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Declining population of giant clams (Cardiidae: Tridacninae) in Palawan, Philippines

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ABSTRACT

For more than two decades, the Philippine government has protected the giant clams (Bivalvia: Cardiidae: Tridacninae) from exploitation and trade. However, there still is lack of information on the impact of these protective measures in conserving the species richness and density, especially in Palawan, the country's last stronghold of these reef-associated bivalves. Hence, to assess the species richness and density of giant clams in Palawan, we conducted 57 photo-transect surveys in six sites covering 12,325 m^2. Out of these transect, 15 measured 5 × 25 m and the rest measured 5 × 50 m. For historical trends in the population of giant clams in Palawan, we used six published papers obtained from online platforms, 13 reports, and five undergraduate theses archived in local libraries. Information derived from recent field surveys indicated high variations in species richness (2 to 5 species) and densities (0.1 to > 3.6 ind.100 m^{-2}). Historical data starting from 1984, including recent fieldwork, indicated very low densities and a declining trend. The current status suggests that giant clam populations' viability and the reefs' health are threatened. Effective mechanisms are needed to safeguard and enhance the remaining giant clam populations.

Keywords: Abundance, Density, Population Trend, Species Richness

INTRODUCTION

The giant clams (Cardiidae: Tridacninae) are among the heavily fished reef-associated invertebrates. The meat of giant clams has been a traditional food for coastal inhabitants in tropical and subtropical regions for more than a millennium (Juinio et al., 1989; Munro, 1993; Wells, 1997; Floren, 2003; Craig et al., 2008, Szabó and Amesbury, 2011). Despite the absence of reliable statistics on the volume of meat harvested for subsistence in the South Pacific, mostly in Papua New Guinea, Fiji, and Maldives, the estimated figure reached about 200 tons per year (Munro, 1993). The overall volume of meat substantially increased when commercial harvesting and trade began (Wells, 1997). In the Philippines, from 1992

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to 1993, records show that more than 39 to > 66 tons of giant clam meat were exported, mainly destined for Japan (Wells, 1997).

Similarly, the shells were traded, but statistical records were also fragmented (Villanoy et al., 1988; Wells, 1997). Specifically, the medium-sized free-living species such as *Hippopus hippopus* (Linnaeus, 1758), *H. porcellanus* Rosewater, 1982, and *Tridacna squamosa* (Lamarck, 1819) dominated the bulk of traded pairs of shells from 1978 to 1981, before the species largely disappeared between 1982 and 1985 (Juinio et al., 1989). However, records of the traded number of paired shells from Zamboanga, Philippines, reached a peak of 90,000 pairs in 1979 before abruptly dropping in the succeeding years, with only about 10,000 pairs being traded in 1985 (Juinio et al., 1989). Despite the decline in shell numbers based on records collected locally, the Philippines dominated the international shell trade in 1990, exporting 1.5 million shells, nearly 350,000 carvings, and over 252 tons of shells before the records dropped in 1992 (Wells, 1997).

The uncontrolled commercial harvesting for international trade of giant clams in the Philippines from the 1900s resulted in the decline of wild populations. An assessment of giant clam populations in the country undertaken by Juinio et al. (1989) indicated low densities in frequently fished areas. At that time, estimated densities from four localities in Palawan (0.111 – 3.266 ind.100 m^{-2}) and from other surveyed sites were much lower compared to Polilio (36.286 ind.100 m^{-2}), an offshore island in northeastern Luzon. Similarly, commercial fisheries of giant clams in many other countries (e.g., Papua New Guinea, Fiji, Maldives) resulted in the rapid stock decline, fishery closure (Munro, 1993), and localized extinction of *T. gigas* (Linnaeus, 1758), *T. derasa* (Röding, 1798), *H. porcellanus* Rosewater, 1982, and *H. hippopus* (Wells, 1997).

To mitigate the eventual harmful effect of widespread overfishing, giant clams were listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1985 (Juinio et al., 1989). In the Philippines, all giant clam species are classified as Endangered under the Republic Act 8550, Fisheries Administrative Order (FAO) 168 series of 1990 (DA, 1990), and FAO 208 series of 2001 (DA, 2001), in which gathering, selling, purchasing, possessing, transporting, and exporting are prohibited with corresponding penalties. Despite these laws, the exploitation of giant clams remained a problem due to its high market price, which encourages many Filipinos to harvest even the fossilized shells of the clams (Fabro, 2021; Lee and Wong, 2023), which could threaten the remaining wild populations of giant clams. Furthermore, there is a need to evaluate the status of giant clam populations in Palawan as information remains poor (see Ecube et al., 2019; Daño et al., 2020; Mecha and Dolorosa, 2020; Requilme et al., 2021), which becomes a management challenge for effective protection and enforcement. To evaluate if the current populations are still threatened, we determined the species richness, density, and population trends of giant clams in the reefs of Palawan.

