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Sea Cucumbers (Holothuroidea) of Northeastern and Western Mindanao, Philippines: The Potential Role of Marine Protected Areas in Maintaining Diversity and Abundance

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ABSTRACT

Marine protected areas (MPAs) are considered strategic tools in conserving biodiversity and maintaining stocks of valuable resources. We assessed sea cucumbers in five provinces in northeastern and western Mindanao to describe the state of diversity and abundance and evaluate the role of MPAs in sustaining stocks of exploited species. We identified 36 species of sea cucumbers from fishery-independent surveys on shallow reef flats and deeper reef slopes, of which 33 species (92%) belong to order Aspidochirotida and three species belong to Order Apodida. The majority are shallow-water holothurians occurring on reef flats and seagrass beds, while a few species are found along reef slopes or in fresh catches by fishers sold to local traders or processors in some sites. Nine species are considered high-value to the global trepang trade but occur at low densities, while the rest are abundant or common species with low commercial value. Species richness (S=17-30 spp.) varies across sites, but species composition similarity is relatively high (Sørensen's SQ = 0.62-0.78). Mean population densities and variances of high-value species are significantly higher inside enforced MPAs than in non-MPA sites (t-test, $p < 0.05$; F-test, $p < 0.005$) across five survey sites. The abundance of high-value *H. scabra* in Tubajon and *H. fuscogilva* in Capayas Island demonstrates the critical role of MPAs in conserving biodiversity, maintaining population levels, and ensuring natural recruitment of sea cucumber resources. Urgent management measures such as formulating a national management plan, regulating harvests, and establishing no-take MPAs are recommended.

INTRODUCTION

Sea cucumbers are among the most diverse and ubiquitous marine invertebrate groups belonging to Class Holothuroidea with some 1,500 species (Conand, 2006), with the list growing as new species are described each year. The most recent account in the World Register of Marine Species listed 1,805 accepted species of holothurians in the world (WoRMS, 2021). Their fisheries are of great social and economic importance to many coastal communities (Anderson et al., 2011), particularly in the Asia-Pacific region where natural diversity is highest (Toral-Granda et al., 2008) but are mainly unmanaged (Conand, 2018). Worldwide more than 70 species of sea cucumbers are commercially exploited (Purcell et al., 2016) and traded in dried form as 'beche-de-mer or 'trepang' mainly for food; however, recent discoveries of high-value bioactive compounds and anti-fungal, anti-microbial, and even anti-cancer properties (Bordbar et al., 2011) had stimulated an emerging market in pharmaceutical, nutraceutical, and cosmetic industries (Toral-Granda et al., 2008).

The rising demand in the global market and economic dependency on the global trepang trade quickly led to the decline of many holothurian populations worldwide. Many natural stocks of large-sized and high-value species are locally depleted or endangered (Lawrence et al., 2004; Anderson et al., 2011), prompting fishers to exploit new locations or to target less valuable species in order to satisfy an insatiable global demand for trepang (Uthicke, 2004; Toral-Granda et al., 2008). This progressive overfishing and habitat degradation resulted in biodiversity loss and reduced stock capacity to reproduce and repopulate the fishing areas (Lawrence et al., 2004). Most fisheries are suspected of operating under illegal, unreported, and unregulated (IUU) regimes (Toral-Granda, et al. 2008; Anderson et al., 2011), often forming a substantial portion of the overall catches even exceeding the reported legal catch (Choo, 2008).

The Philippines plays a significant part in the global trepang market (Gamboa et al., 2004; Labe, 2010; Devanadera et al., 2015), second only to Indonesia in early 2000 (Ferdouse, 2004). However, this 'boom and bust' enterprise resulted in widespread population declines such that the entire archipelago is now considered a sea cucumber 'hotspot' in Asia (Choo, 2008). Over decades of unmanaged exploitation, the capture fishery has shifted from a high-value, low-volume to low-value, high-volume species production (Schoppe, 2000a; Akamine, 2005; Brown et al., 2010). Hookah or compressor divers gather much larger, high-value sea cucumbers from deeper and previously unexplored areas of the reef (Choo, 2008; De Guzman and Quiñones, 2013).

Estimates of the total number of sea cucumber species in the Philippines had varied through time and by location (Domantay, 1934, 1960; Clark and Rowe, 1971; Schoppe, 2000b; Kerr et al., 2006; Olavides et al., 2010). A recent report by De la Cruz et al. (2015) identified 132 species from pooled lists of Philippine holothurians based on recent taxonomic reviews and corrections (mainly Samyn et al., 2005; Uthicke et al., 2010, Purcell et al., 2012, Kim et al., 2013). Baseline information on the species diversity, distribution, and status of sea cucumber stocks in many geographical areas is inadequate for developing an appropriate and science-based management strategy. Although marine protected areas (MPAs) are known to be an effective fisheries management tool (Alcala, 1999; Abesamis et al., 2006; De Guzman, 2016), few studies have evaluated their role in maintaining diversity and populations of sea cucumbers (Cariglia et al., 2013; De la Cruz et al., 2015). This paper is an output of a nationwide program funded by the Commission on Higher Education (CHED) on *the Species Inventory and Fisheries Assessment of Sea Cucumbers in Key Biogeographical Regions* in the Philippines. The paper's main objective is to contribute to describe the biodiversity, distribution, abundance, and size ranges of sea cucumbers in selected reef sites in Mindanao, with notes on commercially exploited species.

MATERIALS AND METHODS

Survey Sites

We carried out inventory and assessment of sea cucumber diversity and abundance in five municipalities across five provinces in northeastern and western Mindanao (Fig. 1), namely, 1) Laguindingan, Misamis Oriental, 2) Lopez Jaena, Misamis Occidental, 3) Hinatuan, Surigao del Sur, 4) Rizal, Zamboanga del Norte, and 5) Tabina, Zamboanga del Sur. All sites had established marine protected areas (MPAs), providing an opportunity of comparing the diversity and abundance of sea cucumbers between protected and unprotected areas.

Species Composition, Abundance, and Size Surveys

We conducted fisheries-independent assessments to determine species richness and abundance of sea cucumbers through day-time transect surveys. Population density of all species in each site was estimated along three 50-m long x 5m wide belt transects established on the shallow reef flats in both vegetated (seagrass and algal beds) and unvegetated areas (sandy, rocky-coralline, and muddy bottoms). All sea cucumbers found within each $250m^2$ transect belt were identified, counted, and collected into basins or buckets for length and weight measurements. In sites where sea cucumbers were rare, more transects were established to increase the probability of encountering them. Occasional surveys in deeper parts (i.e., reef slopes) were made using scuba. We also conducted night-time sampling using timed searches (instead of transect surveys) to complete each site's species inventory, but no density estimates were made.

Each specimen's total body length (in cm) was measured using a fiberglass measuring tape while the sea cucumbers were in a relaxed state in their natural environment or inside large basins. Body weight (in g) of each sea cucumber was measured on a top-loading digital scale after wiping off excess water. Voucher specimens of each species were collected and preserved in formaldehyde-ethanol solution for identification and collection of spicules in the laboratory. All other specimens were returned to the reef flats where they were found.

