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**RESEARCH ARTICLE**

# MPA-FishMApp – A Citizen Science App That Simplifies Monitoring of Coral Reef Fish Density and Biomass in Marine Protected Areas

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ABSTRACT

Monitoring changes in fish density and biomass inside marine protected areas (MPAs) through fish visual census (FVC) can determine if MPAs are achieving their goal of promoting fish population recovery. Simplified FVC methods have been developed for citizen scientists to enable them to monitor fish populations in MPAs. However, MPA monitoring programs led by local stakeholders remain rare and difficult to sustain due to technical barriers related to FVC data management. Here, we describe and evaluate a novel online app called MPA-FishMApp, which we developed to help stakeholders of MPAs that protect coral reefs in the Philippines efficiently store, analyze, and visualize FVC data. MPA-FishMApp is coupled to a simplified FVC method wherein the observer records only 21 reef fish species groups during surveys. The app provides a simple data entry interface, cloud storage, and algorithms to estimate fish density and biomass. Spatial and temporal trends in fish density and biomass can be instantaneously visualized in the app based on relative importance to fisheries. Field testing suggested that the MPA-FishMApp methodology (simplified FVC and app) is sensitive enough to detect qualitative patterns showing differences in density and biomass that may develop between MPAs and fished sites, especially in fishes that are highly important to fisheries. However, users must have sufficient training and experience in simplified FVC to produce reliable data. MPA-FishMApp may help reverse the lack of monitoring in MPAs across the Philippines and offers an accessible, transparent, and auditable venue for collaboration between citizen scientists and professional scientists.

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## 1. INTRODUCTION

A primary goal of marine protected areas (MPAs – sea areas where fishing has been lawfully prohibited) is to promote the conservation and population recovery of fish species exploited by fisheries. Therefore, monitoring changes in the density and biomass of local fish populations from year to year can reveal whether MPAs are achieving this goal amidst human-induced and natural disturbances (Williamson et al. 2014; Russ et al. 2021). For MPAs situated on coral reefs, fish density and biomass monitoring are usually done by snorkel divers or SCUBA skilled in underwater fish visual census (FVC) techniques. Typically, FVC involves identifying dozens to hundreds of fish species to a specific taxonomic level (family, genus, or species), recording their abundance, and estimating their body sizes (length) visually along replicate belt transects (English et al. 1997; Hodgson et al. 2006).

Monitoring the effects of MPAs on fish populations is traditionally considered an undertaking confined to the domain of expert scientists. However, this view is changing due to increasing participation by citizen scientists (i.e., people who are not trained as scientists but can systematically collect and analyze data to test hypotheses) in ecological studies (Bonney et al. 2014; Forrester et al. 2015; Stuart-Smith et al. 2017). Citizen scientists can become effective force multipliers in quantifying the ecological effects of MPAs, provided they are sufficiently trained on methods cross-validated by expert data (Leopold et al. 2009; Edgar et al. 2020). For instance, trained citizen scientists were instrumental in a large-scale study on the drivers of the conservation benefits of MPAs, which required conducting FVCs across 964 sites in 87 MPAs and 1,022 non-MPA sites around the world (Edgar et al. 2014).

MPAs are widely implemented and advocated as an approach to biodiversity conservation and fisheries management in coastal areas of the Philippines. Close to 1,800 MPAs have been established nationwide over the past four decades, a large proportion of which protect coral reefs in the Visayas region (Alcala et al. 2008; Cabral et al. 2014). Most of these MPAs are small and managed by local stakeholders (e.g., people's organizations, barangay, and local government units) (Weeks et al. 2010). Monitoring reef fish standing stock and timely reporting of findings to decision-making bodies constitute important benchmarks for gauging management effectiveness in these MPAs (Uychiaoco et al. 2001; Alcala et al. 2008; Lowry et al. 2009). Furthermore, monitoring of MPAs by or with the participation of the local community can have multiple benefits for adaptive resource management, including enhanced knowledge transfer and cooperation among stakeholders (Uychiaoco et al. 2005).

Simplified FVC and associated data reporting mechanisms suitable for stakeholders of MPAs in the Philippines have been available for the past two decades (e.g., Uychiaoco et al. 2001). Yet, the uptake of these methodologies has been slow, and MPA monitoring programs led by local stakeholders remain very rare and difficult to sustain. This situation probably persists due in part to unresolved challenges related to the management of FVC data, most especially concerning data storage, analysis, and visualization. However, these challenges can be minimized by harnessing existing technologies such as the internet or developing technical innovations such as apps that are accessible to stakeholders to empower them as citizen scientists (Bonney et al. 2014).

This paper has two objectives. First is to present MPA-FishMApp (short for MPA Fish Monitoring App), a novel online app coupled with a simplified FVC method. We developed MPA-FishMApp to help stakeholders of MPAs in the Philippines efficiently capture and store FVC data and quickly generate and visualize estimates of reef fish density and biomass. We describe the MPA-FishMApp methodology, which consists of the simplified FVC method and the app's data entry, storage, analysis, and visualization functionalities. The assumptions behind how the app calculates fish density and biomass are also discussed. The second objective is to assess the performance of the MPA-FishMApp methodology, given its relative simplicity and computational assumptions. We asked two questions, the first of which focused on the quantitative accuracy of MPA-FishMApp outputs, while the second focused on qualitative accuracy: 1) How different are the quantitative estimates of fish density and biomass generated by the MPA-FishMApp methodology from those derived from expert data, specifically, absolute estimates of average density or biomass inside and outside MPAs? 2) How different are the qualitative patterns generated by the MPA-FishMApp methodology from those derived from expert data, specifically, expected patterns of higher or lower density or biomass inside versus outside MPAs? These questions were addressed in a field test where density and biomass estimates generated by MPA-FishMApp from simplified FVC conducted by citizen scientists across several MPAs and fished sites at one time were directly compared to estimates generated by conventional analysis of expert-level FVC done at the same sites and time.

## 2. MATERIALS AND METHODS

### 2.1 MPA-FishMApp methodology

#### 2.1.1 Simplified fish visual census

The simplified FVC method that works with MPA-FishMApp requires recording counts of fish according to only 21 species groups instead of the dozens to hundreds of fish species that may be encountered during surveys on coral reefs (Supplementary Material – Appendix 1). Most of these species groups correspond to scientific families or reef fish species that are also fully or partially represented in other simplified FVC methods (see Uychiaoco et al. 2001; Hodgson et al. 2006). The relevance of these species groups to MPA effects and importance to reef fisheries was validated in a consultation workshop with stakeholders of MPAs in five municipalities in southern Negros (total of 18 key informants from Cauayan, Sipalay, and Hinoba-an in Negros Occidental, and Siaton and Zamboanguita in Negros Oriental) and follow up discussions with local fishers led by two key informants.

