



HAL
open science

Baseline assessment and early effects of a network of marine protected areas

Victor Brun, Laure Thierry de Ville d'Avray, Ma. May Saludsod, Roger Dolorosa, Niño Jess Mar F. Mecha, Kent Elson S. Sorgon, Joachim Claudet

► **To cite this version:**

Victor Brun, Laure Thierry de Ville d'Avray, Ma. May Saludsod, Roger Dolorosa, Niño Jess Mar F. Mecha, et al.. Baseline assessment and early effects of a network of marine protected areas. Conservation Science and Practice, inPress, 10.1111/csp2.13121 . hal-04558835

HAL Id: hal-04558835

<https://hal.science/hal-04558835>

Submitted on 25 Apr 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **Baseline assessment and early effects of a network of community-** 2 **based marine protected areas**

3 Authors: Victor Brun^{1,2}, Laure Thierry de Ville d'Avray², Ma. May Saludsod², Roger G.
4 Dolorosa³, Niño Jess Mar F. Mecha³, Kent Elson S. Sorgon⁴, Joachim Claudet¹

5 ¹ National Center for Scientific Research, Paris Université PSL, CRIOBE, CNRS-EPHE-UPVD, Maison de l'Océan, 195 rue Saint Jacques,
6 Paris 75005 France.

7 ² Sulubaañ Environmental Foundation (SEF), Pangatalan Island, Barangay Depla, Taytay 5312 Palawan, Philippines.

8 ³ Western Philippines University, Puerto Princesa Campus, Palawan, Philippines.

9 ⁴ Institute of Biological Sciences, College of Arts and Sciences, University of the Philippines Los Baños, College, Laguna, Philippines
10 4031.

11 **Data accessibility**

12

13 Data and codes used for all analyses are accessible on the first author's GitHub page

14 (<https://github.com/victor-brun>).

15 **Acknowledgements**

16 We thank the Palawan Council for Sustainable Development (PCSD) for their continuous

17 support, including in granting a Wildlife Gratuitous Permit (2021-09). We thank the

18 Municipality of Taytay for their valuable efforts in marine conservation and support. We also

19 thank the National Mapping and Resource Information Authority (NAMRIA) for providing

20 spatial data on coastal resources. This study was funded by the Sea Academy partners:

21 French Facility for Global Environment, Blancpain Ocean Commitment, Prince Albert II of

22 Monaco Foundation, and the Pure Ocean foundation. JC was supported by Fondation de

23 France (MultiNet) and Biodiversa (METRODIVER and MOVE). The authors declare no
24 conflict of interest.

25

26

27 **Baseline assessment and early effects of a network of marine** 28 **protected areas**

29

30 Abstract: Marine protected areas (MPAs) can be a useful tool to manage coastal fisheries,
31 delivering both social and ecological outcomes. However, in many instances, relevant data
32 are missing to conduct proper impact assessments, which is key to identify ecological and
33 social synergies and potential trade-offs, and to adapt management according to local
34 objectives. The ecological effects of an MPA established in Palawan, Philippines, in 2016,
35 were assessed. The most common species targeted by fisheries were identified by local
36 fishers. Species size and number were collected through underwater visual census (UVC)
37 with n=288 belt transects assigned in different sites and locations to ensure to provide both
38 protected and control (fished) locations for the MPA assessment, and baseline data for three
39 new MPAs that were created in 2022. 91 coral-reef fish species belonging to 12 families were
40 recorded. Mixed effect linear regression was used to compare target fish populations in
41 protected and control sites. Compared to control locations, 5 years after its implementation,
42 the MPA showed significantly higher species richness ($p < 0.01$), abundance ($p < 0.05$), mean
43 size ($p < 0.001$) and biomass ($p < 0.001$); no significant different was found on the average
44 trophic level between MPA and control sites. While collecting the first year of data for the
45 future MPA network impact assessment, which is vital for its management, rapid effects of an

46 existing MPA were demonstrated, an important condition for their local acceptability and
47 subsequent management decisions.

48 1. Introduction

49 Marine protected areas (MPAs) can be a useful tool for ocean stewardship. In many areas
50 where the dependence on natural coastal resources for livelihoods and wellbeing is high,
51 MPAs are often preferred over other regulations (Delevaux et al., 2018; Ferse et al., 2010;
52 Jupiter et al., 2014; Mahajan et al., 2021; Tranter et al., 2022). When effective and properly
53 implemented, while delivering conservation outcomes, MPAs can also deliver social
54 outcomes such as improving livelihoods and empowering communities, and can prove
55 adaptable to changing social and environmental conditions (Jupiter et al., 2014; Kockel et al.,
56 2020; Weeks and Jupiter, 2013). However, to ensure conservation and social objectives are
57 reached and outcomes maintained over time, proper impact assessments should be carried
58 out. In addition, these can inform their adaptive co-management. Yet, in the way most MPAs
59 are designed and implemented, resources and capacity are lacking to identify counterfactuals
60 and collect relevant data, making monitoring a prime objective for their sustainability
61 (Abesamis et al., 2006; Ahmadia et al., 2015; Begger et al., 2004; Gill et al., 2017; Gurney et
62 al., 2023; Marriott et al., 2021).

63 Assessing the ecological effects of MPAs, in particular, can prove challenging due to the
64 variability and changing nature of ecological conditions in marine ecosystems (Ahmadia et
65 al., 2015; Claudet and Guidetti, 2010; Maina et al., 2016; Mascia et al., 2017, 2014). Baseline
66 data and spatial and temporal replication are therefore important to study the effects of
67 protection over space and time. Moreover, monitoring often focuses on studying trends rather
68 than measuring outcomes which limits the ability to assess the impact of conservation
69 policies, while possibly investing on inefficient measures (Fraser et al., 2019; Miteva et al.,
70 2012; Pressey et al., 2021).