Preliminary identification of each species was made based on gross external morphology using available taxonomic references (e.g., Rowe and Gates, 1995; Conand, 1998; Schoppe, 2000b; SPC, 2004; Kerr et al., 2006; Massin et al., 2009) and confirmed by microscopic examination of spicules obtained from different parts of the body, namely, bivium (dorsal surface), trivium (ventral side), and tentacles (Conand, 2006). Uncertain identification of sea cucumbers was later verified by taxonomy experts from FAO (Dr. Alessandro Lovatelli, pers. comm., January 2013) and University of Hawaii (Dr. François Michonneau, pers. comm., August 2013), researchers from the UP Marine Science Institute (Christine Edullantes, pers. comm., August 2013), and also by later taxonomic works of Kim et al. (2013, 2014).

Data Analysis

Sea cucumber diversity is expressed simply as species richness (S) or the number of species occurring in each site (*i.e*., alpha diversity). We calculated similarity in species composition of sea cucumbers among sites (i.e., beta diversity) using the Sørensen Similarity Coefficient (Magurran, 2004) QS = 2C/A+B, where QS is the Quotient of Similarity, A and B refer to the number of species found in site 1 and 2, respectively, and C is the number of species common to both sites. Abundance is expressed as density or the number of individuals per hectare estimated from counts of each species along belt transects. We compared mean population densities between MPA and non-MPA areas across five survey sites using a simple test to compare means (t-test, a = 0.05) and variances (F-test, a = 0.05). Statistical analysis of data was performed using the open-source software PAleontological STatistics (PAST) version 4.02 (Hammer et al., 2001). Length and weight measurements are presented as mean size ranges of each species with calculated standard errors in bar charts.

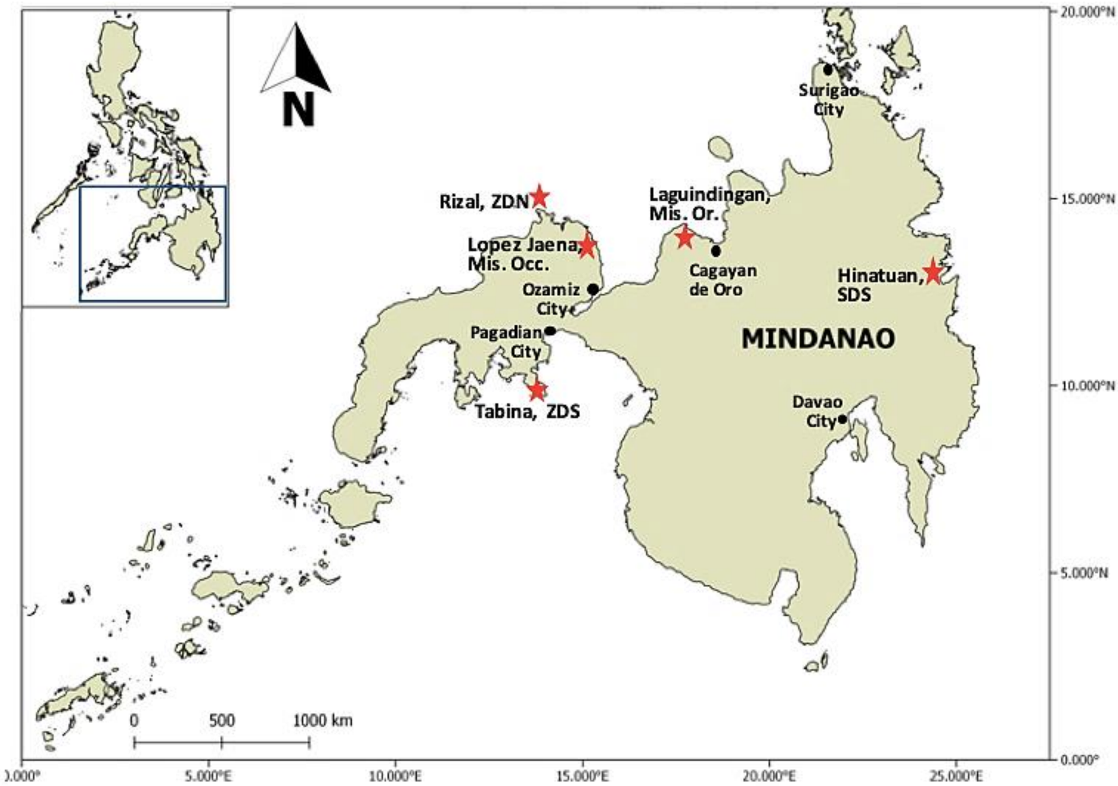

Figure 1. Location of project survey sites in Mindanao (red stars).

RESULTS AND DISCUSSION

Species Richness and Distribution

We identified 36 species of sea cucumbers in five sites in northeastern and western Mindanao, of which 33 species (92%) belong to order Aspidochirotida and three species of synaptids belong to Order Apodida (Table 1). Most of these are shallow-water holothurians encountered in transect surveys, while a few deep-water species were identified from reef slope surveys and specimens sold to buying stations or processors. Nine species are high-value or commercially important species of *Actinopyga*, *Holothuria*, *Stichopus*, and *Thelenota* (Fig. 2). Twelve species are common to most sites with low to medium economic value, while 12 species are rare, many of them with no known commercial value.

Three species of synaptids (Order Apodida) are common on the reef flats in all sites but are not harvested. One species of the genus *Holothuria*, locally known as "batuli", and another species of the genus Bohadschia are still unidentified, and may be new records for the Philippines (Francois Michonneau, pers.comm., August 2013). Figure 3 shows the distribution map of commercially important sea cucumbers across five northeastern and western Mindanao sites.

The highest species richness was found in Tabina (30 spp.) and Lopez Jaena (25 spp.) (Table 2 and Fig. 4), which have strictly enforced MPAs. Several non-MPA sites in Tabina representing varied habitats (*i.e.*, sand flats, seagrass beds, and coral reefs) were also surveyed, contributing 18 species to the list. In contrast the non-MPA site in Lopez Jaena had only four species.

The two survey sites in Laguindingan (namely Barangays Tubajon and Mauswagon) also have MPAs but gleaning in these areas are not regulated, resulting in overharvesting even of small, low-value species which are consumed as a local delicacy.

Transect surveys in the two Hinatuan sites found only eight species in the MPA (which is not strictly enforced) and in non-MPA sites. The other species in the list were identified from fresh sea cucumber catch sold to a local buyer and processor. The last site in Rizal has the fewest species (17 spp.) of sea cucumbers, with only six species found in the transect surveys even inside the MPA. At the time of the survey gleaning on the reef flats within the MPA was active. These results indicate that adequately managed MPAs or 'no take' areas can increase biodiversity by protecting valuable invertebrates from overharvesting.

