Impact of Super Typhoon Odette on the Reefs of Northeastern Palawan, Philippines

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ABSTRACT

This study assessed the damage to the reefs in northeastern Palawan, Philippines, brought by super typhoon Odette, which hit the country on 17 December 2021. Reefs in four marine protected areas (MPAs) and seven open-access areas, each represented by a permanent 75×25 m (1,875 m^2) station, were surveyed following the C30 method in August and September 2021 (pre-Odette). These sites were revisited in February and March 2022 (post-Odette) to determine the changes in percent benthic cover, species richness and abundance of butterflyfishes, and the abundance of selected macroinvertebrates. The results showed a significant reduction in hard coral (HC) cover (from 33.84 to 9.65%) and other living organisms (OTL) (from 5.03 to 0.53%). Open-access sites had significantly lower ($p<0.05$) HC cover compared to MPAs. The species richness of butterflyfishes remained unchanged from pre- (6.25±4.79) to post-Odette (6.25±5.19). Although there was no significant change in general density (indi·1,875 m^{-2}) of butterflyfishes, a considerable decline happened in one of the sites in Araceli (Cambari: from 41 to 9) and in Roxas (Salvacion MPA: from 29 to 0). Meanwhile, macroinvertebrates showed a declining trend, especially the small giant clams (from 399 to 40 ind·1,875 m^{-2}). With the increasing incidence of super typhoons hitting the island province of Palawan, areas that are less likely to be affected are potential conservation sites. The site recovery rate requires regular monitoring for long-term protection and management.

Keywords: Butterflyfishes, C30 method, Macroinvertebrates, Natural calamity impacts, Reef monitoring

INTRODUCTION

Tropical storms are among the natural disturbances heavily affecting coral reefs today (Lugo-Fernández and Gravois, 2010; Majumdar *et al*., 2018; Moriarty *et al*., 2020; Wolanski *et al*., 2020; Muñiz-Castillo and Arias-González, 2021; Castro-Sanguino *et al*., 2022). The physical destruction caused by severe tropical storms has a direct negative impact on coral reef communities; other indirect effects, such as increased turbidity, disease outbreaks, changes in predator behavior, and freshwater inflow, are adding stresses on the reefs (Lugo-Fernández and Gravois, 2010; Gardner *et al*., 2014; Hénaff *et al*., 2019; Moriarty *et al*., 2020). Such effects can range greatly in size and spatial extent, from minor disruptions to complete reef destruction. Numerous studies have shown that direct mechanical disruption, sedimentation, salinity changes, and turbidity can all result in reef damage. Strong waves brought about by storms can cause dislodgement, overturning, and breakage of corals, deposit a large amount of sediment, and toss debris over reef flats. In addition, heavy rains brought by typhoons can induce river flooding, and rapidly changing sea surface salinity and temperature (Butler *et al*., 2015; Soria *et al*., 2018; Hénaff *et al*., 2019; Safuan *et al*., 2020; Yu *et al*., 2020; Gallentes *et al*., 2021; Castro-Sanguino *et al*., 2022).

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In Hervey Bay, Queensland, Australia, a three-year cumulative impact of flooding resulted in a 56% decrease in coral abundance (Butler *et al*., 2015). A strong typhoon in Yongle Atoll, Xisha Islands, South China Sea, caused a decline of 46% in living hard corals (HC) at 2 m depth but caused minimal damage at depths of 6 and 15 m (Yang *et al*., 2015). A storm also caused a 60% decline (from 47.9±5.02 to 28.75±3.90%) of live coral cover in the shallow reefs (3 m deep) of Pulau Bidong, south of the South China Sea (Safuan *et al*., 2020). In a typhoon-exposed reef habitat in Okinawa, Japan, typhoons showed a negative relationship with the downward migration of free-living corals (Ohara *et al*., 2021), while in the Central Visayas region, Philippines, marine protected areas (MPAs) affected by typhoons provided higher benefits to fish biomass than fished areas (McClure *et al*., 2020).

While the effects of a tropical storm on corals and their associated fauna have been documented in other places (Butler *et al*., 2015; Terry *et al*., 2015; Yang *et al*., 2015; Tajima *et al*., 2016; Soria *et al*., 2018; McClure *et al*., 2020; Yu *et al*., 2020; Castro-Sanguino *et al*., 2022), little is known about its impact on the reefs of Palawan. Historically, the province of Palawan in the Philippines has seldom been exposed to tropical storms (La Viña *et al*., 2023). But in November 2013, the first super typhoon (ST Yolanda) hit the province, which has since become increasingly vulnerable to tropical storms (Haysom, 2022). The latest was on 17 December 2021, when the center of ST Odette, with sustained wind of up to 120 km·h^{-1} and gusts of up to 205 km·h^{-1} made landfall in Palawan, which greatly affected Puerto Princesa City, Roxas, Dumaran, Araceli, Taytay, and El Nido (Haysom, 2022). This caused extensive damage to the landscape, agriculture, and infrastructure (ECOWEB, 2021; Haysom, 2022).

A few months before ST Odette's landfall in Palawan, 11 reef sites in northeastern Palawan were assessed as part of the MPA monitoring program and capacity building of the WWF-Philippines. Hence, this study determined the impact of ST Odette on the benthic cover, species richness and abundance of butterflyfishes, and selected macroinvertebrates on the abovementioned reef sites. Information on which reefs can withstand the impact of many upcoming tropical storms can aid conservation workers and policymakers in declaring appropriate areas as MPAs.

