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

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Data accessibility

Data and codes used for all analyses are accessible on the first author's GitHub page (<https://github.com/victor-brun>).

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

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

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

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

2. Methods

2.1. Study site and management context

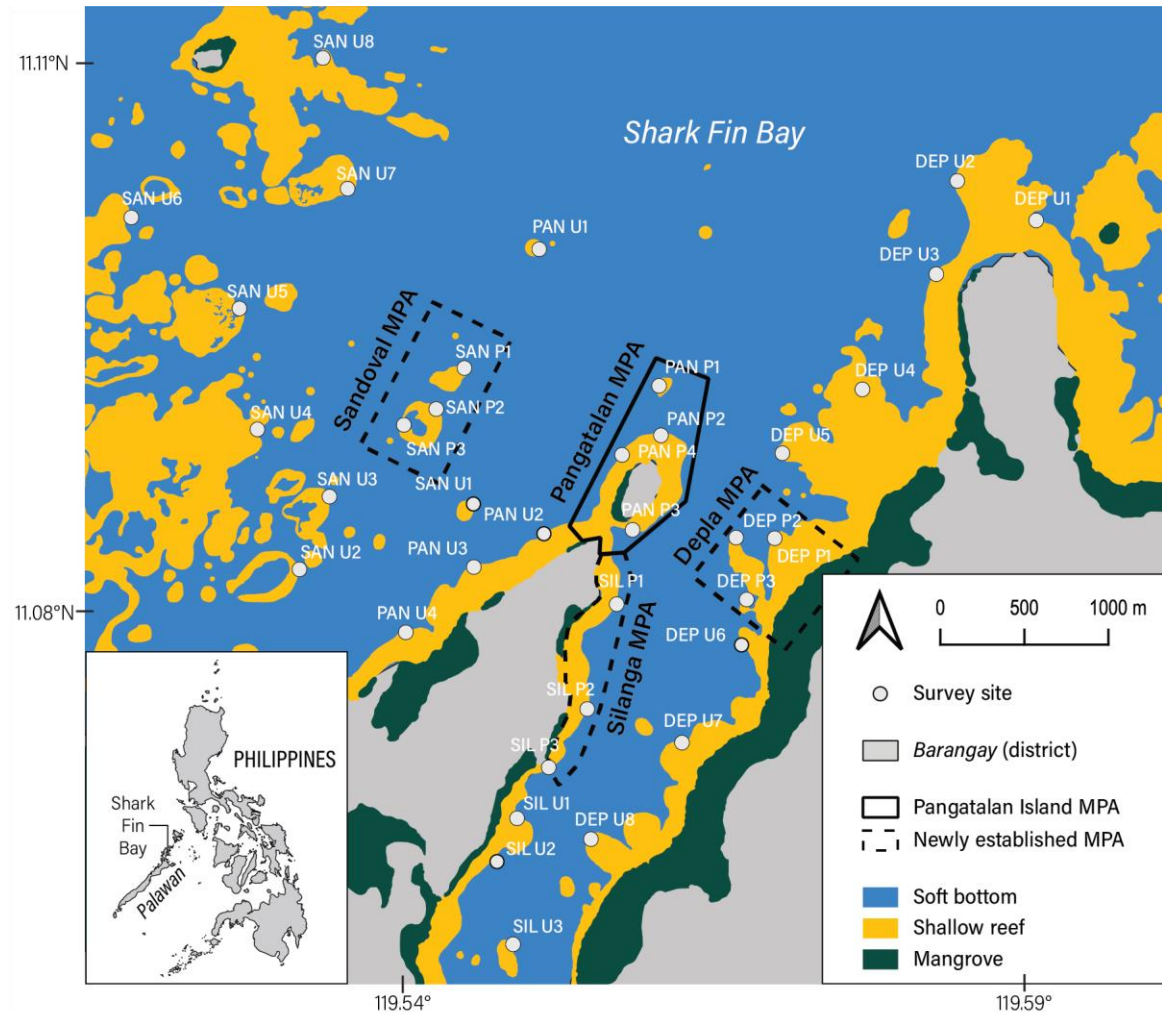


Figure 1. Map of the study area in Shark Fin Bay, Palawan, Philippines.

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

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

2.2. Identification of target species

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

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

2.3. Underwater visual census

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

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

2.4. Fish community metrics

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

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

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

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

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).

