ECOSYSTEM RESEARCH AND MONITORING REPORT

2022

Tubbataha Reefs Natural Park
Ecosystem Research and Monitoring Report 2022

Editors:
Maria Retchie Alaba, Gerlie Gedoria, Rowell Alarcon, and Angelique Songco

Suggested Report Citation:
Alaba, M.R., Gedoria, G., Alarcon, R., and Songco A. 2022. TRNP Ecosystem Research and Monitoring Report 2022. Tubbataha Protected Area Management Board.

Suggested Chapter Citation:
Gedoria, G., Conales S., Arceo, H. & Caranay C. 2022. Chapter 1: Reef Fish. In Alaba, M.R., Alarcon, R., Gedoria, G., and Songco A. (eds). TRNP Ecosystem Research and Monitoring Report 2022. Tubbataha Protected Area Management Board.

Cover Photo: Yvette Lee

ACKNOWLEDGEMENT

We want to extend our sincerest gratitude to the following individuals who significantly contributed to this year's ERM report through data collection – Mary Joan Pecson, Kymry Delijero, Ace Nińo Andrew Acebuque, Jomil Rodriguez, Anton Rey Cornel, Benjamin Ted Jimenez, CG SN1 Eugene Robert P Atienza, CG SN1 Henerson D Jaranilla, CG ASN Rusty T Velila, P01 Jose J De Castro PN, P02 Rizal A Fernandez, Rex P. Cayabo. We also thank the crew of M/Y Navorca, WWF-Philippines' research vessel, for the safe voyages, logistical support, and for great food.

This year's research and monitoring activities were funded by the Department of Environment and Natural Resources, Metro Pacific Investment Foundation, and Jimenez Group of Companies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

To date, there are 17,786 marine protected areas in the world, occupying 8.15% of our oceans (IUCN 2022). There are 35 legislated marine protected areas in the Philippines, covering 1.42% of the country's national waters (DENR 2022). The country's coastline, spanning 36,290 kilometers, is the third longest coastline in the world. Thus, the country relies on its coastal and marine ecosystems for food and livelihood. In the Philippines, coral reefs span around 26,000 square kilometers, the second largest in Southeast Asia (ADB 2014). Coral reefs provide numerous ecosystem services, e.g., fisheries production, coastal protection, and tourism.

The latest nationwide assessment of coral reefs in the Philippines conducted between 2015 to 2017 revealed an average hard coral cover (HCC) of 22%; reefs below this average HCC would be considered "poor" in reference to the previous threshold set by Gomez et al. in 1981 (Licuanan et al. 2017). Licuanan et al. (2017) cited Tubbataha Reefs as having 33% or above average HCC based on surveys done between 2012 to 2014.

However, last year's reef benthos monitoring revealed a significant decline in the hard coral cover of TRNP. Questions on the factors that contributed to the decline and the impacts this phenomenon on other organisms beg to be asked.

This finding highlighted the value of regular monitoring to detect changes in the reefs. Constant monitoring of the water quality would also provide insights into non-anthropogenic and anthropogenic factors that might be influencing the declining HCC, e.g., elevated nutrients, pollutants, or temperature.

This finding also underlined the importance of continuous fish population monitoring to determine how these changes in the coral reef health affect them. Seabirds, which rely on healthy seas for survival, are also vital components of marine ecosystems (Mallory et al. 2010; Raipar et al. 2018). Tubbataha supports more than 30,000 individuals (Jensen et al. 2021) that feed in its waters. Hence, they can indicate the condition of a reef (Mallory et al. 2010), justifying regular monitoring of the species.

The four components included in this year's report – reef benthos, fish population, seabird population, and water quality – form part of the ecosystem research and monitoring strategy of the TRNP. This serves as one of the pillars of park management aiming to:

1. determine ecosystem health;
2. generate sound scientific information;
3. provide the basis for formulating strategies; and
4. measure biophysical indicators of management effectiveness.

The results of these assessments will provide guidance to the Tubbataha Protected Area Management Board in formulating strategies to better manage the park.

REFERENCES

Asian Development Bank. 2014. State of the Coral Triangle: Philippines. ISBN 978-92-9254-518-5

Department of Environment and Natural Resources. 2022. http://www.philchm.ph/coastal-and-marine/ Accessed on 30 September 2022 International Union for the Conservation of Nature. 2022. https://www.protectedplanet.net/en/thematic-areas/marine-protected-areas. Accessed on 30 September 2022

Jensen, A., Songco, A., & Pagliawan, MR. 2021. Chapter 4: Seabirds. In In Alaba, M.R., Alarcon, R., Gedoria, G., and Songco A. (eds). TRNP Ecosystem Research and Monitoring Report 2021. Tubbataha Protected Area Management Board.

Licuanan, A.M., Reyes, M.Z., Luzon, K.S., Chan, M.A., & Licuanan, W.Y. (2017). Philippine Journal of Science 146(2):177-185, June 2017 ISSN 0031-7683

Mallory, M.L., Robinson, S.A., Herbert, C.E., & Forbes, M.R (2010) Seabirds as indicators of aquatic ecosystem conditions: A case for gathering multiple proxies of seabird health. Marine Pollution Bulletin 60 (2010)7-12 doi:10.1016/j.marpolbul.2009.08.024

Rajpar, M. N. , Ozdemir, I., Zakaria, M., Sheryar, S., & Rab, A. (2018). Seabirds as Bioindicators of Marine Ecosystems. In (Ed.), Seabirds. IntechOpen. https://doi.org/10.5772/intechopen.75458

EXECUTIVE SUMMARY

The Tubbataha Reefs Natural Park is the largest no-take marine protected area in the Philippines. It was inscribed as a UNESCO World Heritage Site in 1993 in recognition of its outstanding natural value and importance to the world's oceans (whs.unesco.og).

The Tubbataha Management Office conducted its annual ecosystem monitoring of four main biological indicators: reef fish, reef benthos, seabirds, and water quality. Twelve regular monitoring stations were assessed for reef fish and benthos, including a newly established one, with shallow (~5m) and deep areas (~10m). Min Ping Yu and USS Guardian grounding sites were also surveyed. Seabird monitoring was conducted on the two islets, the Bird and the South Islets. Meanwhile, 20 monitoring sites were revisited for *in situ* measurement of water quality parameters and for collecting samples for laboratory analysis.