Species composition of day-time and night-time sampling was variable across sites (Fig. 5), with most genera found at both sampling periods (60%) in various habitat types. Many species were found only at night (27%) while only four out of 32 species (13%) were observed only during the day, namely, *H. coluber*, *H. edulis*, and *Holothuria sp*., which were found partially hidden under seagrass or loose rocks or partially buried in sand, and Synaptula recta, a small synaptid found clinging to rocky-coralline surfaces. Two species of *Actinopyga* (*A. lecanora* and *A. capillata*) and two species of *Bohadschia* (*B. ocellata* and *B. vitiensis*) were intercepted only at night. These species often burrow in well-aerated sand during the day but are nocturnally active (Kerr et al., 2006).

Table 1. Sea cucumber species in northeastern and western Mindanao with notes on taxonomic authority and economic value. (Subgeneric names are enclosed in parentheses).

Species	Common English Name	Local Names
Order ASPIDOCHIROTIDA		
Actinopyga capillata[c] Rowe and Massin, 2006	Hairy sea cucumber	-
Actinopyga echinites[a] (Jaeger, 1833)	Spiny sea cucumber/redfish	Mani-mani, Khaki
Actinopyga lecanora[a] (Jaeger, 1835)	Stonefish	Monang, Bakungan
Bohadschia argus[b] Jaeger, 1833	Leopardfish/Tigerfish	Mat-an, Tagukan
Bohadschia marmorata[b] Jaeger, 1833	Brown-spotted sandfish	Tagukan, Lawayan
Bohadschia vitiensis[b] (Semper, 1868)	Speckled sea cucumber	Tagukan, Lawayan
Bohadschia argus x vitiensis[c*] (Ref: Kim et al. 2013)	Leopardfish-chalkfish hybrid	Tagukan, Lawayan
Bohadschia ocellata[c] Jaeger, 1833	Ocellated sea cucumber	Tagukan, Mat-an
Bohadschia sp.[b]	Dark speckled sea cucumber	Tagukan, Lawayan
Holothuria (Metriatyla) albiventer[c,d] Semper, 1868	Marten's sea cucumber	Batunan
Holothuria (Thymiosycia) arenicola[c,d] Semper, 1868	Burrowing sea cucumber	Balat-pisot
Holothuria (Halodeima) atra[b] Jaeger, 1833	Lollyfish	Balat-uwak
Holothuria coluber[b] Semper, 1868	Snakefish	Kulaw-ot
Holothuria (Halodeima) edulis[c] Lesson, 1830	Pinkfish	Hotdog
Holothuria (Stauropora) fuscocinerea[b] Jaeger, 1833	Variegated sea cucumber	Yoyo
Holothuria (Microtele) fuscogilva[a] Cherbonnier 1980	White teatfish	Sus-an puti
Holothuria (Microtele) fuscopunctata[c] Jaeger, 1833	Elephant trunkfish	Sapatos
Holothuria (Thymiosycia) gracilis[c] Semper, 1868	Yellow-bellied sea cucumber	Tagukan
Holothuria (Mertensiothuria) hilla[b,d] Lesson, 1830	Tigertail sea cucumber	Batuli
Holothuria (Thymiosycia) impatiens[b,d] (Forsskål, 1775)	Impatient sea cucumber	Balat-pisot
Holothuria (Cystipus) inhabilis[c,d] Selenka, 1867	-	Batunan
Holothuria lessoni[a] Massin, Uthicke, Purcell, Rowe and Samyn, 2009	Golden Sandfish	Kagisan, Higiran
Holothuria (Mertensiothuria) leucospilota[b] Brandt,1865	Shy black sea cucumber	Balat-pisot
Holothuria (Stauropora) pervicax[b,d] Jaeger, 1833	Stubborn sea cucumber	Sunlot
Holothuria (Cystipus) rigida[c,d] Selenka, 1867	Rigid sea cucumber	Uking
Holothuria (Metriatyla) scabra[a] Jaeger, 1833	Sandfish	Kagisan, Higiran
Holothuria (Microtele) whitmaei[a] Bell, 1887	Black teatfish	Sus-an Itom
Holothuria sp.[c]	-	Batuli
Pearsonothuria graeffei[b] (Semper, 1868)	Blackspotted sea cucumber	Hangad-hangad
Stichopus herrmanni[a] Semper, 1868	Curryfish	Hanginan
Stichopus horrens[a] Selenka, 1867	Dragonfish /	Hanginan, Gamat
Stichopus noctivagus[c] Cherbonnier, 1980	Night-wandering SC	Hanginan
Thelenota anax[a] Clark, 1921	Amber fish	Paag daga, Legs

Order APODIDA			
Euapta godeffroyi[d]	Semper, 1868	Medusan sea cucumber	Bahag-bahag
Synapta maculata[d]	Chamisso and Eysenhardt, 1821	Medusan sea cucumber	Bahag-bahag
Synaptula recta[d]	Semper, 1867	Medusan sea cucumber	Bahag-bahag

Legend: [a]High-value, [b]Common, medium- to low-value, [c]Rare species in the study sites, [d]No commercial value; [*]Putative classification

Sea cucumbers occur in a variety of habitats, from shallow seagrass meadows to muddy bottoms and deeper coralline areas. Majority of the sea cucumber species found in the five sites (Fig. 6) are residents of sandy-seagrass beds (61%) while other species occur in sandy-rocky substrata with patchy seagrass (17%) or in shallow to deep coralline areas (15%). A smaller proportion (7%) of sea cucumbers (e.g. composed of H. scabra, H. lessoni, H. fuscocinerea and A. echinites) thrive in sandy to muddy areas where seagrass such as Enhalus acoroides provide shelter for these animals during the day.

Calculated values of similarity quotient (SQ) or index show relatively high similarity among sites (SQ = 0.62-0.78) with Laguindingan and Rizal having the most similar species composition (78%) while Lopez Jaena and Hinatuan sites have the least similarity (62%) (Table 3). The Sørensen model demonstrates not only similarity in species composition but also highlights the level of dissimilarity between sites. Laguindingan and Rizal have lower species richness and fewer common species (n=14) compared to other site pairs, however, they also have the fewest number of unique or uncommon species (n=7). Conversely, Lopez Jaena and Tabina have the highest species richness (S=25 and S=30, respectively) and number of common species (n=19) but have 16 uncommon species, with 11 of these found only in Tabina, resulting in a lower similarity index (SQ=0.69). High similarity in species composition among sites in northeastern and western Mindanao is influenced by similarity in habitat types rather than geographical location. All sites have wide seagrass-dominated sandy substrata with muddy portions and shallow sandy-coralline areas. Capayas Island in Lopez Jaena, on the other hand, has primarily coarse coralline sand.

Certain high-value species (Fig. 2) such as the sandfish *Holothuria scabra* Jaeger, 1968, the dragonfish *Stichopus horrens* Selenka, 1867, the redfish *Actinopyga echinites* Jaeger, 1833, and the stonefish or white-bottomed sea cucumber *A. lecanora* Jaeger, 1833 are found in all or most sites. A newly described species, the golden sandfish *H. lessoni* Massin, Uthicke, Purcell, Rowe & Samyn, 2009, is also common.