MATERIALS AND METHODS

Study sites

The study included the four municipalities in northeastern Palawan, namely Araceli, Dumaran, Roxas, and Taytay. Five reefs were surveyed in Araceli, and two reefs were surveyed in each of the other three municipalities. Seven of the 11 reef sites were within open-access areas, while the other four were within MPAs (Figure 1). Marine protected areas have certain restrictions on human exploitation activities and are provided with management strategies for the conservation of resources and ecosystems, while open-access areas do not. Most of the surveyed sites were within fringing reefs with a depth ranging from 2–9 m, and were dominated by branching corals (Table 1).

Data collection

Eleven reef sites were surveyed between August and September 2021 (pre-Odette) and reassessed in February and March 2022 (post-Odette). Each reef site has a permanent 75×25 m station following the C30 method (Licuanan *et al*., 2021; Climaco *et al*., 2022). The benthic cover was assessed by either skin diving in shallow reefs (about 2–5 m deep) or by SCUBA diving in deeper reefs such as Hart Reef MPA and Baby Hart Reef, which typically involved two or four divers with function as navigator and photographer. The navigator held a buoy marker and guided the photographer to random spots. The photographer took photos of the benthic cover at the spot given by the navigator using a monopod while facing the shore/mainland. Both divers started at the center of the station. The divers swam back inside the surveyed station if the random spot exceeds the boundary until the remaining distance is completed. These steps were repeated within each station until 50 pictures were captured.

The documentation of species richness of butterflyfishes and target benthic macroinvertebrates was done by dividing the station's width (25 m) into two segments (12.5 m). From the first segment, three to four divers swam side-by-side up to the endpoint and returned through the second segment to the starting point. Using a laminated A4 identification field guide that contains photos of 37 butterflyfish species (Licuanan *et al.*, 2021), all butterflyfishes observed were counted and identified to species level. After the fish survey, the divers repeated the steps to document the target macrobenthic species. Using the same laminated field guide, the size classification of giant clams was determined. A one-half width of the field guide is considered small (<10.5 cm), while one-half to full width is medium (10.6–29.7 cm). An individual larger than the full width of an A4 laminated field guide was considered large (>29.7 cm).

Table 1. Coordinates, depth, and characteristics of reefs in each surveyed site in northeastern Palawan.

Surveyed Reef	Coordinates	Depth (m)	Remarks
Cambari	10º33'5.9" N 120º5'38" E	2–7	A fringing reef that extends approximately 50 m away from the shoreline. Dominated by branching coral with massive and coralline algae.
Cotad	10º31'49.6" N 120º1'4.4" E	2–5	A fringing reef that extends 100 m away from the shoreline. Dominated by branching and massive corals.
Langoy	10º29'33.5" N 119º59'21.9" E	2–5	A fringing reef that extends up to 100 m from shore and is dominated by branching corals with few massive corals.
Hart Reef MPA	10°48'40.0" N 119°51'58.6" E	6–9	An offshore reef dominated by branching corals with few massive corals.
Baby Hart Reef	10°45'39.2" N 119°49'38.3" E	4–6	An offshore reef dominated mostly by branching corals.
Dalarat MPA	10°29'03.6" N 119°45'00.0" E	3–5	A fringing reef within the bay of Dumaran, located near mangroves and seagrass beds. Dominated by branching corals with few massive corals.
Piawe	10°26'33.7" N 119°46'04.9" E	3–5	A fringing reef dominated by branching and massive corals.
Salvacion MPA	10°12'18.1" N 119°14'56.8" E	2–4	A fringing reef dominated by massive corals. Reefs are affected by sedimentation coming from river outflow.
Rawis	10°11'07.9" N 119°16'00.3" E	3–5	A fringing reef dominated by branching mixed with massive corals. Reefs are affected by sedimentation coming from river outflow.
Black Rock Reef MPA	10°48'50.0" N 119°39'38.0" E	4–5	An offshore reef mostly dominated by branching mixed with massive corals.
Raket-Raket	10°53'59.3" N 119°38'10.2" E	4–5	A fringing reef composed of branching with few massive corals.

