

RESEARCH ARTICLE

Reef Fish Diversity, Abundance and Biomass in Marine Protected and Unprotected Areas in Misamis Oriental, Northern Mindanao, Philippines

Michael Jeriel I. Bersaldo^{1,2,5*} , Geson Earl P. Dalagan^{3,5}, Chev Benedict R. Duay^{4,5}, Ramil B. Tutor⁵,
Ivane R. Pedrosa-Gerasmio⁵, Annielyn D. Tampus⁵

¹Department of Marine Biology, Institute of Fisheries and Marine Sciences, Southern Philippines Agri-business and Marine and Aquatic School of Technology, Poblacion, Malita, Davao Occidental 8012, Philippines

²Aquamarine Research Center and Learning Site, Southern Philippines Agri-business and Marine and Aquatic School of Technology, Poblacion, Malita, Davao Occidental 8012, Philippines

³University of Science and Technology of Southern Philippines-Panaon (USTP-Panaon), Punta, Panaon, Misamis Occidental 7205, Philippines

⁴Bureau of Fisheries and Aquatic Resources Region X, Macabalan, Cagayan De Oro City, Misamis Oriental 9000, Philippines

⁵Department of Marine Science, College of Science and Mathematics (CSM), Mindanao State University-Iligan Institute of Technology (MSU-IIT), Tibanga, Iligan City, Lanao del Norte 9200, Philippines

ABSTRACT

The establishment of marine protected areas (MPAs) has positively impacted reef fish diversity, abundance, and biomass, and these MPAs are often assessed based on these fish parameters. In the Philippines, government support for marine conservation is evident in various policies instituted. In this paper, we assessed the three established MPAs (Molugan, Hermano, Mambayaan) within Misamis Oriental, Northern Mindanao, Philippines, through underwater fish visual census (FVC). Reef fishes' diversity, abundance, and biomass between inside and outside the MPAs were computed, and sites were categorized based on established criterion. Diversity (moderate to high), abundance (moderate to high), and biomass (medium to very high) of reef fishes were not significantly different inside and outside the MPA, except for Hermano's reef fish abundance. However, the numerical values for reef fishes' diversity, abundance, and biomass were observed to be higher inside the MPAs compared to outside the MPAs. With these findings, it is evident that MPAs influence an increase in diversity, abundance, and biomass, particularly for target fish species that are more economically valuable. We suggest that conservation actions for reef fishes through the establishment of MPAs were effective and, therefore, must be continuously implemented and monitored.

*Corresponding Author: mjbersaldo@spamast.edu.ph

Received: November 28, 2023

Accepted: February 16, 2026

Keywords: Coral reef fish, fish visual census, marine reserves, non-target fish, target fish

1. INTRODUCTION

The Coral Triangle, which stretches across Indonesia and the Philippines, is home to around 4,350 marine reef fish species and is one of the world's most important conservation areas (Limmon et al. 2020). The Philippines, consisting of more than 7,100 islands, is in the center of the Coral Triangle and is one of the top priorities for marine conservation worldwide (Roberts et al. 2002). Reef fish species are generally classified into three

groups: economically important food and aquarium fishes are grouped as target fishes (important to fisheries); fishes directly linked to coral health are called indicator species; and fishes that are neither target nor indicators are called major fishes (visually dominant species with no commercial value; English et al. 1997). Albeit having no economic value to humans, the dominant fish groups are nevertheless ecologically important, providing food for the highly priced target species as well as playing important roles in nutrient cycling. Reef-associated fish diversity

distribution was driven by multiple factors like area, temperature, environmental stability, and geological processes, based on large geographic scales (Mora et al. 2003). On a finer scale, however, reef fish distribution and structure were linked to biological and physical variables such as the cover of living hard corals, encrusting corals, branching corals, depth, and distance from the mainland's coast (Van Nguyen and Kim Phan 2008; Ticzon et al. 2012). Reefs and their associated resources have provided livelihoods for a considerable percentage of the coastal community for decades and are currently under pressure due to overexploitation and the impacts of climate change on the marine environment (Arin et al. 2000; Macusi et al. 2021). A continued decline in coral reefs has been observed in recent studies (Licuanan et al. 2019), which directly impacts the diversity and biomass of reef fisheries, and thus protecting their habitat will positively affect reef fish biomass (Friedlander et al. 2003). Increasing fishing pressure, overexploitation of reefs, and habitat degradation have led to declining populations and poor condition in coral reef fishes. To counteract this decline, Marine Protected Areas (MPAs) have been established all over the Philippines for many decades. These MPAs have already demonstrated their effectiveness; some studies have reported significant increases in fish abundance and biomass, particularly among large-bodied target fish species within MPAs (Alcala 1988; Magdaong et al. 2014; Samoilys et al. 2007). Several studies have shown that MPAs have higher biomass, abundance, and density per year than unprotected areas, indicating that effective conservation strategies have positively impacted fisheries resources (Corrales et al. 2015; Gonzales and Gonzales 2016; Samoilys et al. 2007). Given its effectiveness, the establishment of MPAs or marine reserves is a critical tool for sustaining the depleted nearshore fishery resources against the threats of overexploitation and other natural calamities, which is why it is vital in the Philippines (Guzman 2016; Wantiez et al. 1997; Abesamis et al. 2006). The most promoted and widely adopted strategy for marine conservation in the Philippines is the establishment of community-based MPAs (Muallil et al. 2019). These MPAs are established through municipal ordinances, as prescribed by the Philippine Fisheries Code (Republic Act 8550, as amended by 10654), which requires the Local Government Unit (LGU) to protect at least 15% of its municipal waters. Hence, these MPAs are under the jurisdiction of the local government units. On a broader scale, the Philippine government implemented the National Integrated Protected Area System Act 1992 (RA

7586, 1992) to classify and administer all designated protected areas to maintain essential ecological processes and life-support systems, to preserve genetic diversity, to ensure sustainable use of resources found therein, and to maintain their natural conditions to the greatest extent possible as part of their efforts in the conservation of its natural resources. As mandated by the NIPAS Act of 1992, the Philippines has nationally managed networks of MPAs administered by the Department of Environment and Natural Resources (DENR). The management responsibility for MPAs established within NIPAS areas is shared among the community, the local government, and the Protected Area Management Board (PAMB), headed by DENR. These MPA sites have relatively small, no-take marine reserves established to curb local overexploitation of fisheries resources (Aurellado et al. 2021). Despite the legal basis for protecting natural resources, especially those in the marine environment, LGUs often lack the political will to implement the law strictly, fearing they will not be re-elected, resulting in weaker and unsustainable implementation if not supported externally (Muallil et al. 2019). At present, numerous MPAs have been investigated and have shown to be successful in preserving coral reef biodiversity and boosting wild fish stock populations, including the Sumilon Island Marine Reserve and Apo Island Marine Reserve, which are currently managed by PAMB (Alcala and Russ 2006; Fidler et al. 2014). However, the conservation and improvement goals of over 70% of locally managed MPAs in the Philippines remain unmet (Muallil et al. 2019). In Macajalar Bay, 10 of the 14 constituent towns have adopted locally managed MPAs covering 4–22 hectares; some have been operational since the late 1990s. A previous assessment of the bay's marine ecological resources showed that average reef fish biomass was in the medium category at 12.6 metric tons/km². Three of the 14 towns have shown high fish biomass (>20 metric tons/km²): Balingasag, Jasaan, and Laguindingan. A third (28%) of the recorded fish biomass in the area was composed of economically important fish species, dominated by surgeonfish (Acanthuridae) and parrotfish (Labridae). More than 300 species of reef fish belonging to 42 families were recorded in the bay. The highest density of reef fish was recorded in Balingasag (1,998 ind/km²) and Jasaan (1,788 fishes/km²), followed by Salay (1,622 fishes/km²).

To determine the effectiveness of the MPAs in achieving its long-term goal for mitigating the effect of overfishing and other natural phenomena that facilitate the decline in reef fisheries, this study on reef fish community structure in the marine

protected area (MPA) was conducted to determine if there are differences in terms of diversity, abundance and biomass between inside (protected) and outside (non-protected) of each of the three established MPAs in Misamis Oriental, Philippines.