In reef fish, a modified Fish Visual Census (English et al. 1997) was employed to measure the fish community biomass, density, and species richness. These three factors were used to quantify the health of the fish population. Statistical tools were also used to analyze long-term trends to compare output values. The threshold Hilomen et al. (2000) and Nañola et al. (2004) established for density, species richness, and biomass were used to translate the values and determine the status of reef fish per Philippine standards.

For reef benthos, the team followed the method detailed in Luzon et al. (2019) with five transects randomly established inside a 75m x 25m shallow reef area and sampled by applying the photo transect method. Meanwhile, in deep stations, four 20-m transects were deployed and photographed. Photos were analyzed using the Coral Point Count with Excel Extension (CPCe). Statistical analyses and visualization were performed to determine trends and changes in the reef. To determine the status of the reef, categories for hard coral cover (HCC) and TAU density established by Licuanan et al. (2019) were used.

Coral recruit survey utilized a 34 x 34 cm quadrat placed in pre-selected 40 randomized points within the regular monitoring transects in shallow and deep stations. Meanwhile, a total of 60 quadrats were placed inside and outside of the permanent plots. Close-up photos were taken per quadrat and processed using the CPCe. Statistical analysis was used to determine differences across sites, depths, and years.

For the seabird survey, distance and direct counts were used to quantify the population of seabirds in two islets. This includes daytime counts of adults and breeding population (juvenile, eggs, nests), inflight data, seabirds in shoreline during high tide, and morning counts. In calculating the annual population, the quarterly count data collected by marine park rangers in one year were included in the analysis. This survey also includes measuring the islets and counting the vegetation.

The water quality survey revisited the 20 monitoring sites established in 2014 covering the lagoon, reef crests, and buffer zone of Tubbataha. Parameters collected in situ include the pH temperature, dissolved oxygen, salinity, and total dissolved solids. Water samples were collected and analyzed in PCSDS Environmental Laboratory for color, total suspended solids, nitrates, phosphates, oil and grease, and fecal coliform.

In general, the reef fish population is healthy, with very high species richness (57 sp/500m^2), high density (1,281 ind/500m^2), and very high biomass (118 g/m^2) values per standard established for Philippine reef fish communities (Nañola et al. 2004; Hilomen et al. 2000). This year's values were similar to 2021 values. Commercially important species still constitute most of the fish biomass in Tubbataha. Schooling fish groups and threatened species, e.g., sharks, Napoleon wrasse, and marine turtles, were also noted in the vicinity of the monitoring sites.

Average hard coral cover (HCC) (26.8%) and TAU density (19.8 TAU) in shallow stations both fell under Category C (Licuanan et al. 2019). These values were lower than the 2021 HCC (32.3%) and TAUs (20 TAUs). Site 5 and Jessie Beazley had the highest HCC among all sites. Meanwhile, three monitoring stations went down at least one category from 2021. In deep stations, the average HCC was 23% with a TAU density of 14.5 TAU, which was also lower than 2021 (27% and 28 TAU) values. Site 1 had the highest HCC and TAU density among all sites, while Station 2 and Jessie Beazley had the lowest HCC and TAU, respectively.

Corallimorph and coral-killing cyanobacteria sponge *Terpios* sp., previously noted in monitoring sites, are still present. *Terpios* sp was noted in shallow stations of Site 1 and Site 3. Meanwhile, corallimorphs were observed to proliferate in Station Jessie Beazley B. Permanent 4 x 4-meter quadrats were established in these three stations to monitor their development.

Coral recruits in shallow and deep stations both had an average density of 53 individuals/m^2. These values were lower than the previous year's density values. However, these values were still higher than in other tropical countries, e.g., Malaysia (25.9 ind/m^2). Brooder species dominated both the shallow and deep stations this year. Brooder species tend to reproduce faster, especially if a site experiences a disturbance, as a survival strategy. However, they are more short-lived than their counterpart, the broadcast spawners. Most coral recruits recorded were also juvenile and mature (≥4cm size), which has a higher survival rate than newly settled ones (>1cm size).

The values produced from this year's monitoring of fish, benthos, and coral recruits were lower than in 2021 (Alaba et al. 2021). The decrease in these three indicators was attributed to damages caused by Typhoon Odette in December 2021. For instance, in Jessie Beazley, the typhoon smothered the foliose *Montipora* sp, affecting the fish population and coral recruitment in the area. For fish, another factor that might have contributed to the decrease in biomass in Jessie Beazley was the suspected dynamite fishing incident in October 2021. Meanwhile, in coral recruits, the increase in dislodged rubbles might have also contributed to the decrease in the density values in all sites.

Like the previous year's survey, the observed decline in HCC continued. The shallow areas are declining at a rate of -0.9%, which was more apparent in South Atoll, corresponding to declining HCC in Site 3 (-3.4%). Jessie Beazley is also declining at a rate of -3.4% annually. Meanwhile, the deep area is also detected to decline at an annual rate of -1.3%, more apparent in North Atoll. The significant decline rate detected in deep stations was in Site 4

(-2.3%) and Site 2 (-1.7%). These decreases in HCC coincided with the annual increase in algal (3.5%) and sponge (0.7%) cover.

The annual decline in fish populations was also noted. An annual decline at a rate of -1.1% was detected in deep stations, with a decrease in demersal (-0.3%) and pelagic (-2.3%) fish groups. These decreases were attributed to factors affecting the movement of fish, e.g., food availability, predator avoidance, and more extensive migration related to temperature, tides, and moon phases.

Grounding sites, Min Ping Yu and USS Guardian were both considered healthy in terms of fish biomass and fish density. The output produced by these two sites was higher than the minimum standard for healthy reef fish communities established in the Philippines. The HCC in both sites also showed recovery since the grounding incident in 2013. The Min Ping Yu grounding site showed a steady recovery, while USS Guardian did not display a significant trend. This contrasted with the 2014-2017 monitoring, where USS Guardian showed a much faster recovery than Min Ping Yu. However, this change in the recovery trend might be due to different factors unrelated to the grounding incident, e.g., benthic composition and exposure to waves.

In terms of the seabird population, this year's count of 39,202 individuals was one of the highest counts since the baseline year of 1981. This population was 38% more than the inventory in 2021. This difference was mainly attributed to increased breeding populations of Great Crested Terns, Sooty Terns, and Brown Booby. Black Noddy, a Philippine endemic species, decreased by 23% from 2021.

Bird Islet hosted 70% of the total population in TRNP this year. In South Islet, an increase of 43% compared to the 2021 survey was noted. The population of Brown Noddy in the South Islet is comparable to years before the lighthouse was constructed in 2020. The Black Noddy population also increased by 9% from 2021 in the South Islet.