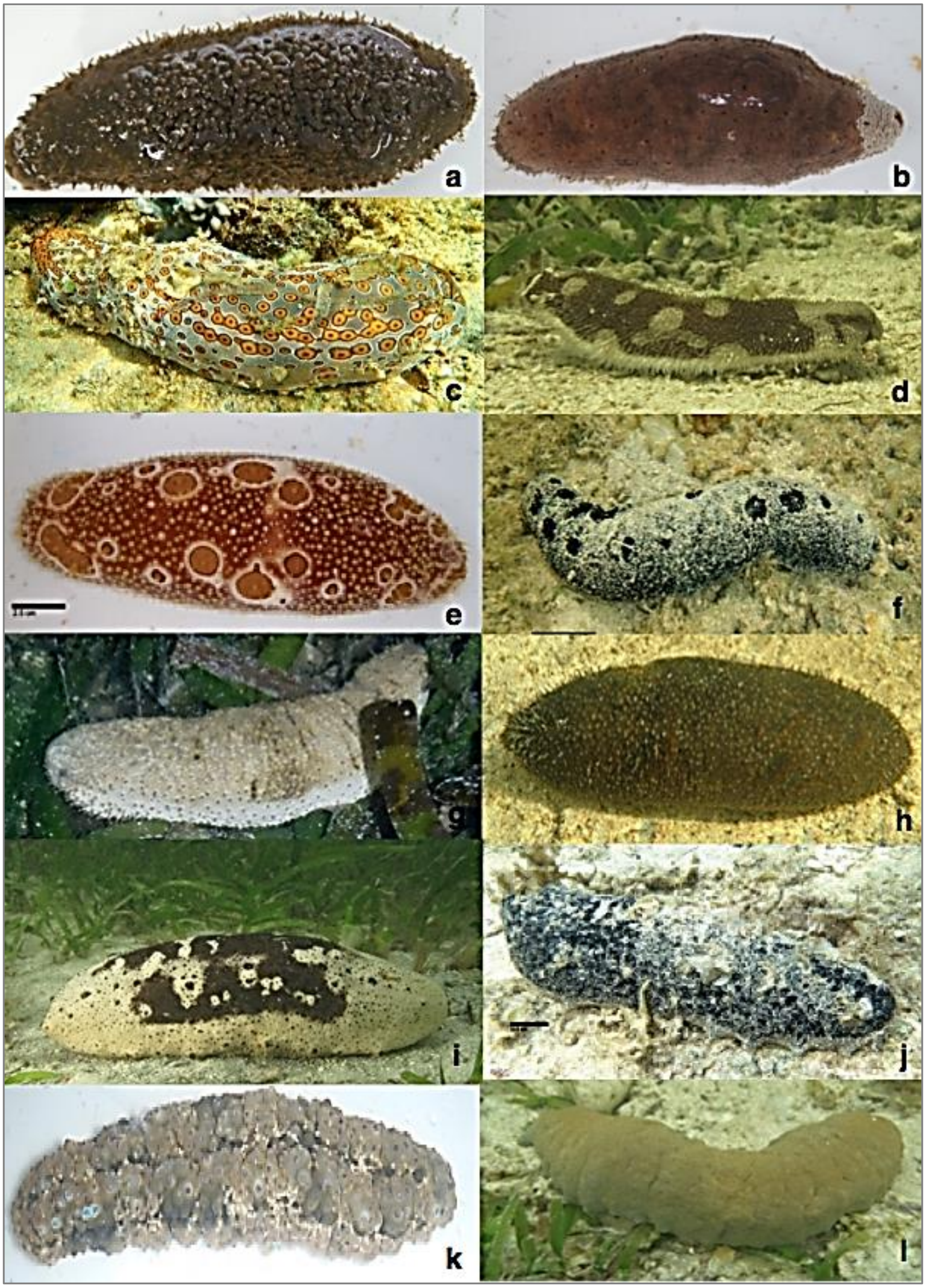

Figure 2. Commercially important sea cucumber species across five sites in Mindanao. a) Actinopyga echinites, b) A. lecanora, c) Bohadschia argus, d) B. marmorata, e) B. ocellata, f) Holothuria atra, g) H. scabra, h) H. lessoni, i) H. fuscogilva, j) H. whitmaei, k) Stichopus cf horrens and l) S. herrmanni. (Photo credits: MB Quiñones, AB de Guzman, JR Santamina & RA Abrea).

Table 2. Occurrence of sea cucumber species across five sites in Mindanao.

	Taxa/Scientific Name	Survey Sites				
		Laguindingan Mis. Or.	Lopez Jaena Mis. Occ.	Hinatuan Surigao DS	Rizal Zambo DN	Tabina Zambo DS
Order ASPIDOCHIROTIDA						
1	*Actinopyga capillata*		+		✷	
2	*Actinopyga echinites*	+	+		+	+
3	*Actinopyga lecanora*	✷	+		✷	✷
4	*Bohadschia argus*	✷	+		✷	+
5	*Bohadschia argus x vitiensis*		✷			
6	*Bohadschia marmorata*	+	+	+	+	+
7	*Bohadschia ocellata*	✷	+	✷	✷	+
8	*Bohadschia vitiensis*	✷	+	✷	✷	✷
9	*Holothuria albiventer*			+		+
10	*Holothuria arenicola*	✷				+
11	*Holothuria atra*	+				+
12	*Holothuria coluber*			+		✷
13	*Holothuria edulis*		✷	+		+
14	*Holothuria fuscocinerea*	+	✷	+	+	+
15	*Holothuria fuscogilva*		+	✷		✷
16	*Holothuria fuscopunctata*		✷			
17	*Holothuria gracilis*					+
18	*Holothuria hilla*			+		+
19	*Holothuria impatiens*			+		✷
20	*Holothuria inhabilis*					+
21	*Holothuria lessoni*	+		✷	✷	✷
22	*Holothuria leucospilota*	+	+	+		✷
23	*Holothuria pervicax*		+		+	+
24	*Holothuria rigida*	+				✷
25	*Holothuria scabra*	+	+	+	✷	+
26	*Holothuria whitmaei*		+	✷		
27	*Pearsonothuria graeffei*	+	+	✷	+	+
28	*Stichopus herrmanni*	+	+			
29	*Stichopus horrens*	+	+	+	+	+
30	*Stichopus noctivagus*					+
31	*Thelenota anax*	+	✷	✷	✷	+
Unidentified species						
32	*Bohadschia* sp.	✷	+	✷	✷	✷
33	*Holothuria* sp.			+	✷	

Order APODIDA						
34	*Euapta godeffroyi*		✷			✷
35	*Synapta maculata*	✷	✷	✷	✷	+
36	*Synaptula recta*		✷			✷
	Number of Species	19	25	20	17	30