2. MATERIALS AND METHODS

2.1 Description of the study site

The study was conducted in Misamis Oriental, which lies in the Bohol Sea and Macajalar Bay, which serve as its main fishing grounds (Figure 1). Misamis Oriental coastal areas are currently undergoing coastal development, including construction and other facilities needed for economic development. MPAs exist in Misamis Oriental in compliance with RA 8550 as amended by RA 10654. The first study site, Barangay Molugan in El Salvador (MPA 1), was declared as an MPA in 2013 through Provincial Resolution No. 15 series of 2013, but has been operational since 2006 (Quiaoit et al. 2010), covering an area of 14.8 hectares, and several freshwater tributaries, like rivers and drainage systems, exist in the vicinity. In Balingasag, two study sites were established: one in Barangay Hermano (MPA 2) and another in Barangay Mambayaan (MPA 3), both instituted under Municipal Ordinance No. 6, series of 2006. A total of 2.25 and 2.92 hectares were designated as marine protected areas in Barangay Hermano and

Mambayaan, respectively, with a mariculture park situated between the two MPAs. The three selected MPAs were identified with the help of the city and municipal agriculturist, and during sampling, the research team was assisted by the Bantay Dagat of each MPA. Sampling was conducted during the daytime and high tide between July and October 2022.

2.2 Data collection and survey

Before sampling, letters were sent to each LGU seeking approval to conduct the study within the MPA. An underwater fish visual census (FVC) belt transect survey was conducted inside and outside the MPAs at three study sites during the daytime from 7:00 AM to 2:00 PM to record diurnally active reef fish (Go et al. 2015). Fish were categorized as "target" if they were intentionally caught by fishermen because of their high market value and "non-target" if they were not (Corrales et al. 2015; Mosquera et al. 2000). Sampling was conducted in July and October 2022 during high tide, as the MPAs have shallow depths. The Bantay Dagat and LGU representatives of each MPA assisted with sampling, especially in determining dense reef fish assemblages in the area.

Following the methods used by Corrales et al. (2015) using a Self-Contained Underwater Breathing Apparatus (SCUBA), two to three replicates of 50 m transect were laid parallel to the shoreline and recorded the count (individual fish) and length (cm) of all reef

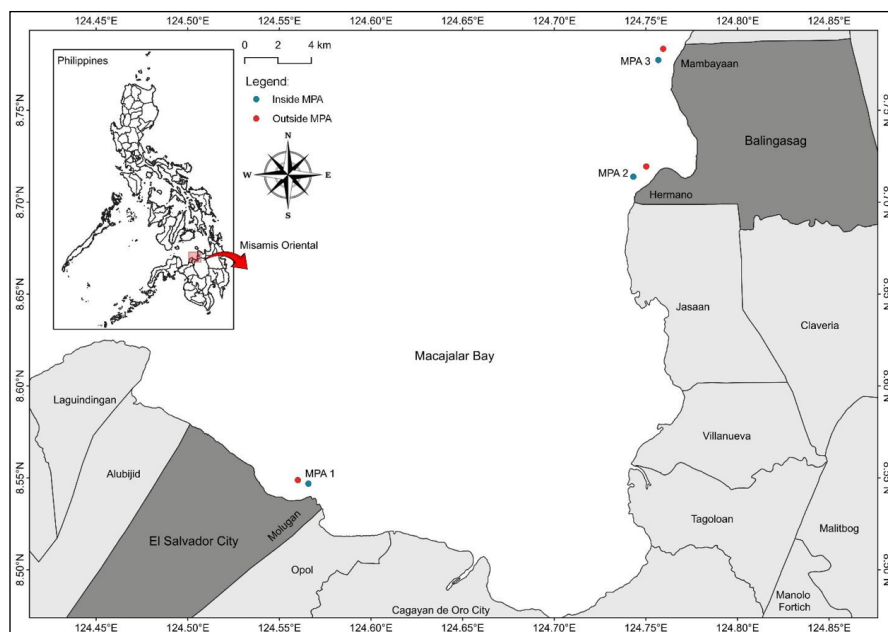


Figure 1. Map of the three study sites showing the three Marine Protected Areas (MPAs) and the locations sites outside these MPAs within the two Municipalities of Misamis Oriental.

fish species encountered approximately 2.5 m on each side of the transect with a total surveyed area of 250m² per transect. Coral reef fish were photographed during FVC for fish identification. The same method was used outside the MPA, approximately more than 200 m from the boundary of the MPA, as suggested in the study by Russ et al. (2004).

The survey was conducted by graduate students (MS in Marine Biology) at Mindanao State University-Iligan Institute of Technology. To limit error and observer bias, only one observer conducted the FVC (Figure 2). The abundance of cryptic, nocturnal, and highly camouflaged fish species was underrepresented in the study because they could avoid detection by hiding in reef crevices, a behavior that was affected by the period of changeover (7:00 AM to 9:00 AM), or they remained hidden for the entire day. Fish species were identified up to the species level through various fish identification guides (Allen et al. 2003; Fischer 2013; Kuitert and Debelius 2006; Gonzales 2013; White et al. 2013) and were classified based on their family and confirmed with the FishBase database, the World Register of Marine Species (WORMS), and Eschmeyer's Catalog of Fishes. The identified fish were then grouped as target and non-target fish based on the FishBase systems glossary (Froese and Pauly 2022).

2.3 Data analysis

Reef fish species were identified, counted, and recorded in every site (inside MPA and outside MPA) and grouped accordingly as target and non-target fish species. Further, the data were utilized to determine the diversity of fish based on the site diversity categories established by Hilomen et al. (2000). In Table 1A, the standards set by Hilomen et al. (2000) were adjusted to reflect the actual surveyed areas, which were 500 m² (Mambayaan and Hermano had two observations) and 750 m² (Molugan has three observations). Specifically, the standard values were multiplied by 0.5 and 0.75, respectively, to generate a scale range suitable for the surveyed areas, compared to the originally suggested 1000 m². For fish abundance, the total number of individual fish on each site was counted based on target and non-target species and was extrapolated by getting the average abundance per m² and was multiplied to 1000 to obtain the total abundance of fish per km² to be used in the classification of sites based on fish abundance as described by Hilomen et al. (2000) presented in Table 1B.

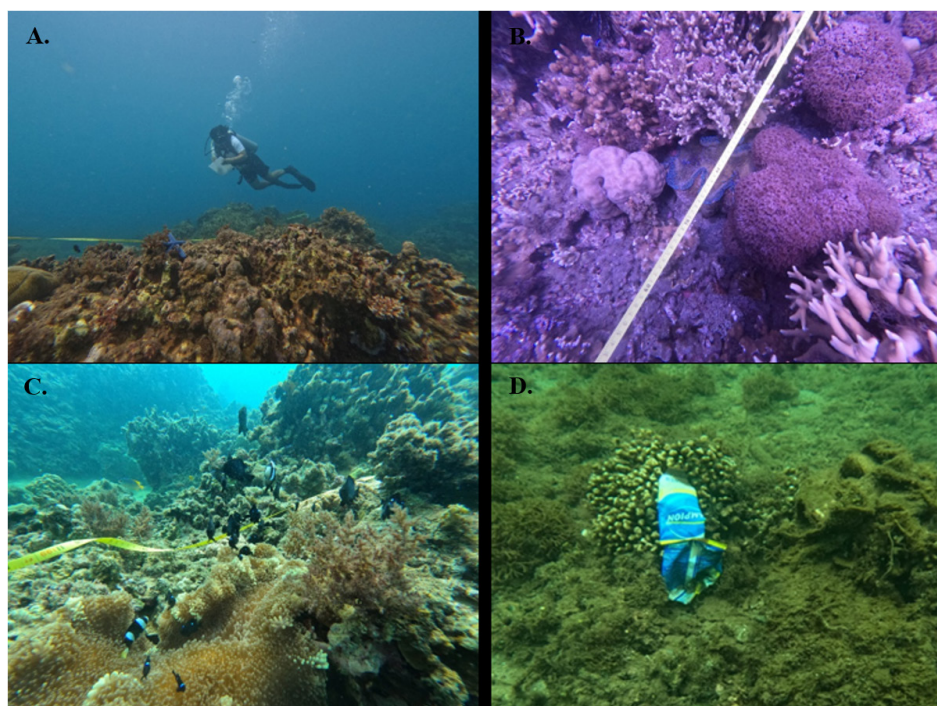


Figure 2. Field sampling pictures during A. FVC where several marine organisms are observed like giant clams (B) demersal fishes (C) and even plastic sachet (D).