3. Results

Out of 7861 individual fishes, 91 species belonging to 12 families were observed in the UVC (complete list of species in the Supporting Information, Table S2). A restricted number of more common species dominated the counts, such as *Cheilinus fasciatus*, *Scarus hypselopterus*, *Lutjanus carponotatus*, or *Scolopsis margaritifera*. Four species were classified as threatened by the IUCN Red List of Threatened Species: *Cheilinus undulatus*, *Bolbometopon muricatum*, *Scarus hypselopterus*, and *Plectropomus areolatus*. Species classified as vulnerable and endangered were more abundant within the boundaries of PIMPA than outside (respectively 1.38% and 0.89% of observations, ANOVA: $p = 0.003$, $F = 9.279$).

In PIMPA, after five years of protection, the protected sites harbored a significantly higher target species richness ($p < 0.01$), higher abundance ($p < 0.05$), larger fish ($p < 0.001$), and a higher biomass ($p < 0.001$) compared to control sites (Figure 2). The average trophic level was found to be slightly higher in protected sites but that trend was not significant ($p > 0.05$).

Complete outputs of the models are available in Supporting Information (Figure S3).

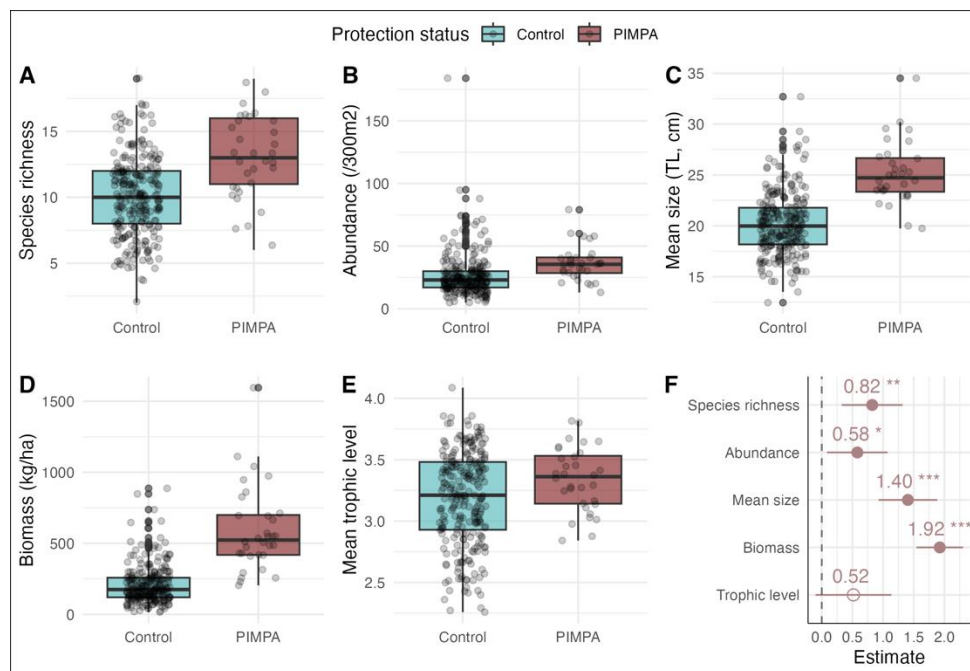


Figure 2. Comparison of community metrics between protected (Pangatalan Island Marine Protected Area, PIMPA) and control (fished) sites. Boxplots showing the difference in community parameters between protected (PIMPA) and control sites (panels A-E); forest plot representing the estimates obtained from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