However, the overall population of Black Noddy is declining due to habitat loss on both islets. The Bird Islet is also eroding, with evidence of erosion in coasts and cemented calcite guano sandstone that used to be the islet's core. Around 400 native beach forest trees were planted in both islets in 2020 and were reduced to only eight (8) tree saplings in Bird islet. All saplings on the South islet died from salt spray carried by strong winds. Tree guards were placed around the remaining saplings in the Bird Islet to protect them from the Red-footed Booby and increase their survival rate.

In the case of water quality, the average this year for Tubbataha is generally within the criteria specified by DENR for protected waters (Class SA). This year's total coliform, fecal coliform, and oil and grease were the lowest values recorded in TRNP since the monitoring in 2014. These improvements in the water quality were attributed to the lockdown due to the COVID-19 pandemic stressing the importance of 'closed season' allowing the water to assimilate the pollutants from anthropogenic activities, e.g., tourism.

Even though Tubbataha has healthy coral reefs and fish populations compared to other sites in the Philippines, the continuous decline in its fish and coral indicates something is going on with the reef. TMO has requested its research partners to conduct studies to help determine the causes of these changes.

Meanwhile, within their capacity, it is recommended that TMO and monitoring partners look at different factors contributing to declining fish biomass and HCC. Collecting, processing, and analysis of auxiliary data (e.g., turf algae, the density of coral recruits, and fish herbivores) is recommended to understand the stressors contributing to the decline in HCC. It is also suggested to develop a rapid assessment method to collect data immediately after a disturbance, to use bathymetric maps and wave exposure data to gain insight into the reef's susceptibility to disturbance and to explore substrate stabilization for stations with large rubble patches, such as in Site 3. It is also recommended to limit the potential stressors, e.g., diving activity, around affected sites that might aggravate the declining state.

Maintaining and restoring the Black Noddy's population is a top priority for seabirds. Thus, it is advised to continue providing this species with nesting structures and materials. The eroding Bird Islet also threatens not only the survival of the Black Noddy but all seabirds in TRNP. Tubbataha has the largest seabird congregations in the Philippines; losing the islet means losing this seabird population. Hence, if the erosion continues and leads to a decline in the seabird population, it is advised by UP-MSI to pump the sand back to the Bird Islet. In the meantime, the management continues efforts to regenerate the beach forest. This year, a tree nursery was established in TMO to grow planting materials for next year.

Finally, the continuous monitoring of water quality parameters is recommended to help detect changes and trends that might affect coral reefs.

CHAPTER I. REEF FISH

Gerlie T. Gedoria[1], Segundo F. Conales Jr[1], Hazel O. Arceo[2], and Cresencio P. Caranay Jr[1]

[1]Tubbataha Management Office

[2]University of the Philippines – Cebu

OVERVIEW

As an offshore atoll, Tubbataha is expected to have greater fisheries potential than other types of reefs (Dantis et al. 1999). However, this premise alone could not account for the outstanding records of fish biomass, density, and species diversity in the park over the years. Being a no-take marine protected area with strong enforcement appears to be one of the primary factors in its healthy fish population despite various threats. According to Campos et al. (2008), Tubbataha is helping the surrounding seas by supplying fish and coral larvae carried by ocean currents, suggesting that TRNP is crucial to sustaining and securing the country's fisheries.

Annual surveys on marine resources, including fish populations, have been conducted since 1999. This is conducted to verify that fish populations remain healthy and to check the integrity of Tubbataha in the face of evolving threats, such as climate change.

Despite being in a healthy condition, the fish population has been declining since 2016 (Gedoria et al. 2021). This report covers the state of the fish community population as well as the trends in the fish population over the years of monitoring.

METHODS

Study Sites

TMO regularly monitors five sites located in the North Atoll, South Atoll, and Jessie Beazley Reef (Figure 2) to describe the condition of the fish and benthic communities. Each Site had two replicate stations, approximately 200 meters apart. This year, another station (Station 5B) was established on the southwest tip of South Atoll, increasing the monitoring stations to six. See Appendix 1 for the geographic location of each monitoring station.

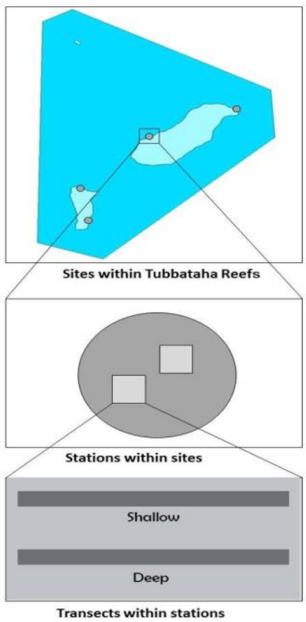


Figure 1. Hierarchical sampling design (Modified from Licuanan et al. 2016).

To better understand the state of the reefs at different depths, we assessed the shallow (~5 meters) and deep (~10 meters) sections in each station, except in Stations 5A and 5B where only shallow stations were established and surveyed due to the characteristics of the reef. Unlike the other sites, Site 5 is not located near the walls, therefore, establishing a permanent station in the deep area was not possible. Figure 1 shows the hierarchical sampling design employed in TRNP.

Since 2013, the two ship grounding sites, USS Guardian (USSG) and Min Ping Yu (MPY), have been monitored to account for changes over time.

Data collection

Each station had three (3) 50-meter replicate transects laid out in shallow (5m) and deep (10m) areas, each one separated by a 10-meter buffer. Each belt transect creates a 10 x 50-meter corridor by imagining a 5-meter width on each side. We further segmented the transect into 5-meter pauses along its length and surveyed each segment separately.