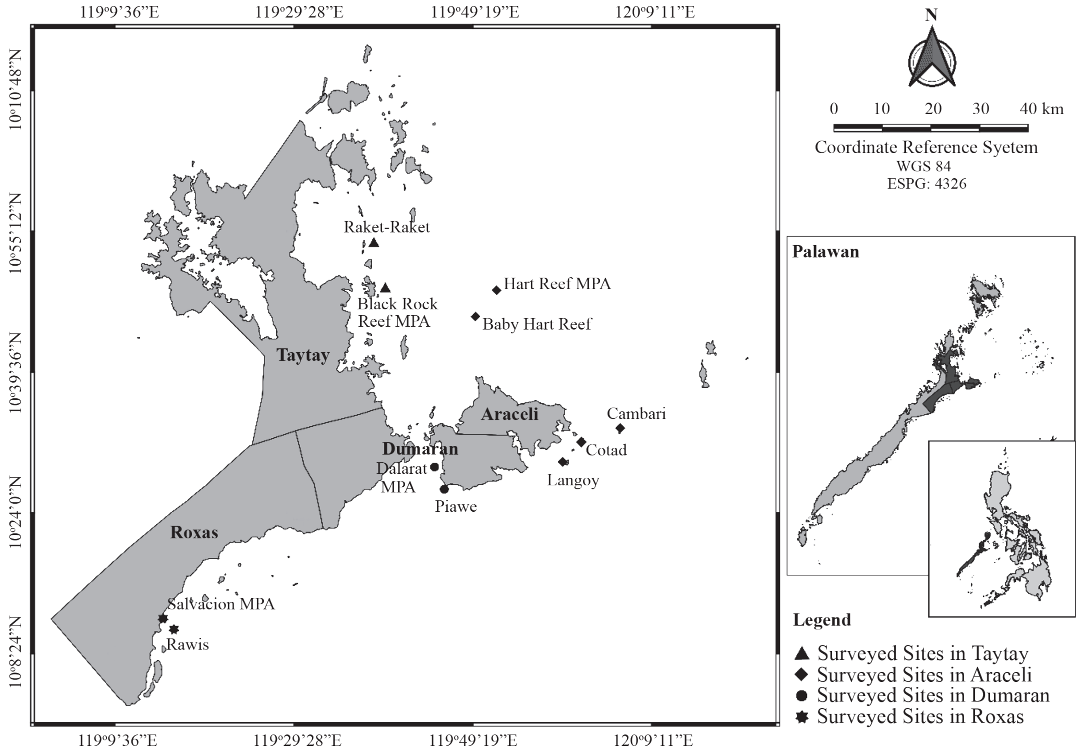

Figure 1. Map of the surveyed sites in the municipalities of Araceli, Dumaran, Roxas, and Taytay in the province of Palawan, Philippines.

Data analysis

The CPCe or Coral Point Count with Excel extension software (Kohler and Gill, 2006) was used to assign ten random-position points within each image to determine the relative frequencies of the following benthic cover categories: hard coral (HC), white coral (WC; either due to bleaching, crown-of-thorns sea star, or disease), macro-algae (SW), other living organisms (OTL), algal assemblage (AA) and abiotic components (AB). Relative frequencies and means (±SD) were determined using the built-in formula in MS Excel before preparing graphs. The data on species richness and abundance of butterflyfishes and macroinvertebrates were graphically presented using MS Excel. In addition, correlation analysis was carried out between HC cover and abundance of butterflyfishes and some macroinvertebrates within MPAs and open-access areas using the built-in formula in MS Excel. The data for benthic cover during the pre- and post-Odette periods were compared using a paired t-test, while a two-sample t-test was used for other data sets. The analyses were run using the MS Excel built-in statistical package. Zero sightings of fishes and macroinvertebrates in some sites pre- and post-Odette precluded the statistical comparison of those data.

RESULTS AND DISCUSSION

Benthic cover

The overall HC cover in all surveyed municipalities declined significantly from 33.84% to 9.65% (a decrease of 71.48%). Among municipalities, Araceli was hardest hit, with an 85.59% decline in HC cover (from 34.98% to 5.04%); Taytay was second with a 66.35% decline (from 45.43% to 15.29%); the third was Dumaran with a 63.29% decline. Roxas was the least affected, with a reduction of only 37.29% in HC. The benthic cover of OTL from the surveyed municipalities also suffered a significant decline, with an overall reduction of 85.15% (from 4.31% to 0.64%). By contrast, there was a significant increase in the overall cover of some benthic components, such as the SW (72.23%) and AB (79.14%). Only WC (from 0.32% to 0.07%) and AA (from 53.17% to 54.25%) had no significant changes (Figure 2 and Table 2).

Looking at the shift in HC cover at each site, the four MPAs and two of the open-access areas showed less impact from ST Odette than the other sites. Among MPAs, Dalarat MPA had the lowest decline of HC (2.33%), followed by Salvacion MPA (44.06%), Hart Reef MPA (47.28%), and Black Rock Reef MPA (73.69%). For open-access areas, Rawis had the lowest HC decline (28.94%), followed by Raket-Raket (58.11%). Areas having the lowest post-Odette HC cover were Cambari (0%), Cotad (0.22%), Langoy (2.19%), and Piawe (3.49%) (Figure 3).

The massive change of HC cover in Araceli during post-Odette could be due to the shallow characteristics of most surveyed sites (2–7 m). According to Butler *et al*. (2015), Yang *et al*. (2015), Anticamara and Go (2017), Safuan *et al*. (2020), shallow reefs are much more vulnerable to the

Table 2. Summary of t-tests comparing overall mean percent benthic cover on coral reefs in four municipalities in northeastern Palawan before and after super typhoon Odette.