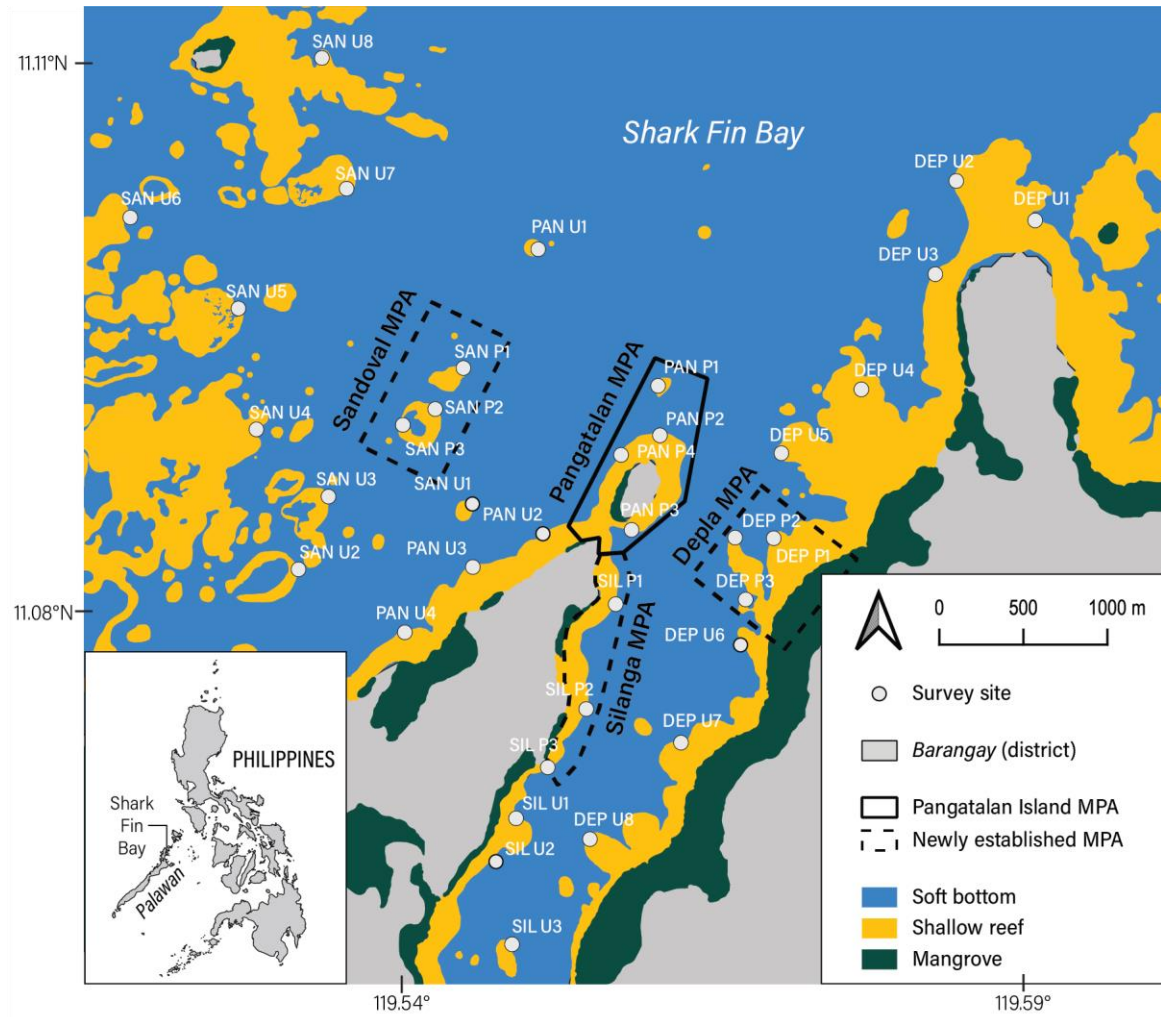
71 Ensuring local communities are engaged in MPA evaluation is important on three levels.
72 First, it matters for the fairness and equity of conservation measures (Bennett, 2022).
73 Depending on the level of protection of an MPA, fishers are often the most exposed to
74 changes in access following its creation (Beger et al., 2004; Blythe et al., 2023; Gill et al.,
75 2023; Horta e Costa et al., 2016; Maypa et al., 2012). Second, their participation in assessing
76 the conservation and potential fisheries outcomes is key to its success as it can increase their
77 general participation to management processes and empower them (Twichell et al., 2018;
78 Uychiaoco et al., 2005). Among the reasons is the expectation of local resource users to
79 witness positive signs when fishery closures can often be perceived as a sacrifice: by
80 participating in MPA evaluation, communities can better witness ecological changes. Third,
81 including local communities in monitoring can help collect more appropriate data based on
82 local knowledge. Another difficulty in monitoring the effects of MPAs on species targeted by
83 local fisheries is the identification of which of these are target species. Global databases such
84 as FishBase (Froese and Pauly, 2010) provide some information on the typical market value
85 of species, but these information neglect local contexts (e.g., gears used, habits and
86 preferences of fishers and consumers, market conditions). Properly assessing the recovery of
87 fished stocks, and associated potential benefits for fisheries, requires an account of which
88 species are actually targeted by fisheries.

89 The Philippines has a long history of marine conservation initiatives undertaken by local
90 communities (Alcala and Russ, 2006; White et al., 2005, 2002). Despite increasing records of
91 effective MPAs in the country (Aurellado et al., 2021; Bayley et al., 2020), large-scale
92 conservation success is still lagging behind and management efforts often lack to translate
93 into social-ecological benefits (Muallil et al., 2019; Weeks et al., 2010). Building the
94 evidence base of MPA outcomes and contributing to improve ongoing and future impact
95 assessment of MPAs is therefore of primary importance in the Philippines.

96 Here, we assessed, using a control-impact (CI) study design, the conservation outcomes of a
97 fully protected MPA (*sensu* Horta e Costa et al., 2016) implemented since 2016, and which
98 has been integrated in 2022 within a network including three newly created MPAs. For these,
99 we provide baseline data and a comparison of protected and control sites to verify for
100 potential differences in fish communities pre-existing to protection measures. We first
101 engaged with local fishers to identify the species they target and their respective market
102 values. Then, using underwater visual census (UVC), we assessed target fish species richness,
103 abundance, mean size, biomass, and trophic level and used linear mixed effect regression to
104 compare protected and control sites.

105 **2. Methods**

106 2.1. Study site and management context



107

108 Figure 1. Map of the study area in Shark Fin Bay, Palawan, Philippines.

109 Palawan is a province of the Philippines that has, for long, been known for the exceptional
110 productivity of its fisheries (Palomares and Pauly, 2014). In recent years, their decline has
111 caused concern for the food security and livelihoods of a growing population despite the
112 existence of a wide array of initiatives, or “fixes” (Fabinyi, 2018) originating from local to
113 national and international actors, including NGOs. The question of sustaining natural
114 resources and their contribution to the well-being of local people remains largely unresolved.

115 Shark Fin Bay is home to a population of about 7000 inhabitants living in five distinct
116 barangays (or districts): Batas, Depla, Mabini, Sandoval and Silanga between the
117 municipalities of Taytay and El Nido. The bay, semi-enclosed and displaying a variety of
118 ecosystems including fringing coral reefs, seagrass meadows, mangroves and soft bottom
119 areas (Figure 1), is also characterized by an extremely varied but declining small scale fishery
120 providing food and revenues for the whole population. While we estimate that 20 to 60% of
121 households are fishing (depending on the village, unpublished data), most of the population
122 directly depends on this marine space through other activities, such as seafood gleaning,
123 transportation, and seaweeds farming.

124 Sulubaai Environmental Foundation (SEF), an NGO that was created in 2011 by French
125 nationals and based on Pangatalan Island, has developed several initiatives including
126 ecological restoration, educational programs in schools, support to local Fisherfolks
127 Associations and marine conservation initiatives. In 2016 it promoted the creation of a 50 ha
128 fully protected MPA, Pangatalan Island Marine Protected Area (PIMPA), in agreement with
129 local communities, but with an initial limited level of engagement in its governance.

130 Observing the effects of PIMPA, the community of Depla requested in 2019 support to create
131 a community-based MPA. After consultations in two other barangays, Sandoval and Silanga,
132 the decision was taken to create a network of community-based MPAs under the municipality
133 of Taytay and integrate PIMPA in that network, hence making the four MPAs community-
134 based. They are now managed by a single management structure that includes representatives
135 of local communities (e.g. fishers, women's groups, fish wardens, elected officials),
136 representatives of the municipality of Taytay, and SEF for technical assistance. Specific
137 committees on enforcement, finance, education and monitoring, are focusing on different
138 dimensions of management processes. Following several public hearings with the
139 communities at large and specific meetings with Fisherfolks Associations to delineate the

140 rules and boundaries of these new MPAs, the full network was finally voted and ratified
141 through a municipal ordinance in 2022, transforming the private endeavor of SEF into a
142 project managed by local stakeholders where SEF now holds the role of technical and
143 advisory body, organizing meetings and facilitating management activities including
144 ecological monitoring. With this new ordinance, three new community-based MPAs (two
145 measuring 50 ha and one 30 ha) were subsequently created making as of May 2023 the whole
146 network actively managed (*sensu* Grorud-Colvert et al., 2021). This study uses data collected
147 in April and November 2021 when PIMPA was actively managed since 2016 (five years of
148 protection) and the three new MPAs were only committed, hence still actively fished areas.
149 “Protected sites” mentioned in this paper are those within PIMPA, and “control sites” are all
150 other sites including those outside of MPAs and those within newly created ones.

151

152 2.2. Identification of target species

153 To assess which species were targeted by local fishers, a list of species found in the area and
154 their vernacular names in Cuyonon, Filipino and Visayan languages was made with the help
155 of an existing guide (Gonzales, 2013) and interviews with local fishers. Key informant
156 interviews were conducted with 6 experienced fishers during which they were asked to
157 describe the existing fishing gears and techniques in the area, and to grade the target value of
158 species based on their vernacular names and pictures (see the key informant interview guide
159 in the Supplementary Information). Four grades were used: 0, the species is never targeted; 1,
160 it can be targeted for consumption; 2, it can be sold; and 3, it can be sold at an even higher
161 price. This grading yielded results at the family, genus or species level depending on the
162 precision of each vernacular name: for instance, *murmor* referred to all Scarinae within the
163 Labridae family, while *bangkilan* referred specifically to *Choerodon anchorago*. These
164 grades were then applied to the species observed; if no grade was available at the species-

165 level, the genus or family-level grade was applied. Only species with an average target score
166 ≥ 1 were included in the survey. Our classification was validated with fishing surveys
167 conducted both onboard with artisanal fishers using hook and line, gillnets, or traps, and on
168 landing sites.