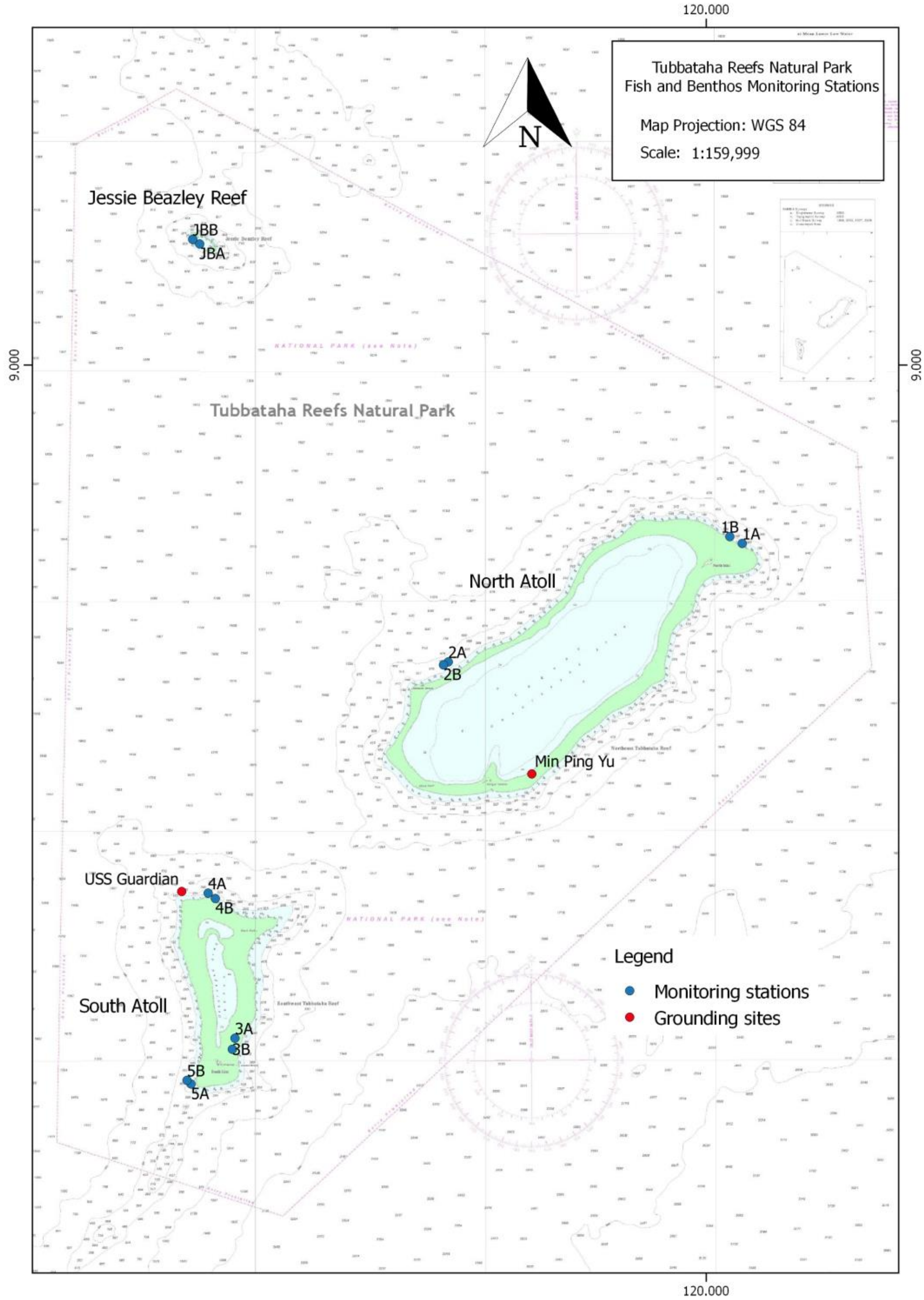


Figure 2. Location map of the fish and benthos monitoring stations.

The daytime Fish Visual Census (FVC), first described by English et al. (1997), was used to measure the fish community's biomass, density, and species richness. Sightings of species of interest off transect were also noted.

Data processing

Fish density was expressed as the number of individuals in an area (individuals per $500m^2$), whereas species richness is the actual number of species identified during the survey. We computed the biomass in grams per square meter (g/m^2) using the length and weight model (Kulbicki et al. 1993), following the formula:

$$W = axL^b$$

> *where W is the calculated weight (g), L is the approximated total length (cm), and a and b are length-weight relationship estimates taken from Fishbase (Froese and Pauly 2022; www.fishbase.org).*

Furthermore, we classified fish populations based on their associations with the reefs (demersal fish or fish that stay on the reef bottom, and pelagic fish or fish that prefer a deeper area of the reef) as well as their commercial and ecological worth (target, indicator, and major). In addition, fish species were classified based on their feeding habits and diet. Planktivores feed on suspended zooplankton, corallivores feed on coral polyps, herbivores consume algal matter, piscivores primarily consume fish but occasionally eat benthic invertebrates, mobile invertivores hunt for moving invertebrates, and omnivores consume both animal and plant matter, including sessile invertebrates.

Data analysis

We used RStudio (RStudio Team 2020) to perform a simple linear regression (LR) and one-factor analysis of variance (ANOVAR) to determine significant changes in biomass over time. The direction and rate of change of biomass estimates from 2013–2022 were determined using linear regression. ANOVAR was performed to see if biomass changed significantly between 2013 and 2022 at a $p<0.05$ level of significance. Site 5 was excluded from the statistical analysis because monitoring in the site only began in 2020 and only covered the shallow area. To determine if there is a significant difference ($p<0.05$) between the outputs for 2021 and 2022, a t-test was also performed. Graphs were visualized using Microsoft Excel 2016. The values of species richness, biomass, and density were then evaluated against national standards for reef fish (Nañola et al. 2004; Hilomen et al. 2004) (Appendix 2).

RESULTS

Present conditions – Regular monitoring sites

Species Diversity and Richness

A total of 312 species belonging to 36 families and subfamilies were recorded during this survey. With a mean species richness of 56.7 species/500m^2, fish diversity ranged from 51 to 60 species/500m^2. Station 3A was the most diverse station, while Jessie Beazley A was the least.

Mobile invertebrate feeders (135 sp) were the most prevalent group, composed mainly of wrasses (Labridae), damsels (Pomacentridae), and triggerfishes (Balistidae). Among the 59 species of herbivorous fish, parrotfish (Scaridae) and surgeonfish (Acanthuridae) species dominated. There were 30 species of omnivores, mostly damselfish and angelfish (Pomacanthidae) families (Pomacentridae). The planktivores group (21 sp) was predominantly composed of other damselfish species. Meanwhile, butterflyfish (Chaetodontidae) and angelfish (Pomacanthidae) made up the majority of the 18 species of corallivores. The presence of huge corallivores such as Titan triggerfish *Balistoides viridescens* and Bumphead parrotfish *Bolbometopon muricatum* were also noted. The piscivore group (17 sp) was primarily represented by jacks (Carangidae) and a few species of groupers (Serranidae).