Benthic cover category	t-value	p value	Remarks
Hard coral (HC)	5.14	<0.05	Significant decline
Macro algae (SW)	2.38	<0.05	Significant increase
Algal assemblage (AA)	0.15	>0.05	No significant change
White coral (WC)	1.48	>0.05	No significant change
Other living organisms (OTL)	2.38	<0.05	Significant decline
Abiotic components (AB)	4.39	<0.05	Significant increase

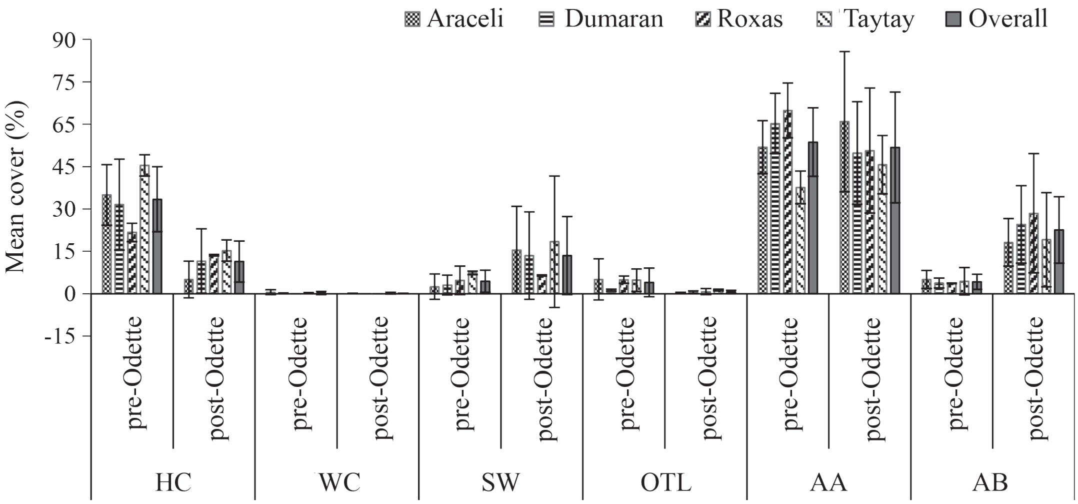

Figure 2. Mean percent benthic cover on coral reefs in four municipalities in northeastern Palawan pre- and post-Odette. Error bars represent the standard deviation of the mean.

Note: HC = Hard coral; WC = White coral; SW = Macro algae; OTL = Other living organisms; AA = Algal assemblage; AB = Abiotic component.

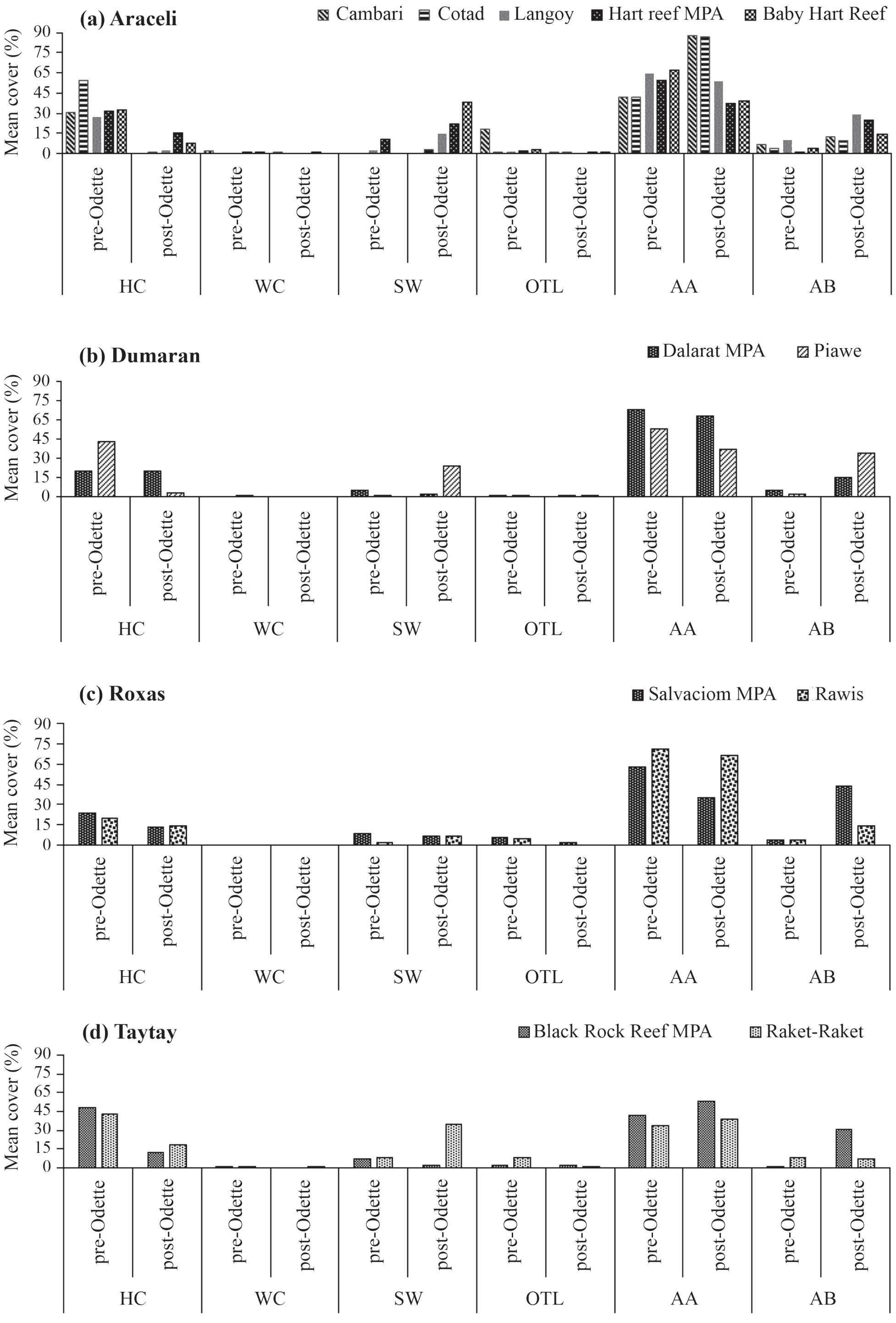

Figure 3. Comparison of mean percent benthic cover of open-access areas and marine protected areas in each municipality surveyed pre- and post-Odette.