Table 1. Categories of sites according to fish diversity (species/1000m²) and abundance (individuals/1000m²) set by Hilomen et al. (2000).

A. Fish species diversity (^a species/1000m ² ; ^b species/500m ² ; ^c species/750m ²)				
Very poor	Poor	Moderate	High	Very High
0-26 ^a	27-47 ^a	48-74 ^a	76-100 ^a	>100 ^a
0-13 ^b	14-24 ^b	25-37 ^b	38-50 ^b	>50 ^b
0-20 ^c	21-35 ^c	36-56 ^c	57-75 ^c	>75 ^c
B. Fish abundance (individuals/1000m ²)				
Very poor	Poor	Moderate	High	Very High
0-201	202-676	677-2267	2268-7592	>7592

The estimated length (cm) of each fish species observed during sampling was used to calculate the fish biomass using the formula:

$$W = aL^b / \text{area}$$

Where: W = weight (g)

L = Total length (cm)

a = multiplying factor

b = exponent

The specific constant values of a and b were derived from FishBase life history tool length-weight data, which were then determined based on the nearest location where the fish species was caught (Froese and Pauly 2022). The computed biomass for every fish species was multiplied by the frequency of each fish species having the same estimated length to obtain the total biomass and was averaged to get the mean biomass of target and non-target fish in each site. The data for reef fish biomass were then converted from g/m² to MT/km² and classified into Nañola et al. (2006) categories of sites according to fish biomass (Table 2).

The standardized categories of Hilomen et al. (2000) and Nañola et al. (2006) provided a clear and effective framework for comparing reef fish diversity, abundance, and biomass between inside and outside MPAs. By adjusting these categories with the actual survey areas and applying uniform scaling, the differences among sites became more consistent and comparable. These classifications allowed the results to be interpreted objectively, highlighting the ecological condition and relative effectiveness of MPAs. Overall, the use of these established categories improved the clarity and reliability of assessing protection effects on reef fish communities.

3. RESULTS

3.1 Reef fish diversity, abundance, and biomass

A total of 111 reef fishes from 26 families were identified in this study, with 87 identified to the species level and 24 to the genus level. In Mambayaan MPA, a total of 34 species (8 target and 26 non-target) were found inside, and 29 species (8 target and 21 non-target) were observed outside the MPA during the survey (n=2). According to Hilomen et al. (2000), categories of site diversity, Mambayaan was considered to have moderate diversity both inside and outside the MPA. Meanwhile, in Hermano MPA, diversity was categorized as moderate to high, with 48 species noted inside the MPA (22 target and 26 non-target) and 37 reef fish species identified outside the MPA (9 target and 28 non-target) (n=2). Further, in Molugan, moderate diversity was observed both inside (55 reef fish species) and outside (43 reef fish species) the MPA (n=3). Inside Molugan MPA, 26 target and 29 non-target fish species were identified, while outside the MPA, 15 target and 28 non-target fish species were determined (Figure 3A, 3D, and 3G).

For fish abundance, all surveyed areas were categorized to have moderate abundance for both inside (Mambayaan=818 ind./km², Molugan=1401 ind./km²) and outside (Mambayaan=1306 ind./km², Hermano=1484 ind./km², Molugan=945 ind./km²), except for Hermano's inside MPA (3066 ind./km²), which has high abundance (Figure 3B, 3E, 3H) based on the categories set by Hilomen et al. (2000).

Table 2. Categories of sites according to fish biomass set by Nañola et al. (2006)

Fish Biomass (MT/km ²)				
Very Low	Low	Medium	High	Very High
<5	6 to 10	11 to 20	21-40	>41

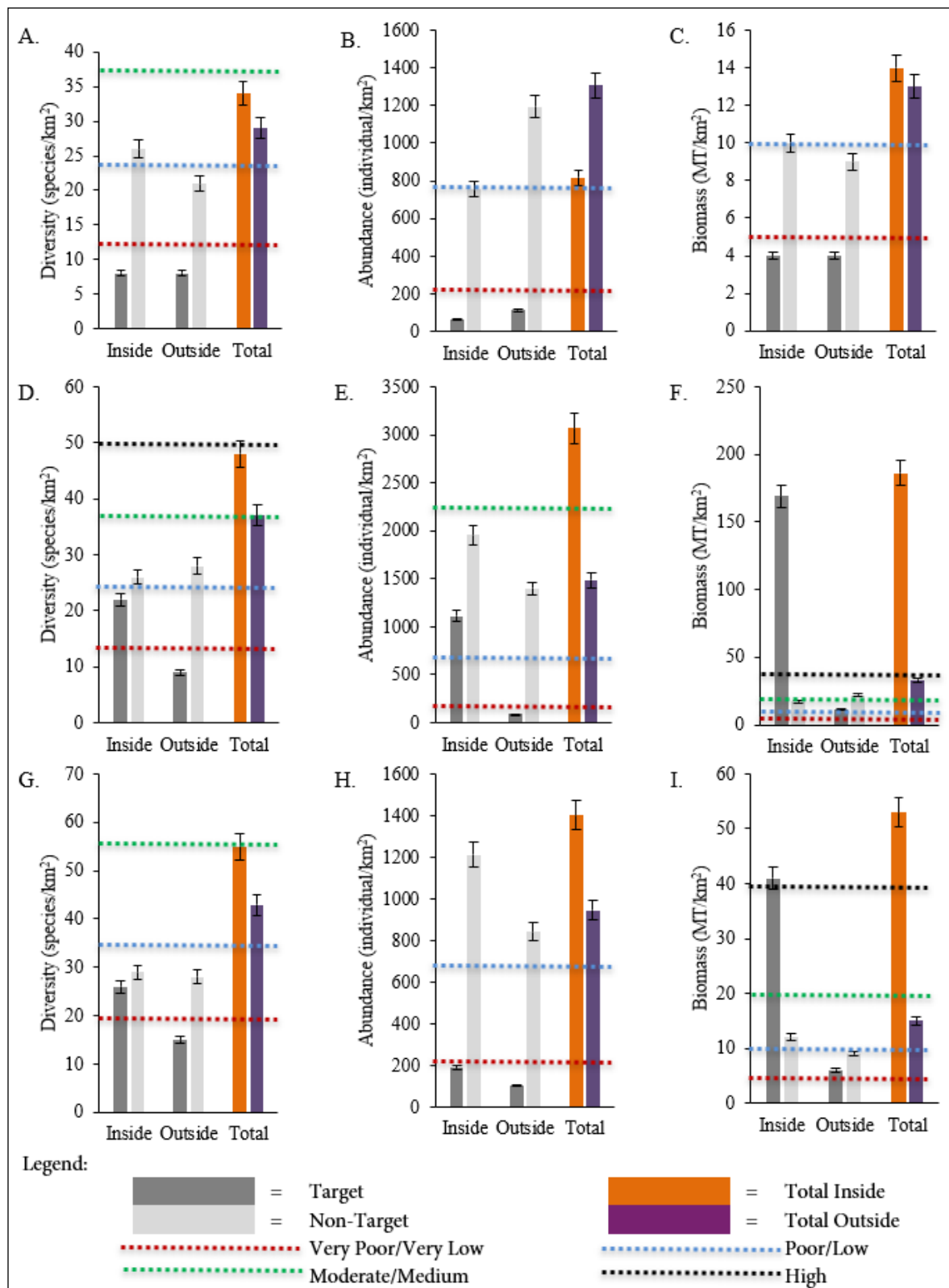


Figure 3. Reef fish community structure inside and outside the three MPA sites. Mambayaan reef fish diversity (A), abundance (B) and biomass (C); Hermano reef fish diversity (D), abundance (E) and biomass (F); Molugan reef fish diversity (G), abundance (H) and biomass (I).

In terms of fish biomass classification on each site based on Nañola et al. (2000), Mambayaan was classified to have medium biomass for both inside (14 MT/km²) and outside (13 MT/km²) the MPA (Figure 3C), while Hermano has high outside MPA (33 MT/km²) to very high inside MPA (186 MT/km²) biomass (Figure 3F). Moreover, in Molugan, biomass inside the MPA (53 MT/km²) was very high, whereas medium biomass was observed outside the MPA (15 MT/km²) (Figure 3I).