169

170 2.3. Underwater visual census

171 To study the populations of these targeted fish species in situ, 36 sites were chosen to be as
172 representative of the ecological diversity of the bay's fringing reefs as possible, and an UVC
173 of target species was conducted in April and November 2021. They included protected sites
174 within PIMPA (declared as a fully protected MPA since 2016) and control sites where fishing
175 was allowed at the time of the study, which include both control sites and sites that were later
176 declared as MPA in 2022. This large number of sites in a relatively small area made it
177 possible to take into account the potential differences in habitat conditions pre-existing to
178 conservation efforts. Adding to that, the initial placement of PIMPA in 2016 was not linked
179 to particular ecological conditions, such as a pre-existing higher biomass or a higher coral
180 cover, but was rather decided based on the fact that it should surround Pangatalan Island
181 (where SEF is based since 2011 to restore terrestrial ecosystems), in order to facilitate its
182 monitoring. The focus on coral reef ecosystems is justified by the fact that they are the main
183 ecosystem targeted by local fishers and marine conservation initiatives. This should not,
184 however, disregard the contribution of other ecosystems, in particular soft bottoms and
185 seagrass meadows, to local livelihoods and food security. In each site, four 50 x 6 m belt
186 transects were conducted at a depth of 3.5-8 m on reef slopes and target fish were identified
187 at the species level, counted, and their total length estimated to the nearest centimeter by
188 trained divers (metadata on the sites surveyed in the Supplementary Information). This
189 survey was repeated twice, in April 2021 and November 2021, to capture potential seasonal

190 differences. Schooling species, including some trevallies and fusiliers, were recorded but not
191 included in the analyses as their sporadic presence in very high numbers would bring
192 statistical noise into our analyses (Claudet et al., 2006).

193

194 2.4. Fish community metrics

195 Five common community metrics were chosen in order to study the effects of protection on
196 the target fish population: total species richness, average total abundance, mean individual
197 size, average total biomass, average weighted trophic level (weighted by biomass).

198 Information on species length-weight relationships, trophic level and maximum length were
199 found on FishBase (Froese and Pauly, 2010) and accessed using the “rfishbase” R package
200 (Boettiger et al., 2012). Up-to-date information on the status of species according to the
201 International Union for the Conservation of Nature (IUCN) Red List of Threatened Species
202 was collected using the “rredlist” package (Chamberlain, 2020). The classification of
203 Parravicini et al. (2020) was used to classify target species in different trophic guilds.

204 We divided species into three size classes based on their maximum length (obtained from
205 FishBase): small (30% of their maximum length), medium (30% to 60% of their maximum
206 length), and large (60% of their maximum length).

207 We further classified sites in three groups based on their average biomass: those with a
208 biomass below a 300 kg/ha threshold, those with a biomass between 300 and 600 kg/ha and
209 those with a biomass above a 600 kg/ha threshold. Those levels correspond respectively to
210 estimates of biomass levels below maximum sustainable yield (MSY), overfished, those
211 lightly fish and those with a biomass above MSY (McClanahan et al., 2015).

212

213 2.5. Statistical analyses

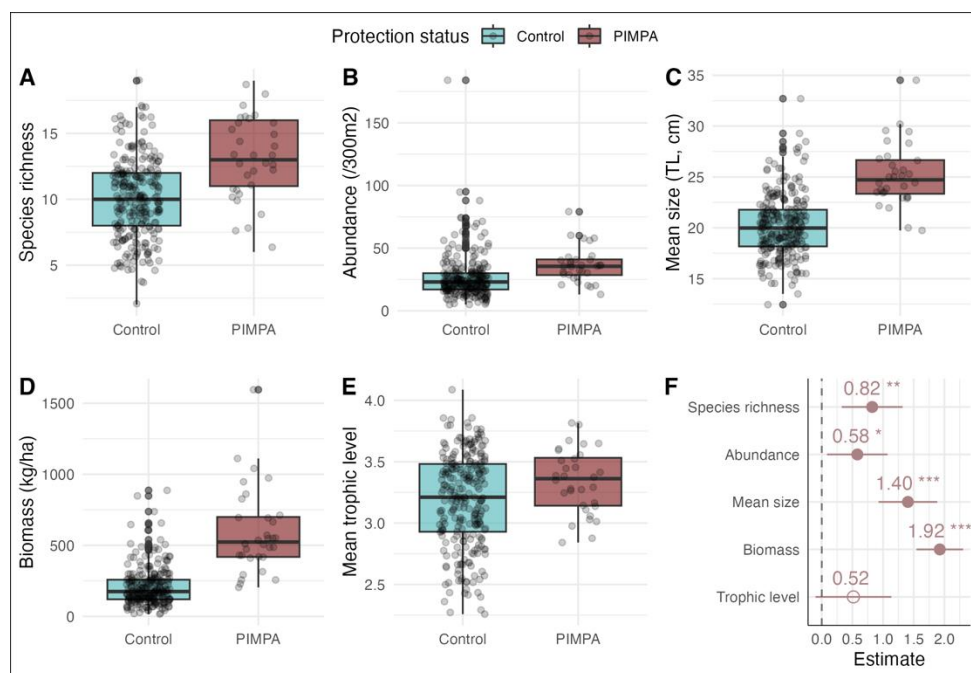
214 To study the early effects of PIMPA on fish communities we compared average fish
215 community metrics between protected and control sites using a CI design. The exact same
216 UVC methodology was used in April and November 2021 and the two surveys were pooled
217 and considered as temporal replicates. Without baseline data, it can be difficult to attribute to
218 an MPA the differences observed between protected and control sites. Using an asymmetrical
219 design with a large number of control sites, “beyond BACI” approaches, can however allow
220 that attribution and proper impact assessment (Underwood, 1994). We therefore collected
221 data in a larger number of control sites (256 transects in 32 fished sites) to better account for
222 the potential variability in habitat conditions (e.g. coral cover, habitat complexity) and
223 attribute any significant difference in fish communities to the MPA (Underwood, 1994). To
224 compare PIMPA and control sites, linear mixed effect regression was used to test the effect of
225 protection on target species i) richness, ii) mean size, iii) abundance, iv) biomass and v) mean
226 trophic level. To standardize estimates, response variables were centered around the mean.
227 Season, location, depth, tide, visibility, and weather were used as random effects in all
228 models. Depth and visibility can be considered as proxies for habitat conditions: Shark Fin
229 Bay being semi-enclosed, turbidity appears as an important driver of coral cover, and sites
230 with lower turbidity and at greater depths usually exhibit a higher coral cover and complexity
231 than sites in turbid and shallow areas. To provide a baseline of fish community metrics in
232 newly protected sites and their respective control sites, we computed one mixed effect linear
233 model per location comparing protected and control sites and using the same random effects.
234 For all regression models, we checked for the normality of residuals’ distribution (Supporting
235 Information, figures S1, S3, S4 & S5).

236 A one-way ANOVA was computed to test for the difference in abundance of species
237 classified by the IUCN as vulnerable and endangered between protected and control sites.

