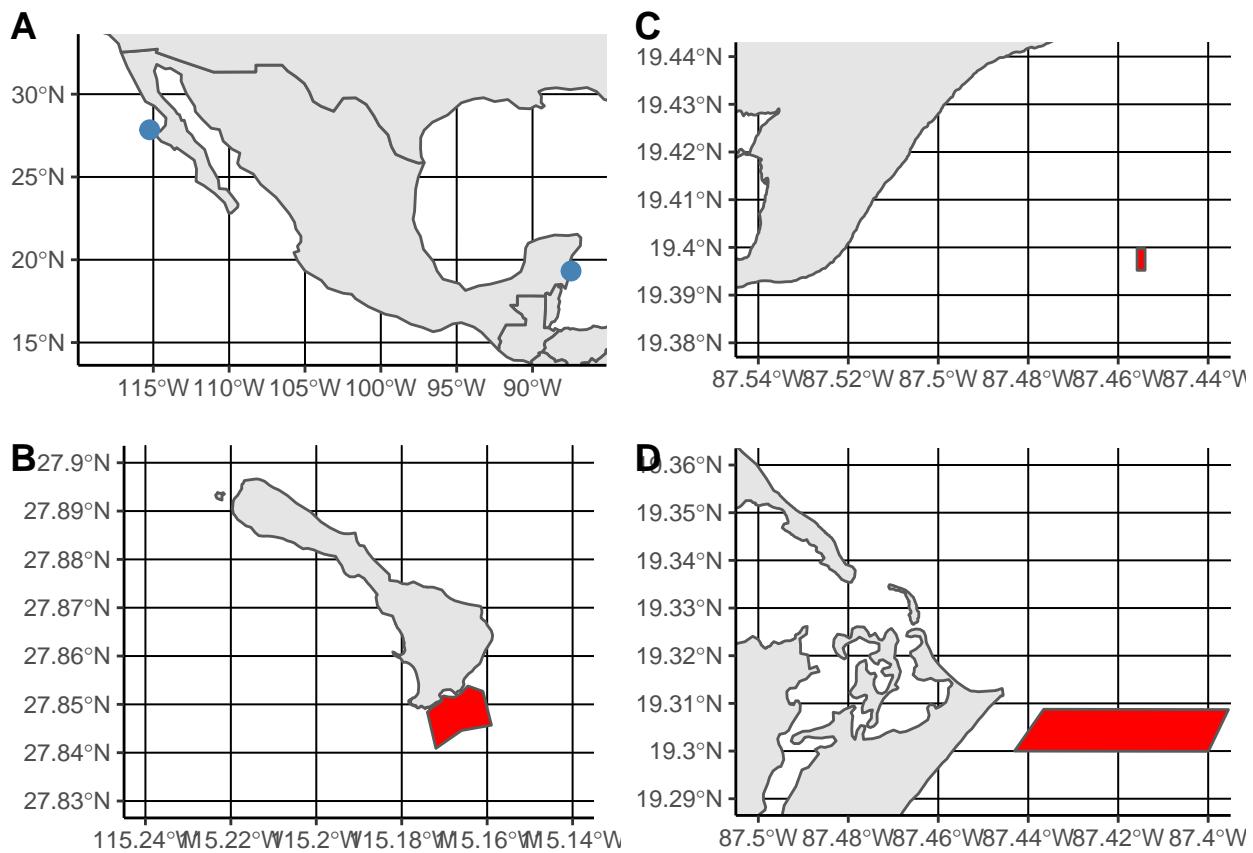


Figure 1. Location of the three coastal communities studied (A). Isla Natividad (B) is located off the Baja California Peninsula, Maria Elena (C) and Punta Herrero (D) are located in the yucatan Peninsula.

91 2.2 Data collection

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

106 Socioeconomic data come from landing receipts reported to the National Commission for Aquaculture
 107 and Fisheries (*Comisión Nacional de Acuacultura y Pesca*; CONAPESCA). Data contain monthly lobster

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	400	241	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

108 landings (Kg) and value (MXP) from 2000 to 2014. This information was aggregated by year, and economic
 109 values were adjusted by the Consumer Price Index (OECD, 2017) via Eq 1.