Density

Across stations, an average of 1,281 individuals/500m^2 were recorded (Figure 3). Damselfish (Pomacentridae) and fairy basslets (Serranidae), which frequently congregate on the coral heads in reef flats and drop-offs, were the main contributors in all the sites. The majority of the damsels and anthias were found in Jessie Beazley. The lowest mean density recorded was at both stations of Sites 3 and 4 where comparatively fewer encounters with fish that form groups, e.g., damselfish, were recorded.

Given that the majority of the anthias found in this survey were in reef drop-offs, deep sites (1,464 individuals/500m^2) had a relatively greater density than shallow (1,313 individuals/m^2) sites. Numerous branching and tabular coral life forms in the shallow areas also support sizable schools of damselfishes and anthias.

The largest fish group, the major species, was primarily made up of damselfish and anthias. Major fish groups are fishes that are not commonly targeted in fishing and those that do not rely on corals for food (coral indicators). Target fish groups, which made up 14% of the total mean density, were primarily composed of surgeonfish/unicornfish (Acanthuridae), fusiliers (Caesionidae), and soldierfish (Holocentridae).

Planktivores, herbivores, and omnivores made up most of the reef assemblages in Tubbataha in terms of trophic groups (Figure 4). The most prevalent planktivores were fairy basslets and fusiliers (Pterocaesio), encountered the most in Site 3 and Jessie Beazley. These fish forage in the water column and near the reef drop-off, where currents bring in prey. Herbivorous fishes were also prevalent. These were Pomacentridae (*Chromis* sp and *Pomacentrus* sp), Acanthuridae, and Balistidae families. Corallivores, comprised of *Centropyge* species and *Chaetodon* sp., among others, were noted in all locations with an average occurrence of 27 individuals per 500m^2. In all monitoring sites, benthic carnivores were relatively rare, with an average of three (3) individuals per 500m^2. These were largely soldierfish *Myripristis* sp. (Holocentridae), which are common inhabitants of wall crevices in Tubbataha. They were most prevalent in the crevices in Jessie Beazley.

Demersal fishes, or those that prefer the bottom and dwell close to coral reefs, were higher in number compared to the pelagics. This year, prominent pelagic species included large (>30 cm) unicorn fishes (Nasinae) and schools of smaller fusiliers (Caesionidae).

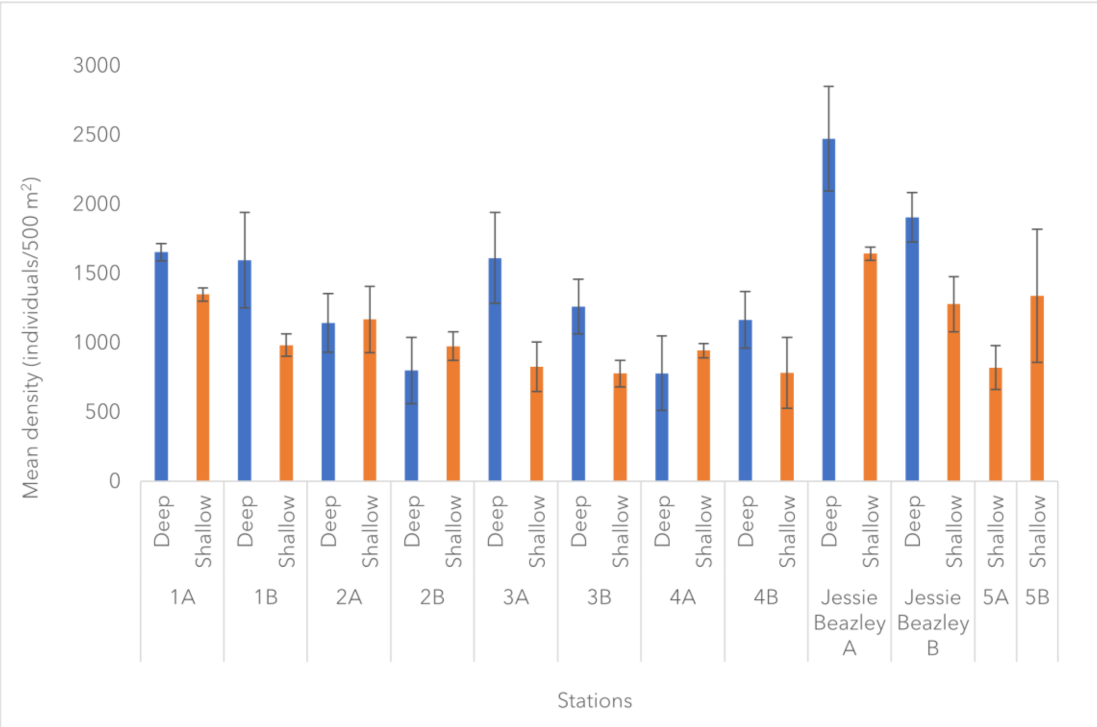


Figure 3. Mean density (ind/500m^2) of shallow and deep areas across stations in 2022. Note: Only shallow stations were established in Stations 5A and 5B. Vertical bars denote standard error of the mean.