METHODS

Study Sites

A total of six sites were surveyed from 2018 to 2019 (Figure 1). These were the Hart Reef (HR), Black Rock (BR), Port Barton (PB), Banwa Private Island (BPI) (also known as Puerco Island), Western Philippines University-Binduyan Marine Research Station (WPU-BMRS), and Rasa Island Wildlife Sanctuary (RIWS). The surveyed area in each site was within the fringing reef or submerged offshore reef dominated by massive and submassive corals (Table 1). Except for WPU-BMRS, all other sites are Marine Protected Areas (MPAs). The RIWS is protected by Presidential Proclamation No. 1000, s. 2006, whereas other sites are protected under municipal ordinances (Table 1). Among the MPAs, only the BPI, which is part of Tumarbong MPA's core zone in the municipality of Roxas, provides an adequate enforcement mechanism to effectively control fishing activities within its vicinity.

Table 1. Site description, legal frameworks, and total area for each surveyed site during the assessment of giant clams from 2018 to 2019.

Study Site	Site Description	Municipality/City	Classification	Total Area (ha)	Legal Framework
Hart Reef	Offshore submerged reef, about 10 m deep; mostly massive and submassive corals; mean (±sd) hard coral cover: 11.9% (±4.1).	Araceli	Marine Protected Area and Marine Sanctuary	20,018.72	Municipal Resolution No. 43-2011
Black Rock	Fringing reef, about 3-4 m deep at the reef slope; mostly massive corals covered with dense growth of the seaweed *Sargassum* spp.; mean (±sd) hard coral cover: 15.4% (±6.9).	Taytay	Marine Protected Area	779.531	Ordinance No. 197, s. 2014
Port Barton	Scattered islands within the bay with fringing reefs about 2-4 m deep at the reef crest and slope; mean (±sd) hard coral cover: 31.5% (±6.5).	San Vicente	Port Barton Marine Protected Area	7,482	Municipal Ordinance No. 110, s. 1997; No. 10-A, S. 2002
Banwa Private Island	Fringing reef slope about 3-4 m deep; generally massive and submassive corals. mean (±sd) hard coral cover: 6.9% (±2.3).	Roxas	Barangay Tumarbong Marine Protected Area	1,896.43	Municipal Ordinance No. 339, s. 2007
Western Philippines University-Binduyan Marine Research Station	Fringing reef slope about 6-8 m deep; mostly massive and submassive corals; mean (±sd) hard coral cover: 18.9% (±3.9).	Puerto Princesa City		~1.0	
Rasa Island Wildlife Sanctuary	Fringing reef slope about 4-6 m deep; mostly massive and submassive corals; mean (±sd) hard coral cover: 22.8% (13.1).	Narra	Protected Area	1,983	Presidential Proclamation No. 1000, s. 2006

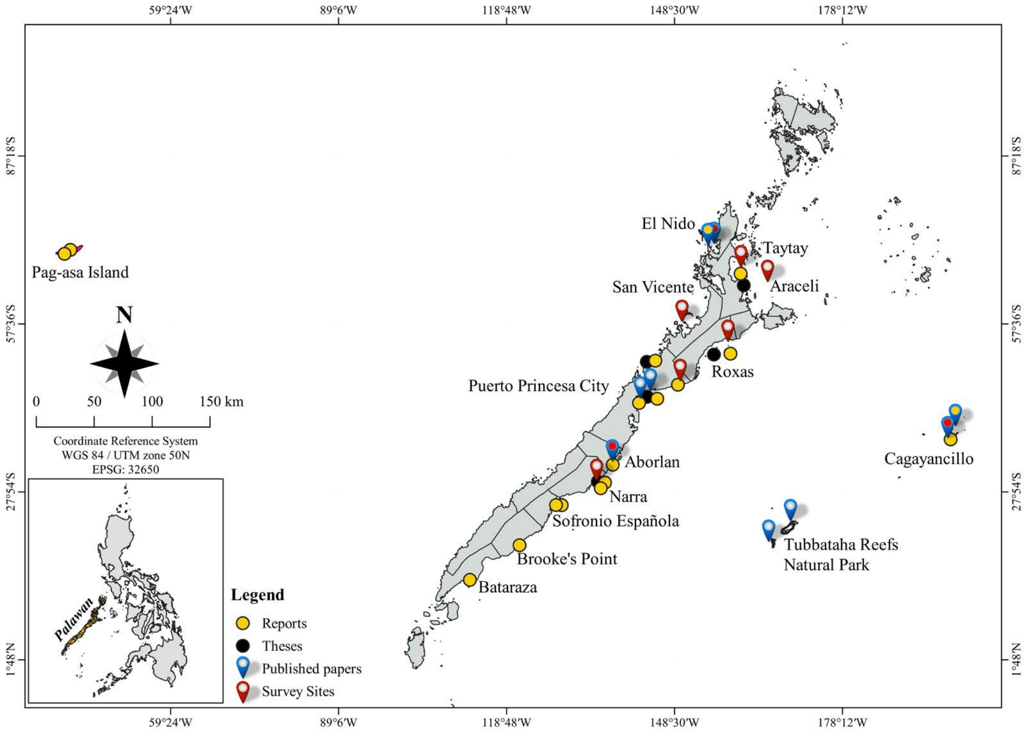

Figure 1. Map of the Philippines (inset) and Palawan indicating distribution of survey sites in 24 references and six recently surveyed areas. Blue icon markers with yellow () and red () circle colors are the same published papers. Some reports covered several sites.