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

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

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

118 2.3 Data analysis

119 Following a framework that relates reserve objectives to performance indicators (Villaseñor-Derbez et al.,
 120 2018), we use five biological and two socioeconomic indicators to evaluate these marine reserves Table 2.
 121 We also use a set of governance indicators to analyze the governance structures of each cooperative (Leslie
 122 et al., 2015). The indicators (Table 3) focus on the resource system (four indicators), governance system
 123 (seven indicators), resource units (three indicators) and actors (three indicators).

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

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

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			

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

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

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

132 species–fixed effects (σ_j). For abundances and richness (*i.e.* count data) the model is estimated with a
 133 quasipoisson error distribution.

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

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

136 This approach does not allow for a causal attribution of the observed changes to the reserve, but still
 137 allows us to draw important information that can inform our conclusions. For both approaches, model
 138 coefficients are estimated via ordinary least–squares and heteroskedastic–robust standard errors (Zeileis,
 139 2004).

3 RESULTS

140 Our methodological approach with biological indicators allows us to make a causal link between the
 141 implementation of marine reserves and the observed trends by accounting for temporal and spatial dynamics
 142 (De Palma et al., 2018). The effect of the reserve is captured by the λ_t coefficient, and represents the
 143 difference observed between the control site before the implementation of the reserve and the reserve site at
 144 time t after controlling for other time and space variations (*i.e.* γ_t and β respectively). Here we present the
 145 effect that marine reserves had on each of the biological indicators for each coastal community, along with
 146 the trends in socioeconomic indicators of lobster catches and revenues. We also provide an overview of the
 147 state of the socioeconomic and governance settings of each community, and discuss how these dimensions
 148 might be intertwined with each other.

149 3.1 Biological

150 Effect sizes for biological indicators are shown in Figure 2, and Figure 3 shows the summarized
 151 biological effects by community. Isla Natividad shows inconsistent effects across data sources (*i.e.* fish
 152 vs. invertebrates). For example, the reserve had a small effect on fish abundances (Fig 2A), where only year
 153 2010 showed significant effect sizes in fish abundances ($p < 0.05$) and all other years oscillated above and
 154 under zero ($p > 0.05$). However, invertebrate abundances (Fig 2B) presented a positive trend relative to the
 155 control site before implementation ($p < 0.05$) for all but 1 year (2008). Maria Elena and Punta Herrero
 156 showed no significant increase in fish and invertebrate abundances ($p < 0.05$), except for invertebrates
 157 in Punta Herrero for 2014 –right after the implementation of the reserves– which showed a significant
 158 increase (*i.e.* $\lambda_{2014} = 2.5$, $p < 0.05$). Full tables with model coefficients are presented in the supplementary
 159 materials (**S1 Table**, **S2 Table**, **S3 Table**).

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

165 Effect sizes for Shannon’s diversity index for fish (Fig 2E) in Isla Natividad oscillated between $\lambda_{2011} =$
 166 -0.45 and $\lambda_{2010} = -0.005$, but were not significantly different from null hypotheses of no change (*i.e.*
 167 $\lambda_t = 0$; $p > 0.05$). For invertebrates in that same community (Fig 2F), Shannon’s diversity index showed
 168 a significant decrease between 2008 and 2014, with largest decrease observed for 2011 ($\lambda_{2011} = -0.91$;

169 $p < 0.05$). In the case of Maria Elena and Punta Herrero, Shannon's diversity index for fish showed
 170 increases in the order of $\lambda_t = 1$. For Maria Elena and Punta Herrero, these effects were only statistically
 171 significant for 2014, and 2014 and 2015 ($p < 0.05$).

172 Biomass was only evaluated for fish data (Fig 2G). In Isla Natividad, fish biomass presented a steady
 173 but small increase ($p > 0.05$), and exhibited an increased variability in biomass between 2013 and 2016.
 174 Maria Elena and Punta Herrero also showed small, non-statistically significant increases in fish biomass
 175 ($p > 0.05$). The last biological indicator is abundance of target species, *Panulirus interruptus* and *P. argus*,
 176 for the Pacific and Caribbean, respectively (Fig 2H). Isla Natividad presented small constantly-positive
 177 effects but were not significantly different from the reference point of control site before the implementation
 178 of the reserve ($p > 0.05$). Maria Elena showed significant increases in lobster densities in the order of
 179 $\lambda_t = 10$ ($p < 0.05$). Finally, Punta Herrero presented alternating negative and positive effects, but these
 180 were not different from the baseline case ($p > 0.05$).