Fifteen of the species groups are fishery targets. Nine of these are of high fishery importance (parrotfishes – Family Labridae/Subfamily Scarinae; surgeonfishes – Acanthuridae; rabbitfishes – Siganidae; groupers – Serranidae/Epinephelinae; snappers – Lutjanidae; emperors – Lethrinidae; sweetlips – Haemulidae; jacks – Carangidae; and fusiliers – Caesionidae). Six are of moderate or low fishery importance (wrasses – Labridae; triggerfishes – Balistidae; coral breams – Nemipteridae; goatfishes – Mullidae; rudderfishes – Kyphosidae; and angelfishes – Pomacanthidae). Species groups of high fishery importance are expected to be the stronger drivers of differences in density and biomass between MPAs and fished sites because they are probably subject to higher fishing pressure than the species groups of moderate or low fishery importance. In contrast, three of the 21 species groups are usually not targeted by fishing: fairy basslets (Serranidae/Anthiinae), damselfishes (Pomacentridae), and butterflyfishes (Chaetodontidae). These species are not likely to show a direct response to protection from fishing inside MPAs. They may also be referred to as potential coral habitat indicators because they may track broad changes in coral habitat quality due to their strong reliance on living corals for shelter or food. The remaining three species groups are considered rare or endangered due to overfishing: Napoleon wrasse (*Cheilinus undulatus*), bumphead parrotfish (*Bolbometopon muricatum*), and sharks (Carcharinidae). The simplified FVC also requires recording counts of two invertebrate species groups (crown-of-thorns starfish and giant clams), but these will not be discussed in the present study.

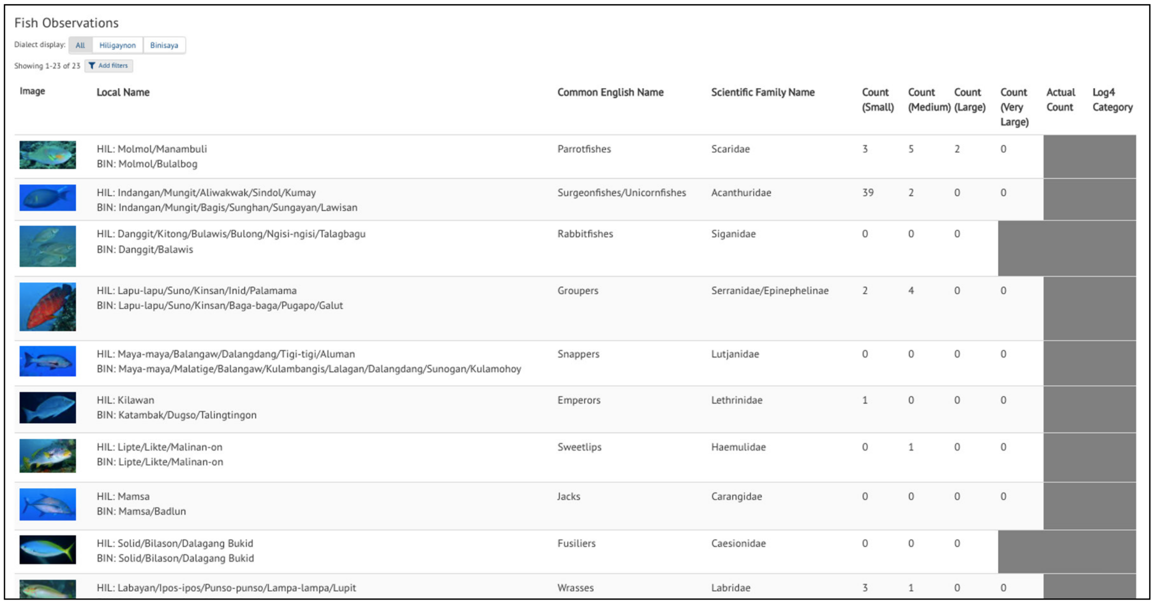
The recommended sampling unit for the simplified FVC is a belt transect that is 50 m long and 5 m wide (equivalent to an area of 250 $m^2$), although MPA-FishMApp can deal with other commonly used transect dimensions that users may specify (e.g., 50 x 10 m). During a census, the observer records the actual counts of fish that belong to the 15 fish species groups targeted by fisheries, the butterflyfishes, and the three rare or endangered species groups. The actual counts are recorded according to four size categories: small (10 cm total length (TL) or less); medium (11 to 30 cm TL); large (31 to 50 cm TL); and very large (51 cm TL or more). On the other hand, the total counts of fairy basslets and damselfishes for the entire transect are estimated following a system that uses eight categories based on a log4 abundance scale: category 1 – 1 fish; category 2 – 2 to 4 fish; category 3 – 5 to 16 fish; category 4 – 17 to 64 fish; category 5 – 65 to 256 fish; category 6 – 257 to 1,024 fish; category 7 – 1,025 to 4,096 fish; category 8 – 4,097 to 16,384 fish (Russ 1985; English et al. 1997). This system of counting is used for fairy basslets and damselfishes because they are small and tend to be very numerous; hence more difficult to count with high precision. MPA-FishMApp recommends using a specific data sheet formatted according to how the 21 species groups of fish should be counted (Supplementary Material - Appendix 2). This data sheet can either be photocopied on underwater paper or reproduced on slate boards.

#### 2.1.2 App platform, data entry, and storage

MPA-FishMApp was developed using an online database platform and can be freely accessed by registered users from a desktop, laptop, tablet, or smartphone via an internet connection: https://cfiusa.knack.com/mpa-fishmapp#. Count data for each replicate transect surveyed in a specific MPA or fished site (control) can be directly entered using a simple interface that closely mirrors the datasheet format (Figure 1). MPA-FishMApp automatically stores the data in the cloud (i.e., the global network of remote servers accessed through the internet). The interface displays photos of representative species and the common names of the 21 fish species groups in Binisaya, Hiligaynon, and English to help with data entry. The design of MPA-FishMApp for its general features, functionality, and languages was informed by inputs from the stakeholders in southern Negros, who were consulted during the same workshop that validated the species groups in the simplified FVC.

#### 2.1.3 Calculations and visualizations

MPA-FishMApp generates data visualizations (i.e., bar graphs) that show the average fish density (number of individuals per unit area) and biomass (collective weight of individuals per unit area) within an MPA or a control calculated across replicate transects. A user can instantaneously generate these visualizations from data records by simply clicking the “Visualizations” button in the app (Figure 2). Bar graphs can be generated for each of the 21 fish species groups or different groupings based on relative


Fish Observations

Dialect display: All | Hiligaynon | Binisaya

Showing 1-23 of 23 | Add filters

| Image | Local Name | Common English Name | Scientific Family Name | Count (Small) | Count (Medium) | Count (Large) | Count (Very Large) | Actual Count | Log4 Category |
|---|---|---|---|---|---|---|---|---|---|
| | HIL: Molmol/Manambuli<br>BIN: Molmol/Bulalbog | Parrotfishes | Scaridae | 3 | 5 | 2 | 0 | | |
| | HIL: Indangan/Mungit/Aliwakwak/Sindol/Kumay<br>BIN: Indangan/Mungit/Bagis/Sunghan/Sungayan/Lawisan | Surgeonfishes/Unicornfishes | Acanthuridae | 39 | 2 | 0 | 0 | | |
| | HIL: Danggit/Kitong/Bulawis/Bulong/Ngisi-ngisi/Talagbagu<br>BIN: Danggit/Balawis | Rabbitfishes | Siganidae | 0 | 0 | 0 | | | |
| | HIL: Lapu-lapu/Suno/Kinsan/Inid/Palamama<br>BIN: Lapu-lapu/Suno/Kinsan/Baga-baga/Pugapo/Galut | Groupers | Serranidae/Epinephelinae | 2 | 4 | 0 | 0 | | |
| | HIL: Maya-maya/Balangaw/Dalangdang/Tigi-tigi/Aluman<br>BIN: Maya-maya/Malatige/Balangaw/Kulambangis/Lalagan/Dalangdang/Sunogan/Kulamohoy | Snappers | Lutjanidae | 0 | 0 | 0 | 0 | | |
| | HIL: Kilawan<br>BIN: Katambak/Dugso/Talingtingon | Emperors | Lethrinidae | 1 | 0 | 0 | 0 | | |
| | HIL: Lipte/Likte/Malinan-on<br>BIN: Lipte/Likte/Malinan-on | Sweetlips | Haemulidae | 0 | 1 | 0 | 0 | | |
| | HIL: Mamsa<br>BIN: Mamsa/Badlun | Jacks | Carangidae | 0 | 0 | 0 | 0 | | |
| | HIL: Solid/Bilason/Dalagang Bukid<br>BIN: Solid/Bilason/Dalagang Bukid | Fusiliers | Caesionidae | 0 | 0 | 0 | | | |
| | HIL: Labayan/Ipos-ipos/Punso-punso/Lampa-lampa/Lupit | Wrasses | Labridae | 3 | 1 | 0 | 0 | | |

