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## 2 ABSTRACT

### 3 Abstract here

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 Reserves  
22 (BRs) that are administered by the National Commission of Protected Areas (*Comisión Nacional de Áreas  
23 Marinas Protegidas*, CONANP). While CONANP has made efforts to have a participatory process, the  
24 implementation of these zones is still characterized by top-down approaches. This motivated Civil Society  
25 Organizations (CSOs) to work with coastal communities to implement community-based marine reserves  
26 (Uribe et al., 2010), which are usually established within a Territorial Use Rights for Fisheries (TURFs);  
27 thus making them TURF-reserves (Afflerbach et al., 2014). This bottom-up approach allows fishers to  
28 design their own reserves, which increases compliance and self-enforcement (Gelcich and Donlan, 2015;

29 Espinosa-Romero et al., 2014; Beger et al., 2004). However, these reserves still lack legal recognition,  
30 making them vulnerable to poaching. In 2014, a new norm (NOM-049-SAG/PESC, 2014) allowed fishers  
31 to request the legal recognition of a community-based reserve under the name of “Fishing Refugia” (*Zona*  
32 *de Refugio Pesquero*, FR). This new norm thus combines bottom-up approaches to design marine reserves,  
33 along with a legal recognition of the management intervention. Since then, 39 FR have been implemented  
34 along the Pacific, Gulf of California, and Mexican Caribbean coastlines, but no formal evaluation of their  
35 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  
50 use causal inference techniques to provide a measurement of the effect of the management intervention,  
51 and combine it with the social-ecological systems framework (Ostrom, 2009).