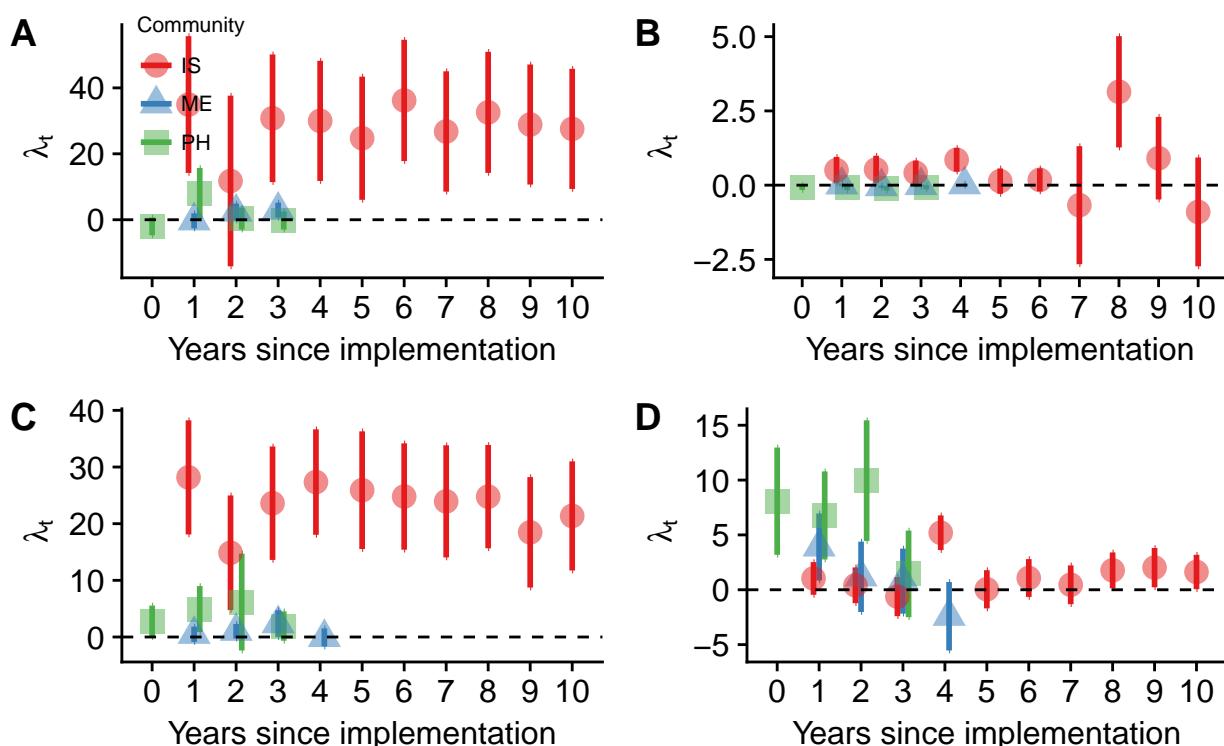


Figure 2. Effect sizes for marine reserves from Isla Natividad (IN; red circles), Maria Elena (ME; blue triangles), and Punta Herrero (PH; green squares) for community-level indicators. Plots are ordered by survey type (left: fish; right: invertebrates) and indicators: Abundance (A, B), Richness (C, 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.