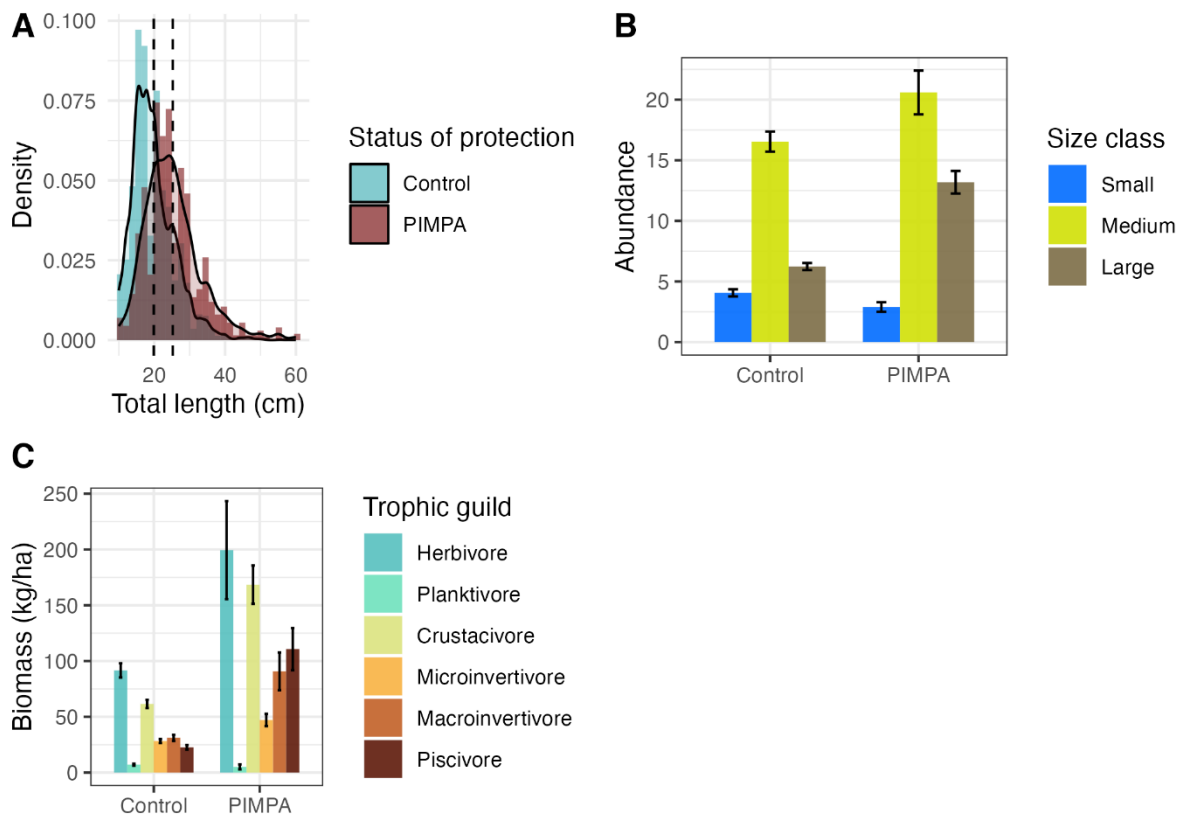
238 Statistical analyses were done using R (v. 4.0.3, R Core Team, 2020).

239 **3. Results**

240 Out of 7861 individual fishes, 91 species belonging to 12 families were observed in the UVC
241 (complete list of species in the Supporting Information, Table S2). A restricted number of
242 more common species dominated the counts, such as *Cheilinus fasciatus*, *Scarus*
243 *hypselopterus*, *Lutjanus carponotatus*, or *Scolopsis margaritifera*. Four species were
244 classified as threatened by the IUCN Red List of Threatened Species: *Cheilinus undulatus*,
245 *Bolbometopon muricatum*, *Scarus hypselopterus*, and *Plectropomus areolatus*. Species
246 classified as vulnerable and endangered were more abundant within the boundaries of PIMPA
247 than outside (respectively 1.38% and 0.89% of observations, ANOVA: $p = 0.003$, $F = 9.279$).
248 In PIMPA, after five years of protection, the protected sites harbored a significantly higher
249 target species richness ($p < 0.01$), higher abundance ($p < 0.05$), larger fish ($p < 0.001$), and a
250 higher biomass ($p < 0.001$) compared to control sites (Figure 2). The average trophic level
251 was found to be slightly higher in protected sites but that trend was not significant ($p > 0.05$).
252 Complete outputs of the models are available in Supporting Information (Figure S3).



254 Figure 2. Comparison of community metrics between protected (Pangatalan Island Marine
 255 Protected Area, PIMPA) and control (fished) sites. Boxplots showing the difference in
 256 community parameters between protected (PIMPA) and control sites (panels A-E); forest plot
 257 representing the estimates obtained from linear mixed effect regression (F). Significance is
 258 indicated as follows: no asterisk for non-significant results, * $p \leq 0.05$, ** $p \leq 0.01$, and *** p
 259 ≤ 0.001 .



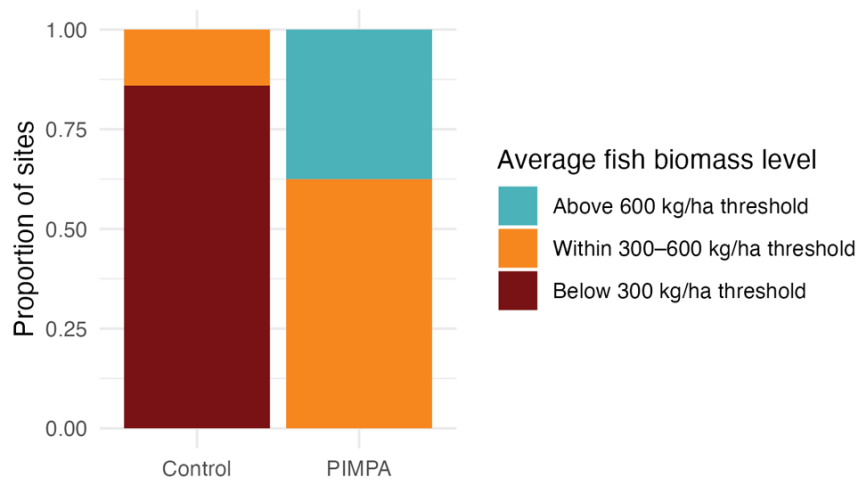
260

261 Figure 3. Comparison of size and trophic structure between protected (Pangatalan Island
 262 Marine Protected Area, PIMPA) and control (unprotected) sites. Effects of protection on total
 263 length (A), abundance per size class (B) and biomass (kg/ha) per trophic guild (C).

264 Across all study sites, the average biomass found was 260 kg/ha (SD=156), which is lower
 265 than the 300 kg/ha threshold indicating a biomass value potentially lower than MSY.

266 However, while control sites had an average biomass of 219 kg/ha (SD=101), the average

267 biomass in the protected sites was 584 kg/ha (SD=145), which is within the 300-600 kg/ha
268 threshold. While 86% of fished sites are in a state of overfishing, none of the protected ones
269 are: 62.5% are within MSY estimates and 37.5% are exceeding it (Figure 3).



270

271 Figure 4. Comparison of average target species biomass levels size between protected
272 (Pangatalan Island Marine Protected Area, PIMPA) and control (unprotected) sites. Average
273 target species biomass levels in control and protected sites.

274 When comparing protected and control sites in newly created MPAs (Depla, Sandoval and
275 Silanga) the linear mixed effects models computed only two significantly different fish
276 community metrics (out of 15 across all sites, Supporting Information, Figure S2, Tables S4-
277 7): in Depla, target species diversity was higher ($p < 0.05$) and in Sandoval the trophic level
278 was lower ($p < 0.05$). Fish communities between protected and control sites in newly
279 protected MPAs were therefore largely similar.

280 **4. Discussion**

281 Here, while providing the baseline data for a designated MPA network, we showed that after
282 5 years of protection, the first MPA of the network improved the status of species that matter
283 to local fisheries.

284 After five years of protection, as can be observed in other MPAs in the Philippines (Abesamis
285 et al., 2014; Aurellado et al., 2021; Fidler et al., 2014; Marriott et al., 2021) the abundance,
286 biomass and diversity of target species showed a significant increase, with large species
287 showing a greater response to protection than smaller species. On average, biomass in the
288 protected sites (584 kg/ha) was lower than the 1000-1200 kg/ha threshold representing the
289 estimated average biomass of coral reefs in the absence of fishing and proposed as a potential
290 conservation target for coral reefs (MacNeil et al., 2015; McClanahan et al., 2015). However,
291 the MPA is still young and biomass can still progress in the future (Babcock et al., 2010;
292 Claudet et al., 2008). While peak biomass and abundance are usually reached between 7-10
293 years for Pomacanthidae and Labridae, it can take more than 40 years for Acanthuridae and
294 Balistidae (Abesamis et al., 2014; McClanahan et al., 2007). Local conditions, as well as the
295 selection of species included in the UVC, values of length-weight relationships and factors
296 such as observation bias, can all significantly affect biomass, making absolute comparisons to
297 a threshold only partially informative.