3.2. Effects of MPA in the target reef fishes

Among the 111 species observed during the survey, 43 were classified as target fish, and 68 were categorized as non-target fish across the three study sites. Within the MPAs, Molugan has low diversity, with 26 reef fish species observed, followed by

Hermano with 22 species (poor) and Mambayaan with 8 species (very poor). Outside the MPAs, target reef fish diversity was similar and categorically had very poor status, with Molugan having the highest number of species observed (15), followed by Hermano (9) and Mambayaan (8). Overall, there were more target reef fish species inside the MPAs compared to outside (Figure 4A, Table 3) and predominantly dominated by surgeonfish and parrotfish.

The abundance of target fish species varies, ranging from very poor in Mambayaan (outside:112 ind./km², inside:62 ind./km²) and Molugan (outside:104 ind./km², inside:189 ind./km²) MPAs to moderate inside Hermano MPA (1112 ind./km²) but very poor outside the MPA (88 ind./km²), as classified by Hilomen et al. (2000) (Figure 4B). Moreover, fish biomass for target fish inside the MPAs was higher compared to those outside. Fish biomass ranged from

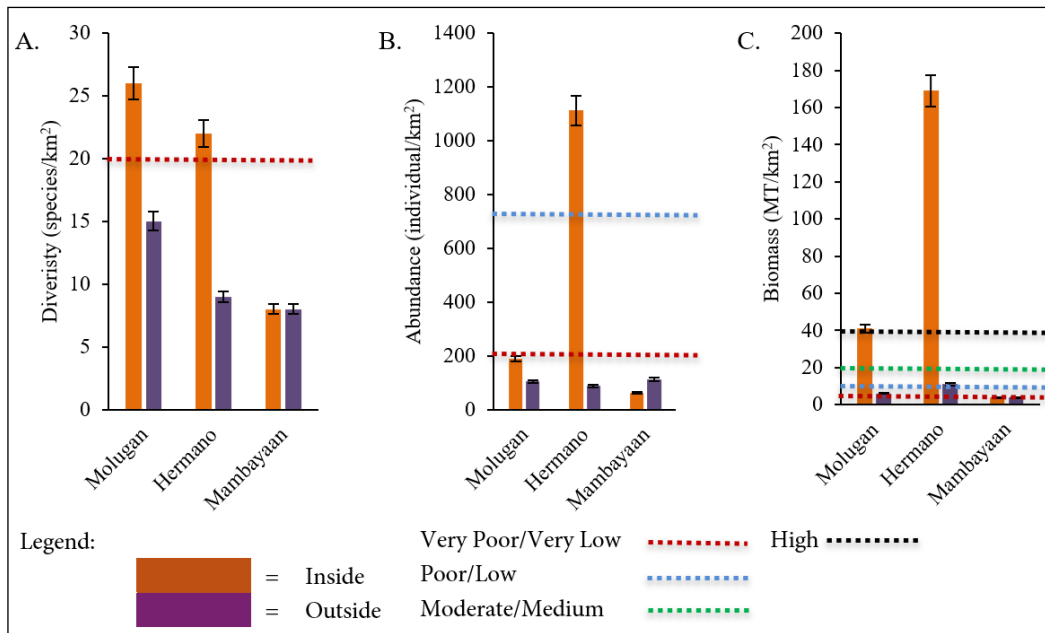


Figure 4. Diversity (A), abundance (B) and biomass (C) of target fishes found inside and outside of the three MPA site (colored lines are standards set by Hilomen et al., 2000 for reef fish abundance and diversity, and by Nañola et al., 2006 for reef fish biomass).

Table 3. Fish diversity of Target (^T) and non-target (^{NT}) fish found inside (IMPA) and outside (OMPA) of the three marine protected areas in the study.

Family	Species	Mambayaan		Hermano		Molugan	
		IMPA	OMPA	IMPA	OMPA	IMPA	OMPA
Acanthuridae	<i>Acanthurus auranticavus</i> ^T	√	-	-	-	√	√
	<i>Acanthurus nigrofusus</i> ^T	√	-	-	-	√	-
	<i>Acanthurus olivaceus</i> ^T	-	-	-	-	√	-
	<i>Acanthurus sp</i> ^{NT}	-	-	-	-	-	√
	<i>Acanthurus thompsoni</i> ^T	-	-	-	-	-	-
	<i>Ctenochaetus sp</i> ^T	-	√	√	√	√	-

Continuation of Table 3. Fish diversity of Target (T) and non-target (NT) fish found inside (IMPA) and outside (OMPA) of the three marine protected areas in the study.

	<i>Ctenochaetus striatus</i> ^T	-	-	-	-	√	√
	<i>Ctenochaetus tominiensis</i> ^T	-	-	-	-	√	-
	<i>Naso sp</i> ^T	-	-	-	-	√	-
	<i>Zebrasoma sp</i> ^{NT}	-	-	-	-	√	-
Apogonidae	<i>Ostorhinchus cyanosoma</i> ^{NT}	√	-	-	-	-	-
	<i>Ostorhinchus fleurieu</i> ^{NT}	-	-	√	-	-	-
	<i>Ostorhinchus sp</i> ^{NT}	-	-	√	-	-	-
	<i>Cheilodipterus sp</i> ^{NT}	-	-	-	-	-	√
Aulostomidae	<i>Sphaeramia sp</i> ^{NT}	-	-	-	-	-	√
	<i>Aulostomus strigosus</i> ^{NT}	√	-	-	-	-	-
Balistidae	<i>Aulostomus sp</i> ^{NT}	-	√	-	-	-	-
	<i>Balistapus sp</i> ^T	-	-	-	-	√	-
Caesionidae	<i>Balistapus undulatus</i> ^T	-	√	√	√	√	-
	<i>Caesio teres</i> ^T	-	-	√	-	√	√
	<i>Pterocaesio pisang</i> ^T	-	-	√	-	√	-
Carangidae	<i>Pterocaesio randalli</i> ^T	-	-	√	-	-	-
	<i>Carangoides bajad</i> ^T	-	-	√	-	-	-
Centriscidae	<i>Caranx sp</i> ^T	-	-	√	√	-	-
Chaetodontidae	<i>Centriscus scutatus</i> ^{NT}	-	-	-	√	-	-
	<i>Chaetodon baronessa</i> ^{NT}	√	√	√	√	√	√
	<i>Chaetodon decussatus</i> ^{NT}	-	-	-	-	-	√
	<i>Chaetodon kleinii</i> ^{NT}	-	-	√	-	√	-
	<i>Chaetodon lunula</i> ^{NT}	-	-	√	-	-	-
	<i>Chaetodon lunulatus</i> ^{NT}	-	√	√	-	√	-
	<i>Chaetodon octofasciatus</i> ^{NT}	-	-	√	√	-	-
	<i>Chaetodon sp</i> ^{NT}	-	-	-	-	√	-
	<i>Chaetodon triangulum</i> ^{NT}	-	-	√	√	-	-
	<i>Chaetodon trifasciatus</i> ^{NT}	√	-	-	-	-	-
	<i>Chaetodon vagabundus</i> ^{NT}	-	-	√	-	√	√
	<i>Heniochus diphreutes</i> ^{NT}	√	-	-	-	-	-
Cirrhitidae	<i>Heniochus varius</i> ^{NT}	-	-	√	-	√	√
	<i>Cirrhitichthys falco</i> ^{NT}	√	-	-	√	-	-
Fistulariidae	<i>Cirrhitichthys sp</i> ^{NT}	-	-	-	√	-	-
Haemulidae	<i>Fistularia sp</i> ^T	-	-	-	-	√	√
Holocentridae	<i>Plectorhinchus chaetodonoides</i> ^T	-	-	-	-	-	√
Labridae	<i>Myripristis sp</i> ^T	-	-	√	-	-	√
	<i>Bodianus mesothorax</i> ^{NT}	√	-	√	√	√	-
	<i>Gomphosus varius</i> ^{NT}	√	-	-	-	√	√
	<i>Halichoeres hortulanus</i> ^{NT}	-	√	√	√	√	-
	<i>Labroides dimidiatus</i> ^{NT}	√	√	√	-	√	-
	<i>Thalassoma hardwicke</i> ^{NT}	√	√	√	√	√	√
	<i>Thalassoma lunare</i> ^{NT}	√	√	√	√	√	√

Continuation of Table 3. Fish diversity of Target (^T) and non-target (^{NT}) fish found inside (IMPA) and outside (OMPA) of the three marine protected areas in the study.