Transect Survey

Reef photo-transect surveys were conducted at 2-10 m deep to collect data on species richness and density. At first, the 5-m wide transects measured 25 m long during the first survey in early 2018 but were later increased in 2019 to 50 m long to cover wider areas (Table 2). Giant clams found within the transect were photo-documented with size reference to distinguish the juvenile from adult clams. Identification of live giant clams follows the work of Neo et al. (2017). Survey efforts varied among sites depending on the size and accessibility of reefs. For example, the total sampled area in PB was 5,750 m^2, while both HR and BPI only covered 750 m^2. In total, 57 transects were surveyed, covering 12,325 m^2.

Table 2. Number of transects and surveyed study sites in Palawan, Philippines (2018 and 2019).

Reef Name (Municipality/City)	Date	Number of transect	Dimension (m)	Total area covered (m^2)
Hart Reef (Araceli)	May 2019	3	5×50	750
Black Rock (Taytay)	May 2019	4	5×50	1,000
Port Barton (San Vicente)	June 2018	12	5×25	1,500
	January and April 2019	17	5×50	4,250
Banwa Private Island (Roxas)	November and December 2018	3	5×50	750
Philippines University-Binduyan Marine Research Station (Puerto Princesa City)	March 2018	3	5×25	375
	December 2018	3	5×50	750
Rasa Island (Narra)	January and May 2019	12	5×50	3,000
Total		57		12,325

Population Trend

Published peer-reviewed papers posted on online platforms (e.g., Science Direct, Google Scholar, JSTOR, Elsevier, and ResearchGate) were searched using the keywords “giant clams” + “Palawan” + “Philippines.” Unpublished reports were requested from the authors and theses were obtained from local libraries. From the 27 references obtained, only 24 were shortlisted for further review as they shared similar survey methods (i.e., belt transects). Among the selected studies, one used the flowmeter method, which is known to produce comparable results with the belt transect surveys (Alcala, 1986). The other three studies used other survey methods such as line-intercept, photo-documentation, and reconnaissance. For historical data on the abundance of giant clams in Palawan from 1984 to 2019 (Figure 1; Supplementary Material Table S1), six published papers, 13 field reports, five undergraduate theses, and the recent survey in six localities were used (Figure 2).

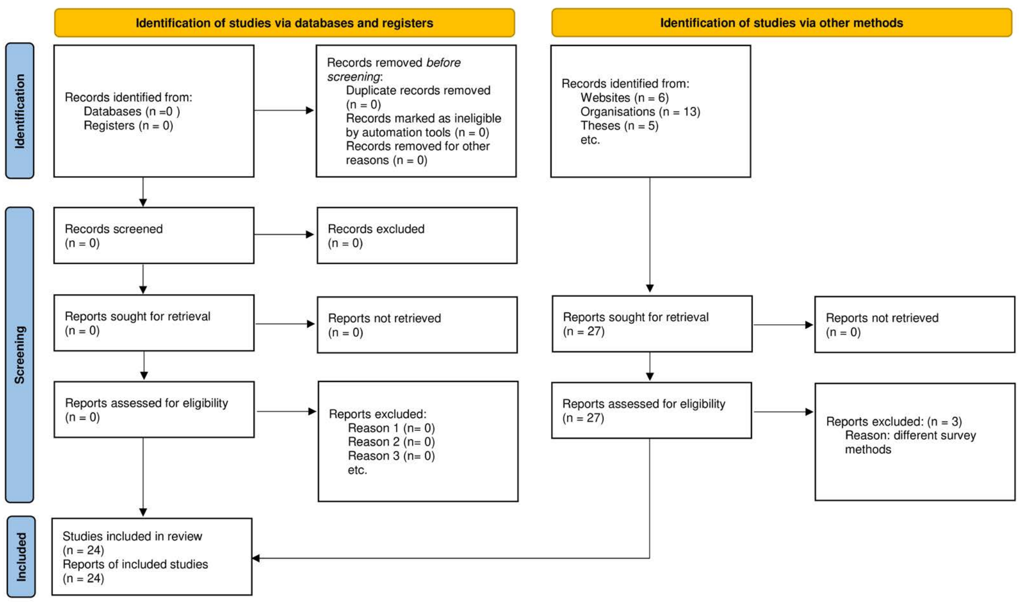

Figure 2. PRISMA flow diagram on giant clam population trend data, extracted from various references. Adopted from Page et al. (2021).