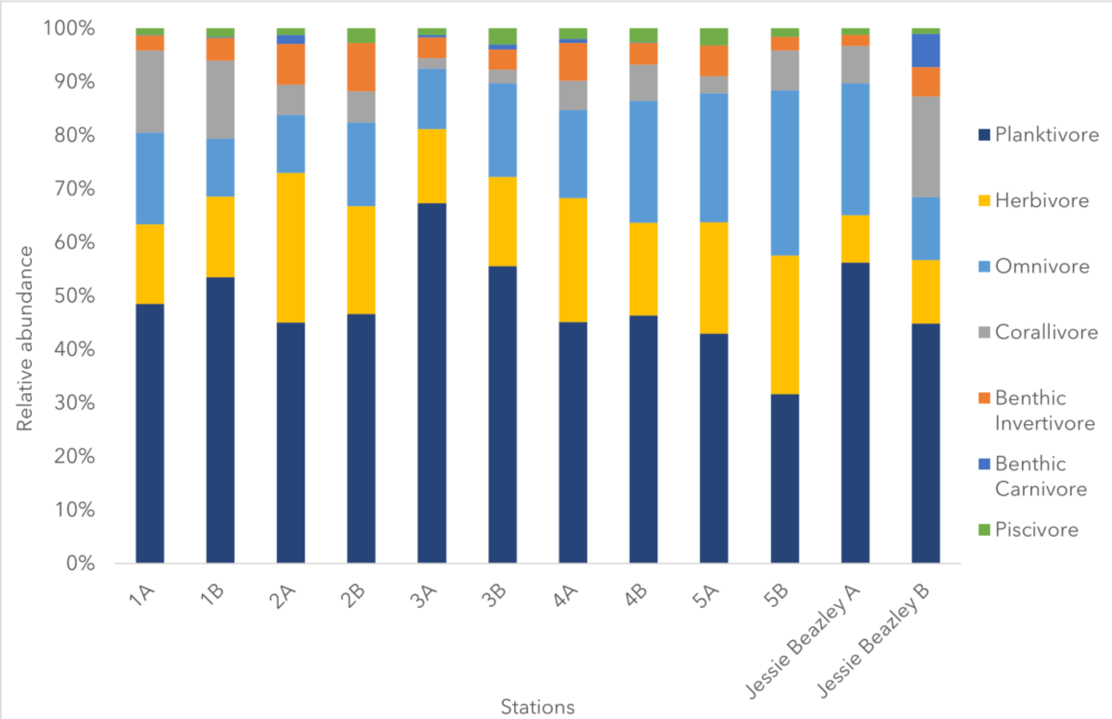


Figure 4. Relative percentage of fish abundance per trophic group across stations in 2022.

Biomass

This year, a mean biomass of 118 g/m^2 was recorded across all sites. This year's major contributors to the overall biomass were parrotfish (Scaridae), unicornfish (Nasinae), and triggerfish (Balistidae). The largest total mean biomass was recorded in Site 4, which was primarily contributed by large-size (>30 cm) parrotfishes (Scaridae), of which 21 were huge (80 cm) Bumphead parrotfish *Bolbometopon muricatum*. Despite having the highest fish abundance, Jessie Beazley A produced the least biomass compared to other stations (Figure 5).

This year, target fish groups accounted for 69% of the overall biomass. The main biomass contributors were parrotfish, triggerfish, unicornfish, and surgeonfish. Most of the population (21%) was composed of different types of fairy basslets, damselfish, and angelfish. Coral indicators were represented by the large (>40cm) Bumphead wrasses *Bolbometopon muricatum* and butterflyfishes (Chaetodontidae).

The difference in mean biomass between deep (110 g/m^2) and shallow (138 g/m^2) areas was not statistically significant. Biomass in the deep stations was mainly influenced by unicornfish and schooling fusiliers (Caesionidae), while Parrotfish and triggerfish had a substantial contribution to the biomass in shallow stations.

Although planktivores were more abundant, their biomass was mostly produced by large-bodied herbivores, piscivores, and omnivores (Figure 6). Herbivorous species were primarily parrotfish, unicornfish, and triggerfish. There are also piscivorous fishes, including groupers (Serranidae), snappers (Genus *Macolor* and *Lutjanus*), and jacks and trevallies (mainly Genus *Carangoides* and *Caranx*). Benthic carnivores, such as those of several soldierfish species and giant sweetlips (*Plectorhinchus albovittaus*), remained comparatively low throughout the stations.

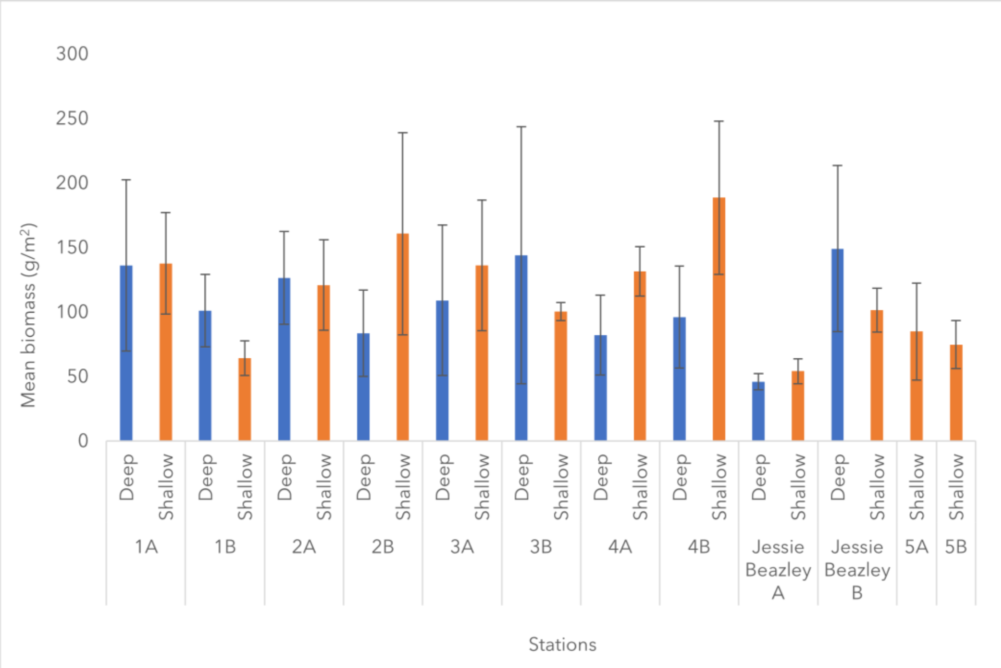


Figure 5. Mean biomass (g/m^2) in deep and shallow stations in TRNP in 2022. Note: Only shallow stations were established in Stations 5A and 5B. The vertical bars denote the standard

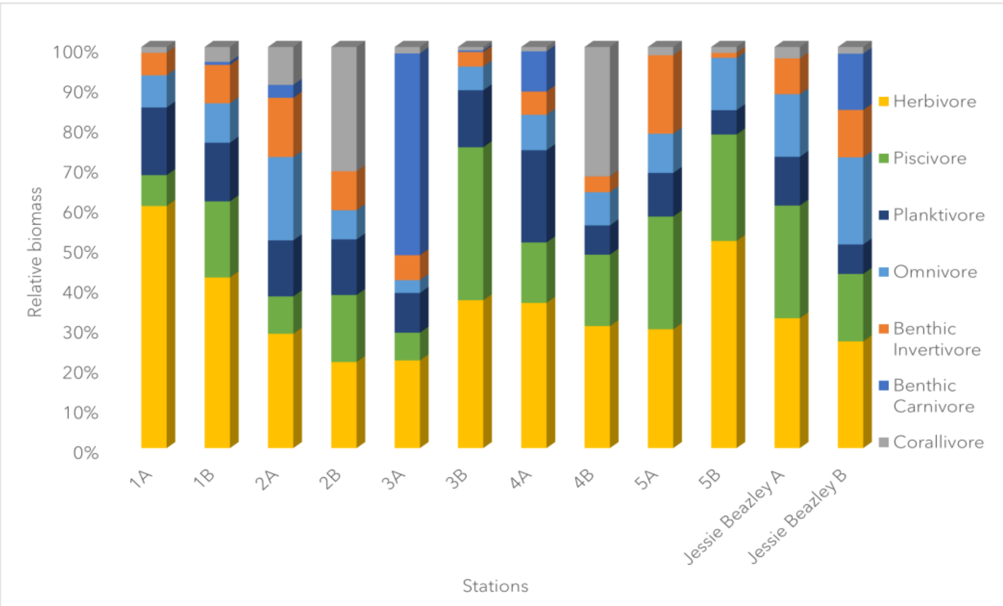


Figure 6. Relative distribution of biomass in terms of trophic groups across stations in both depths in 2022. Note: Only shallow stations were established in Stations 5A and 5B.