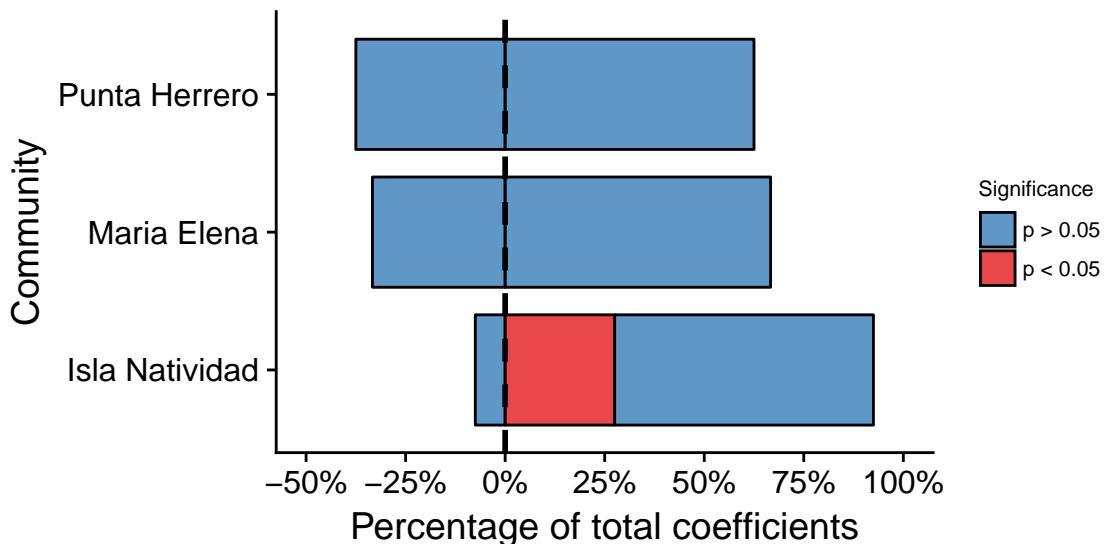


Figure 3. Summarized effects of the marine reserves by direction (positive - negative) and significance.

181 3.2 Socioeconomic

182 Lobster catches and income showed a increase after the implementation of the reserves for Isla Natividad
 183 and Maria Elena, but not for Punta Herrero (Fig 4). However, the differences in catches and and revenue
 184 were not different in the periods before and after the implementation ($p > 0.05$) except for revenues in Isla
 185 Natividad, which presented a significant increase of 14.37 (M MXP; $p < 0.05$). Table 4 presents all the
 186 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						
Constant	126.61***	12.24***	5.96***	18.55***	2.22***	1.05***
Observations	15	14	13	15	14	13
R ²	0.00	0.00	0.00	0.00	0.00	0.00

Note: *p<0.1; **p<0.05; ***p<0.01

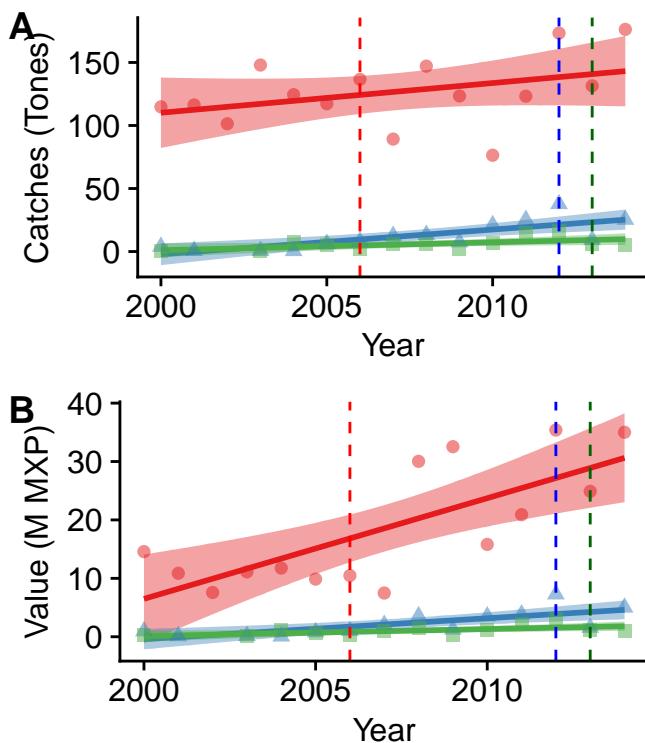


Figure 4. Time series of lobster catches (A) and revenues (B) in at Isla Natividad (IN; red circles), Maria Elena (ME; blue triangles), and Punta Herrero (PH; green squares).

187 3.3 Governance

188 Although we have little information on the social dimension of these fisheries, using the SES framework
 189 indicators (Table 3), we can analyze the performance of each governance system with respect to MR
 190 enforcement (Table 5). In general, the presence and success of conservation initiatives depends on the
 191 incentives of local communities to maintain a healthy status of the resources they depend upon (Jupiter
 192 et al., 2017). The enabling conditions for conservation seem to be strongly present in Isla Natividad. Due
 193 to the clarity of access rights and isolation, the benefits of conservation directly benefit the members of
 194 the fishing cooperative. These conditions have favored the development of an efficient community based
 195 enforcement system. In contrast, the communities of Maria Elena and Punta Herrero are located near
 196 other fishing communities and cities. In Maria Elena, the fishing pressure caused by outsiders can be
 197 reduced by implementing a strong enforcement system (in water and land) supported by CSOs and the
 198 local government (CONANP). Lastly, the community of Punta Herrero shows the highest levels of illegal
 199 activities which can be attributed to its connectedness to other communities and the lack of appropriate
 200 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
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 technology	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