Data Analysis

To determine the current status of giant clams, the mean densities at each study site were computed. As for historical trends, mean densities from the various reviewed references, including the collected density data from surveyed sites, were pooled. The year of publications were grouped into three clusters, 1984-1995; 1996-2007; and 2008-2019, involving five, eight, and 22 study sites, respectively. The species richness represents the total number of species observed along the transects in the six study sites. Due to the variation in transect sizes, the mean (±sd) density was standardized to individuals per 100 m^{-2}. The Coral Point Count with Excel extension (CPCe; Kohler and Gill, 2006) was used to measure the sizes of giant clams in the photos and distinguish adult and juvenile clams. The shell lengths of recruits or juveniles were classified based on Mingoa-Licuanan and Gomez (2007), and the recent composition of juvenile clam for each species was determined. All computations were conducted using Microsoft Excel.

RESULTS

Species richness

In total, we found five giant clam species inside the transects. Banwa Private Island had the highest number of species (five species), whereas BR, WPU-BMRS, and RIWS had the lowest (two species). The two other sites had three species each. *Tridacna crocea* occurred in five sites, with the highest occurrence observed in HR, while *Tridacna maxima* (Röding, 1798) was recorded in all study sites, with a high relative frequency in BR. We found no *T. squamosa* in BR and WPU-BMRS; however, it was found in HR and RIWS (one individual), BPI (five individuals), and PB (11 individuals). Both *H. hippopus* and *H. porcellanus* only occurred in BPI (Figure 3).

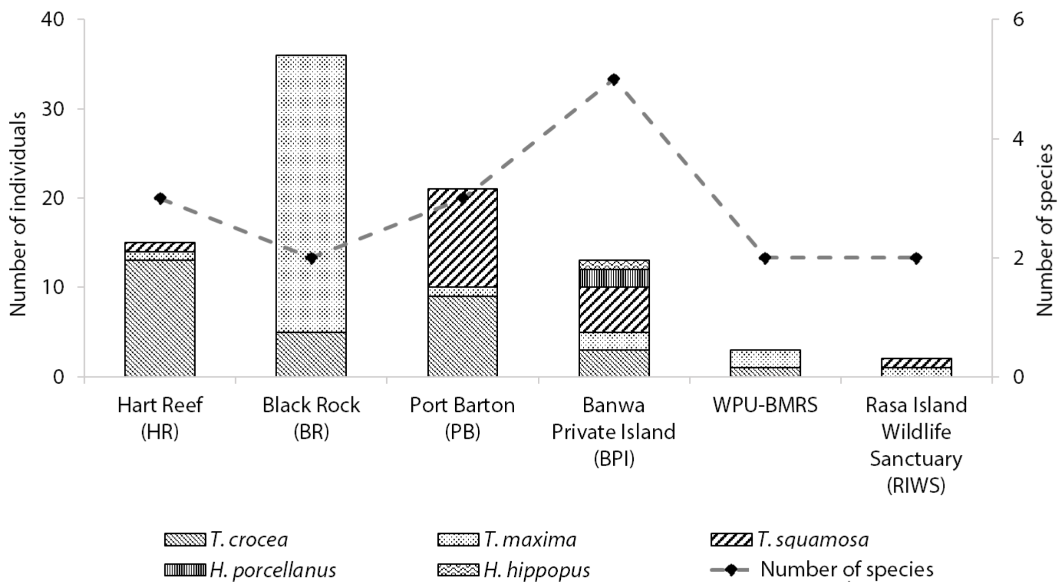

Figure 3. Number of individuals and species richness of giant clams found along the reef transects at each study site in Palawan.

Density

All sites exhibited very low densities of giant clams, ranging from 0.1 to 3.6 ind.100 m^{-2}. Port Barton, WPU-BMRS, and RIWS had the lowest (< 1 ind.100 m^{-2}), whereas BR had the highest (3.6 ind.100 m^{-2}). Densities at HR and BPI were 2.0 and 1.7 ind.100 m^{-2}, respectively. The juvenile clams accounted for 58.59 % of the total. Only juvenile clams were observed in WPU-BMRS and RIWS, while only adult clams were noted in HR. The remaining sites harbored both juvenile and adult clams (Figure 4). Among the five species, only *T. crocea, T. maxima,* and *T. squamosa* were represented by both juveniles and adults, while only one juvenile of *H. hippopus* and two adults of *H. porcellanus* were encountered in all study sites (Figure 5).