Figure 1. Screenshot of the data entry interface of MPA-FishMApp partially showing the 23 species groups (21 fish and 2 invertebrates) included in the simplified FVC.

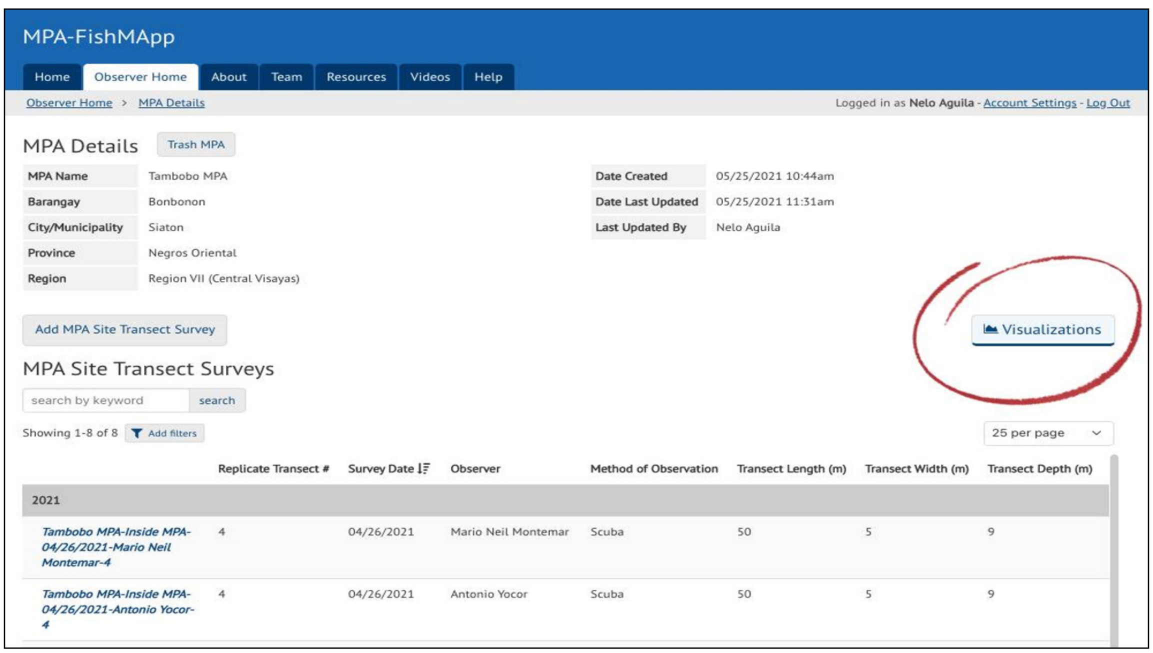



Figure 2. Screenshot of the MPA Details page of MPA-FishMApp where records of FVC data per transect in an MPA and corresponding control are displayed. Bar graphs of the average density and biomass of the different species groups can be instantaneously generated from these records by simply clicking the encircled "Visualizations" button.

importance to fisheries (Figure 3). Comparisons between an MPA and control can be generated for different years to show spatial and temporal trends.

The app expresses fish density in terms of the average number of fish per 1000 square meters. However, counts of fairy basslets and damselfishes based on log4 categories are first converted to best count estimates before calculating density: category 1 – 1 fish; category 2 – 3 fish; category 3 – 10 fish; category 4 – 40 fish; category 5 – 160 fish; category 6 – 640 fish; category 7 – 1,025 fish; category 8 – 4,097 fish (e.g., Russ et al. 2021). These best estimates roughly correspond to the midpoint of the count range per category, except for the last two, which are equivalent to the lower end of the corresponding count range.

Estimates of biomass are calculated only for

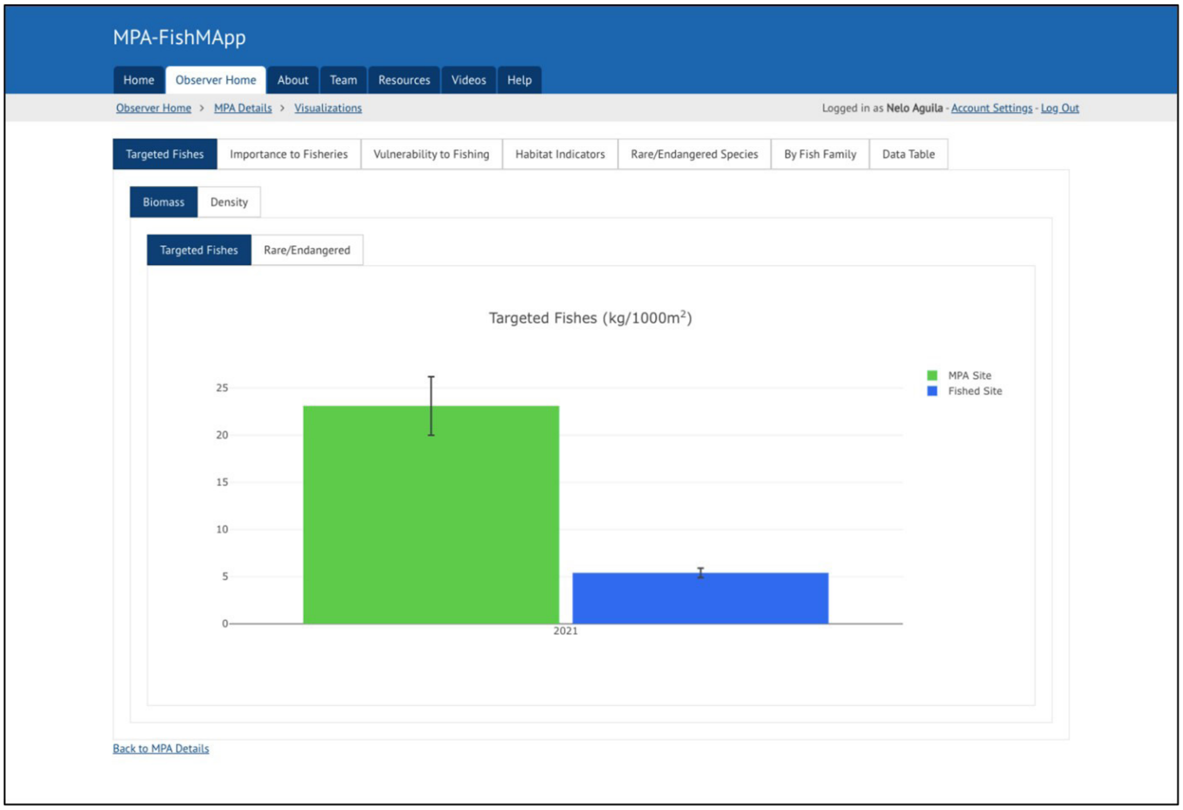



Figure 3. Screenshot of the Visualizations page of MPA-FishMApp showing a sample bar graph comparing the average biomass of all targeted fish inside an MPA (green) versus a corresponding control (blue) for a specific year. Similar bar graphs can be displayed by simply clicking on the different tabs shown on this page. Error bars represent standard errors (SE).