298 No significantly different average trophic level was observed in protected sites compared to
299 control sites. Piscivores and macroinvertebrates tend to show the fastest and largest response
300 to protection (Campbell et al., 2018; MacNeil et al., 2015) as fisheries tend to target and
301 erode disproportionately the higher trophic levels (Pauly et al., 1998; Shannon et al., 2014).
302 However, in this case study, many sites with low biomass still exhibited a high trophic level.
303 This is due to the fact that in these sites, the fish biomass observed mainly consisted of small

304 microinvertebrates such as *Scolopsis ciliata* and herbivore biomass (in particular *Scarinae*)
305 was low. A large-scale study spanning over 250 reef sites globally showed a negative
306 correlation between biomass and trophic level, with sites of lower biomass displaying higher
307 trophic levels (Graham et al., 2017). Habitat, in particular coral cover, can have a strong
308 effect on trophic biomass (Russ et al., 2021).

309 This study has been designed to provide the baseline data for a future BACI assessment of the
310 newly implemented MPA network. We show that very little significant difference in fish
311 communities exist between newly protected sites and their respective control sites prior to
312 protection measures. Potential future differences would therefore likely be attributed to
313 protection. We were also able to provide a CI assessment of the first MPA of the network,
314 which is already implemented and actively managed (*sensu* Grorud-Colvert et al., 2021),
315 showing that the differences observed between protected and control sites are likely linked to
316 the conservation measures implemented. Future sampling can be improved by collecting fine
317 scale habitat data (e.g. benthic composition including coral cover, habitat complexity) in each
318 site to use as co-variate in our analyses (McClure et al., 2020; Russ et al., 2021; Sievers et al.,
319 2020). The fact to select a large number of control sites and to place all sites in similar depth
320 ranges and habitat (i.e. reef slope) conditions could capture the variability in habitat
321 conditions found around the bay. The use of water turbidity and depth also constituted the
322 best available proxies for habitat condition. Yet, having more robust habitat data such as coral
323 cover could both make a stronger case for the effects of protection and estimate more finely
324 these effects in each individual site based on local habitat conditions. The collection of
325 fishing effort and catch data, in partnership with local fishers, could also complement
326 analyses in order to show potential effects of protection on fisheries outcomes, or use fishing
327 effort as a covariate to better capture the effects of habitat and protection (Claudet and
328 Guidetti, 2010; Li et al., 2020a; Sultan, 2021; Ziegler et al., 2022). Just as habitat, fishing

329 effort can significantly shape fish communities (Russ et al., 2021), and using fine-scale effort
330 data would better isolate habitat effects in individual sites. Pre-existing fishing effort, in
331 particular, can significantly shape the effects of later protection measures (Li et al., 2020b). In
332 the case of PIMPA, local fishers describe an important depletion of fish communities linked
333 to legal and illegal fishing activities that included mainly blast and cyanide fishing (personal
334 communication). That important depletion could explain the changes in fish communities
335 observed and the fact that biomass was almost three times higher in protected sites after five
336 years of protection. Finally, other drivers can influence fish communities such as nutrient
337 availability, currents, or ecological connectivity (Graham et al., 2018; Morais et al., 2021).
338 Our approach to include a large number of sites made it unlikely that these drivers would
339 significantly vary between sites, in particular between protected and control sites.

340 The present study focused on five common metrics to study the effects of protection on fish
341 populations, but other dimensions could also be studied such as recruitment, age structure, or
342 functional redundancy (Blowes et al., 2020; Loiseau and Gaertner, 2015; Mascia et al., 2017).
343 The productivity of ecosystems can also represent a valuable indicator, aside from standing
344 biomass, opening the door to the deeper study of potential and actual impacts of marine
345 protection –and other drivers– on fisheries (Hamilton et al., 2022; Morais and Bellwood,
346 2020; Seguin et al., 2022).

347 The engagement of small-scale fishers in the study (see Supplementary Information for the
348 detailed questionnaire used) proved beneficial to properly delineate the benefits of
349 conservation for exploited fishes. Other engagement included participation of the authors in
350 fishing activities, information campaigns to discuss and disseminate the results, including
351 meetings with Fisherfolks Associations and with the larger communities. It also opened a
352 dialogue on the importance of monitoring the effects of MPAs, along with discussions on the
353 socio-cultural importance of fish, paving the way for more research on the social dimensions

354 of conservation and a better inclusion of fishers in management. Collaborative approaches
355 have the potential to improve management outcomes (Andrachuk et al., 2022; Bennett et al.,
356 2019; Bodin, 2017; Delevaux et al., 2018; Di Franco et al., 2020; Mason et al., 2020;
357 Pomeroy et al., 2007) but can also allow local users to participate in the monitoring of
358 resources. To push this further, local fisher are currently being trained to conduct ecological
359 and fisheries monitoring of the MPAs network in Shark Fin Bay.

360 6. References

- 361 Abesamis, R.A., Green, A.L., Russ, G.R., Jadloc, C.R.L., 2014. The intrinsic vulnerability to
362 fishing of coral reef fishes and their differential recovery in fishery closures. *Rev.*
363 *Fish Biol. Fish.* 24, 1033–1063. <https://doi.org/10.1007/s11160-014-9362-x>
- 364 Abesamis, R.A., Russ, G.R., Alcala, A.C., 2006. Gradients of abundance of fish across no-
365 take marine reserve boundaries: evidence from Philippine coral reefs. *Aquat. Conserv.*
366 *Mar. Freshw. Ecosyst.* 16, 349–371. <https://doi.org/10.1002/aqc.730>
- 367 Ahmadia, G.N., Glew, L., Provost, M., Gill, D., Hidayat, N.I., Mangubhai, S., Purwanto, Fox,
368 H.E., 2015. Integrating impact evaluation in the design and implementation of
369 monitoring marine protected areas. *Philos. Trans. R. Soc. B Biol. Sci.* 370, 20140275.
370 <https://doi.org/10.1098/rstb.2014.0275>
- 371 Alcala, A.C., Russ, G.R., 2006. No-take Marine Reserves and Reef Fisheries Management in
372 the Philippines: A New People Power Revolution. *AMBIO J. Hum. Environ.* 35, 245–
373 254. <https://doi.org/10.1579/05-A-054R1.1>
- 374 Andrachuk, M., Epstein, G., Andriamalala, G., Bambridge, T., Ban, N., Cunningham, E.,
375 Darling, E., Gurney, G.G., Litsinger, E., McIntosh, E., Mills, M., Morrison, T.,
376 Mangubhai, S., Oates, J., Pietri, D., Ruano-Chamorro, C., Tirona, R.S., Wabnitz, C.,
377 Young, J., 2022. CORAL REEF GOVERNANCE: STRENGTHENING
378 COMMUNITY AND COLLABORATIVE APPROACHES 17.
- 379 Aurellado, M.E.B., Ticzon, V.S., Nañola, C.L., Cabansag, J.B.P., Bacabac, M.M.A., Sorgon,
380 K.E.S., Simon, A.N.P., Hilomen, V.V., 2021. Effectiveness of Philippine Nationally
381 Managed Marine Reserves in Improving Biomass and Trophic Structure of Coral
382 Reef Fish Communities. *Coast. Manag.* 49, 293–312.
383 <https://doi.org/10.1080/08920753.2021.1899944>
- 384 Babcock, R.C., Shears, N.T., Alcala, A.C., Barrett, N.S., Edgar, G.J., Lafferty, K.D.,
385 McClanahan, T.R., Russ, G.R., 2010. Decadal trends in marine reserves reveal
386 differential rates of change in direct and indirect effects. *Proc. Natl. Acad. Sci.* 107,
387 18256–18261. <https://doi.org/10.1073/pnas.0908012107>
- 388 Bayley, D.T.I., Purvis, A., Nellas, A.C., Arias, M., Koldewey, H.J., 2020. Measuring the
389 long-term success of small-scale marine protected areas in a Philippine reef fishery.
390 *Coral Reefs* 39, 1591–1604. <https://doi.org/10.1007/s00338-020-01987-7>
- 391 Beger, M., Harborne, A.R., Dacles, T.P., Solandt, J.-L., Ledesma, G.L., 2004. A Framework
392 of Lessons Learned from Community-Based Marine Reserves and Its Effectiveness in
393 Guiding a New Coastal Management Initiative in the Philippines. *Environ. Manage.*
394 34, 786–801. <https://doi.org/10.1007/s00267-004-0149-z>
- 395 Bennett, N.J., 2022. Mainstreaming Equity and Justice in the Ocean. *Front. Mar. Sci.* 9,
396 873572. <https://doi.org/10.3389/fmars.2022.873572>
- 397 Bennett, N.J., Di Franco, A., Calò, A., Nethery, E., Niccolini, F., Milazzo, M., Guidetti, P.,
398 2019. Local support for conservation is associated with perceptions of good
399 governance, social impacts, and ecological effectiveness. *Conserv. Lett.* 12.
400 <https://doi.org/10.1111/conl.12640>
- 401 Blowes, S.A., Chase, J.M., Di Franco, A., Frid, O., Gotelli, N.J., Guidetti, P., Knight, T.M.,
402 May, F., McGlenn, D.J., Micheli, F., Sala, E., Belmaker, J., 2020. Mediterranean