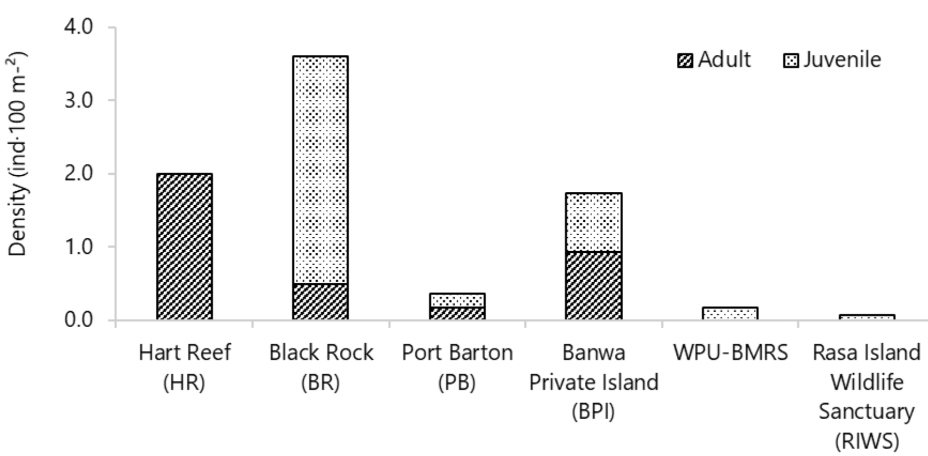

Figure 4. Density of giant clams at the six surveyed sites in Palawan, Philippines.

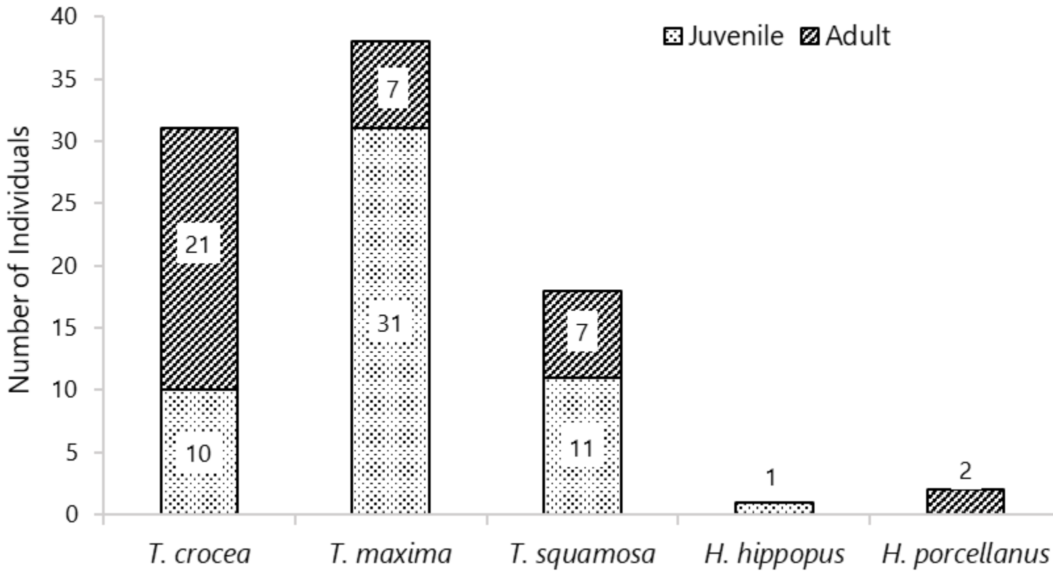

Figure 5. Numbers of juveniles and adults of five giant clams species found at the six surveyed sites in Palawan, Philippines.

Population Trend

The density of giant clams exhibited a declining trend from 1984 to 2019 (Figures 6 and 7) with an increasing number of surveyed sites (Figure 7). Moreover, from 1984 to 1995, the mean (±sd) density of giant clams (7.75 ± 12.75 ind.100 m^{-2}) remained relatively stable from 1996 to 2007 (9.02 ± 8.57 ind.100 m^{-2}). However, from 2008 to 2019, the density severely declined to 0.98 (± 1.65) ind.100 m^{-2} (Figure 6). Figure 7 shows that, as early as 1984-1995 and 1996-2007, some areas presented extremely low densities, with <4 ind.100 m^{-2}, which became more common for sites surveyed in 2008-2019.