	<i>Chlorurus bowersi</i> ^T	-	-	√	-	-	-
	<i>Chlorurus sordidus</i> ^T	-	-	√	-	-	-
	<i>Chlorurus bleekeri</i> ^T	-	-	√	-	√	√
	<i>Scarus dimidiatus</i> ^T	-	-	√	-	√	-
	<i>Scarus globiceps</i> ^T	-	-	√	-	-	-
	<i>Scarus rivulatus</i> ^T	√	-	√	√	√	√
	<i>Scarus sp</i> ^T	√	√	-	√	√	-
	<i>Scarus sp 2</i> ^T	-	-	-	-	√	-
	<i>Scarus sp 3</i> ^T	-	-	-	-	-	√
Lutjanidae	<i>Scarus tricolor</i> ^T	-	-	-	-	√	√
	<i>Lutjanus argentimaculatus</i> ^T	-	-	√	-	-	-
	<i>Lutjanus decussatus</i> ^T	√	√	√	-	√	√
	<i>Lutjanus fulvus</i> ^T	-	-	-	√	-	-
Mullidae	<i>Lutjanus quinquelineatus</i> ^T	-	-	√	-	-	-
	<i>Parupeneus barberinus</i> ^T	-	-	-	-	√	√
Nemipteridae	<i>Parupeneus sp</i> ^T	√	-	√	√	√	√
	<i>Scolopsis bilineata</i> ^T	√	√	√	-	-	-
Pinguipedidae	<i>Scolopsis sp</i> ^T	-	-	-	-	√	√
Pomacanthidae	<i>Parapercis clathrata</i> ^{NT}	-	-	-	√	-	-
Pomacentridae	<i>Pygoplites diacanthus</i> ^T	-	-	-	-	√	-
	<i>Abudefduf sexfasciatus</i> ^{NT}	√	-	-	-	√	-
	<i>Abudefduf vaigiensis</i> ^{NT}	√	√	-	√	√	√
	<i>Amblyglyphidodon aureus</i> ^{NT}	√	-	-	-	-	-
	<i>Amblyglyphidodon curacao</i> ^{NT}	√	√	√	√	-	√
	<i>Amblyglyphidodon leucogaster</i> ^{NT}	√	-	-	-	-	-
	<i>Amphiprion clarkii</i> ^{NT}	√	√	-	√	-	-
	<i>Centropyge vrolikii</i> ^{NT}	√	√	√	√	√	√
	<i>Chromis viridis</i> ^{NT}	-	-	-	-	√	-
	<i>Chromis weberi</i> ^{NT}	-	-	-	-	√	√
	<i>Chromis xanthura</i> ^{NT}	-	√	-	-	-	-
	<i>Chrysiptera talboti</i> ^{NT}	-	√	-	-	-	-
	<i>Dascyllus aruanus</i> ^{NT}	-	-	-	-	√	√
	<i>Dascyllus reticulatus</i> ^{NT}	-	-	-	-	-	√
	<i>Dascyllus trimaculatus</i> ^{NT}	√	√	-	√	√	-
	<i>Neoglyphidodon nigroris</i> ^{NT}	-	-	√	√	-	√
	<i>Neopomacentrus nemurus</i> ^{NT}	√	√	√	√	√	√
	<i>Stegastes lacrymatus</i> ^{NT}	√	√	√	√	-	√
	<i>Pomacentrus alexanderae</i> ^{NT}	-	-	√	√	-	-
	<i>Pomacentrus armillatus</i> ^{NT}	-	-	√	√	-	-
	<i>Pomacentrus auriventris</i> ^{NT}	-	√	√	-	-	-
	<i>Pomacentrus bankanensis</i> ^{NT}	-	-	-	-	√	√

Continuation of Table 3. Fish diversity of Target (T) and non-target (NT) fish found inside (IMPA) and outside (OMPA) of the three marine protected areas in the study.

	<i>Pomacentrus brachialis</i> ^{NT}	-	-	√	√	√	√
	<i>Pomacentrus coelestis</i> ^{NT}	-	-	-	√	√	-
	<i>Pomacentrus littoralis</i> ^{NT}	-	-	-	√	-	-
	<i>Pomacentrus margaretifer</i> ^{NT}	-	-	-	√	-	-
	<i>Pomacentrus moluccensis</i> ^{NT}	√	√	√	√	√	√
	<i>Pomacentrus sp</i> ^{NT}	-	-	-	√	√	√
	<i>Pomacentrus sp 2</i> ^{NT}	-	-	-	-	-	√
	<i>Pycnochromis amboinensis</i> ^{NT}	-	-	-	-	-	√
	<i>Pycnochromis retrofasciatus</i> ^{NT}	√	√				
Scorpaenidae	<i>Pycnochromis margaretifer</i> ^{NT}	-	-	-	-	√	√
Serranidae	<i>Pterois volitans</i> ^T	-	√	-	-	-	-
	<i>Cephalopholis argus</i> ^T	√	√	√	√	√	-
	<i>Epinephelus sp</i> ^T	-	-	√	√	-	-
	<i>Pseudanthias dispar</i> ^{NT}	-	-	-	√	-	-
Siganidae	<i>Pseudanthias huchtii</i> ^{NT}	√	-	-	-	-	-
Sphyraenidae	<i>Siganus virgatus</i> ^T	-	-	-	-	√	-
Synodontidae	<i>Sphyraena forster</i> ^T	-	-	√	-	-	-
Tetraodontidae	<i>Synodus sp</i> ^T	-	-	-	-	√	√
	<i>Arothron nigropunctatus</i> ^{NT}	-	√	-	-	-	-
	<i>Arothron sp</i> ^{NT}	√	-	-	-	-	-
Zanclidae	<i>Canthigaster valentini</i> ^{NT}	-	-	-	-	√	√
	<i>Zanclus cornutus</i> ^{NT}	√	√	√	√	√	√

very low to very high (Figure 4C) according to the criteria set by Nañola et al. (2006). The positive impact of the MPAs was particularly evident in Molugan and Hermano, which had significantly higher biomass inside (41 MT/km² for Molugan, 169 MT/km² for Hermano) than outside (6 MT/km² and 11 MT/km², respectively). In contrast, Mambayaan exhibited very low biomass both inside and outside the MPA (4 MT/km² in each area).

4. DISCUSSION

4.1 Reef fish diversity, abundance, and biomass

The 1998 Fisheries Code mandates that every municipality designate at least 15% of its municipal waters as marine protected areas (MPAs) (RA 10654, 2015; RA 8550, 1998; Weeks et al. 2010). This national law supports the country's conservation efforts, as the Philippines is recognized as the center of a global marine biodiversity hotspot (Carpenter and Springer 2005; Go et al. 2015). It is this adherence to the law and

the recognition of the area's conservation value that led El Salvador City and the municipality of Balingasag in Misamis Oriental, Northern Mindanao, Philippines, to establish MPAs in their respective municipal waters. These MPAs aim to restore degraded marine resources and enhance their productivity (Alcala and Russ 2006; Barnett and Baskett 2015). Studies show that MPAs can lead to higher diversity of reef fish assemblages (Pettersen et al. 2022; Sanabria-Fernandez et al. 2019), as observed in Mambayaan, Hermano, and Molugan MPAs, where reef fish diversity is higher compared to areas outside MPAs (Figure 3A, 3D, 3G). Despite being rated from very poor to moderate in terms of diversity according to categories developed by Hilomen et al. (2000), these MPAs still exhibit positive effects, with relatively greater reef fish diversity in protected areas, indicating their effectiveness in enhancing fish diversity.

However, some studies report that the establishment of MPAs does not always result in increased fish diversity or coral cover, which directly affects reef fish diversity (Alonso-Aller et

al. 2017; Cox et al. 2017). Additionally, fish in MPAs may still be impacted by fishing pressure outside protected zones, as they can move freely between these areas. Environmental factors such as increasing temperatures have also led to organism migration (Thomas and Gillingham 2015), with fish and other marine organisms moving to waters that meet their biological requirements (Potts et al. 2015; Salik et al. 2015). Reef fishes, in particular, exhibit high site fidelity behavior, resulting in minimal migration and similar fish populations inside and outside MPAs (Bucol et al. 2020; McGregor and Strydom 2020).