Legend: + found in transects; ✷found outside transects or collected by fishers

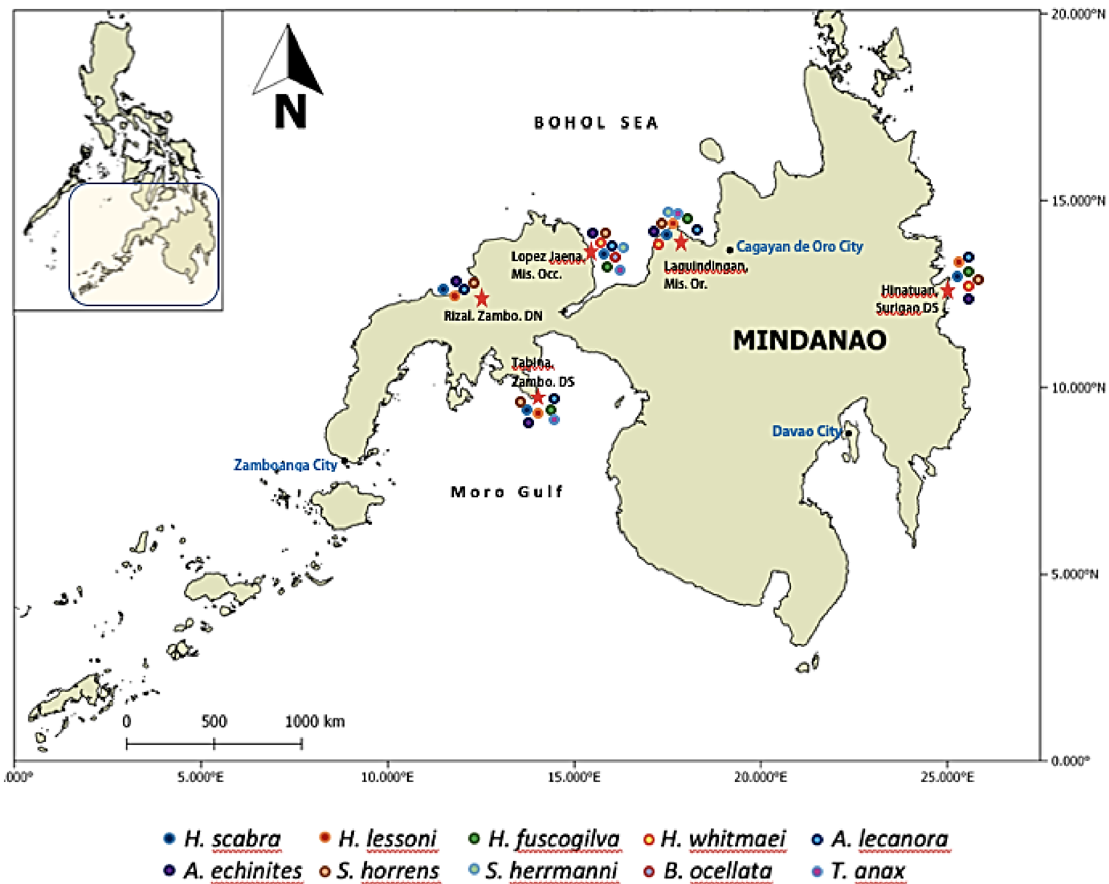

Figure 3. Distribution of commercially important sea cucumber species in five sites (red stars) in northeastern and western Mindanao, Philippines.

Among the most high-value species in the trepang trade are the white teatfish *Holothuria fuscogilva* Cherbonnier, 1980 and the black teatfish *H. whitmae* Bell, 1887 which thrive in protected shallow (1-3m deep) seagrass and reef habitats in Capayas Island MPA in Lopez Jaena. Specimens of these species were found in catches sold to processors in Hinatuan and Tabina by fishers who gather them from very deep areas using compressors. Fishers in Laguindingan and Rizal also reported that teatfish are found in deeper waters and accessible only by compressor fishing.

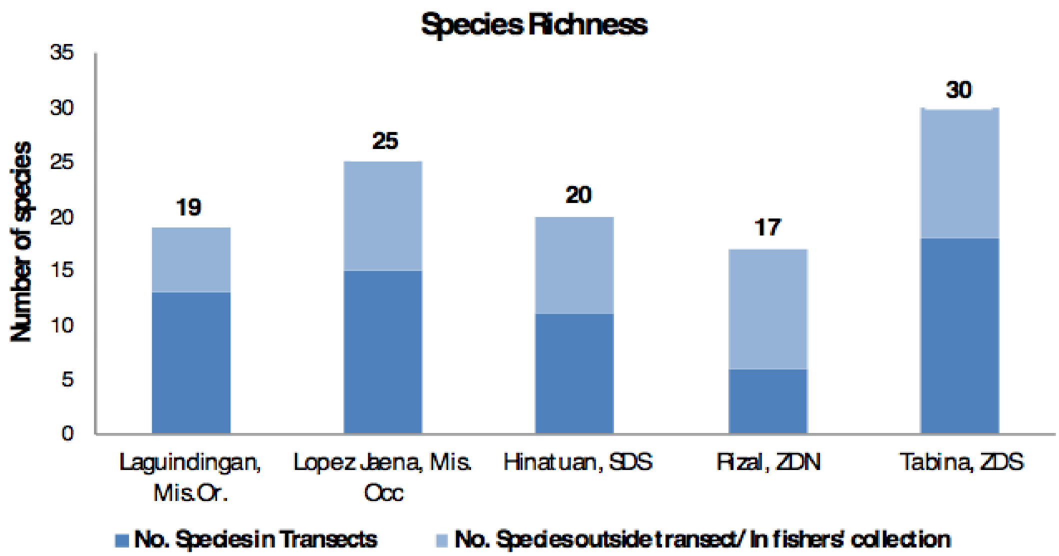

Figure 4. Comparison of species richness of sea cucumbers across survey sites.

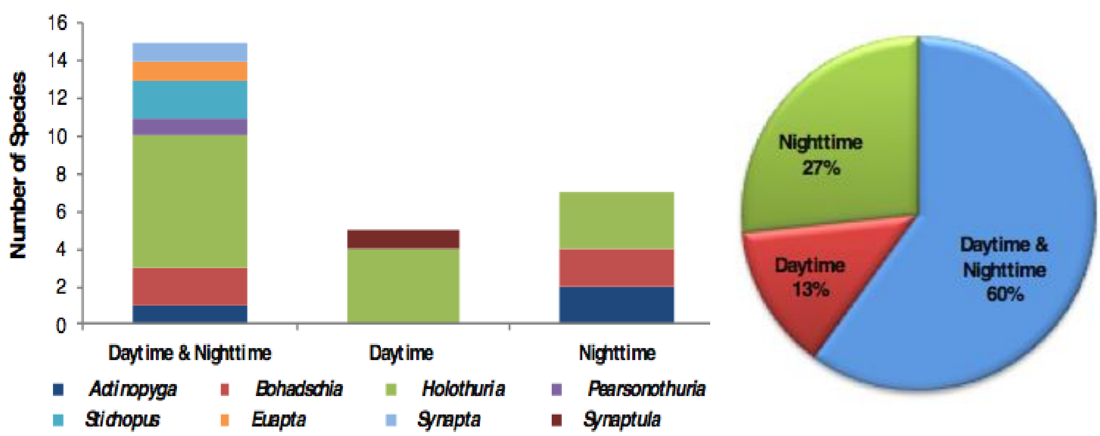

Figure 5. Comparative species richness (a) and overall relative abundance (b) of sea cucumbers intercepted during daytime and night-time sampling in five sites.