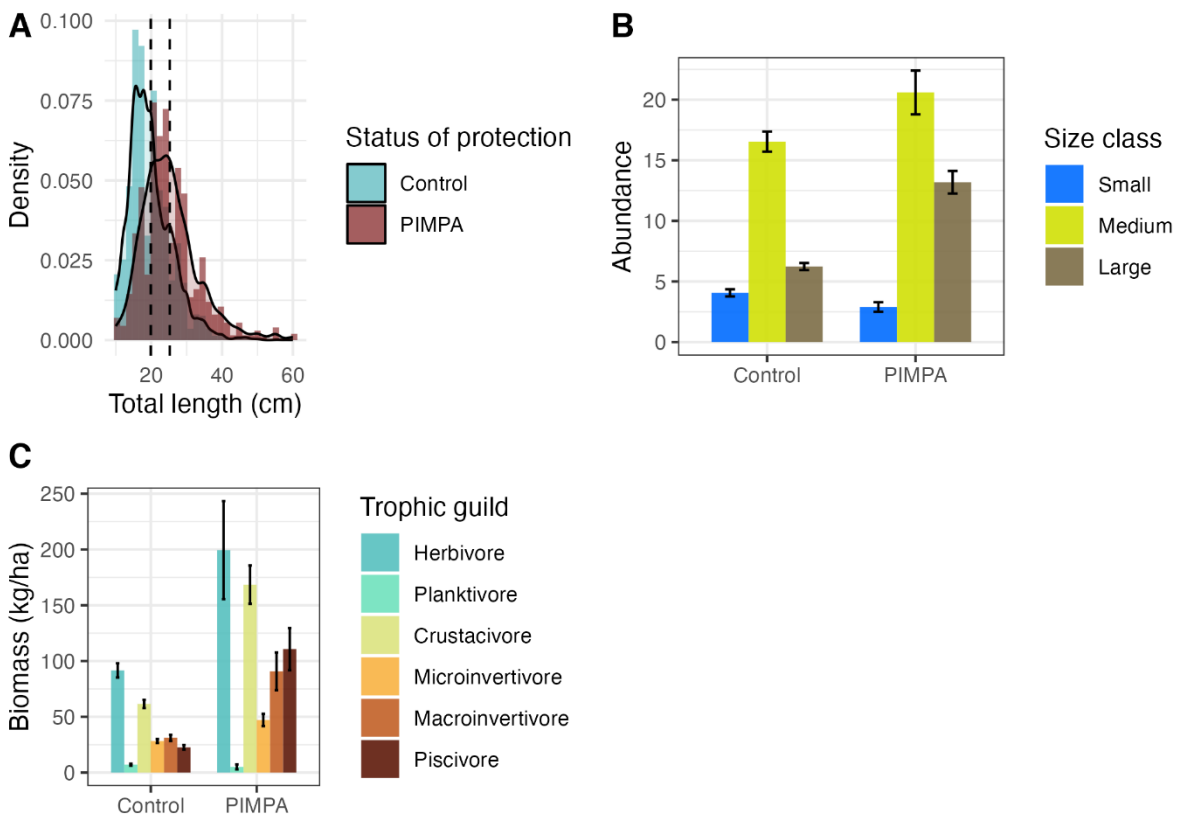


Figure 3. Comparison of size and trophic structure between protected (Pangatalan Island Marine Protected Area, PIMPA) and control (unprotected) sites. Effects of protection on total length (A), abundance per size class (B) and biomass (kg/ha) per trophic guild (C).

Across all study sites, the average biomass found was 260 kg/ha (SD=156), which is lower than the 300 kg/ha threshold indicating a biomass value potentially lower than MSY. However, while control sites had an average biomass of 219 kg/ha (SD=101), the average

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

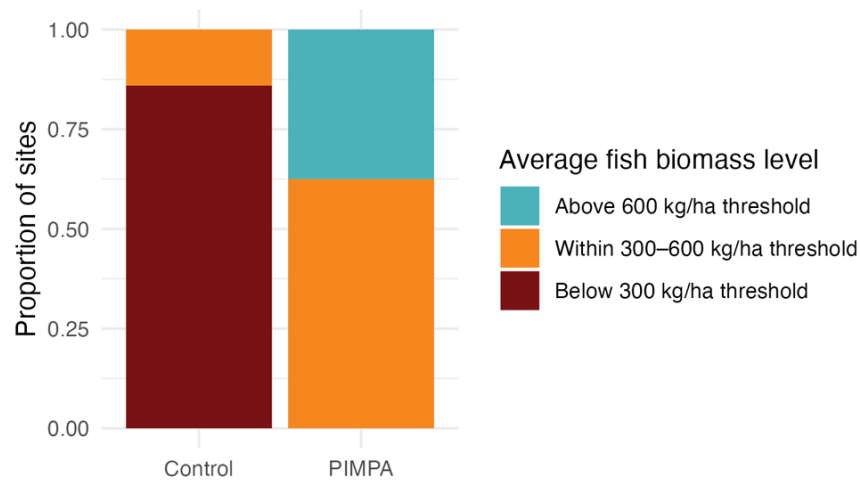


Figure 4. Comparison of average target species biomass levels size between protected (Pangatalan Island Marine Protected Area, PIMPA) and control (unprotected) sites. Average target species biomass levels in control and protected sites.

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

4. Discussion

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

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

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

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

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

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

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

The engagement of small-scale fishers in the study (see Supplementary Information for the detailed questionnaire used) proved beneficial to properly delineate the benefits of conservation for exploited fishes. Other engagement included participation of the authors in fishing activities, information campaigns to discuss and disseminate the results, including meetings with Fisherfolks Associations and with the larger communities. It also opened a dialogue on the importance of monitoring the effects of MPAs, along with discussions on the 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.

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