species groups that are counted according to the four size categories (small, medium, large, and very large), which excludes the fairy basslets and damselfishes. Before calculating biomass, best size estimates (TL) are first assigned to the four size categories: small = 10 cm; medium = 20 cm; large = 40 cm; very large = 70 cm. These best size estimates were arbitrarily defined for each size category. The biomass () of a species group within a size category is then estimated using the formula:

$$B=( a * L^b ) * C$$

where $L$ is the best size estimate for the size category, $C$ is the recorded total count within the size category, and $a$ and $b$ are the parameters of a length (in cm TL) to weight (in grams) model assigned to the size category. Values for a and b are based on a length-to-weight model of a representative species and are specific to each size category within a species group (Supplementary Material – Appendix 3). The biomass of a species group or combinations of species groups (e.g. all species groups targeted by fisheries) is then given by the sum of $B$ across all size categories, which MPA-FishMApp displays in kilograms per 1000 square meters.

#### 2.1.4 Resources

A detailed description of the MPA-FishMApp methodology is available in a User's Manual, which can be freely downloaded from the website. Recommended data sheets and a visual guide to the fish (and invertebrate) species groups are also available on the website. The website also hosts a three-part video series introducing users to the basic principles of sampling design, FVC protocols, and data management processes.

### 2.2 Field test of the MPA-FishMApp methodology

#### 2.2.1 Fish visual census

FVC data were collected by two types of observers. The first type is the citizen scientist, which was represented by two observers (co-authors MM and AY) who are not marine biologists and have little to no experience conducting FVC but have a combined fishing experience of 44 years at the time of the study and therefore very knowledgeable of the local names (in Binisaya) of reef fishes. They conducted surveys using the simplified FVC method after a brief orientation. The second type is the expert scientist. This was represented by one observer (lead author RA), a marine biologist with 23 years of experience conducting underwater fish visual surveys at the time of the study. The expert scientist conducted surveys at a higher level of detail, identifying fish species using scientific names, recording actual counts, and estimating individual sizes (TL) to the nearest 1 cm.

The two citizen scientists and one expert scientist conducted surveys on SCUBA simultaneously along the same belt transects within the same sites. Nine sites were surveyed in the Municipality of Siaton, Negros Oriental, in April-May 2021. Six of the sites consisted of three pairs of existing MPAs (sites 1, 3, 5) and corresponding "controls" that are open to fishing (sites 2, 4, 6) (Table 1). In addition, three of the sites were proposed MPAs still open to fishing (sites 7, 8, 9) (Table 1). To the best of our knowledge, the existing MPAs were strictly protected from fishing for at least 10 years prior to the surveys. In addition, the existing MPAs ranged in age from 20 to 28 at the time of the survey.

Four replicate 50-m-long belt transects were surveyed at each site (n = 36 replicate transects for the entire study). Transects were placed along the reef crest or slope, parallel to the shoreline, between depths of 6 to 10 m. The citizen scientists conducted surveys using a transect width of 5 m, with one observer on each side of the transect line. The expert scientist conducted surveys using a transect width of 10 m, recording fish that occurred within 5 m on either side of the transect line. All observers recorded the larger and more mobile fish species during the first pass along the transect. The smaller and more site-attached fish species were recorded during the return swim to the transect starting point.

We expected the expert scientist to detect a pattern of higher average density and biomass of fishery target species groups inside the three MPAs versus their corresponding controls, especially species groups of high fishery importance. However, this pattern should be absent or less apparent in species groups not directly affected by fishing, i.e., the potential coral habitat indicators (butterflyfishes, fairy basslets, and damselfishes). On the other hand, the average density and biomass of fishery target species groups should be lower in the three proposed MPAs relative to the existing MPAs.

### 2.2.2 Data analysis

We compared estimates of fish density and biomass generated by MPA-FishMApp from the citizen science data (see 2.1.3 Calculations and visualizations) with those generated by conventional expert data analysis. In contrast to the outputs of MPA-FishMApp, estimates of fish density derived from expert data used actual counts for all species groups. Furthermore, estimates of fish biomass derived from expert data used actual counts and size estimates at the individual level (not counts per size category) and species-specific a and b values of length-to-weight models (not representative species per species group). Data collected by the two citizen scientists were combined at the transect level to match the transect dimensions surveyed by the expert scientist. Fish species recorded by the expert scientist that did not belong to any of the

Table 1. Location and sampling depths of 9 sites in the Municipality of Siaton, Negros Oriental, where citizen scientists and the expert scientist conducted FVCs to assess the performance of MPA-FishMApp

| Site Number | Site Name | Depth (m) | Latitude ( °N ) | Longitude ( °E ) |
|---|---|---|---|---|
| 1 | Andulay MPA | 6-8 | 9.0599 | 123.1404 |
| 2 | Andulay Control | 7-8 | 9.0668 | 123.1484 |
| 3 | Tambobo MPA | 9 | 9.0500 | 123.1158 |
| 4 | Tambobo Control | 9 | 9.0534 | 123.1098 |
| 5 | Salag MPA | 10 | 9.0407 | 123.0096 |
| 6 | Salag Control | 10 | 9.0442 | 123.0023 |
| 7 | Giligaon Proposed MPA | 7 | 9.0842 | 122.9343 |
| 8 | Cabangahan Proposed MPA | 8 | 9.0701 | 122.9569 |
| 9 | Maloh Proposed MPA | 8-10 | 9.0528 | 122.9848 |

21 species groups in MPA-FishMApp were omitted in the comparisons.

Relative differences in estimates of fish density and biomass between the citizen scientist and expert data were quantified using the formula:
where D is the % relative difference as a proportion of

$$D = \left(\frac{CS - E}{E}\right) \times 100\%$$

the site-level average density or biomass estimated by the expert, and *CS* and *E* are the site-level estimates of average density or biomass derived from citizen scientist and expert data, respectively. A positive *D* value would indicate that the density or biomass estimated from citizen scientist data was higher relative to expert data; a negative *D* value would indicate the opposite. Average values of *D* across sites were computed for the different species groups, expressed as $\bar{D}$.

The quantitative and qualitative accuracy of MPA-FishMApp outputs were scored separately using three-point scales, with 3 being the highest score. To reiterate, quantitative accuracy addresses the question: How different are the quantitative estimates generated by MPA-FishMApp from those derived from expert data? This was scored based on specific qualifications under the following criteria: visual comparison of bar graphs, ANOVA results in relation to the effect of "Observer" and the absolute value of (Table 2a). On the other hand, qualitative accuracy addresses the question: How different are the qualitative patterns generated by MPA-FishMApp from those derived from expert data? Similarly, this was scored based on specific qualifications under the following criteria: visual comparison of bar graphs, ANOVA results in relation to the effect of "Site x Observer," and the strength of r (Table 2b). In addition, each comparison was given a score of 1, 2, or 3 if it met at least two specific qualifications for that score. Finally, scores for quantitative and qualitative accuracy were summed for each species group to give an overall picture of MPA-FishMApp performance per group. Total scores ≥4 were considered the highest.