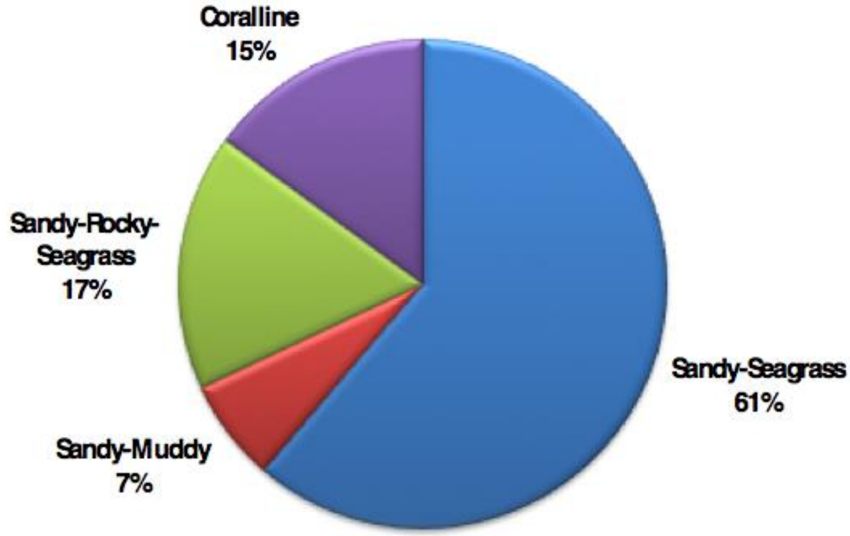

Figure 6. Preferred habitat types of sea cucumbers in various sites in Mindanao.

Table 3. Similarity matrix of Sørensen's similarity coefficients across site pairs in northeastern and western Mindanao.

	Laguindingan	Lopez Jaena	Hinatuan	Rizal	Tabina
Laguindingan (S = 19 spp)	1	0.73	0.67	0.78	0.73
Lopez Jaena (S = 25 spp.)		1	0.62	0.71	0.69
Hinatuan (S=20 spp.)			1	0.65	0.72
Rizal (S = 17 spp.)				1	0.64
Tabina (S = 30 spp.)					1

Species richness of sea cucumbers aggregated across five sites in the northeastern and western parts of Mindanao is lower than those reported in broad-scale systems such as Tawi-Tawi with 39 species (MSU-TCTO, 2013), Palawan with 44 spp. (Jontila et al., 2014), the Bolinao-Anda system (Olavides et al., 2010) and central Visayas (Kerr et al., 2006) both with 49 spp., Davao region with 52 spp. (DNSC, 2013) and Samar and Leyte provinces with 60 spp. (De la Cruz et al., 2015). Diversity of sea cucumbers in Tabina (30 spp.) and Lopez Jaena (25 spp.) reported in this paper, on the other hand, is higher than that in Panglao Island, Bohol (17 species; Vito, 2019) and comparable with islands off Cebu (27 species; Tan Tiu, 1981) and Calatagan, Batangas (28 species; Reyes-Leonardo, 1984). However, as an index of diversity species richness is sensitive to sample size (Magurran, 2004) and increases with more transects or sites surveyed.

Sea cucumber diversity in the entire Philippines is high. However, reports on total number of species have varied through time, from 66 species (Domantay, 1934) to 90 species (Domantay, 1960), 100 species (Schoppe, 2000b) and 170 species from pooled lists of Clark and Rowe (1971) and other reports (Olavides et al., 2010). A recent report by de la Cruz et al. (2015), however, lists only 132 species from these pooled lists and recent taxonomic reviews and corrections, mainly by Samlyn, 2006; Samlyn et al., 2010; and O'Loughlin, 2011 cited by De la Cruz et al. (2015) and Purcell et al., 2012. Recent advances in molecular methods such as genetic barcoding (Uthicke et al., 2010; Alcudia-Catalma et al., 2020) are vital to confirming species identification and updating the biodiversity list of Philippine sea cucumbers.

Sea cucumber diversity is being modified by fishing patterns, particularly in the absence of effective management. Disappearances or local extinctions of valuable species are linked to the overharvesting of wild stocks. As stocks of the large-sized, commercially important sea cucumbers became effectively fished out in shallow areas under an open-access regime, Filipino gatherers go farther out and deeper to chase the few remaining individuals (Schoppe 2000b; Brown et al. 2010; Olavides et al., 2010). Many fishers, confronted with declining catches and progressively smaller sizes, have resorted to the unsustainable practice of compressor diving (Brown et al., 2010; DNSC, 2013; De la Cruz et al., 2015). Others continue to scour the shallow reefs but shift to gathering small-sized species of little value to the trepang trade, but are consumed locally as pickled delicacies (De Guzman and Quiñones, 2013).

Abundance and Size Structure

Sea cucumber stock densities are generally low across northeastern and western Mindanao, particularly high-value species except those found inside enforced MPAs. Overall population densities are consistently higher inside MPAs than in unprotected areas (Fig. 7) across five sites. However, the comparison of mean densities shows no significant differences between MPA and non-MPA sites (t-test, $p>0.05$). On the other hand, a test comparing variances in density estimates between MPA and non-MPA sites shows that sea cucumber densities vary significantly (F-test, $p<0.01$) between protected and unprotected areas. This apparent inconsistency in the results of the two statistical models may be influenced by the small sample size (N=5 sites) and the low overall densities in most MPA sites.

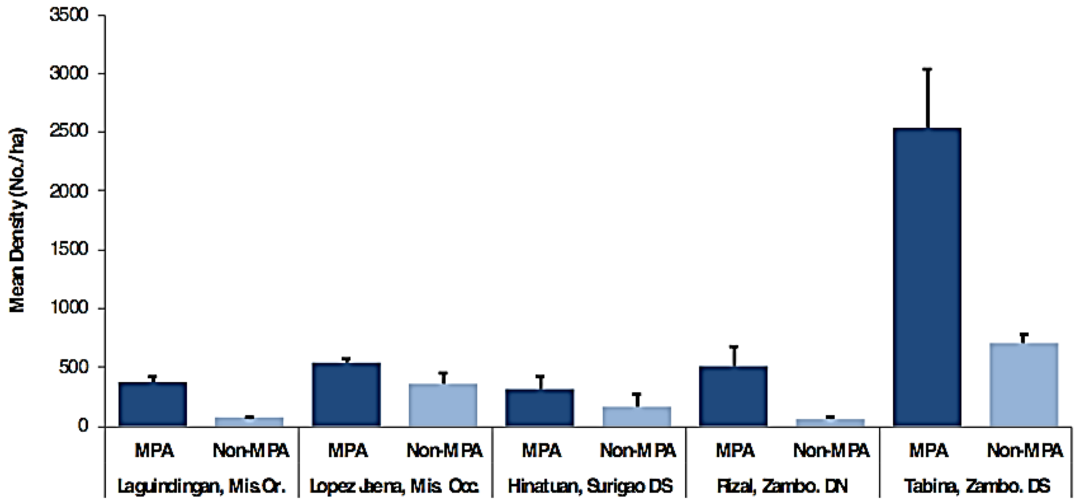

Figure 7. Comparative mean density of all sea cucumber species in MPA and non-MPA sites (F-test shows significant differences ($p<0.05$) in variances of population densities between protected and open-access sites).