201 4.1 Summary of main findings

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

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

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

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

232 The way in which we measure changes in catches and revenues can not identify whether the observed
233 differences are simply caused by pre-existing temporal trends or by the implementation of the reserve. Yet,
234 there were no detectable changes in these indicators, except for landings in Isla Natividad. Other research
235 has shown that reserves in Isla Natividad yield fishery benefits for the abalone fishery (Rossetto et al.,
236 2015). Since the trend was not detected in catches –directly related to abundance and fishing effort– it is
237 plausible that these differences are purely explained by an increase in market-level prices.

238 The fact that there was no detectable change in catches for Maria Elena and Punta Herrero can be explained
239 by a combination of factors related to the design, management, age, or ecological factors. Reserves in these
240 communities are relatively small and young, and may need more time for lobster abundances to increase
241 enough to export larvae or adult organisms. Other community-based marine reserves in tropical ecosystems

242 have taken up to six years to show a spillover effect (da Silva et al., 2015). A complimentary explanation
243 lies in the results observed for the governance system. The lack of enforcement in Punta Herrero, for
244 example, could explain the lack of effectiveness observed in their reserves.

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

254 **4.2 Limitations**

255 **4.3 Conclusions**

5 THOUGHTS FROM GAINESLAB MEETING

256 **5.1 General thoughts**

257 A nice story to tell is that reserves need to have optimal social and environmental conditions to work. But
258 they also need to be optimally designed, accounting for size and location. It is worth mentioning that even
259 when these reserves did not have nice effects on the ecological or fisheries side, they were a project that
260 brought together the community, and also gave fishers access to a network of resources facilitated by the
261 NGO. I still need to get data that support these.

262 Creo que hay que agregar informacion de la variabilidad ambiental. Posiblemente SST o algo similar. Ver
263 si se puede obtener datos de oxigeno disuelto... Tal vez algo de ENSO / ONI / NAO o algo asi

264 Quitar analisis de riqueza (la metodologia es restrictiva) y diversidad (aunque shannon provee una buena
265 mezcla del cambio en abundancias y el cambio en riquezas)

266 revisar biomasa!

267 Revisar poisson o binomial negativa

268 Mapa de El Manchon

269 Las graficas y el analisis de Profit y Catches tienen que ser de langosta entera fresca solamente, y revisar
270 que no haya habido un cambio de commodity a traves del tiempo para justificar usar solamente entera
271 fresca... Tratar de obtener valores hasta 2017

272 Pedir datos biologicos hasta 2017

273 Distinguis profit / revenue / income

274 **5.2 Comentarios del Lab**

275 Owen

276 Are there confounding effects because reserves are so close to control sites?

277 Dan

- 278 Are the data good enough to answer these questions?
- 279 Karly
- 280 Think about other social indicators that do not depend on catches or revenue from these
- 281 Alexa
- 282 Daniel
- 283 Sebas
- 284 Look at other indicators of success (adaptive capacity) in the social / governance data
- 285 Steve
- 286 Would we expect to see effects in the first five years? (ME and PH)
- 287 Are the designs good enough to see effects?
- 288 Becky
- 289 Ignacia
- 290 Perhaps interesting follow-up projects include comparing perceptions vs. reality
- 291 Estimating the benefits of being friends with an NGO

CONFLICT OF INTEREST STATEMENT

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

AUTHOR CONTRIBUTIONS

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

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- 296 JCVD CONACyT + LAFF ASC SF JT

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

SUPPLEMENTAL DATA

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

303 **S1 Figure**

304 Timeseries of indicators for IN

305 **S2 Figure**

306 Timeseries of indicators for ME

307 **S3 Figure**

308 Timeseries of indicators for PH

309 **S1 Table**

310 Coefficient estimates for Isla Natividad

311 **S2 Table**

312 Coefficient estimates for Maria Elena

313 **S3 Table**

314 Coefficient estimates for Punta Herrero

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FIGURE CAPTIONS