Note: HC = Hard coral; WC = White coral; SW = Macro algae; OTL = Other living organisms; AA = Algal assemblage; AB = Abiotic component.

impact of typhoons than deeper reefs. This was observed in one of Araceli's deepest sites, Hart Reef MPA (6–9 m), with minimal changes in HC cover (from 31.09% to 15.39%) despite the similarity in coral reef composition to shallower sites in the same area (Table 1). In addition, the geographical location of surveyed sites in Araceli is much more exposed to the waves brought by the impact of ST Odette compared to other sites in Dumaran, Roxas, and Taytay. The surrounding landscape and seascape of the sites in the latter municipalities situated close to the mainland could have offered cover against strong waves.

Typhoons can cause upwelling that carries nutrients from the bottom to the surface waters (Chai *et al*., 2021; Wang and Zhang, 2021). As a result, the nutrients can trigger phytoplankton blooms and enhance primary production (Lü *et al*., 2020; Kuttippurath *et al*., 2021), and favor the growth of some macroalgal species (Fabricius, 2005; Mumby *et al*., 2005; Anticamara and Go, 2017). The dominance of AA on the reef could also be due to the absence of herbivorous fishes like parrotfishes and continued reef disturbance from destructive fishing activities (Valiela *et al*., 1997; Wang *et al*., 2020; Wang and Zhang, 2021). However, algal growth may be variable and species-dependent (Mumby *et al*., 2005; Anticamara and Go, 2017) and could be the reason for a lower percentage of algal assemblages in Dumaran and Roxas even after 91–146 days post-Odette.

For the corals to recover in the study sites, controlling any detrimental factors contributing to reef degradation is important. While the rates of coral recovery from the storm are often variable, fast-growing branching coral species, including broken branches, can recover quickly or regrow in new areas (Anticamara and Tan, 2018). However, many factors can influence the recovery of the corals including the movement and accumulation of coral rubble, anthropogenic activities, increases in the abundance of algae, and absence of herbivorous fishes and some macroinvertebrates that regulate the growth of algal assemblages (Majumdar *et al*., 2018). Terrestrial runoff can also contributes to coral stress through sedimentation, algal growth due to eroded nutrients, and other undesirable water parameters (Heron *et al*., 2005). In addition, the significantly reduced coral cover will likely shift in favor of the species that survived the disturbance, such as fleshy macro-algae (Connell *et al*., 1997). Active coral restoration (ADB, 2017; Shaver *et al*., 2020) may play critical roles in the recovery of affected surveyed sites and their resources by minimizing fishing efforts, establishing more no-take marine reserves, and diversification of economic activities (Alcala, 1998; Russ and Alcala, 1999). Moreover, studies about the coral recovery phase may help foresee changes and acclimatization of coral reef ecosystems to climate change. Hence, with the increasing incidence of typhoons in Palawan due to the impact of climate change, the establishment of MPAs must consider the appropriate characteristics of an area, such as the coral reef structure (more massive to sub-massive corals than branching corals). Reefs dominated by branching corals are much more vulnerable to sea temperature change and crown-of-thorns attacks than reefs with fewer of these species (Grimsditch and Salm, 2006; Steneck *et al*., 2019).

Species richness and abundance of butterflyfishes

In total, 23 butterflyfish species were documented during pre- and post-Odette surveys. Some of these species were recorded pre-Odette but absent post-Odette, and vice versa. Hence, only 17 and 18 species were documented pre- and post-Odette, respectively (Figure 4). In addition, the overall species richness of butterflyfishes was unaffected, as indicated by a similar mean of five species during the pre- and post-Odette surveys (Figure 4). However, interesting increases were noted in Cotad and Langoy, where the number of species doubled or nearly doubled post-Odette. Rawis also showed an increase in richness, from zero to ten species.

Meanwhile, the overall mean abundance of butterflyfishes pre- (17.5±11.97) and post-Odette (13.40±9.17) did not differ significantly ($t = 0.90$, $p>0.05$) (Figure 5). Among sites, the abundance of butterflyfishes in Cambari was greatly reduced from 41 to 9, followed by Salvacion MPA (from 29 to zero). Despite this, some surveyed sites such as Langoy (from 13 to 25), Dalarat MPA (from