No-take MPAs had been proven to build up populations and biomass of target food fish (Abesamis et al., 2006; De Guzman, 2016; Muallil et al., 2019) and valuable invertebrates such as sea cucumbers (DNSC, 2013; De Guzman and Quiñones, 2013; Calagui et al., 2015; De la Cruz et al., 2015). Tests comparing mean densities and variances of seven high-value species found across five survey sites (Fig. 8) show significant differences between MPA and non-MPA sites (t-test, $p <0.05$; F-test, $p<0.005$). High-value species thrive under protection inside strictly enforced MPAs in the Philippines and other sea cucumber fishing grounds in Pacific island states (Kerr et al., 2006).

The most abundant species across sites is the low-value black lollyfish *Holothuria atra* Jaeger, 1833 (Fig. 9), the dominant sea cucumber inside the Tambunan MPA in Tabina (mean of 2,363 indivs/ha). The high densities of this species are attributed to its ability for vegetative reproduction through binary fission along its transverse section. However, many *H. atra* inside the Tambunan MPA exhibited what appears to be vegetative reproduction through budding or longitudinal fission. From Fig. 9, it is clear that most of the dominant sea cucumbers inside protected areas are commercial species, while those in unprotected sites are mostly low-value species and those with no known market value.

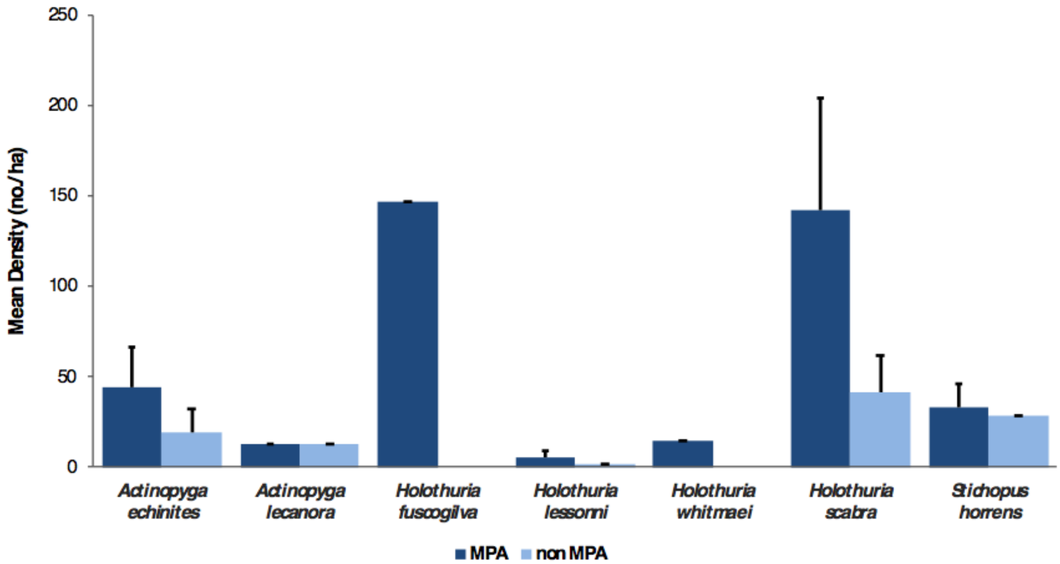

Figure 8. Comparative densities of high-value sea cucumbers in protected and unprotected areas across five sites in Mindanao.

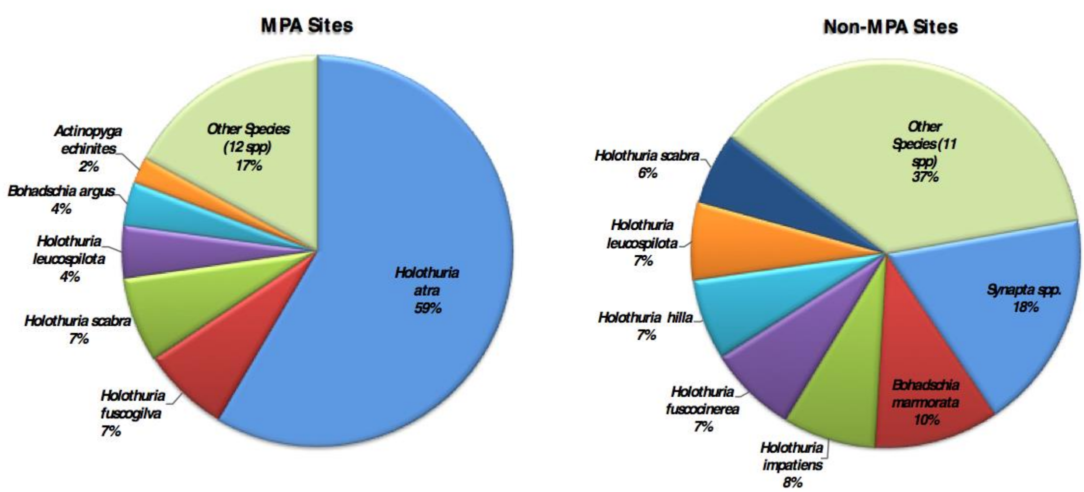

Figure 9. Comparison of relative abundances of most common sea cucumbers based on mean population densities (no. indivs/ha) between MPA and non-MPA sites in northeastern and western Mindanao.

Sandy-seagrass beds support the highest aggregate population densities exceeding 2,500 indivs/ha while mean densities of 703 indivs/ha and 621 indivs/ha were found in sandy-rocky and coralline habitats, respectively. High density in seagrass beds is attributed to large numbers of *H. atra*, *H. fuscogilva*, and *B. marmorata* while *B. argus* and *H. fuscogilva* contributed to population density in sandy-rocky and coralline substrata. A lower sea cucumber density of 280 indivs/ha was observed in sandy-muddy areas across five sites. This lower density was contributed mainly by the high-value sandfish *H. scabra* (mean of 141 indivs/ha) found at moderate abundances in the Tubajon MPA in Laguindingan (313 indivs/ha) and a non-MPA site in Lopez Jaena (168 indivs/ha).

The highly valued but diminishing white teatfish *H. fuscogilva* is still abundant on sandy seagrass beds and shallow coralline habitats inside the Capayas Is. MPA in Lopez Jaena at a mean density of 147 indivs/ha. This estimate far exceeds reported population densities in the Maldives (29 indivs/ha) by Reichenbach, 1999 and in the Pacific Island Countries (11 indivs/ha) by Conand (1990). Worldwide populations of *H. fuscogilva* are decreasing. The IUCN Redlist cites this species as vulnerable (Conand et al., 2013). High densities inside the Capayas Is. MPA highlights the importance of protection in maintaining viable stocks of commercial sea cucumbers. Population densities of *H. fuscogilva* as high as 1,800-2,130 indivs/ha were recently reported on sandy areas inside the well-enforced Pharoan MPA in the Red Sea (Hassan and Johnson, 2019) while populations have collapsed in unprotected sites.