A baseline assessment in Macajalar Bay by Quiaoit et al. (2010) reported high reef fish abundance and very high biomass in the Mambayaan MPA, with 4,080 ind/km² and 44.45 MT/km², respectively. However, the current study shows a significant decrease in these parameters, with fish abundance at 2,124 ind/km² and biomass at 27 MT/km². In contrast, Hermano MPA saw an increase in fish abundance from 1,467 ind/km² in 2008 to 4,550 ind/km² in the current study, and biomass increased from 22.69 MT/km² to 270 MT/km². Molugan MPA also experienced an increase in fish abundance from 1,758 ind/km² in 2008 to 2,347 ind/km² in the current study, and biomass increased from 12.74 MT/km² to 69 MT/km². These changes in diversity, abundance, and biomass may reflect varying levels of enforcement and changes in the physical, chemical, and biological features of the area from 2008 to 2021.

Effective MPA management involves rigorous implementation of laws and policies, community involvement, and public awareness (Guidetti et al. 2008; Read et al. 2015). However, the size and age of MPAs also play significant roles in their success. Larger MPAs generally exhibit more pronounced increases in fish biomass, as seen in Molugan MPA. Therefore, comprehensive assessments are needed to understand the contributions of these factors to MPA outcomes fully. While MPAs generally support marine resource conservation, their effectiveness can vary based on local conditions and management practices (Chessman 2013; Kwik and Yeo 2015; Go et al. 2015; Elston et al. 2020; Farré et al. 2015).

The level of enforcement is a critical determinant of MPA effectiveness, although this was not evaluated in this study. Guidetti et al. (2008) underscored that rigorous implementation of laws and policies is crucial in enhancing the growth and recovery of protected reefs and fish populations. However, strict enforcement alone does not guarantee MPA success; community involvement and public awareness are equally vital in achieving the common

goal of marine resource protection (Read et al. 2015). Therefore, it is premature to attribute the observed increases in fish diversity, abundance, and biomass solely to enforcement or community involvement in the study area. Other factors, such as MPA size and age, may also play significant roles. All three MPAs in this study were established in 2006 and have shown notable improvements in abundance, diversity, and biomass, particularly among target fish species. The larger MPAs have generally exhibited more pronounced increases in fish biomass, exemplified by the significant growth observed in Molugan MPA. However, comprehensive assessments are needed to fully understand the contributions of these factors to MPA outcomes.

4.2 Effects of MPA on the target reef fishes

Though marine protected areas commonly boost marine resource conservation, some studies question their efficacy in increasing fish abundance (Chessman 2013). Furthermore, some studies recorded higher fish abundance in the unprotected area than in the protected area (Kwik and Yeo 2015). The abundance of target fish species, ranging from very poor (in Mambayaan and Molugan MPAs) to moderate (in the Hermano MPA) in this study, is consistent with the findings of Go et al. (2015). Their report indicated that most of the fish species reported during their sampling were low in abundance, influenced by the fishing effort in the area and the overall health of the coral reefs (Elston et al. 2020), though assessment of these factors was not considered in the current study. In addition, the lack of significant differences in the abundance of target fishes inside and outside the three MPAs indicates that fish abundance inside the protected area is comparable to that outside the MPA. These findings were influenced by the homogeneity of the three study sites, where the same environmental parameters that drive fish distribution, abundance, and diversity are almost similar across sites (Farré et al. 2015). Moreover, it is plausible that the comparable fish abundance inside and outside MPAs could also be influenced by fish migration.

Marine protected areas usually provide positive effects in the area where they were established. Although the three MPAs in this study were classified as very poor to moderate for target fish, if we base our assessment solely on the number of individual fish present within the MPAs, the establishment of MPAs at the three sites has greatly impacted their reef fishes, enhancing fish abundance. This is supported by studies by Putra et al. (2021) and Kumar Sarkar et al. (2013),

which show that MPAs increase fish abundance, biomass, and richness due to the protection afforded to fish inhabiting the protected zones, especially those of high economic value. The establishment of MPAs benefits the conservation of wild populations of high-value reef fishes by significantly reducing fishing pressure and other human-induced activities, and indirectly improving water quality and the overall health of marine ecosystems.

Marine protected areas are very important for reducing human-induced degradation of marine resources caused by pollution, illegal fishing, and overexploitation (Xuereb et al. 2019). A study shows that MPAs could help areas with high poverty rates after a few years of establishment through spillover effects that enhance fish biomass both inside the MPA and outside the protected zone (Da Silva et al. 2015). A study by Sanabria-Fernandez et al. (2019) states that fish biomass is one of the contributors to the effectiveness of the implementation of marine protected areas. Higher fish biomass in an area means that the fish were protected, and this was evident in the results of the current study. Here, the positive impact of the MPAs was evident at the Molugan site, where fish biomass was significantly higher inside than outside the MPA, according to statistics. This result supports the claim of Cacabelos et al. (2020) that MPAs enhance fish biomass, which makes this tool very effective in conservation because of the level of protection given to the exploited species. Another study by Keppeler et al. (2017) reached similar conclusions, finding that MPAs produced high fish biomass due to reduced fishing pressure and increased fishing productivity. However, lenient protection and weak management in certain protected zones may also lead to lower biomass and productivity in the area (Arai, 2015), as observed in Mambayaan MPA, which had very poor fish biomass of target species. A proper and strict implementation of marine protected areas positively impacted fish biomass, especially for fish species that were heavily targeted by fishers. In addition, information and education at the community level and governmental support are vital in the success of a certain marine protected area (Putra et al. 2021).

5. CONCLUSION

This study evaluated reef fish diversity, abundance, and biomass inside and outside three marine protected areas (MPAs) in Northern

Mindanao, Philippines. Our findings indicate that MPAs generally supported moderate to high reef fish diversity, abundance, and significantly greater biomass, compared to adjacent fished areas. Notably, targeted fish species exhibited marked increases within MPAs, demonstrating their efficacy as a conservation tool for recovering exploited populations.

However, the results were not uniform; one MPA (Mambayaan) showed a decline compared to 2008 baseline data, underscoring that MPA benefits are not automatic. Sustained success depends on robust enforcement, strengthened community-led management, and unwavering support from local government units. This study confirms that well-implemented MPAs are vital for enhancing fish productivity and ecosystem resilience, though their outcomes are contingent on consistent and dedicated management.

ACKNOWLEDGMENT

We would like to extend our gratitude to the Department of Marine Science, Mindanao State University-Iligan Institute of Technology (MSU-IIT) and the Department of Science and Technology Accelerated Science and Technology Human Resource Development Program (DOST-ASTHRDP) for allowing and funding this project. The same gratitude are also extended to the BLGUs and bantay dagat of Brgy. Molugan, El Salvador and Brgys. Hermano and Mambayaan, Balingasag for their support during the whole duration of sampling.

AUTHOR CONTRIBUTION

Bersaldo MJJ: Conceptualization, Methodology, Data Curation, Writing Original Draft Preparation, Visualization, Validation, Investigation, Writing-Reviewing and Editing. **Dalagan GE:** Conceptualization, Methodology, Investigation, Writing-Reviewing and Editing. **Duay CB:** Conceptualization, Methodology, Data Curation, Investigation, Validation, Writing-Reviewing and Editing. **Tutor R:** Conceptualization, Methodology, Investigation, Writing-Reviewing and Editing. **Pedrosa-Gerasmio IR:** Conceptualization, Methodology, Data Curation, Validation, Supervision, Writing-Reviewing and Editing. **Tampus AD:** Conceptualization, Methodology, Validation, Supervision, Writing-Reviewing and Editing.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL STATEMENT

The authors obtained an authorization allowing the study to be conducted inside and outside the Marine Protected Area from the City Agriculturist Office of El Salvador City and Municipal Agricultures Office of Balingasag, Misamis Oriental on April 6, 2023.