## 3. RESULTS

### 3.1 Pooled counts across sites

Data pooled across all sites indicated that the expert and citizen scientists recorded the same general pattern of presence/absence across different species groups during FVC, with rare or endangered fish species and rudderfishes being entirely absent (Table 3). They also recorded a similar general pattern of relative abundance across species groups. Rabbitfishes, snappers, emperors, sweetlips, and jacks were much less abundant than other groups. For brevity, these groups were not included in further analyses except

Table 2. Criteria used in scoring the quantitative accuracy (a) and qualitative accuracy (b) of density and biomass estimates generated by MPA-FishMApp relative to expert data. $\bar{D}$ is the average relative difference between citizen scientist and expert data; Pearson's r indicates the strength of a linear association between citizen science and expert data; SE is standard error.

| a) Quantitative accuracy | | | |
|---|---|---|---|
| **Score** | **Comparison of bar graphs** | **ANOVA** | **Absolute value of $\bar{D}$** |
| 1 | Mean values mostly dissimilar, SEs not overlapping | Effect of "Observer" is significant | ≥50% |
| 2 | Mean values mostly similar, SEs overlapping | Effect of "Observer" may or may not be significant | <50% |
| 3 | Mean values mostly similar, SEs overlapping | Effect of "Observer" is not significant | ≤30% |
| b) Qualitative accuracy | | | |
| **Score** | **Comparison of bar graphs** | **ANOVA** | **Strength of *r*** |
| 1 | Very dissimilar patterns or trends | Effect of "Site x Observer" is significant | Weak or very weak |
| 2 | Somewhat similar patterns or trends | Effect of "Site x Observer" is not significant | Modest or weak |
| 3 | Very similar patterns or trends | Effect of "Site x Observer" is not significant | Strong or modest |

in comparisons involving pooled data for fishery target species. Evidently, however, the combined counts of the citizen scientists were often greater than those of the expert (Table 3). This was most obvious for the fairy basslets and damselfishes, which used log4 categories that were converted to best count estimates.

Table 3. Pooled counts across all fish sites in different species groups were estimated by the two citizen scientists (CS1 and CS2) and the expert (EXP).

| Species groups | CS1 | CS2 | CS1+CS2 | EXP |
|---|---|---|---|---|
| All fishery targets | 1888 | 3374 | 5262 | 4496 |
| | | | | |
| High fishery importance | *754* | *1952* | *2706* | *2850* |
| *Parrotfishes* | *104* | *134* | *238* | *203* |
| *Surgeonfishes/unicornfishes* | *287* | *931* | *1218* | *1314* |
| *Rabbitfishes* | *4* | *10* | *14* | *11* |
| *Groupers* | *98* | *220* | *318* | *150* |
| *Snappers* | *25* | *40* | *65* | *93* |
| *Emperors* | *10* | *40* | *50* | *18* |
| *Sweetlips* | *5* | *18* | *23* | *1* |
| *Jacks* | - | - | - | *2* |
| *Fusiliers* | *221* | *559* | *780* | *1058* |
| | | | | |
| Moderate/low fishery importance | 1134 | 1422 | 2556 | 1646 |
| *Wrasses* | *556* | *392* | *948* | *943* |
| *Triggerfishes* | *110* | *147* | *257* | *153* |
| *Coral breams* | *113* | *239* | *352* | *145* |
| *Goatfishes* | *215* | *304* | *519* | *281* |
| *Rudderfishes* | - | - | - | - |
| *Angelfishes* | *140* | *340* | *480* | *124* |
| | | | | |
| Habitat indicators | 23613 | 24878 | 48491 | 19559 |
| *Butterflyfishes* | *263* | *333* | *596* | *483* |
| *Damselfishes* | *15530* | *17140* | *32670* | *16471* |
| *Fairy basslets* | *7820* | *7405* | *15225* | *2605* |
| | | | | |
| Rare/endangered | - | - | - | - |
| *Napoleon wrasse* | - | - | - | - |
| *Bumphead parrotfish* | - | - | - | - |
| *Sharks* | - | - | - | - |
| | | | | |
| **Grand total** | **25501** | **28252** | **53753** | **24055** |

### 3.2 Accuracy of density estimates

Estimates of fish density generated by MPA-FishMApp from citizen scientist data were often greater than those of the expert (Figures 4–7; Table 4, see values of $\bar{D}$). The scores for the quantitative accuracy of the density estimates of MPA-FishMApp were generally higher for species groups of high fishery importance than for those of moderate/low fishery importance and the potential coral habitat indicators (Table 4). This trend was also apparent in the scores for qualitative accuracy of the density estimates. However, many of the species groups of moderate/low fishery importance or potential coral habitat indicators showed higher scores for the qualitative accuracy of density estimates than quantitative accuracy. The species groups with the highest total scores (≥4) for the accuracy of density estimates were the parrotfishes, surgeonfishes/ unicornfishes, groupers, fusiliers, wrasses, goatfishes, and butterflyfishes. Fishery-targeted species treated as one group and species of high fishery importance treated separately also had some of the highest total scores. All species groups with the highest total scores had absolute values of $\bar{D}$ that were less than 50%, except for goatfishes. Parrotfishes, surgeonfishes/unicornfishes, wrasses, butterflyfishes, species of high fishery importance treated as one group, and all fishery targets treated as one group had absolute values of $\bar{D}$ that were less than 30%.

### 3.3 Accuracy of biomass estimates

Unlike density, estimates of biomass generated by MPA-FishMApp were often lower than those of the expert (Figures 4-7; Table 5, see values of $\bar{D}$). The scores for the quantitative accuracy of biomass estimates were also generally lower than those of density, particularly for species groups of high fishery importance (Table

Table 4. Appraisal of the degree of qualitative and quantitative correspondence between estimates of fish density derived by MPA-FishMApp from citizen scientist data and estimates of fish density derived by conventional analysis of expert data. Results of the two-way ANOVA are summarized by a "Yes" and "No," which indicates the presence or absence of a statistically significant difference ($\alpha = 0.05$) for the factor in question (see Supplementary Material - Appendix 4 for full results of the ANOVA). $\bar{D}$ is the average relative difference between citizen scientist and expert data; Pearson's *r* indicates the strength of a linear association between citizen science and expert data; SE is standard error. For Pearson's *r* values, the text style indicates statistical significance: boldface = p<0.01; boldface and italicized = p<0.05; normal = not significant.