403 marine protected areas have higher biodiversity via increased evenness, not
404 abundance. *J. Appl. Ecol.* 57, 578–589. <https://doi.org/10.1111/1365-2664.13549>

405 Blythe, J.L., Gill, D.A., Claudet, J., Bennett, N.J., Gurney, G.G., Baggio, J.A., Ban, N.C.,
406 Bernard, M.L., Brun, V., Darling, E.S., Di Franco, A., Epstein, G., Franks, P., Horan,
407 R., Jupiter, S.D., Lau, J., Lazzari, N., Mahajan, S.L., Mangubhai, S., Naggea, J.,
408 Turner, R.A., Zafra-Calvo, N., 2023. Blue justice: A review of emerging scholarship
409 and resistance movements. *Camb. Prisms Coast. Futur.* 1, e15.
410 <https://doi.org/10.1017/cft.2023.4>

411 Bodin, Ö., 2017. Collaborative environmental governance: Achieving collective action in
412 social-ecological systems. *Science* 357, eaan1114.
413 <https://doi.org/10.1126/science.aan1114>

414 Boettiger, C., Lang, D.T., Wainwright, P.C., 2012. “rfishbase: exploring, manipulating and
415 visualizing FishBase data from R”. In: *Journal of Fish Biology* 81.6 (Nov. 2012),
416 pp. 2030-2039. DOI: 10.1111/j.1095-8649.2012.03464.x.

417 Campbell, S.J., Edgar, G.J., Stuart-Smith, R.D., Soler, G., Bates, A.E., 2018. Fishing-gear
418 restrictions and biomass gains for coral reef fishes in marine protected areas. *Conserv.*
419 *Biol.* 32, 401–410. <https://doi.org/10.1111/cobi.12996>

420 Chamberlain, S., 2020. rredlist: “IUCN” Red List Client. R package version 0.7.0.
421 <https://CRAN.R-project.org/package=rredlist>.

422 Claudet, J., Guidetti, P., 2010. Improving assessments of marine protected areas. *Aquat.*
423 *Conserv. Mar. Freshw. Ecosyst.* 20, 239–242. <https://doi.org/10.1002/aqc.1087>

424 Claudet, J., Osenberg, C.W., Benedetti-Cecchi, L., Domenici, P., García-Charton, J.-A.,
425 Pérez-Ruzafa, Á., Badalamenti, F., Bayle-Sempere, J., Brito, A., Bulleri, F., Culioli,
426 J.-M., Dimech, M., Falcón, J.M., Guala, I., Milazzo, M., Sánchez-Meca, J.,
427 Somerfield, P.J., Stobart, B., Vandeperre, F., Valle, C., Planes, S., 2008. Marine
428 reserves: size and age do matter. *Ecol. Lett.* 11, 481–489.
429 <https://doi.org/10.1111/j.1461-0248.2008.01166.x>

430 Claudet, J., Pelletier, D., Jouvenel, J.-Y., Bachet, F., Galzin, R., 2006. Assessing the effects
431 of marine protected area (MPA) on a reef fish assemblage in a northwestern
432 Mediterranean marine reserve: Identifying community-based indicators. *Biol.*
433 *Conserv.* 130, 349–369. <https://doi.org/10.1016/j.biocon.2005.12.030>

434 Delevaux, J., Winter, K., Jupiter, S., Blaich-Vaughan, M., Stamoulis, K., Bremer, L., Burnett,
435 K., Garrod, P., Troller, J., Ticktin, T., 2018. Linking Land and Sea through
436 Collaborative Research to Inform Contemporary applications of Traditional Resource
437 Management in Hawai‘i. *Sustainability* 10, 3147. <https://doi.org/10.3390/su10093147>

438 Di Franco, A., Hogg, K.E., Calò, A., Bennett, N.J., Sévin-Allouet, M.-A., Esparza Alaminos,
439 O., Lang, M., Koutsoubas, D., Prvan, M., Santarossa, L., Niccolini, F., Milazzo, M.,
440 Guidetti, P., 2020. Improving marine protected area governance through collaboration
441 and co-production. *J. Environ. Manage.* 269, 110757.
442 <https://doi.org/10.1016/j.jenvman.2020.110757>

443 Fabinyi, M., 2018. Environmental fixes and historical trajectories of marine resource use in
444 Southeast Asia. *Geoforum* 91, 87–96. <https://doi.org/10.1016/j.geoforum.2018.02.033>

445 Ferse, S.C.A., Máñez Costa, M., Máñez, K.S., Adhuri, D.S., Glaser, M., 2010. Allies, not
446 aliens: increasing the role of local communities in marine protected area

- 447 implementation. *Environ. Conserv.* 37, 23–34.
448 <https://doi.org/10.1017/S0376892910000172>
- 449 Fidler, R., Maypa, A., Apistar, D., White, A., Turingan, R., 2014. Body Size Shifts in
450 Philippine Reef Fishes: Interfamilial Variation in Responses to Protection. *Biology* 3,
451 264–280. <https://doi.org/10.3390/biology3020264>
- 452 Fraser, K.A., Adams, V.M., Pressey, R.L., Pandolfi, J.M., 2019. Impact evaluation and
453 conservation outcomes in marine protected areas: A case study of the Great Barrier
454 Reef Marine Park. *Biol. Conserv.* 238, 108185.
455 <https://doi.org/10.1016/j.biocon.2019.07.030>
- 456 Froese, R., Pauly, D., 2010. FishBase. Fisheries Centre, University of British Columbia
457 Vancouver, BC.
- 458 Gill, D.A., Blythe, J., Bennett, N., Evans, L., Brown, K., Turner, R.A., Baggio, J.A., Baker,
459 D., Ban, N.C., Brun, V., Claudet, J., Darling, E., Di Franco, A., Epstein, G.,
460 Estradivari, Gray, N.J., Gurney, G.G., Horan, R.P., Jupiter, S.D., Lau, J.D., Lazzari,
461 N., Lestari, P., Mahajan, S.L., Mangubhai, S., Naggea, J., Selig, E.R., Whitney, C.K.,
462 Zafra-Calvo, N., Muthiga, N.A., 2023. Triple exposure: Reducing negative impacts of
463 climate change, blue growth, and conservation on coastal communities. *One Earth* 6,
464 118–130. <https://doi.org/10.1016/j.oneear.2023.01.010>
- 465 Gill, D.A., Mascia, M.B., Ahmadi, G.N., Glew, L., Lester, S.E., Barnes, M., Craigie, I.,
466 Darling, E.S., Free, C.M., Geldmann, J., Holst, S., Jensen, O.P., White, A.T., Basurto,
467 X., Coad, L., Gates, R.D., Guannel, G., Mumby, P.J., Thomas, H., Whitmee, S.,
468 Woodley, S., Fox, H.E., 2017. Capacity shortfalls hinder the performance of marine
469 protected areas globally. *Nature* 543, 665–669. <https://doi.org/10.1038/nature21708>
- 470 Gonzales, B.J., 2013. Field guide to coastal fishes of Palawan. Coral Triangle Initiative.
- 471 Graham, N.A.J., McClanahan, T.R., MacNeil, M.A., Wilson, S.K., Cinner, J.E., Huchery, C.,
472 Holmes, T.H., 2017. Human Disruption of Coral Reef Trophic Structure. *Curr. Biol.*
473 27, 231–236. <https://doi.org/10.1016/j.cub.2016.10.062>
- 474 Graham, N.A.J., Wilson, S.K., Carr, P., Hoey, A.S., Jennings, S., MacNeil, M.A., 2018.
475 Seabirds enhance coral reef productivity and functioning in the absence of invasive
476 rats. *Nature* 559, 250–253. <https://doi.org/10.1038/s41586-018-0202-3>
- 477 Grorud-Colvert, K., Sullivan-Stack, J., Roberts, C., Constant, V., Horta e Costa, B., Pike,
478 E.P., Kingston, N., Laffoley, D., Sala, E., Claudet, J., Friedlander, A.M., Gill, D.A.,
479 Lester, S.E., Day, J.C., Gonçalves, E.J., Ahmadi, G.N., Rand, M., Villagomez, A.,
480 Ban, N.C., Gurney, G.G., Spalding, A.K., Bennett, N.J., Briggs, J., Morgan, L.E.,
481 Moffitt, R., Deguignet, M., Pikitch, E.K., Darling, E.S., Jessen, S., Hameed, S.O., Di
482 Carlo, G., Guidetti, P., Harris, J.M., Torre, J., Kizilkaya, Z., Agardy, T., Cury, P.,
483 Shah, N.J., Sack, K., Cao, L., Fernandez, M., Lubchenco, J., 2021. The MPA Guide:
484 A framework to achieve global goals for the ocean. *Science* 373, eabf0861.
485 <https://doi.org/10.1126/science.abf0861>
- 486 Gurney, G.G., Adams, V.M., Álvarez-Romero, J.G., Claudet, J., 2023. Area-based
487 conservation: Taking stock and looking ahead. *One Earth* 6, 98–104.
488 <https://doi.org/10.1016/j.oneear.2023.01.012>
- 489 Hamilton, M., Robinson, J.P.W., Benkwitt, C.E., Wilson, S.K., MacNeil, M.A., Ebrahim, A.,
490 Graham, N.A.J., 2022. Climate impacts alter fisheries productivity and turnover on
491 coral reefs. *Coral Reefs* 41, 921–935. <https://doi.org/10.1007/s00338-022-02265-4>