REFERENCES

- Abesamis RA, Russ GR, Alcala AC. 2006. Gradients of abundance of fish across no-take marine reserve boundaries: Evidence from Philippine coral reefs. *Aquat Conserv*. 16(4):349–371. <https://doi.org/10.1002/aqc.730>
- Alcala AC, Russ GR. 2006. No-take marine reserves and reef fisheries management in the Philippines: A new people power revolution. *Ambio*. 35(5):245–254. <https://doi.org/10.1579/05-A-054R1.1>
- Alcala AC. 1988. Effects of Marine Reserves on Coral Fish Abundances and Yields of Philippine Coral Reefs. *Ambio*. 17(3):194–199. <http://www.jstor.org/stable/4313453>
- Allen GR, Steene R, Humann P, DeLoach N. 2003. Reef Fish Identification: Tropical Pacific. Jacksonville: New World Publications Inc. p. 457
- Alonso Aller E, Jiddawi NS, Eklöf JS. 2017. Marine protected areas increase temporal stability of community structure, but not density or diversity, of tropical seagrass fish communities. *PLoS ONE*. 12(8):1–23. <https://doi.org/10.1371/journal.pone.0183999>
- Arai T. 2015. Diversity and conservation of coral reef fishes in the Malaysian South China Sea. *Rev Fish Biol Fish*. 25(1):85–101. <https://doi.org/10.1007/s11160-014-9371-9>
- Arin T, White A, Vogt H. 2000. Philippine coral reefs under threat: The economic losses caused by reef destruction. *Mar Pollut Bull*. 40(7):598–605. [https://doi.org/10.1016/S0025-326X\(00\)00022-9](https://doi.org/10.1016/S0025-326X(00)00022-9)
- Aurellado MEB, Ticzon VS, Naniola CL, Cabansag JBP, Bacabac MMA, Sorgon KES, Simon ANP, Hilomen VV. 2021. Effectiveness of Philippine nationally managed marine reserves in improving biomass and trophic structure of coral reef fish communities. *Coast Manage*. 49(3):293–312. <https://doi.org/10.1080/08920753.2021.1899944>
- Barnett LAK, Baskett ML. 2015. Marine reserves can enhance ecological resilience. *Ecol Lett*. 18(12):1301–1310. <https://doi.org/10.1111/ele.12524>
- Bucol LA, Romano EF, Cabcanan SM, Siplon LMD, Madrid GC, Bucol AA, Polidoro B. 2020. Microplastics in marine sediments and rabbitfish (*Siganus fuscus*) from selected coastal areas of Negros Oriental, Philippines. *Mar Pollut Bull*. 150:110685. <https://doi.org/10.1016/j.marpolbul.2019.110685>
- Cacabelos E, Martins GM, Faria J, Prestes ACL, Costa T, Moreu I, Neto AI. 2020. Limited effects of marine protected areas on the distribution of invasive species, despite positive effects on diversity in shallow-water marine communities. *Biol Invasions*. 22(3):1169–1179. <https://doi.org/10.1007/s10530-019-02171-x>
- Carpenter KE, Springer VG. 2005. The center of the center of marine shore fish biodiversity: The Philippine Islands. *Environ Biol Fishes*. 72(4):467–480. <https://doi.org/10.1007/s10641-004-3154-4>
- Chessman BC. 2013. Do protected areas benefit freshwater species? A broad-scale assessment for fish in Australia's Murray-Darling Basin. *J Appl Ecol*. 50(4):969–976. <https://doi.org/10.1111/1365-2664.12104>
- Corrales CM, Delan GG, Rica RLV, Piquero AS, Monte IA. 2015. A Baseline Study on Coral Reef Fishes in the Marine Protected Areas in Southern Cebu, Philippines. *Trop Tech J*. 19(1):1–8. <https://doi.org/10.7603/s40934-015-0004-2>

- Cox C, Valdivia A, McField M, Castillo K, Bruno JF. 2017. Establishment of marine protected areas alone does not restore coral reef communities in BelizeMar Ecol Prog Ser. 563:65–79. <https://doi.org/10.3354/meps11984>
- da Silva IM, Hill N, Shimadzu H, Soares AMVM, Dornelas M. 2015. Spillover Effects of a Community-Managed Marine Reserve. PLoS ONE. 10(4):e0111774. <https://doi.org/10.1371/journal.pone.0111774>
- Elston C, Dallison T, Jones PR. 2020. Factors influencing the abundance patterns of reef fish functional guilds in two coastal bays, Philippines. Ocean Coast Manag. 198:105386. <https://doi.org/10.1016/j.ocecoaman.2020.105386>
- English S, Wilkinson C, Baker V, editor. 1997. Survey manual for tropical marine resources, 2nd ed. Townsville, Queensland: Australian Institute of Marine Science. p. 390.
- Farré M, Lombarte A, Recasens L, Maynou F, Tuset VM. 2015. Habitat influence in the morphological diversity of coastal fish assemblages. J Sea Res. 99:107–117. <https://doi.org/10.1016/j.seares.2015.03.002>
- Fidler RY, Maypa A, Apistar D, White A, Turingan RG. 2014. Body size shifts in Philippine reef fishes: Interfamilial variation in responses to protection. Biol. 3(2):264–280. <https://doi.org/10.3390/biology3020264>
- Fischer J, editor. 2013. Fish identification tools for biodiversity and fisheries assessments: review and guidance for decision-makers. FAO Fisheries and Aquaculture Technical Paper 585. Rome, Italy: Food and Agriculture Organization of the United Nations
- Friedlander AM, Brown EK, Jokiel PL, Smith WR, Rodgers KS. 2003. Effects of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago. Coral Reefs. 22(3):291–305. <https://doi.org/10.1007/s00338-003-0317-2>
- Froese R, Pauly D. 2022. FishBase. In: World Wide Web electron. publ. www.fishbase.org. Accessed 10 Oct 2022
- Go KTB, Anticamara JA, de Ramos JAJ, Gabona SE, Agao DE, Herrera EC, Bitara AU. 2015. Species richness and abundance of non-cryptic fish species in the Philippines: a global center of reef fish diversity. Biodiv Conserv. 24(10):2475–2495. <https://doi.org/10.1007/s10531-015-0938-0>
- Gonzales BJ. 2013. Field Guide to Coastal Fishes of Palawan. Manila: Coral Triangle Initiative on Coral Reefs, Fisheries, and Food Security (CTI-CFF). pp. 208. https://www.coraltriangleinitiative.org/sites/default/files/resources/42_Field%20Guide%20to%20Coastal%20Fishes%20Palawan.pdf
- Gonzales BJ, Gonzales MMG. 2016. Trends of coral, fish, and fisheries near and far from human developments in Coral Bay, Southwest Sulu Sea, Palawan, Philippines. Aquac Aquar Conserv Legis. 9(2):396–407. <http://bioflux.com.ro/docs/2016.396-407.pdf>
- Guidetti P, Milazzo M, Bussotti S, Molinari A, Murenu M, Pais A, Spano N, Balzano R, Agardy T, Boero F, Carrada G. 2008. Italian marine reserve effectiveness: does enforcement matter? Biol Conserv. 141(3):699–709. <https://doi.org/10.1016/j.biocon.2007.12.013>
- de Guzman AB. 2016. A Fishery in Transition: Impact of a Community Marine Reserve on a Coastal Fishery in Northern Mindanao, Philippines. In: Olewiler N, Francisco H, Ferrer A, editors. Marine and Coastal Ecosystem Valuation, Institutions, and Policy in Southeast Asia. Springer, Singapore. pp. 249–266. https://doi.org/10.1007/978-981-10-0141-3_12
- Hilomen VV, Nañola Jr CL, Dantis AL. 2000. Status of Philippine reef fish communities. Gomez, editor. Philippine coral reefs, reef fishes, and associated fisheries: status and recommendations to improve their management. GCRMN Report Appendix B.
- Keppeler FW, Hallwass G, Silvano RAM. 2017. Influence of protected areas on fish assemblages and fisheries in a large tropical river. ORYX. 51(2):268–279. <https://doi.org/10.1017/S0030605316000247>