Temporal patterns

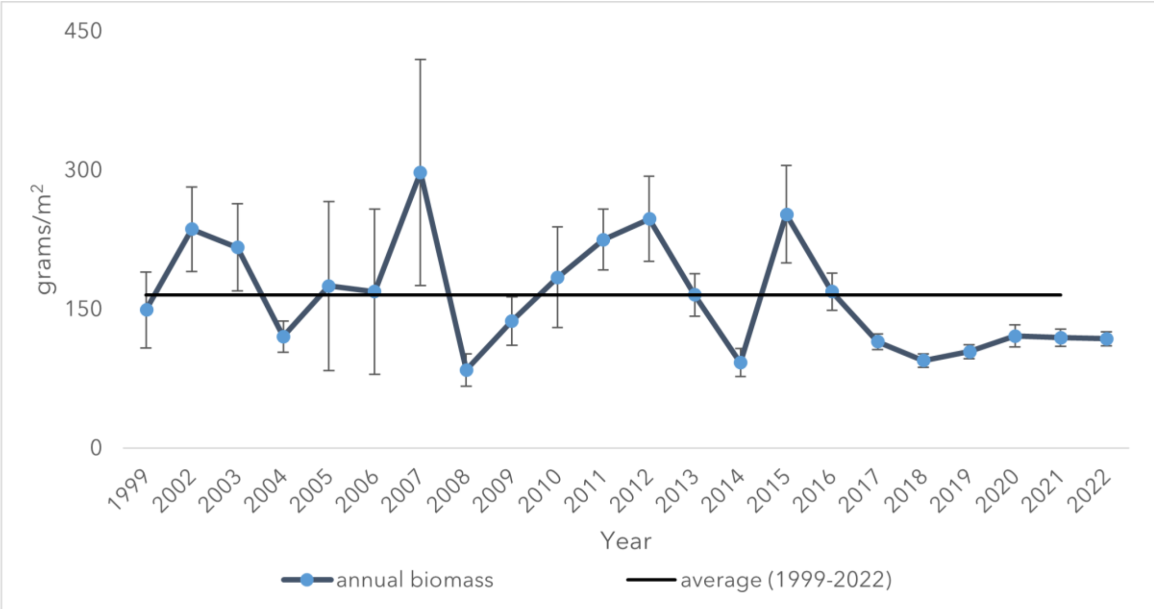
The annual biomass outputs are shown in Figure 7. It should be noted that sharks and schooling fish with more than 100 individuals were omitted because they would skew the data. This includes schools of large-bodied fishes such as unicornfish (Nasinae), fusiliers (Caesionidae), jacks and trevallies (Carangidae), and barracudas (Sphyraenidae). Offshore reefs like Tubbataha are frequently visited by schools of large, active pelagic fish. These fish groups were recorded in some years, substantially influencing the biomass outputs and causing fluctuations in the data.

The biomass estimates for 2004, 2008, and 2014 were among the lowest ever recorded and a consistently decreasing trend was recorded from 2016 to 2022 (Figure 7).

Separate biomass results for shallow transects and deep transects also show that the outputs from deep transects were noticeably higher than those from shallow ones (Figure 7). The fluctuating trend observed in overall mean biomass is also more prominent in deep stations than in the shallow.

For statistical analysis, we excluded the school of 60 Bumphead Parrotfish *Bolbometopon muricatum,* which was only recorded in 2015 and had an estimated length of 110 cm. This sighting contributed to the increase in biomass output in 2015. Site 5 was also not included in the analysis due to the incomparable data which was only collected in the shallow areas for one year.

From the years 2013 to 2022, the mean biomass of the fish population at the deep stations in Tubbataha decreased by -1.06% a year (Table 1). The rate of decline for the pelagic and demersal fish groups since 2013 was -2.29% and -0.33%, respectively. The biomass outputs at the four stations likewise dramatically decreased (Table 1) over the years. Sites 1 (-0.73%), 2 (-0.37%), 3 (-0.49%), 4 (-0.84%), and Jessie Beazley (-0.47) showed annual declines since 2013 at the site level. The yearly rate of significant decline varied per station: Station 4A had the highest annual decline of -1.1%, followed by Station 1A at -0.96%. Station 2A had an annual decrease of -0.54%, and in Stations 1B and Jessie Beazley A at -0.49% (Table 1).