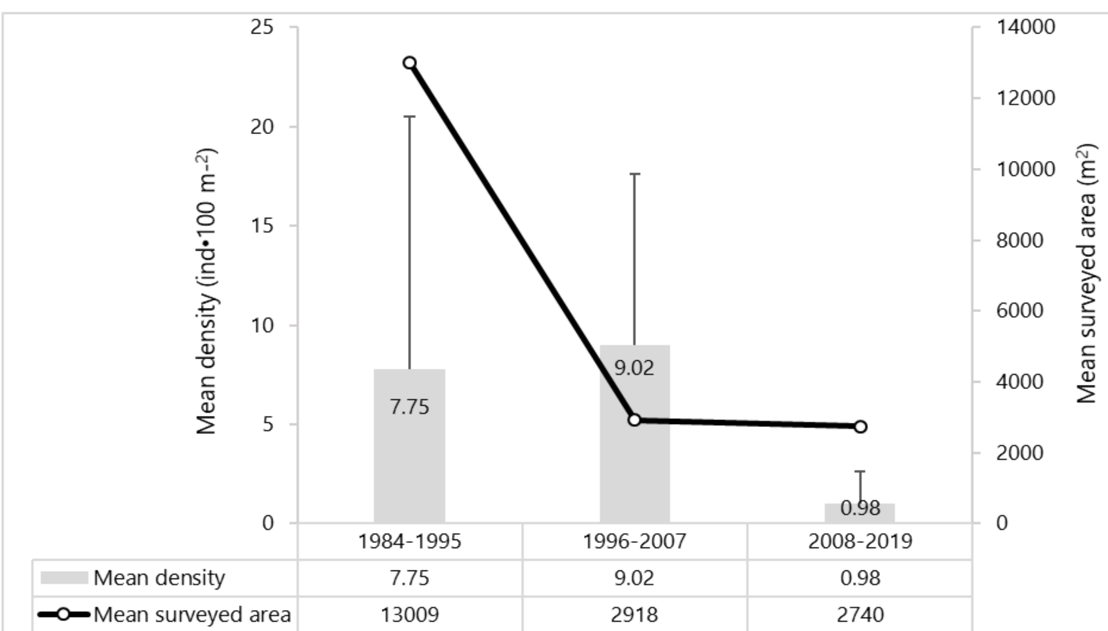

Figure 6. Trends in the density of giant clams in Palawan, Philippines.

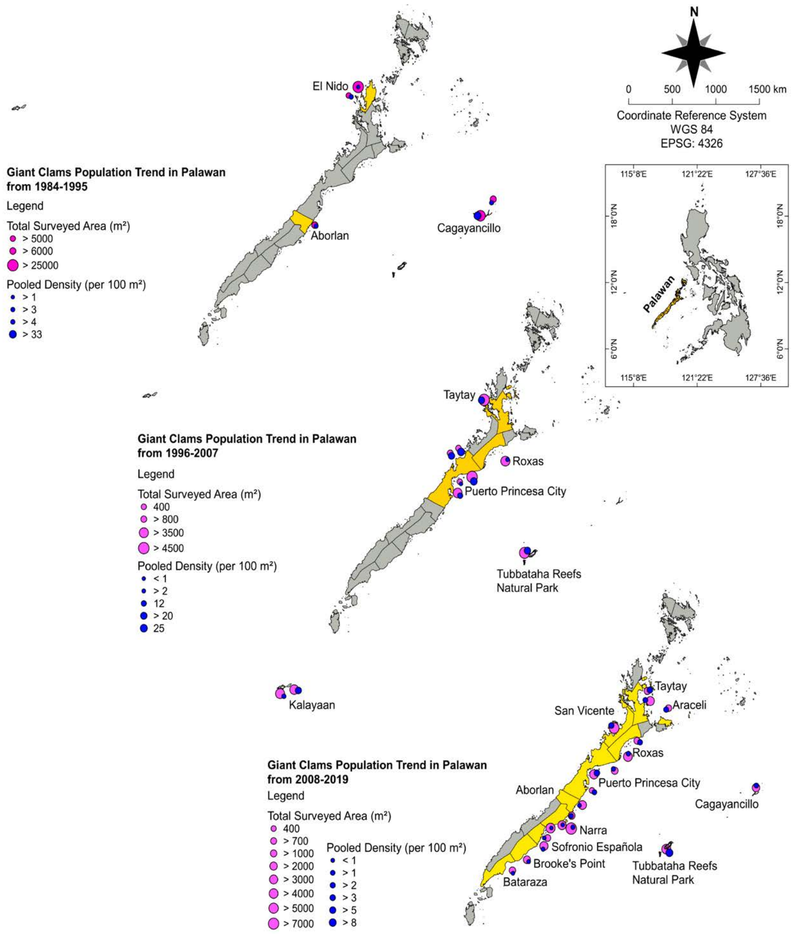

Figure 7. Three clusters (top – 1984 to 1995; middle – 1996 to 2007; bottom – 2008 to 2019) of giant clam population trends in Palawan from 1984-2019.