| | | ANOVA | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\bar{D}$ ± SE | Site | Observer | Site x Observer | *r* | *r* strength | Quantitative | Qualitative | Total |
| All fishery targets | 27 ± 14% | Yes | Yes | No | **0.69** | modest | 2 | 3 | 5 |
| High fishery importance | -1 ± 10% | Yes | No | No | **0.72** | strong | 3 | 3 | 6 |
| *Parrotfishes* | 21 ± 12% | Yes | No | No | **0.52** | modest | 3 | 3 | 6 |
| *Surgeonfishes/ unicornfishes* | 29 ± 23% | Yes | No | No | **0.35** | weak | 3 | 2 | 5 |
| *Groupers* | 234 ± 79% | Yes | Yes | No | **0.72** | strong | 1 | 3 | 4 |
| *Fusiliers* | -42 ± 18% | Yes | No | No | **0.60** | modest | 3 | 3 | 6 |
| Moderate/low fishery importance | 85 ± 29% | Yes | Yes | Yes | 0.29 | weak | 1 | 1 | 2 |
| *Wrasses* | 31 ± 27% | Yes | No | No | 0.22 | weak | 2 | 2 | 4 |
| *Triggerfishes* | 115 ± 57% | Yes | Yes | No | 0.25 | weak | 1 | 2 | 3 |
| *Coral breams* | 608 ± 264% | Yes | Yes | No | **0.59** | modest | 1 | 2 | 3 |
| *Goatfishes* | 133 ± 41% | Yes | Yes | No | **0.66** | modest | 1 | 3 | 4 |
| *Angelfishes* | 318 ± 73% | Yes | Yes | No | 0.12 | very weak | 1 | 1 | 2 |
| Potential coral habitat indicators | 183 ± 42% | Yes | Yes | No | **0.72** | strong | 1 | 2 | 3 |
| *Fairy basslets* | 810 ± 238% | Yes | Yes | No | **0.45** | modest | 1 | 2 | 3 |
| *Damselfishes* | 116 ± 39% | Yes | Yes | No | **0.74** | strong | 1 | 2 | 3 |
| *Butterflyfishes* | 23 ± 11% | Yes | Yes | No | **0.55** | modest | 2 | 3 | 5 |

5). However, similar to density, many species groups had higher scores for the qualitative accuracy of biomass estimates compared to quantitative accuracy. The species groups with the highest total scores (≥4) were the parrotfishes, fusiliers, goatfishes, and butterflyfishes. Fishery-targeted species treated as one group or separated into high fishery importance and moderate or low fishery importance had some of the highest total scores for the accuracy of biomass estimates. All species groups with the highest total scores had absolute values of $\bar{D}$ that were less than 50% (parrotfishes, fusiliers and goatfishes, and butterflyfishes). Fishery-targeted species treated as one group or separated into high, and moderate or low fishery importance had absolute values of $\bar{D}$ ranging from 17–55%.

## 4. DISCUSSION

Our primary motivation for developing MPA-FishMApp was to reduce or remove some of the major technical barriers that prevent stakeholders from initiating and sustaining the monitoring of MPAs in the Philippines. These are: 1) capturing demographic data for highly diverse fish assemblages typical of coral reefs; 2) efficiently storing the complex data; and 3) efficiently analyzing the data and generating visualizations to inform MPA management efforts. These barriers were tackled by designing MPA-FishMApp around a simplified FVC method, building-in cloud storage and relevant algorithms to the app, and incorporating crucial stakeholder inputs to the design of the simplified FVC and the functionality of the app. The resulting MPA-FishMApp methodology is a technology-assisted process for MPA monitoring that can be used by stakeholder citizen scientists with minimal expert guidance.

Several methodologies that can be adopted by citizen scientists for monitoring fish assemblages in MPAs were already available before the development of MPA-FishMApp. Two of these also facilitate monitoring through simplified FVC, but their data management methods are limited to using paper forms or electronic spreadsheets, which are laborious and require significant computational and analytical skills (Uychiaoco et al. 2001; Hodgson et al. 2006). In contrast, one methodology emphasizes rigorous training of highly motivated citizen scientists on what can be considered expert-level FVC and data entry but relies on professional scientists and research institutions to compile and analyze the data (Edgar et al. 2020). None of these methodologies provide efficient means for citizen scientists to store, analyze, and visualize FVC data by themselves. Thus, the MPA-FishMApp methodology may have much greater potential than previous methodologies in empowering stakeholders to monitor MPAs, manage data and report monitoring findings on their own.

The field test results pointed to a potential weakness of the MPA-FishMApp methodology, which is the low quantitative accuracy of density and biomass estimates relative to expert-level estimates for almost all fish species groups that were considered. These estimates usually had a wide margin of error, even for species groups with the highest overall accuracy scores (within ± 50% of expert-level estimates). The low quantitative accuracy may have been largely due to different sources of observer

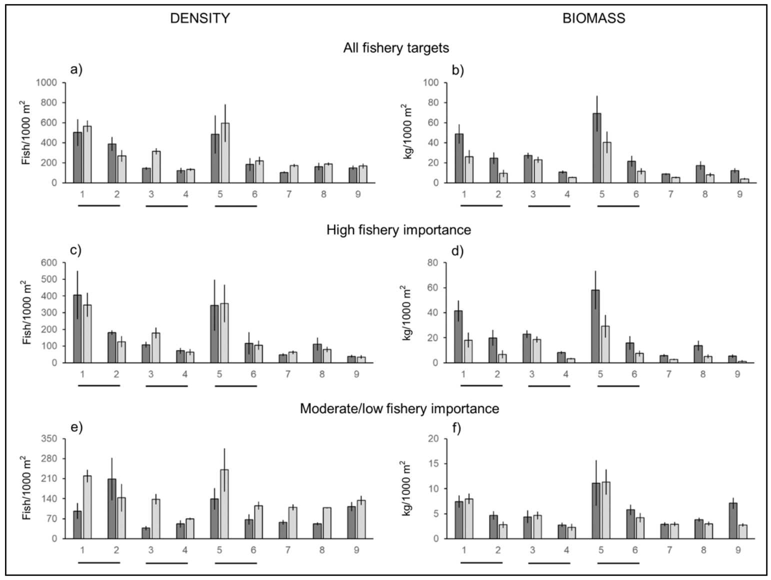



Figure 4. Average density (left column) and biomass (right column) of fish species grouped according to their relative importance to fisheries (a-f) across nine sites (MPAs – 1, 3, 5; corresponding controls – 2, 4, 6; proposed MPAs – 7, 8, 9). Density and biomass were estimated from conventional analysis of expert FVC data (dark bars) and analysis of combined citizen scientist FVC data using MPA-FishMApp (light bars). Horizontal bars indicate paired MPA and fished sites. Error bars represent standard errors (SE).