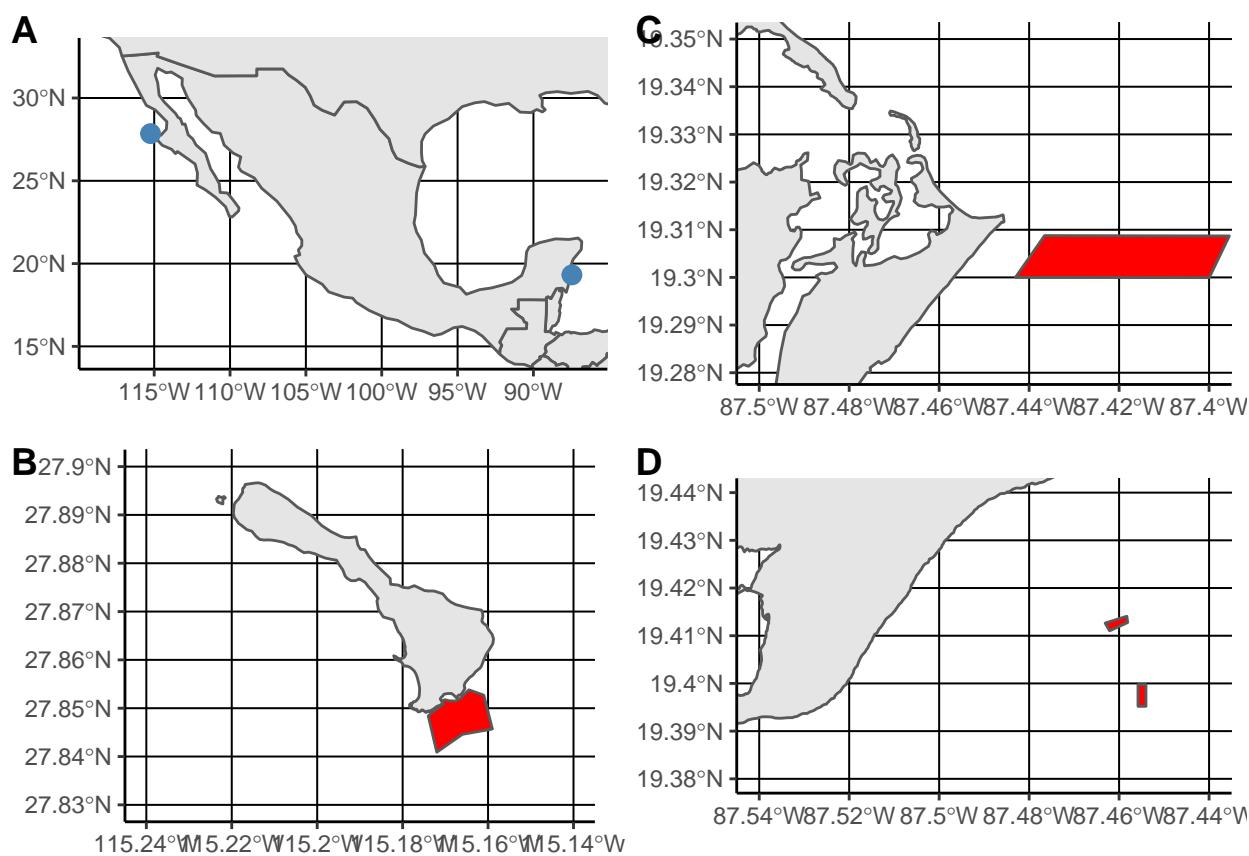
## 2 MATERIALS AND METHODS

### 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 (yellowtail 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 is  
67 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  
 74 from the annual ecological monitorings of reserve and control areas, carried out by members from  
 75 each community and personnel from the Mexican CSO “Comunidad y Biodiversidad” (COBI). These  
 76 monitorings record richness and abundances of fish and invertebrate species in the reserves and control sites.  
 77 For fish census, size structures are also collected to derive biomass. We define control sites as regions with  
 78 habitat characteristics similar to the corresponding reserves, and that presumably had the same probability  
 79 of being selected as reserves during the design phase. From all the reserves in these three communities, we  
 80 use the ones that have data for reserve and control sites before and after the implementation of the reserve  
 81 ( $n = 4$ ), thus providing us with a Before–After–Control–Impact (*i.e.* BACI) design that allows us to capture  
 82 and control for temporal and spatial dynamics (De Palma et al., 2018; Ferraro and Pattanayak, 2006). BACI  
 83 designs and causal inference techniques have proven effective to evaluate marine reserves, as they allow us  
 84 to causally attribute observed changes to the intervention (Moland et al., 2013; Villaseñor-Derbez et al.,  
 85 2018).

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

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

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

93 **Governance data were collected at the community-level, using key informants to collect the**  
 94 **necessary information on X, Y, and Z. Algo mas de Ere.**

### 95 2.3 Data analysis

96 Following a framework that relates reserve objectives to performance indicators (Villaseñor-Derbez et al.,  
 97 2018), we use five biological, two socioeconomic, and five governance indicators to evaluate these marine  
 98 reserves Table 1.

**Table 1.** 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
Governance	Type of access to the fishery
	Perceived degree of illegal fishing
	Reserve surveillance and enforcement
	Type of fishing organization
	Age of the reserve

99 Biological indicators are analyzed with a difference-in-differences analysis (Eq 2), which allows us to  
 100 estimate the effect that the reserve has on the biological indicators by comparing trends across time and  
 101 space (*i.e.* reserve and control sites) (Moland et al., 2013; Villaseñor-Derbez et al., 2018). The analysis is  
 102 performed with generalized linear models of the form:

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

103 Where year-fixed effects are represented by  $\gamma_{it} Year_t$ ,  $\beta Zone_i$  captures the difference between reserve  
 104 ( $Zone = 1$ ) and control ( $Zone = 0$ ) sites, and the interaction term  $\lambda_{it} Year_t \times Zone_i$  represents the average

105 treatment effect for each year. When evaluating biomass and abundances, we include species–fixed effects  
106 ( $\sigma_j$ ), and when more than one reserve is present we also include site–fixed effects ( $\Pi_k$ ). For abundances  
107 (*i.e.* count data) the model is estimated with a quasipoisson error distribution.