DISCUSSION

Species Richness

Among the eight species of giant clams known from Palawan (Dolorosa et al., 2015; Ecube et al., 2019), only five species were found along the transects in the recent survey. The absence of three other species—*Tridacna gigas*, *T. derasa,* and *T. noae*—and the considerable variation in the species richness across sites could be due to the nature of habitats and the level of management and enforcement efforts (Neo and Todd, 2012a, 2021b; Ramah et al., 2019). Previous studies have shown that both *Hippopus* species typically inhabit lagoonal reefs. For instance, *H. hippopus* in New Caledonia was more abundant in the lagoon than in the barrier reef (Purcell et al., 2020), the same with *H. porcellanus* in Tubbataha Reefs Natural Park (TRNP), which occurred in the shallow part of the lagoon (Dolorosa et al., 2014). The larger species, such as *T. gigas, T. derasa*, and *T. squamosa*, prefer shallow, sheltered lagoonal, and reef flat habitats (Braley, 1987). Meanwhile, *T. crocea*, *T. maxima*, and *T. noae* are boring species that require consolidated hard substrata for settlement (Kubo and Iwai, 2007; Conales et al., 2015; Ecube et al., 2019). The apparent absence of large and free-living species in the study sites may be attributed to harvesting patterns. For example, only a few numbers of live *T. gigas* were found in some island resorts and well-managed protected areas (see Mecha and Dolorosa, 2020). A single *T. derasa* was observed in Tecas Reef, a marine sanctuary in the municipality of Taytay, and the recently rediscovered species, *T. noae*, was observed in an island resort in the municipality of San Vicente (Ecube et al., 2019). Ad-hoc snorkeling observations in shallow sandy-seagrass areas that were not covered by transects also did not reveal the presence of other species, indicating that most giant clam species have been overfished in the study sites.

In the Philippines, the larger species of giant clams, such as *T. gigas*, *T. derasa,* and *H. porcellanus*, were considered locally extinct as early as the 1980s (Alcala, 1986) based on their absence or scarce numbers in the first nationwide giant clam assessment. A fossilized shell of *T. gigas* found in the intertidal flat of BPI suggests that the species once occurred in the area. In addition, the presence of fossilized shells in various areas (Mecha and Dolorosa, 2020; Fabro, 2021; Lee and Wong, 2023) reflects their abundance and widespread distribution in the reefs of Palawan in the past. The continued harvesting for its meat and the high demand for its shell, as manifested by hundreds of tons of recently confiscated fossilized and newly harvested giant clam shells in Palawan (Fabro, 2021; Miranda, 2021), threatens the last remaining living individuals in the wild. Localized extinction for larger giant clam species is also becoming widespread with reports in Singapore (Neo and Todd, 2012a), Fiji, Guam, New Caledonia and the Northern Marianas, Japan, Taiwan, Tuvalu, the Federated States of Micronesia, and Vanuatu (Wells, 1997). To enhance the protection of the five giant clam species found within the survey sites, urgent measures are required such as strict enforcement of laws and better management strategies to conserve the remaining population in the wild. This should also apply to the three larger species that were not found in the study sites but are present in other reefs of Palawan. Breeding of some rare species of giant clams may serve as an important genetic seed source for other depleted reefs and as significant sources of gametes for hatchery-based conservation initiatives.

Density

The mean densities of giant clams (0.1 – 3.6 ind.100 m^{-2}) were very low and inversely proportional to sampling efforts. Areas with low sampling efforts (750 – 1000 m^2), such as BPI, HR, and BR, presented the highest densities. This is contrary to areas with high sampling efforts but low densities.

The variations in mean densities across sites could be a result of various factors, such as exploitation frequency, level of protection, and nature of habitats. Despite various government laws aimed at the conservation of giant clams, harvesting continues as part of the long tradition and culture of the people (Larrue, 2006; Ardines et al., 2020; Abd-Ebrah and Peters, 2021). Giant clams have been harvested for their meat and shells for both subsistence and commercial purposes (Juinio et al., 1989; Larson, 2016; Neo et al., 2017; Mecha and Dolorosa, 2020; Fabro, 2021; Jones, 2021). Even in marine protected areas (MPAs), these clams remained vulnerable due to continued incursion and challenges in law enforcement (White et al., 2005; Weeks et al., 2009). In pristine and undisturbed habitats, giant clams could occur in extremely high densities. For example, an area covering 1.18 km^{-2} in Fangatua Atoll (Eastern Tuamotu, French Polynesia) can shelter around 10.39 million *T. maxima*, which is equivalent to 8.8 ind.m^{-2} (Andréfouët et al., 2005). In TRNP, an exposed massive coral head can host 2–22 ind.m^{-2} of *T. crocea* (Conales et al., 2015), while in a well-guarded private Rita Island in Ulugan Bay, Puerto Princesa City, *T. crocea* occupied small patches of subtidal coral rocks in densities of 2.69 – 59.91 ind.m^{-2} (Daño et al., 2020). Success stories of giant clam conservation in other areas may be adopted to restore the giant clam populations (Gomez and Mingoa-Licuanan, 2006; Requilme et al., 2021).