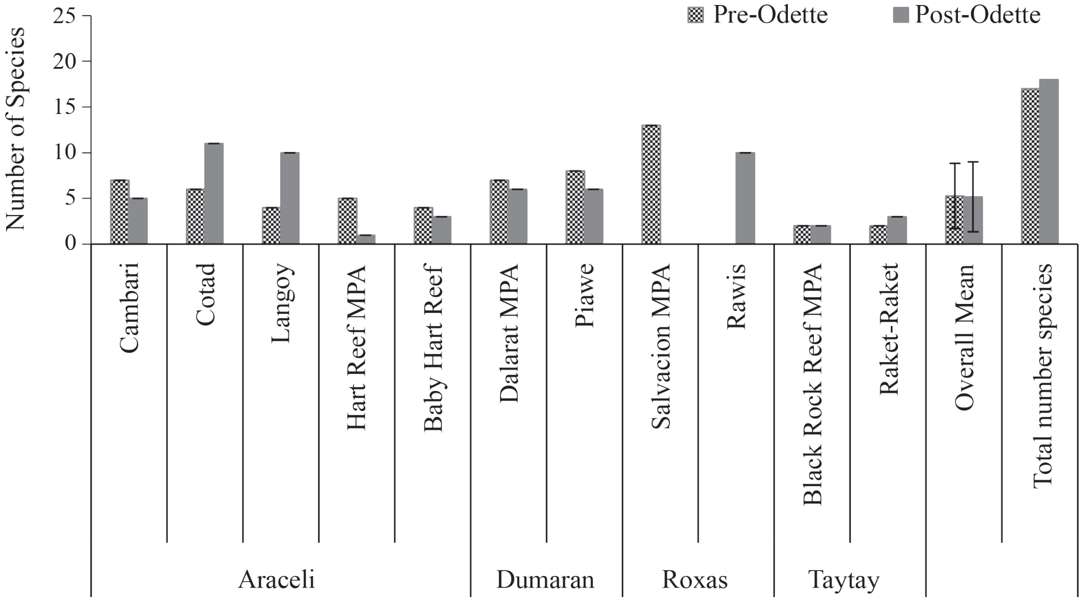

Figure 4. Species richness of butterflyfishes in the surveyed sites pre- and post-Odette. Error bars indicates the standard deviation of the mean.

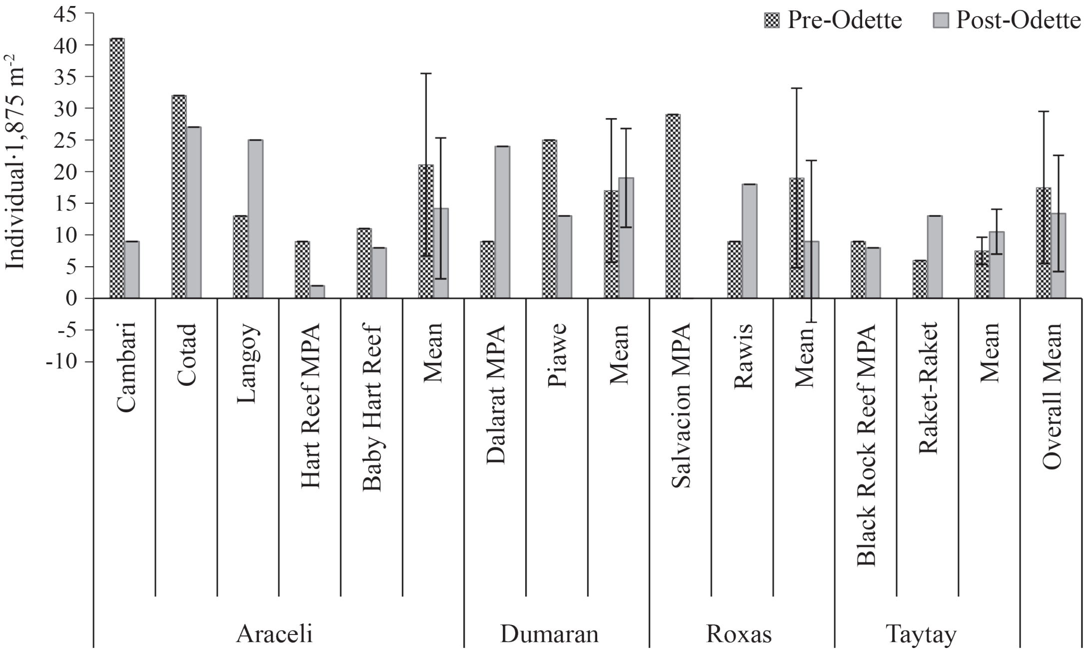

Figure 5. Abundance (ind·1,875 m^{-2}) of butterflyfishes in the surveyed sites pre- and post-Odette. Error bars indicates the standard deviation of the mean.

9 to 24), Rawis (from 9 to 18), and Raket-Raket (from 6 to 13) showed an increase in the abundance of butterflyfishes post-Odette (Figure 5).

The densities of butterflyfishes were not correlated with HC cover or level of protection. Open-access areas showed a higher abundance of butterflyfishes than in the MPAs. After the typhoon, the abundance of butterflyfishes remained high in open-access sites even when the HC cover declined significantly (Figure 6).

Fishes can swim and seek refuge in bad weather and have a higher chance of survival than other less mobile species. For example, the migration pattern of oceanic demersal fish (*Balistes capriscus*) was 100% and 2,550% higher compared to days with no storms (Bacheler *et al*., 2019). In addition, the increase in the movement rates was strongly correlated with orbital wave velocity such as the wave-generated oscillatory flow at the seabed. Moreover, the movement of mobile animals was partially influenced by the structure of marine ecosystems due to tropical storms (Bacheler *et al*., 2019). However, evidence that tropical storms (cyclones, hurricanes, and typhoons) contribute to the mortality of reef fishes are still lacking (Stoddart, 1971). Broken coral fragments can reduce reef complexity, expose less visible fish species, and change the community and composition of fishes in the affected area (Letourneur *et al*., 1993; Syms and Jones, 2000; Adams and Ebersole, 2004; Barbosa, 2019). This explains the increase of butterflyfish species and abundance in some surveyed reef sites, such as in Langoy, Rawis, and Raket-Raket (Figures 4 and 5). Moreover, population and species numbers increase or stability may not be the most critical factor limiting population abundance for many species of coral reef fish in areas that lost substantial amounts of live coral and spatially complex habitats (Walsh, 1983).