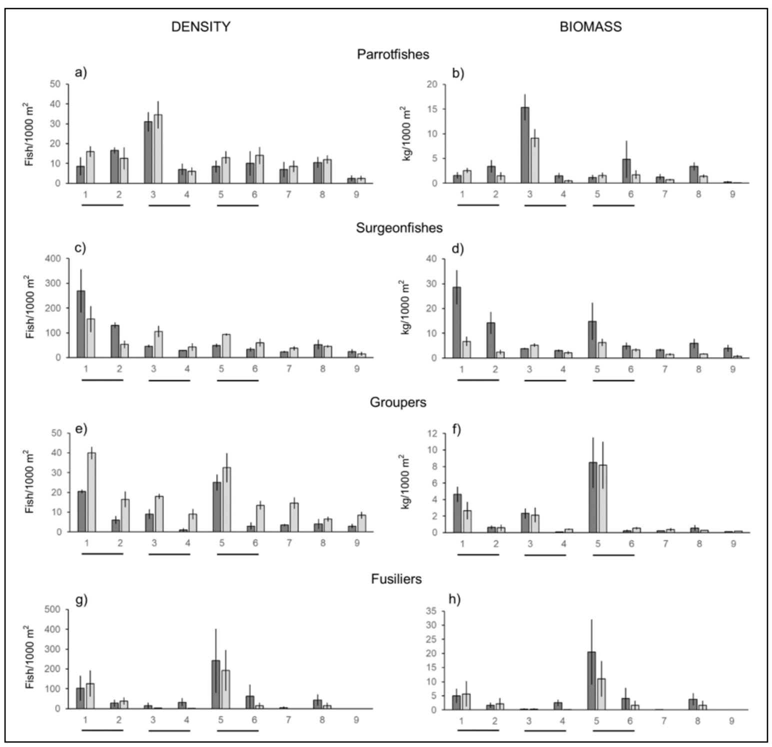



Figure 5. Average density (left column) and biomass (right column) of four fish species groups of high fishery importance (parrotfishes – a, b; surgeonfishes – c, d; groupers – e, f; fusiliers – g, h) across nine sites (MPAs – 1, 3, 5; corresponding controls – 2, 4, 6; proposed MPAs – 7, 8, 9). Density and biomass were estimated from conventional analysis of expert FVC data (dark bars) and analysis of combined citizen scientist FVC data using MPA-FishMApp (light bars). Horizontal bars indicate paired MPA and fished sites. Error bars represent standard errors (SE).

Table 5. Appraisal of the degree of qualitative and quantitative correspondence between estimates of fish biomass derived by MPA-FishMApp from citizen scientist data and estimates of fish biomass derived by conventional analysis of expert data. Results of the two-way ANOVA are summarized by a “Yes” and “No,” which indicates the presence or absence of a statistically significant difference ($\alpha = 0.05$) for the factor in question (see Supplementary Materials – Appendix 4 for full results of the ANOVA). $\bar{D}$ is the average relative difference between citizen scientist and expert data; Pearson’s r indicates the strength of a linear association between citizen science and expert data; SE is standard error. For Pearson’s *r* values, the text style indicates statistical significance: boldface = p<0.01; boldface and italicized = p<0.05; normal = not significant.

| | | ANOVA | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\bar{D}$ ± SE | Site | Observer | Site x Observer | *r* | *r* strength | Quantitative | Qualitative | Total |
| All fishery targets | -46 ± 5% | Yes | Yes | No | **0.74** | strong | 1 | 3 | 4 |
| High fishery importance | -55 ± 5% | Yes | Yes | No | **0.73** | strong | 1 | 3 | 4 |
| *Parrotfishes* | -34 ± 16% | Yes | No | No | **0.28** | weak | 2 | 2 | 4 |
| *Surgeonfishes/ unicornfishes* | -50 ± 13% | Yes | Yes | Yes | **0.33** | weak | 1 | 2 | 3 |
| *Groupers* | 75 ± 58% | Yes | Yes | Yes | **0.64** | modest | 1 | 2 | 3 |
| *Fusiliers* | -35 ± 16% | Yes | No | No | **0.54** | modest | 2 | 3 | 5 |
| Moderate/low fishery importance | -17 ± 8% | Yes | Yes | No | 0.47 | modest | 2 | 3 | 5 |
| *Wrasses* | -37 ± 7% | Yes | Yes | No | 0.36 | weak | 1 | 2 | 3 |
| *Triggerfishes* | -17 ± 16% | Yes | No | No | 0.17 | very weak | 2 | 1 | 3 |
| *Coral breams* | 82 ± 80% | Yes | Yes | No | **0.27** | weak | 1 | 2 | 3 |
| *Goatfishes* | 44 ± 37% | Yes | No | No | **0.61** | modest | 2 | 2 | 4 |
| *Angelfishes* | 125 ± 37% | Yes | Yes | No | 0.17 | very weak | 1 | 1 | 2 |
| Potential coral habitat indicators | NA | NA | NA | NA | **NA** | NA | NA | NA | NA |
| *Fairy basslets* | NA | NA | NA | NA | **NA** | NA | NA | NA | NA |
| *Damselfishes* | NA | NA | NA | NA | **NA** | NA | NA | NA | NA |
| *Butterflyfishes* | -25 ± 18% | Yes | Yes | No | **0.35** | weak | 2 | 2 | 4 |

bias that operate during FVC, such as variation in experience level, species detection, counts, and size estimation between observers (Williams et al. 2006; Bernard et al. 2013). However, certain biases may have been introduced by the MPA-FishMApp methodology itself, specifically to the simplified counting and size estimation methods in the FVC and the computational methods of the app. For instance, the methodology appeared to overestimate significantly the density of fairy basslets and damselfishes, which may have resulted from inexperience by the citizen scientists in using the log4 system of counting and certain log4 categories (possibly categories 5 and 6) assigning inflated best count estimates relative to actual counts. Conversely, the methodology seemed to underestimate biomass in many species groups despite a general tendency for citizen scientists to overestimate density. This could be due to the representative length-to-weight models in the app generating overly conservative biomass estimates relative to the extant species that occurred in the sites. Also, the method of recording counts in broad size categories during FVC and subsequent assignment of best size estimates by the app may produce lower than expected biomass estimates in cases where the assigned sizes were much smaller than actual fish sizes. This potential issue may be exacerbated in larger size categories due to the hyperallometric scaling of fish weight relative to body size, as suggested by some length-to-weight models used in the app, which is a common characteristic of coral reef fishes (Supplementary Material – Appendix 3; Kulbicki et al. 2005).

The low quantitative accuracy of biomass estimates generated by MPA-FishMApp was not entirely unexpected because the recording of fish counts according to broad size categories, subsequent assignment of best size estimates, and use of length-to-weight models from representative species are major simplifications to the expert-level methodology. The magnitude and direction of the errors that may result from these simplifications are likely influenced by the size structure and species composition of local fish assemblages. In contrast with the field test results, MPA-FishMApp will likely overestimate biomass in cases where the assigned best size estimates are usually much larger than the actual fish sizes in an assemblage. Biomass may also be over- or underestimated depending on how well the length-to-weight models in the app approximate true length-to-weight relationships of the many fish species that can occur in an assemblage. The errors associated with these significant simplifications are challenging to minimize even with sufficient training in the simplified FVC methodology. Until better solutions are developed, these errors can be considered unavoidable trade-offs for the significant advantages of simplification, particularly in lowering the threshold for citizen scientists to conduct MPA monitoring more independently.

Notwithstanding its biases, the MPA-FishMApp methodology seemed capable of generating qualitative patterns of fish density and biomass with relatively high accuracy relative to expert data. In terms of density, this was most evident for pooled data on all fishery targets, pooled data on species of high fishery importance, parrotfishes, groupers, fusiliers, goatfishes, and butterflyfishes. In terms of biomass, the qualitative patterns were likewise most accurate for pooled data on all fishery targets and pooled data on species of high fishery importance, but also fusiliers and pooled data on species groups of moderate/low fishery importance. These findings suggest that the methodology is sensitive enough to detect relative differences in the density and biomass of targeted reef fish species that could develop between a well-protected MPA and a site open to fishing, especially for species that are highly important to