- Kuiter RH, Debelius H. 2006. World atlas of marine fishes. Frankfurt, Germany: IKAN-Unterwasserarchiv. ISBN: 3-925919-77-5. p 720
- Kumar Sarkar U, Kumar Pathak A, Kumar Tyagi L, Mohan Srivastava S, Prakash Singh S, Kumar Dubey V. 2013. Biodiversity of freshwater fish of a protected river in India: Comparison with unprotected habitat. *Rev Biol Trop*. 61(1):161–172. <https://doi.org/10.15517/rbt.v61i1.10942>
- Kwik JTB, Yeo DCJ. 2015. Differences in fish assemblages in protected and non-protected freshwater streams in a tropical urbanized country. *Hydrobiologia*. 762(1):143–156. <https://doi.org/10.1007/s10750-015-2344-8>
- Licuanan WY, Robles R, Reyes M. 2019. Status and recent trends in coral reefs of the Philippines. *Mar Pollut Bull*. 14:544–550. <https://doi.org/10.1016/j.marpolbul.2019.04.013>
- Limmon G, Delrieu-Trottin E, Patikawa J, Rijoly E, Dahrudin H, Busson F, Steinke D, Hubert, N. 2020. Assessing species diversity of Coral Triangle artisanal fisheries: A DNA barcode reference library for the shore fishes retailed at Ambon harbor (Indonesia). *Ecol Evol*. 10(7):3356–3366. <https://doi.org/10.1002/ece3.6128>
- Macusi ED, Camaso KL, Barboza A, Macusi ES. 2021. Perceived Vulnerability and Climate Change Impacts on Small-Scale Fisheries in Davao Gulf, Philippines. *Front Mar Sci*. 8:597385. <https://doi.org/10.3389/fmars.2021.597385>
- Magdaong ET, Fujii M, Yamano H, Licuanan WY, Maypa A, Campos WL, ... & Martinez R. 2014. Long-term change in coral cover and the effectiveness of marine protected areas in the Philippines: a meta-analysis. *Hydrobiologia*. 733:5–17. <https://doi.org/10.1007/s10750-013-1720-5>
- McGregor S, Strydom NA. 2020. Feeding ecology and microplastic ingestion in *Chelon richardsonii* (Mugilidae) associated with surf diatom *Anaulus australis* accumulations in a warm temperate South African surf zone. *Mar Pollut Bull*. 158:111430. <https://doi.org/10.1016/j.marpolbul.2020.111430>
- Mora C, Chittaro PM, Sale PF, Kritzer JP, Ludsin SA. 2003. Patterns and processes in reef fish diversity. *Nature*. 421(6926):933–936. <https://doi.org/10.1038/nature01393>
- Mosquera I, Côté I, Jennings S, Reynolds J. 2000. Conservation benefits of marine reserves for fish populations. *Anim Conserv*. 4:321–332. <https://doi.org/10.1111/j.1469-1795.2000.tb00117.x>
- Muallil RN, Deocadez MR, Martinez RJS, Campos WL, Mamauag SS, Nañola CL, Aliño PM. 2019. Effectiveness of small locally-managed marine protected areas for coral reef fisheries management in the Philippines. *Ocean Coast Manag*. 179:104831. <https://doi.org/10.1016/j.ocecoaman.2019.104831>
- Nañola C, Aliño P, Arceo H, Licuanan W, Uychiaoco A, Quibilan M, ..., Gomez E. 2006. Status report on coral reefs of the Philippines-2004. In: *Proceedings of the 10th International Coral Reef Symposium, Okinawa, Japan*. pp. 1055–1061.
- Pettersen A., Marzinelli EM, Steinberg PD, Coleman MA. 2022. Impact of marine protected areas on temporal stability of fish species diversity. *Conserv Biol*. 36(2). p. 11 <https://doi.org/10.1111/cobi.13815>
- Potts WM, Götz A, James N. 2015. Review of the projected impacts of climate change on coastal fishes in southern Africa. *Rev Fish Biol Fish*. 25(4):603–630. <https://doi.org/10.1007/s11160-015-9399-5>
- Putra RD, Siringiringo RM, Suryanti A, Sari NWP, Sinaga M, Hidayati NV, Hukom FD, Abrar M, Makatipu PC, Sianturi R, Ilham Y. 2021. Impact of marine protected areas on economical important coral reef fish communities: An evaluation of the biological monitoring of coral reef fish in anambas islands, indonesia. *Biodivers*. 22(10):4169–4181. <https://doi.org/10.13057/biodiv/d221006>
- Quiaoit HR, de Guzma, AB, Villaluz EA, Dawang DR, Quimpo FS, Mabao AS, Martinez LS. 2010. Ecological and fisheries profile of Macajalar Bay 2008.

- Read AD, West RJ, Kelaher BP. 2015. Using compliance data to improve marine protected area management. *Mar Pol.* 60:119–127. <https://doi.org/10.1016/j.jenvman.2011.05.022>
- Republic Act No. 7586 (1992). An act providing the establishment and management of National Integrated Protected Areas System Act, defining its scope and coverage, and for other purposes. Official Gazette No. 29. pp. 4641–4653.
- Republic Act No. 8550 (1998). An act providing for the development, management and conservation of the fisheries and aquatic resources, integrating all laws pertinent thereto, and for other purposes. Republic of the Philippines. Congress of the Philippines. Tenth Congress. Fifth special session. February 17, 1998.
- Republic Act No. 10654 (2015). An act to prevent, deter, and eliminate illegal, unreported and unregulated fishing, amending Republic Act No. 8550, otherwise known as The Philippine Fisheries Code of 1998 and for other purposes. Republic of the Philippines. Congress of the Philippines. Sixteenth Congress. Second Regular Session. July 28, 2014.
- Roberts CM, McClean CJ, Veron JEN, Hawkins JP, Allen GR, McAllister DE, Mittermeier CG, Schueler FW, Spalding M, Wells F, Vynne C, Werner TB. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Sci AAAS.* 295(5558):1280–1284. <https://doi.org/10.1126/science.1067728>
- Russ GR, Alcala AC, Maypa AP, Calumpong HP, White AT. 2004. Marine reserve benefits local fisheries. *Ecol Appl.* 14(2):597–606. <https://doi.org/10.1890/03-5076>
- Salik KM, Jahangir S, Zahdi W, ul Z, Hasson S. 2015. Climate change vulnerability and adaptation options for the coastal communities of Pakistan. *Ocean Coast Manag.* 112:61–73. <https://doi.org/10.1016/j.ocecoaman.2015.05.006>
- Samoilys MA, Martin-Smith KM, Giles BG, Cabrera B, Anticamara JA, Brunio EO, Vincent ACJ. 2007. Effectiveness of five small Philippines’ coral reef reserves for fish populations depends on site-specific factors, particularly enforcement history. *Biol Conserv.* 136(4):584–601. <https://doi.org/10.1016/j.biocon.2007.01.003>
- Sanabria-Fernandez JA, Alday JG, Lazzari N, Riera R, Becerro MA. 2019. Marine protected areas are more effective but less reliable in protecting fish biomass than fish diversity. *Mar Pollut Bull.* 143:24–32. <https://doi.org/10.1016/j.marpolbul.2019.04.015>
- Ticzon VS, Mumby PJ, Samaniego BR, Bejarano-Chavarro S, David LT. 2012. Microhabitat use of juvenile coral reef fish in Palau. *Environ Biol Fishes.* 95:355–370. <https://doi.org/10.1007/s10641-012-0010-9>
- Thomas CD, Gillingham PK. 2015. The performance of protected areas for biodiversity under climate change. *Biol J Linn Soc Lond.* 115(3):718–730. <https://doi.org/10.1111/bij.12510>
- Van Nguyen L, Kim Phan H. 2008. Distribution and factors influencing on structure of reef fish communities in Nha Trang Bay Marine Protected Area, South-Central Vietnam. *Environ Biol Fishes.* 82(3):309–324. <https://doi.org/10.1007/s10641-007-9293-7>
- Wantiez L, Thollot P, Kulbicki M. 1997. Effects of marine reserves on coral reef fish communities from five islands in New Caledonia. *Coral Reefs.* 16(4):215–224. <https://doi.org/10.1007/s003380050077>
- Weeks R, Russ GR, Alcala AC, White AT. 2010. Effectiveness of Marine Protected Areas in the Philippines for Biodiversity Conservation. *Conserv Biol.* 24(2):531–540. <https://doi.org/10.1111/j.1523-1739.2009.01340.x>

- White WT, Last PR, Dharmadi G, Faizah R, Chodrijah U, Prisantoso BI, Pogonoski JJ, Puckridge M, Balber SJM. 2013. Market fishes of Indonesia. Australian Centre for International Agricultural Research. p. 155. https://www.aciar.gov.au/sites/default/files/legacy/node/15500/mn155_fishes_of_indonesia_pdf_19137.pdf
- Xuereb A, D'Aloia CC, Daigle RM, Andrello M, Dalongeville A, Manel S, Mouillot D, Guichard F, Côté IM, Curtis JMR, Bernatchez L, Fortin MJ. 2019. Marine Conservation and Marine Protected Areas. In *Pop Genom: Mar Org.* pp. 423–446. https://doi.org/10.1007/13836_2018_63



© 2026 The authors. Published by the National Fisheries Research and Development Institute. This is an open access article distributed under the [CC BY-NC 4.0](https://creativecommons.org/licenses/by-nc/4.0/) license.