Abundance of macroinvertebrates

The target macroinvertebrates generally declined in number and showed no correlation to HC cover pre and post-Odette (Figure 7). For example, the post-Odette survey recorded a total of only 40 individuals of blue Linckia among all sites, compared to 282 individuals recorded pre-Odette (Figure 7). In Rawis, however, the blue Linckia increased from zero to 10 individuals. The crinoids considerably declined in Hart Reef MPA and Baby Hart Reef. Other sites harbored very few or showed the absence of crinoids during the pre- and post-Odette surveys. The number of crown-of-thorns sea stars (COTS) remained low in all sites (Figure 7).

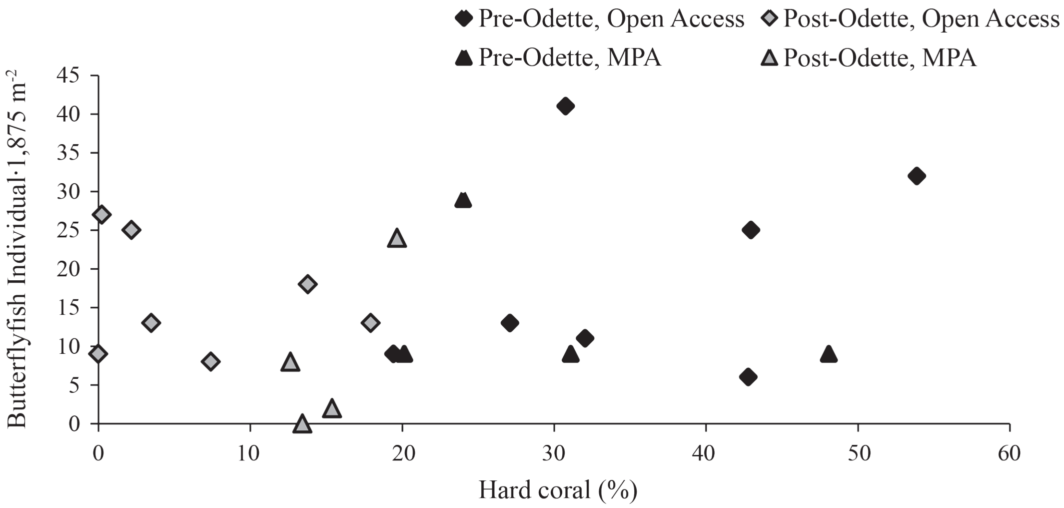

Figure 6. Percent hard coral (HC) cover in relation to the abundance of butterflyfishes in MPAs and open-access areas pre- and post-Odette.

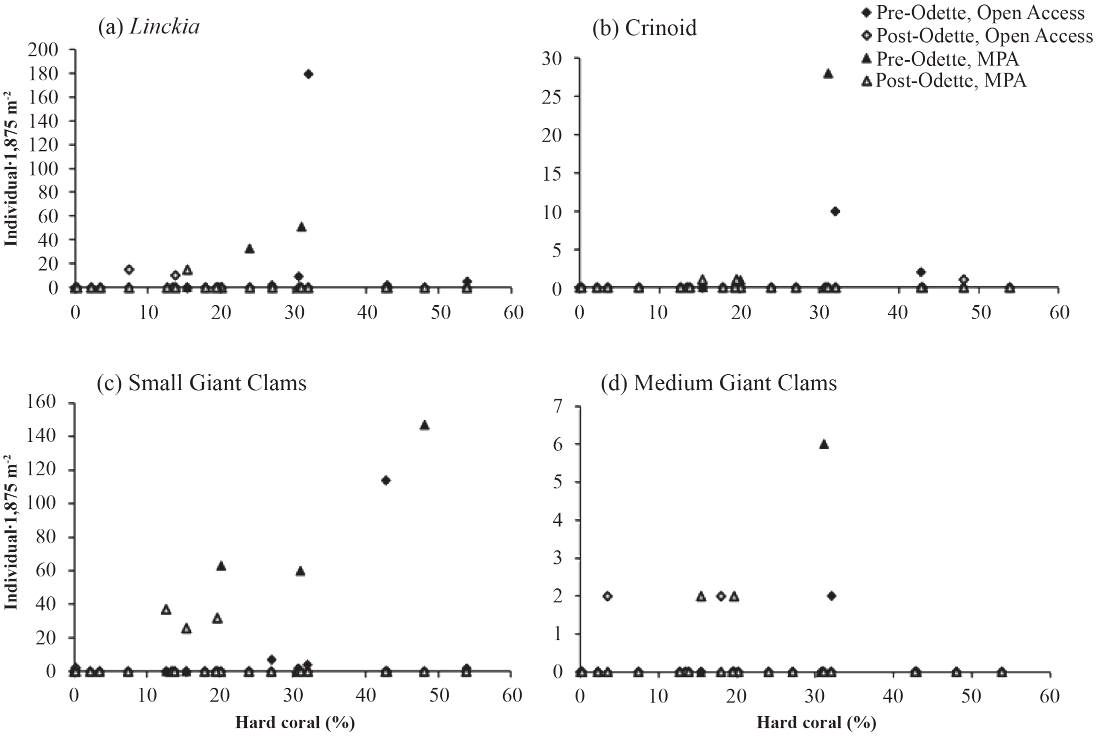

Figure 7. Scatter graph showing the relationship between the percent coral cover and abundance of macroinvertebrates on reefs in MPAs and open-access areas pre- and post-Odette.