In the recent survey, the few numbers or absence of adult clams in some sites could be an indication of extreme fishing pressures that have also been reported in many other localities (Wells, 1997; Neo and Todd, 2012b; Neo and Todd, 2013; Abd-Ebrah and Peters, 2021). Despite prohibiting the harvesting of giant clams, fishers can secretly excise the meat of large individuals, leaving the shells on the reef. In some island villages, giant clams are aggregated in shallow waters nearby, which can be easily used as food when fishing becomes difficult, especially in times of bad weather (pers. obs.). In addition, the recent reports on the widespread confiscation of fossilized giant clam shells (Fabro, 2021; Lee and Wong, 2023) posed a threat to the remaining populations of giant clams, particularly large-sized species. The rare occurrence or absence of adults *T. gigas, T. derasa, T. squamosa, H. hippopus*, and *H. porcellanus* could lead to poor fertilization rates and failure of natural recovery (Neo et al., 2013). By contrast, the presence of juveniles of *T. squamosa, T. maxima*, and *T. crocea* indicates continued recruitment. Giant clams are broadcast spawners, and the larvae that settled in the study sites may have come from distant parent populations. Thus, it is important to protect both the parent populations and the settlement sites to enhance natural giant clam population recovery. In addition, the protection accorded to sites can enhance populations; for instance, the effective management of Mo'orea's protected sites resulted in nearly a threefold increase in *T. maxima* populations (Armstrong, 2017). Therefore, the establishment of a guard house with advanced monitoring equipment and deployment of rangers with financial support, following similar strategies and level of management found in MPAs, such as TRNP, Rita Island, and Mo'orea, may help restore the lost giant clam populations in six study sites and elsewhere.

Population Trend

Information on the unfished and protected populations of giant clams is lacking in the Philippines since the 1980s. However, the historical international shell trade dominated by the Philippines in the early 1990s (Wells, 1997) and the recent confiscations of hundreds of tons of fossilized giant clam shells worth more than PhP1 billion (Fabro, 2021; Jones, 2021) is a clear indication of giant clams' high abundance in the past. Although a nationwide assessment of giant clams was conducted in the 1980s, the state of natural populations had already been overharvested, as manifested by low-density records in many surveyed sites (Alcala 1986, Juinio et al. 1989). The trend continued to decline in Palawan, as reflected in the current study (Figures 6 and 7; Table S1) and in many other countries (Othman et al., 2010; Neo and Todd, 2013; Ramah et al., 2019). The uncontrolled decline could be associated with small population size, considerable problems in law enforcement (Wells, 1997), local consumption of giant clam meat (pers. obs.) and its attractive price, along with their shells, in the black market (Fabro, 2021). In Mauritius, Ramah et al. (2019) identified anthropogenic pressures, such as overharvesting and many other factors (e.g., natural climatic catastrophes) affecting the drastic decline of *T. maxima* and *T. squamosa*, both within and outside MPAs. Despite this, recovering populations of giant clams have been reported in other well-managed reserves in Palawan such as the numerous individuals of *H. porcellanus* (Dolorosa et al., 2014) and *T. crocea* in TRNP (Conales et al., 2015), after more than 20 years of protection, and the undisturbed population of *T. crocea* in Rita Island (Daño et al. 2020).

CONCLUSION

The low species richness (2-5 species) with the absence of large-sized species (e.g., *T. gigas* and *T. derasa*) and density ranging from 0.1 and 3.6 ind.100 m^{-2} is an indication of continued harvesting and the inability of the species to recover via natural recruitment. The presence of five species in BPI reflects the essential role of island resorts in conserving large-sized giant clam species (see Mecha and Dolorosa, 2020; Daño et al., 2020). The dominance of small-sized individuals could be attributed to the fishing mortalities of large-sized individuals, which are highly noticeable in a complex reef habitat. However, the occurrence of juvenile *T. crocea, T. maxima, T. squamosa*, and *H. hippopus* in the study sites indicated continued settlement and the presence of breeding populations elsewhere. The declining populations could be associated with the failure to manage these resources, which could boil down to the lack of political will (Carbonetti et al., 2014) and the people's economic background and tradition to harvest giant clams. Restored giant clam populations can help mitigate overfishing by enhancing fish population and biomass (Cabaitan et al., 2008; Neo et al., 2015), function as seed sources for other depleted reefs (Requilme et al., 2021), and act as a source of livelihood and revenue when developed for eco-tourism. Therefore, effective engagement and communication with relevant stakeholders could be beneficial to the protection of the remaining giant clam populations in the wild. Moreover, local initiatives involving the aggregation of giant clams in MPAs and private resorts (pers. obs.) might also help protect the species from fish poachers; however, this must be coupled with proper documentation and monitoring to avoid its use as a front in exploiting the species.

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AUTHOR CONTRIBUTIONS

R.G.D.: Supervision; Conceptualization; Funding Acquisition; Data Collection; Formal Analysis; Investigation; Methodology; Writing – original draft; Writing – review & editing.

N.J.M.F.M.: Software; Formal Analysis; Data Collection; Writing – review & editing.

J.D.B.: Project Administration; Formal Analysis; Data Collection; Writing – original draft.

K.M.A.E.: Project Administration; Data Collection; Writing – original draft.

E.G.V.: Project Administration; Formal Analysis; Data Collection.

P.C.C.: Conceptualization; Funding Acquisition; Writing – review & editing.

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