- 492 Horta e Costa, B., Claudet, J., Franco, G., Erzini, K., Caro, A., Gonçalves, E.J., 2016. A
493 regulation-based classification system for Marine Protected Areas (MPAs). *Mar.*
494 *Policy* 72, 192–198. <https://doi.org/10.1016/j.marpol.2016.06.021>
- 495 Jupiter, S.D., Cohen, P.J., Weeks, R., Tawake, A., Govan, H., 2014. Locally-managed marine
496 areas: multiple objectives and diverse strategies. *Pac. Conserv. Biol.* 20, 165.
497 <https://doi.org/10.1071/PC140165>
- 498 Kockel, A., Ban, N.C., Costa, M., Dearden, P., 2020. Evaluating approaches for scaling-up
499 community-based marine-protected areas into socially equitable and ecologically
500 representative networks. *Conserv. Biol.* 34, 137–147.
501 <https://doi.org/10.1111/cobi.13368>
- 502 Li, Y., Sun, M., Evans, K.S., Ren, Y., Chen, Y., 2020a. Rethinking marine conservation
503 strategies to minimize socio-economic costs in a dynamic perspective. *Biol. Conserv.*
504 244, 108512. <https://doi.org/10.1016/j.biocon.2020.108512>
- 505 Li, Y., Sun, M., Ren, Y., Chen, Y., 2020b. Impact of pre-closure fishing effort on marine
506 protected area performance in social-ecological dimensions: Implications for
507 developing marine conservation plans. *Sci. Total Environ.* 729, 138936.
508 <https://doi.org/10.1016/j.scitotenv.2020.138936>
- 509 Loiseau, N., Gaertner, J., 2015. Indices for assessing coral reef fish biodiversity: the need for
510 a change in habits. *Ecol. Evol.* 5, 4018–4027. <https://doi.org/10.1002/ece3.1619>
- 511 MacNeil, M.A., Graham, N.A.J., Cinner, J.E., Wilson, S.K., Williams, I.D., Maina, J.,
512 Newman, S., Friedlander, A.M., Jupiter, S., Polunin, N.V.C., McClanahan, T.R.,
513 2015. Recovery potential of the world’s coral reef fishes. *Nature* 520, 341–344.
514 <https://doi.org/10.1038/nature14358>
- 515 Mahajan, S.L., Jagadish, A., Glew, L., Ahmadi, G., Becker, H., Fidler, R.Y., Jeha, L., Mills,
516 M., Cox, C., DeMello, N., Harborne, A.R., Masuda, Y.J., McKinnon, M.C., Painter,
517 M., Wilkie, D., Mascia, M.B., 2021. A theory-based framework for understanding the
518 establishment, persistence, and diffusion of community-based conservation. *Conserv.*
519 *Sci. Pract.* 3. <https://doi.org/10.1111/csp2.299>
- 520 Maina, J., Kithiia, J., Cinner, J., Neale, E., Noble, S., Charles, D., Watson, J.E.M., 2016.
521 Integrating social–ecological vulnerability assessments with climate forecasts to
522 improve local climate adaptation planning for coral reef fisheries in Papua New
523 Guinea. *Reg. Environ. Change* 16, 881–891. <https://doi.org/10.1007/s10113-015-0807-0>
- 525 Marriott, S.E., Cox, C., Amolo, R.C., Apistar, D., Mancao, R.H., de Mutsert, K., 2021.
526 Implications of Community-Based Management of Marine Reserves in the
527 Philippines for Reef Fish Communities and Biodiversity. *Front. Mar. Sci.* 8, 731675.
528 <https://doi.org/10.3389/fmars.2021.731675>
- 529 Mascia, M.B., Fox, H.E., Glew, L., Ahmadi, G.N., Agrawal, A., Barnes, M., Basurto, X.,
530 Craigie, I., Darling, E., Geldmann, J., Gill, D., Holst Rice, S., Jensen, O.P., Lester,
531 S.E., McConney, P., Mumby, P.J., Nenadovic, M., Parks, J.E., Pomeroy, R.S., White,
532 A.T., 2017. A novel framework for analyzing conservation impacts: evaluation,
533 theory, and marine protected areas. *Ann. N. Y. Acad. Sci.* 1399, 93–115.
534 <https://doi.org/10.1111/nyas.13428>
- 535 Mascia, M.B., Pailler, S., Thieme, M.L., Rowe, A., Bottrill, M.C., Danielsen, F., Geldmann,
536 J., Naidoo, R., Pullin, A.S., Burgess, N.D., 2014. Commonalities and

537 complementarities among approaches to conservation monitoring and evaluation.
538 *Biol. Conserv.* 169, 258–267. <https://doi.org/10.1016/j.biocon.2013.11.017>

539 Mason, E.T., Kellum, A.N., Chiu, J.A., Waltz, G.T., Murray, S., Wendt, D.E., Starr, R.M.,
540 Semmens, B.X., 2020. Long-term participation in collaborative fisheries research
541 improves angler opinions on marine protected areas. *PeerJ* 8, e10146.
542 <https://doi.org/10.7717/peerj.10146>

543 Maypa, A.P., White, A.T., Cañares, E., Martinez, R., Eisma-Osorio, R.L., Aliño, P., Apistar,
544 D., 2012. Marine Protected Area Management Effectiveness: Progress and Lessons in
545 the Philippines. *Coast. Manag.* 40, 510–524.
546 <https://doi.org/10.1080/08920753.2012.709465>

547 McClanahan, T., Graham, N., Maina, J., Chabanet, P., Bruggemann, J., Polunin, N., 2007.
548 Influence of instantaneous variation on estimates of coral reef fish populations and
549 communities. *Mar. Ecol. Prog. Ser.* 340, 221–234.
550 <https://doi.org/10.3354/meps340221>

551 McClanahan, T.R., Graham, N.A.J., MacNeil, M.A., Cinner, J.E., 2015. Biomass-based
552 targets and the management of multispecies coral reef fisheries: Biomass-Based
553 Targets and the Management of Multispecies Coral Reef Fisheries. *Conserv. Biol.* 29,
554 409–417. <https://doi.org/10.1111/cobi.12430>