During the typhoon, macroinvertebrates such as the blue *Linckia*, crinoids, and COTS could have been easily dislodged by strong waves and battered by rolling rocks and coral fragments. Habitat disturbances like scouring and changes in salinity have been reported to cause significant reduction in benthic communities, H′ diversity, numbers of taxa, and abundance, including the shifts in composition and ranking of dominant taxa (Kobluk and Lysenko, 1993; Engle *et al*., 2009). The COTS, on the other hand, are serious coral predators but the low abundance (1 ind·1,875 m^{-2} or about 5 ind·ha^{-2}) on the surveyed reef sites indicates the absence of an outbreak (Fraser *et al*., 2000). Crown-of-thorns feed on corals, especially *Acropora* spp., and its outbreak can cause extremely rapid destruction of the reef ecosystem (Endean, 1982; Uthicke *et al*., 2015). This study did not look into the coral species, but most surveyed sites were dominated by branching coral which may have been highly affected by the typhoon, and their absence can limit the abundance of COTS. While the current COTS density is not alarming, regular reef monitoring is needed for early detection of any possible outbreak, which could bring further reef damage.

As for the small giant clams, out of 399 individuals found pre-Odette, only a total of 97 remained, representing a 75.69% decline. The decline of small giant clams was highly evident for Hart Reef MPA (from 60 to 26 ind·1,875 m^{-2}), Dalarat MPA (from 63 to 32 ind·1,875 m^{-2}), Black Rock MPA (from 147 to 37 ind·1,875 m^{-2}) and Raket-Raket (from 114 to 0 ind·1,875 m^{-2}). Small giant clams were scarce or absent in other reef sites (Cambari, Cotad, Langoy, Baby Hart Reef, Piawe, Salvacion MPA, and Rawis) before and after Odette. Among the four MPAs, only Salvacion MPA had zero records for small giant clams both pre- and post-Odette. The absence of data from other sites precluded any statistical comparison. When the data were grouped according to the level of protection, both MPAs and open-access areas showed a decline in the abundance of macroinvertebrates. However, MPAs seemed to have provided better protection for small giant clams (Figure 7). There were not many changes in the abundance of medium-sized giant clams, although some reef sites (Dalarat MPA, Piawe, and Raket-Raket) having zero records pre-Odette had at least two individuals post-Odette.

The small giant clams are embedded in rocks and therefore less affected by strong waves, but they may have suffered from scouring reef fragments and other environmental changes. Komagoe *et al*. (2018) found that *Tridacna maxima* exhibited a decline in shell increment thickness and some unstable growth increments corresponding to lower sea surface temperature caused by typhoons. Sayco *et al*. (2019) reported that lower salinity conditions could reduce fertilization rates and delay embryonic development among *Tridacna gigas*, which suggests that intensified precipitation events could further hinder the survival of giant clams on the reef.

The low numbers of giant clams in some sites, even during the pre-Odette survey, could have resulted from anthropogenic impacts such as fishing and habitat degradation. Giant clams, particularly small individuals, can occur in higher numbers in undisturbed reefs (Conales *et al*., 2015; Daño *et al*., 2021), but due to unregulated exploitation, they become scarce in the reefs. Meanwhile, the largest species have become virtually extinct in most parts of Palawan (Alcala, 1986; Juinio *et al*., 1989; Ardines *et al*., 2020; Mecha and Dolorosa, 2020) and from their global distribution range (Othman *et al*., 2010; Neo and Todd, 2013; Ramah *et al*., 2019), since they can easily be seen on the reef. Because of their enormous ecological (Neo *et al*., 2015; Arossa *et al*., 2019) and economic importance (Tisdell, 1992; Tisdell *et al*., 1994), studies and conservation of giant clams have been a priority for local reef management. Long-term efforts to restock depleted reefs have been carried out (Gomez and Mingoa-Licuanan, 2006; Cabaitan and Conaco, 2017) to restore the lost wild populations of larger giant clam species. A successfully restored population of giant clams developed into an eco-tourism site can serve as a potential source of alternative livelihood and revenues (Garcia-Gomez and Roebeck, 2017).

CONCLUSION

In general, the significant decline of overall HC cover and macroinvertebrates in all surveyed sites indicates that the reefs of Palawan and the resources they support were highly vulnerable to the impacts of ST Odette, especially those MPAs dominated by branching corals. This means the establishment of MPAs should consider the vulnerability of the reefs to the impacts of typhoons. On the other hand, the species richness and abundance of butterflyfishes remained less affected by ST Odette due to their mobility. Open-access areas with lesser impact from typhoons may be declared as MPAs.

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