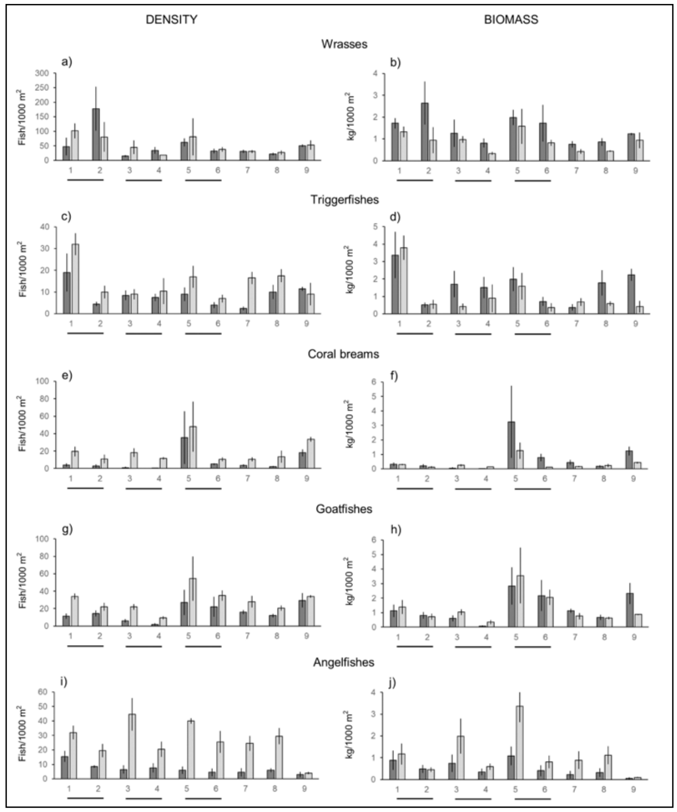



Figure 6. Average density (left column) and biomass (right column) of five fish species groups of moderate or low fishery importance (wrasses – a, b; triggerfishes – c, d; coral breams – e, f; goatfishes – g, h; angelfishes – i, j) across nine sites (MPAs – 1, 3, 5; corresponding controls – 2, 4, 6; proposed MPAs – 7, 8, 9). Density and biomass were estimated from conventional analysis of expert FVC data (dark bars) and analysis of combined citizen scientist FVC data using MPA-FishMApp (light bars). Horizontal bars indicate paired MPA and fished sites. Error bars represent standard errors (SE).

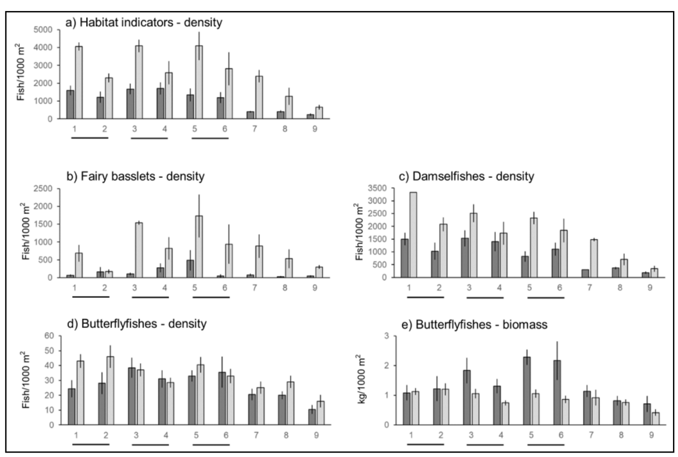



Figure 7. Average density or biomass of fish species groups that are potential indicators of coral habitat quality (a – total density; b – density of fairy basslets; c – density of damselfishes; d – density of butterflyfishes; e – biomass of butterflyfishes) across nine sites (MPAs – 1, 3, 5; corresponding controls – 2, 4, 6; proposed MPAs – 7, 8, 9). Density and biomass were estimated from conventional analysis of expert FVC data (dark bars) and analysis of combined citizen scientist FVC data using MPA-FishMApp (light bars). Horizontal bars indicate paired MPA and fished sites. Error bars represent standard errors (SE).

fisheries. Detection of such relative differences may be considered as evidence for an MPA promoting fish population recovery if the average density and/or biomass is much higher in the MPA than in a control, especially if standard errors (SEs) in the visualizations do not overlap (i.e., the difference is probably statistically significant). However, the sensitivity of the MPA-FishMApp methodology in capturing temporal trends in the development of relative differences in fish density and biomass between MPAs and controls can only be validated with actual data from long-term monitoring by citizen scientists using the methodology.

The field test we conducted was by no means comprehensive, given the minimal number of test subjects involved. It was also constrained to a small geographic area where assemblages of reef fish species are unlikely to be representative of other regions in the Philippines, as indicated by biogeographic patterns (Nañola et al. 2011). Further studies are needed to understand better the different potential sources of bias in the methodology and how it performs in various circumstances depending on observer skill, experience level, and the size structure and species composition of fish assemblages. Nonetheless, it is clear from the present study that users of the MPA-FishMApp methodology must be reasonably skilled and experienced in the simplified FVC to generate reliable data. This cannot be overemphasized, and we strongly encourage less experienced early adopters to undergo sufficient training on basic FVC techniques to reduce observer bias and improve the accuracy and precision of fish density and biomass estimates (the User's Manual describes many of these techniques). While accounting for observer bias is not possible in the current version of MPA-FishMApp, it is conceivable that a future version could allow users to quantify and even correct for observer bias by classifying data contributors based on their skill level and experience in FVC. Correcting observer bias would likely require the curation and analysis of a large amount of data, the computational methods of which can be automated within the app. However, using data within MPA-FishMApp for this purpose or other objectives must abide by the highest data stewardship principles, which we strongly advocate for.

## 5. CONCLUSION

The technical innovation we described and evaluated here can help reverse the severe and long-standing lack of ecological monitoring of MPAs in the Philippines. While it is not perfect, MPA-FishMApp offers a way for local stakeholders to become bona fide citizen scientists who can determine for themselves if their efforts to protect MPAs benefit fisheries resources and endangered species. Indirectly, adopting the MPA-FishMApp methodology may also help increase MPA management effectiveness by providing verifiable records of monitoring efforts and an evidentiary basis for adaptive decision-making. Beyond its potential benefits for local stakeholders, widespread use of the MPA-FishMApp methodology may eventually open opportunities for citizen scientists and professional scientists to work together to elucidate how MPAs maintain or lose their effectiveness in varying ecological conditions and disturbance regimes. MPA-FishMApp provides an accessible, transparent, and auditable venue for such a collaboration.

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## SUPPLEMENTARY MATERIAL

Below is the link to the electronic supplementary material.
[Supplementary file]

## AUTHOR CONTRIBUTIONS

**Abesamis RA**: Conceptualization, Methodology, Investigation, Formal Analysis, Resources, Funding Acquisition, Project Administration, Writing – Original Draft. **Balingit R:** Conceptualization, Methodology, Resources, Funding Acquisition, Writing – Review and Editing. **de Castro**

**R:** Conceptualization, Methodology, Resources, Funding Acquisition, Project Administration, Writing – Review and Editing. **Aguila RN:** Conceptualization, Methodology, Investigation, Writing – Review and Editing. **Cabiguin M:** Conceptualization, Methodology, Formal Analysis, Writing – Review and Editing. **Villagracia J:** Methodology, Investigation, Writing – Review and Editing; **Susmeña M:** Investigation, Project Administration, Writing – Review and Editing. **Montemar MN:** Methodology, Investigation, Writing – Review and Editing. **Yocor A:** Methodology, Investigation, Writing – Review and Editing.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## ETHICS STATEMENT

Permission was granted by the Municipality of Siaton and relevant barangays prior to the conduct of fish surveys in MPA and non-MPA sites. Development of the MPA-FishMApp methodology adhered to relevant institutional and national guidelines.

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