555 McClure, E.C., Sievers, K.T., Abesamis, R.A., Hoey, A.S., Alcalá, A.C., Russ, G.R., 2020.
556 Higher fish biomass inside than outside marine protected areas despite typhoon
557 impacts in a complex reefscape. *Biol. Conserv.* 241, 108354.
558 <https://doi.org/10.1016/j.biocon.2019.108354>

559 Miteva, D.A., Pattanayak, S.K., Ferraro, P.J., 2012. Evaluation of biodiversity policy
560 instruments: what works and what doesn't? *Oxf. Rev. Econ. Policy* 28, 69–92.
561 <https://doi.org/10.1093/oxrep/grs009>

562 Morais, R.A., Bellwood, D.R., 2020. Principles for estimating fish productivity on coral
563 reefs. *Coral Reefs* 39, 1221–1231. <https://doi.org/10.1007/s00338-020-01969-9>

564 Morais, R.A., Siqueira, A.C., Smallhorn-West, P.F., Bellwood, D.R., 2021. Spatial subsidies
565 drive sweet spots of tropical marine biomass production. *PLOS Biol.* 19, e3001435.
566 <https://doi.org/10.1371/journal.pbio.3001435>

567 Muallil, R.N., Deocadez, M.R., Martinez, R.J.S., Campos, W.L., Mamaug, S.S., Nañola,
568 C.L., Aliño, P.M., 2019. Effectiveness of small locally-managed marine protected
569 areas for coral reef fisheries management in the Philippines. *Ocean Coast. Manag.*
570 179, 104831. <https://doi.org/10.1016/j.ocecoaman.2019.104831>

571 Palomares, M.L.D., Pauly, D., 2014. Philippine marine fisheries catches: a bottom-up
572 reconstruction, 1950 to 2010. *Fish. Cent. Res. Rep.* 22, 176.

573 Parravicini, V., Casey, J.M., Schiettekate, N.M.D., Brandl, S.J., Pozas-Schacre, C., Carlot,
574 J., Edgar, G.J., Graham, N.A.J., Harmelin-Vivien, M., Kulbicki, M., Strona, G.,
575 Stuart-Smith, R.D., 2020. Delineating reef fish trophic guilds with global gut content
576 data synthesis and phylogeny. *PLOS Biol.* 18, e3000702.
577 <https://doi.org/10.1371/journal.pbio.3000702>

578 Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., Torres, F., 1998. Fishing Down Marine
579 Food Webs. *Science* 279, 860–863. <https://doi.org/10.1126/science.279.5352.860>

- 580 Pomeroy, R., Parks, J., Pollnac, R., Campson, T., Genio, E., Marlessy, C., Holle, E., Pido,
581 M., Nissapa, A., Boromthanasarat, S., Thu Hue, N., 2007. Fish wars: Conflict and
582 collaboration in fisheries management in Southeast Asia. *Mar. Policy* 31, 645–656.
583 <https://doi.org/10.1016/j.marpol.2007.03.012>
- 584 Pressey, R.L., Visconti, P., McKinnon, M.C., Gurney, G.G., Barnes, M.D., Glew, L., Maron,
585 M., 2021. The mismeasure of conservation. *Trends Ecol. Evol.* 36, 808–821.
586 <https://doi.org/10.1016/j.tree.2021.06.008>
- 587 R Core Team, 2020. R: A language and environment for statistical computing. R Foundation
588 for Statistical Computing.
- 589 Russ, G.R., Rizzari, J.R., Abesamis, R.A., Alcalá, A.C., 2021. Coral cover a stronger driver
590 of reef fish trophic biomass than fishing. *Ecol. Appl.* 31.
591 <https://doi.org/10.1002/eap.2224>
- 592 Seguin, R., Mouillot, D., Cinner, J.E., Stuart Smith, R.D., Maire, E., Graham, N.A.J.,
593 McLean, M., Vigliola, L., Loiseau, N., 2022. Towards process-oriented management
594 of tropical reefs in the anthropocene. *Nat. Sustain.* [https://doi.org/10.1038/s41893-](https://doi.org/10.1038/s41893-022-00981-x)
595 [022-00981-x](https://doi.org/10.1038/s41893-022-00981-x)
- 596 Shannon, L., Coll, M., Bundy, A., Gascuel, D., Heymans, J., Kleisner, K., Lynam, C.,
597 Piroddi, C., Tam, J., Travers-Trolet, M., Shin, Y., 2014. Trophic level-based
598 indicators to track fishing impacts across marine ecosystems. *Mar. Ecol. Prog. Ser.*
599 512, 115–140. <https://doi.org/10.3354/meps10821>
- 600 Sievers, K.T., McClure, E.C., Abesamis, R.A., Russ, G.R., 2020. Non-reef habitats in a
601 tropical seascape affect density and biomass of fishes on coral reefs. *Ecol. Evol.* 10,
602 13673–13686. <https://doi.org/10.1002/ece3.6940>
- 603 Sultan, R., 2021. Fisheries benefits of a marine protected area with endogenous fishing
604 efforts – A bioeconomic analysis. *Ocean Coast. Manag.* 207, 105594.
605 <https://doi.org/10.1016/j.ocecoaman.2021.105594>
- 606 Tranter, S.N., Estradivari, Ahmadi, G.N., Andradi-Brown, D.A., Muenzel, D., Agung, F.,
607 Amkieltiela, Ford, A.K., Habibi, A., Handayani, C.N., Iqbal, M., Krueck, N.C.,
608 Lazuardi, M.E., Muawanah, U., Papilaya, R.L., Razak, T.B., Sapari, A., Sjahrudin,
609 F.F., Veverka, L., Yusri, S., Beger, M., 2022. The inclusion of fisheries and tourism
610 in marine protected areas to support conservation in Indonesia. *Mar. Policy* 146,
611 105301. <https://doi.org/10.1016/j.marpol.2022.105301>
- 612 Twichell, J., Pollnac, R., Christie, P., 2018. Lessons from Philippines MPA Management:
613 Social Ecological Interactions, Participation, and MPA Performance. *Environ.*
614 *Manage.* 61, 916–927. <https://doi.org/10.1007/s00267-018-1020-y>
- 615 Underwood, A.J., 1994. On Beyond BACI: Sampling Designs that Might Reliably Detect
616 Environmental Disturbances. *Ecol. Appl.* 4, 3–15. <https://doi.org/10.2307/1942110>
- 617 Uychiaoco, A.J., Arceo, H.O., Green, S.J., Cruz, M.T.D.L., Gaité, P.A., Aliño, P.M., 2005.
618 Monitoring and Evaluation of Reef Protected Areas by Local Fishers in the
619 Philippines: Tightening the Adaptive Management Cycle. *Biodivers. Conserv.* 14,
620 2775–2794. <https://doi.org/10.1007/s10531-005-8414-x>
- 621 Weeks, R., Jupiter, S.D., 2013. Adaptive Comanagement of a Marine Protected Area
622 Network in Fiji. *Conserv. Biol.* 27, 1234–1244. <https://doi.org/10.1111/cobi.12153>

- 623 Weeks, R., Russ, G.R., Alcala, A.C., White, A.T., 2010. Effectiveness of Marine Protected
624 Areas in the Philippines for Biodiversity Conservation. *Conserv. Biol.* 24, 531–540.
625 <https://doi.org/10.1111/j.1523-1739.2009.01340.x>
- 626 White, A.T., Courtney, C.A., Salamanca, A., 2002. Experience with Marine Protected Area
627 Planning and Management in the Philippines. *Coast. Manag.* 30, 1–26.
628 <https://doi.org/10.1080/08920750252692599>
- 629 White, A.T., Eisma-Osorio, R.-L., Green, S.J., 2005. Integrated coastal management and
630 marine protected areas: Complementarity in the Philippines. *Ocean Coast. Manag.* 48,
631 948–971. <https://doi.org/10.1016/j.ocecoaman.2005.03.006>
- 632 Ziegler, S.L., Brooks, R.O., Hamilton, S.L., Ruttenberg, B.I., Chiu, J.A., Fields, R.T., Waltz,
633 G.T., Shen, C., Wendt, D.E., Starr, R.M., 2022. External fishing effort regulates
634 positive effects of no-take marine protected areas. *Biol. Conserv.* 269, 109546.
635 <https://doi.org/10.1016/j.biocon.2022.109546>
- 636