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

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

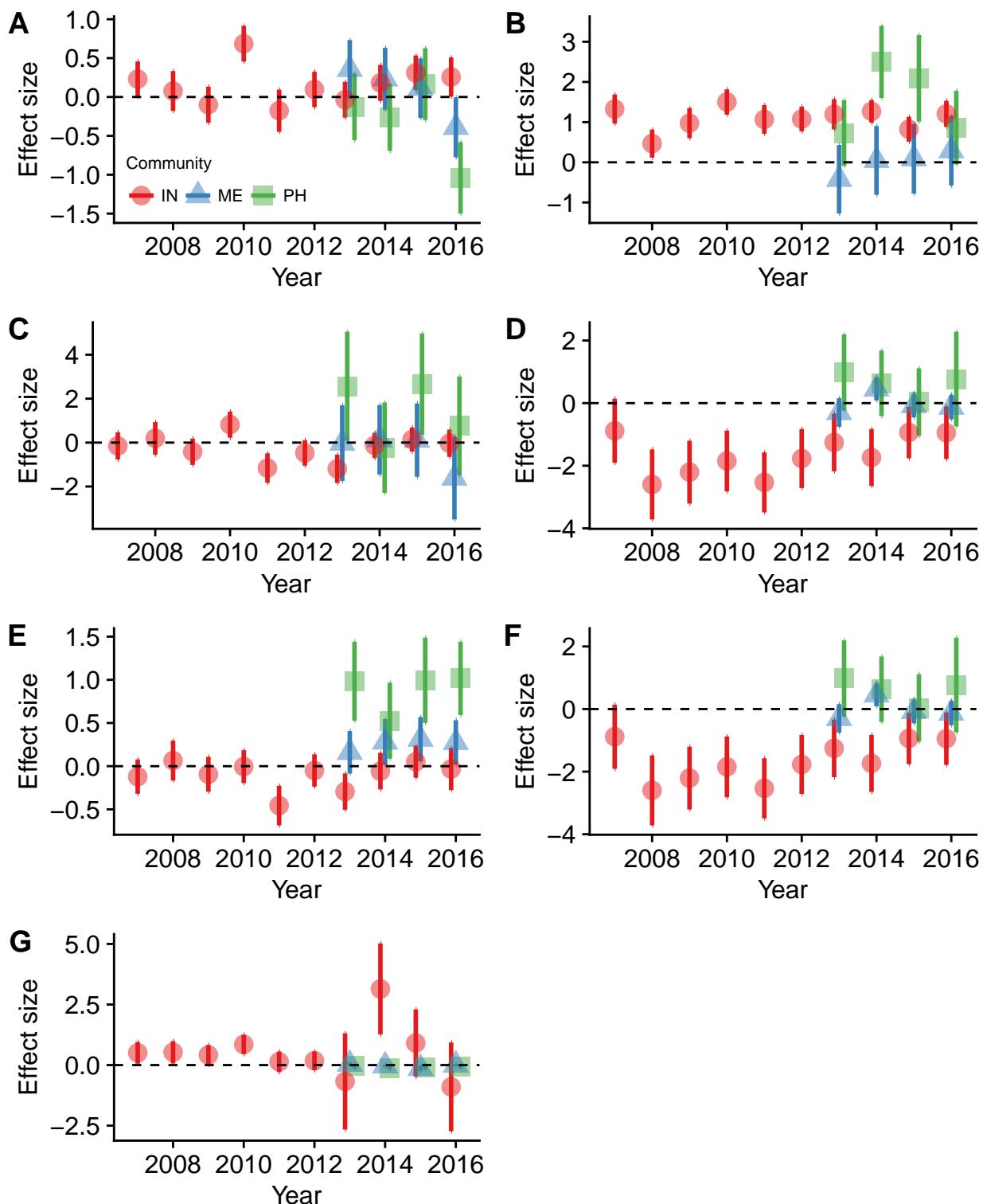
110 This approach does not allow for a causal attribution of the observed changes to the reserve, but still  
111 allows us to draw important information that can inform our conclusions. For both approaches, model  
112 coefficients are estimated via ordinary least–squares and heteroskedastic–robust standard errors (Zeileis,  
113 2004).