Sea cucumbers vary widely in size according to species and location across the five municipalities in northeastern and western Mindanao (Fig. 10). Size ranges of most species (46.7%) are small, with a mean length of <20cm, while 36.7% have mean lengths ranging from 21-30cm. A few species (16.7%) are larger than 30cm, but these sizes are rare, and very few individuals were encountered. Among the larger species is the amberfish *Thelenota anax* Clark, 1921 found in Tabina, Zamboanga del Sur, which had a body length of 59cm and body weight of 1.95kg. The white teatfish *H. fuscogilva* found in the shallow reef flats of Capayas Is. had a mean size of 23cm, but the largest specimen was 43cm long and weighed 2.2kg. The heaviest sea cucumber ever encountered in this project was the 39cm S. horrens weighing 2.5kg in the Mabunao MPA in Rizal. No early juvenile teatfish (<10cm) was found during repeated surveys in Capayas Island, but juveniles (2-3 cm long) of *S . horrens*, and *S. herrmanii* occurred on the seagrass beds of Mauswagon, Laguindingan in October and November 2012, suggesting recruitment during this period.

Through time the average sizes of most sea cucumbers had been getting smaller, particularly in open access areas, mainly due to the high fishing effort expended on these diminishing resources and the absence of regulation on body size of gathered specimens. To date, the Philippines does not have a management plan in place. However, an effort toward formulating a framework for a sea cucumber conservation and management plan was initiated in June 2007 by a group of Philippine scientists and government officers (Choo, 2008). Fisheries management should adopt an ecosystem approach to preserve the biodiversity values of fishery resources and the ecosystems that support them. Effective management also safeguards the long-term social and economic benefits to local communities (Purcell, 2010).

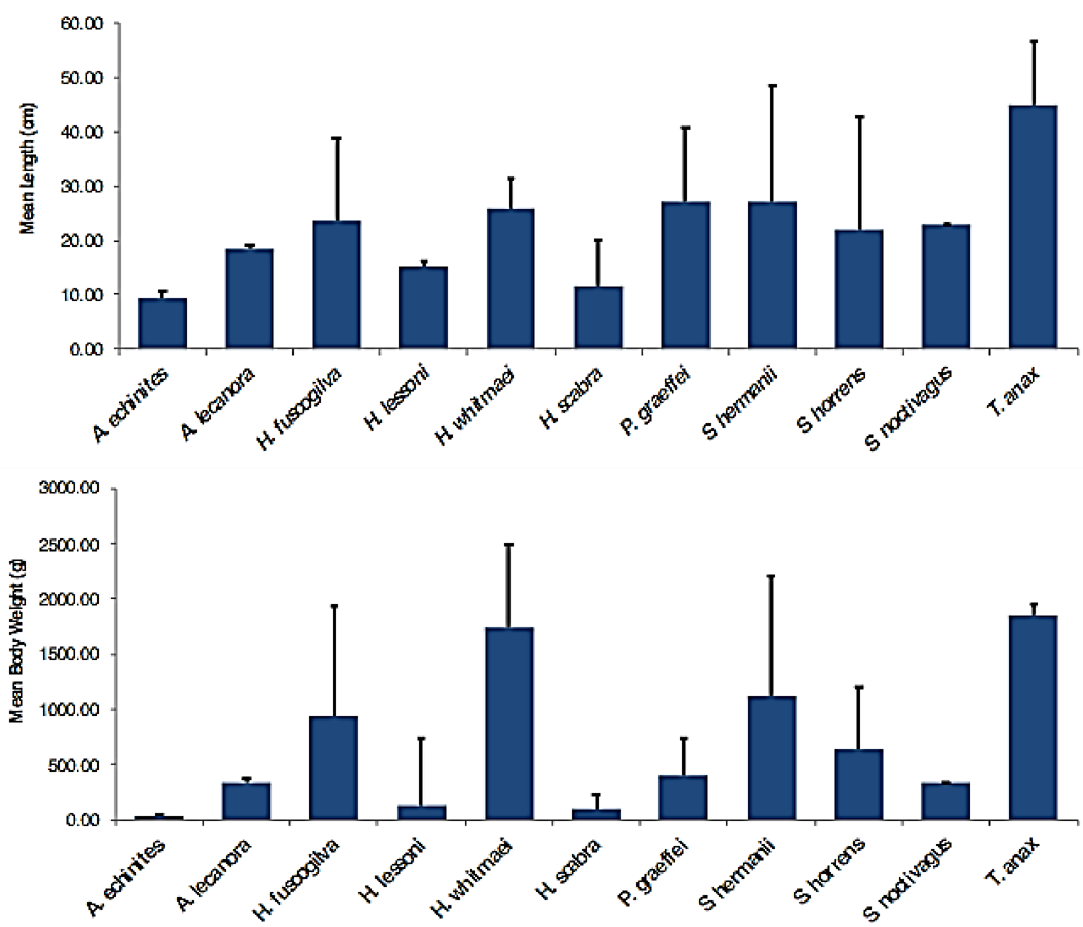

Figure 10. Comparative average length (top panel) and weight (bottom panel) measurements of commercially important sea cucumbers in northeastern and western Mindanao.

CONCLUSION AND RECOMMENDATIONS

This research has provided information on the biodiversity and abundance of sea cucumbers in northern and western Mindanao, yet results are far from complete in supporting biodiversity conservation and fisheries management. Regular monitoring of sites, particularly where high-value species still thrive, should be done to track changes in species richness, population density, size distribution, and ecological conditions in support of adaptive and ecosystem-based fisheries management of these valuable resources. Accurate identification of sea cucumbers, particularly rare species, can be challenging due to geographical variations in marking pattern, shape, and cryptic coloration. Taxonomic classification and nomenclature evolve over time and across areas, and research needs to keep up with these developments.

As in many sea cucumber gathering grounds in the Philippines, species diversity and population levels in northeastern and western Mindanao tend to be higher in no-take MPAs than in open-access sites where regulation or any form of management is visibly absent. No-take MPAs play a crucial role in conserving the diversity and maintaining stocks of high-value sea cucumbers through the protection of adult populations, allowing successful natural recruitment into fished areas. Strict enforcement of the 'no fishing' policy inside MPAs is possibly the best chance of sustaining precious sea cucumber resources in the Philippines. The discovery of abundant broodstock of *H. fuscogilva* inside the Capayas island MPA in Lopez Jaena, Misamis Occidental offers opportunities for research and development efforts toward mariculture and stock enhancement.

This project recommends formulating and adopting a National Sea Cucumber Management Plan as among the urgent policy measures to conserve and promote sustainable sea cucumber fisheries in the Philippines, including establishing more MPAs to protect adult stocks, allow natural recruitment, and enhance biodiversity.

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