#### 114 2.3.1 Governance

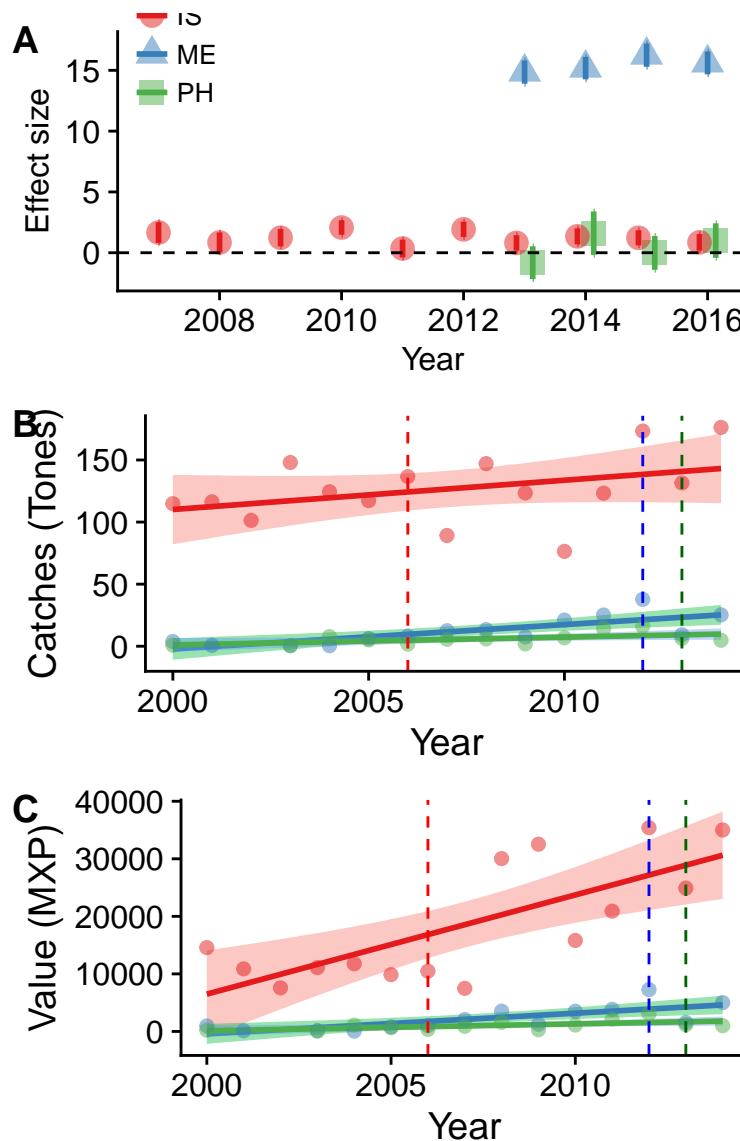
#### 115 Texto de ere y los SES

### 3 RESULTS

116 A continuación se presentan los resultados de cada una de las comunidades. Los resultados biológicos se  
117 presentarán para cada comunidad, discutiendo primero los indicadores en común con otras comunidades  
118 (Shannon, Riqueza, Densidad, Nivel Trófico, Biomasa para peces e invertebrados) y, según su caso, las  
119 densidades de las especies objetivo. Habiendo presentado los resultados biológicos, nos enfocaremos  
120 después en los socioeconómicos y de gobernanza. Usaremos esta información para identificar las causas  
121 (sociales) del éxito (biológico) de las reservas.



**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), and fish biomass (G)



**Figure 3.** Effect sizes for lobster abundances in marine reserves from Isla Natividad (IN; red romboids), Maria Elena (ME; blue triangles), and Punta Herrero (PH; green squares).

## 4 DISCUSSION

### CONFLICT OF INTEREST STATEMENT

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

### AUTHOR CONTRIBUTIONS

124 JC analyzed and interpreted data, discussed the results and wrote the manuscript. SF and JT edited the  
 125 manuscript and discussed the results.

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127 add all necessary funding information, as after publication this is no longer possible.

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## SUPPLEMENTAL DATA

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

133 **S1 Figure**

134 Maps of the marine reserves and corresponding control sites at each community.

135 **S2 Table**

136 Table with a general overview of on the governance characteristics of each community.

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## FIGURE CAPTIONS