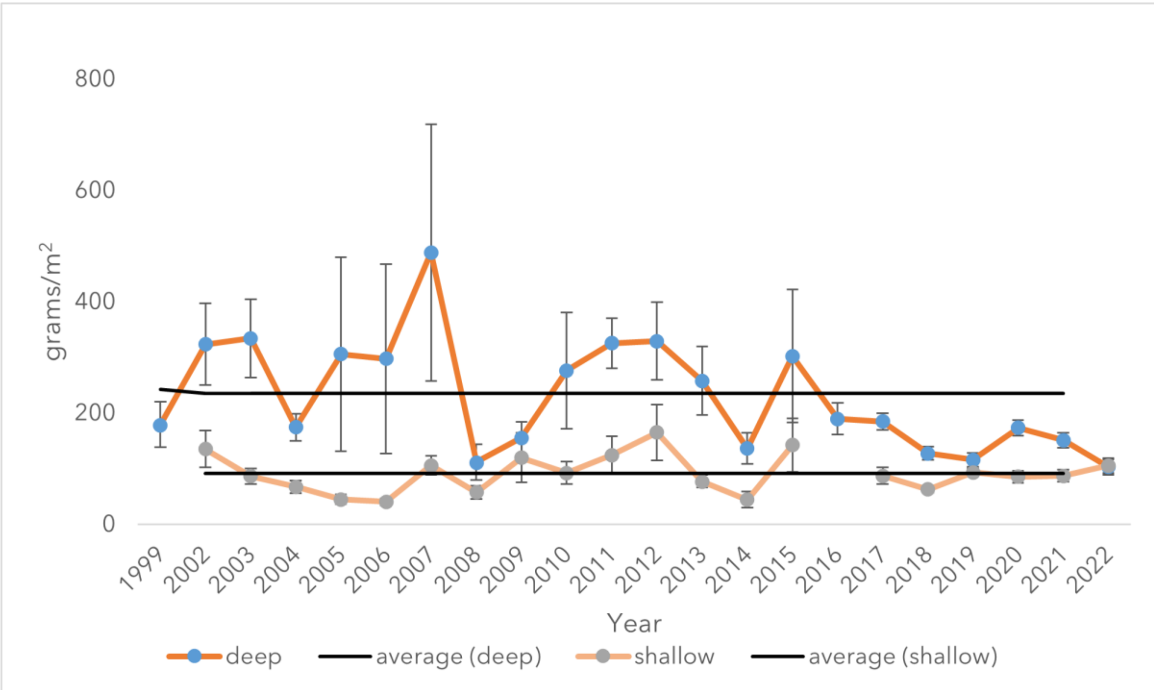


Figure 7. Yearly mean fish biomass of TRNP in grams per square meter (top) and annual distribution per depth (below). Vertical bars denote standard error of the mean.

Table 1. Summary of linear regression and analysis of variance results in the regular monitoring sites. Statistically significant (p<0.05) rates of change are highlighted in red. ns = not significant (p > 0.05).

	Rate of change in mean biomass (Linear Regression)	Difference Among Years in Mean Biomass (ANOVAR)
	2013-2022	2013-2022
SITE Level		
Site 1	-0.7	ns
Site 2	-0.4	0.05
Site 3	-0.5	0.05
Site 4	-0.8	0.001
Jessie Beazley	-0.5	ns
STATION Level		
Station 1A	-0.9	ns
Station 1B	-0.5	ns
Station 2A	-0.5	ns
Station 2B	-0.2	ns
Station 3A	-0.4	ns
Station 3B	-0.5	ns
Station 4A	-1.1	0.001
Station 4B	-0.6	ns
Jessie Beazley A	-0.5	ns
Jessie Beazley B	-0.5	ns
NATURE		
Demersal	-0.3	0.001
Pelagic	-2.3	0.001
DEPTH		
Deep	-1.1	0.001
Shallow	0.0	ns

Ship Grounding Sites

USS Guardian

This year, we identified 134 species of fish belonging to 21 families and subfamilies at the USSG grounding site. The mean abundance was 1,224 individuals/500m^2, resulting to mean biomass of 97.60 g/m^2. Planktivores, such as anthias (*Pseudanthias* sp.), damsels (mainly of *Chromis* sp.), and wrasse (Genus *Thalassoma*), were the most prevalent group, similar to the monitoring stations. The USSG grounding site had a shallow reef flat with a depth of 5 to 6 meters at the reef edge, followed by a sharp drop-off. Fish groups that feed on plankton were common along the drop-off.

Herbivores, which included some *Chromis* sp. and triggerfish *Melichthys* sp., dominated the site. Corallivores, such as angelfish of the genus *Centropyge* sp. and butterflyfish of the genus *Chaetodon* sp., which are indicators of coral health, were also seen at the site.

Surgeonfish, triggerfish, and parrotfish comprise most of the biomass (Figure 8). The biomass was primarily composed of benthic invertebrates, mainly the squirrelfish (Holocentridae) and red-toothed triggerfish (*Odonus niger*). The biomass was also significantly influenced by herbivores, such as some parrotfish and triggerfish species. Apart from a few unicornfish *Naso* sp. and Bluefin trevally (*Caranx melampygus*), almost all the species found were demersal fish.

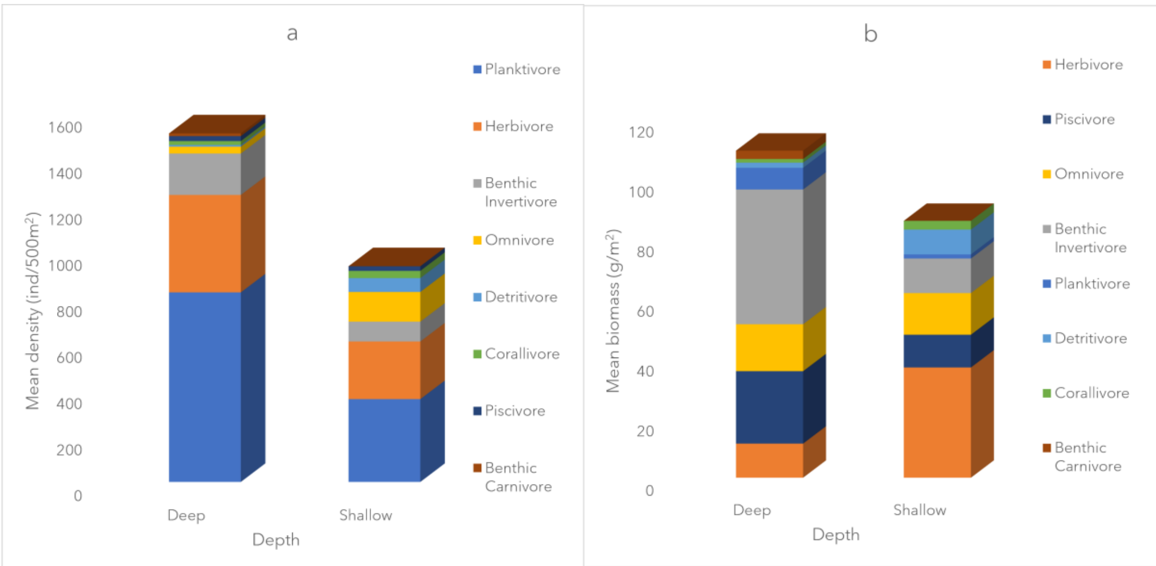


Figure 8. Mean density (a) and biomass (b) in the USS Guardian grounding site classified according to trophic levels.

Min Ping Yu

Min Ping Yu grounding site had 144 species that belong to 26 families and subfamilies, with mean species richness of 55 species/500m^2. The average biomass for this year was 52 g/m^2 and the mean density was 1,315 individuals/500 m^2.

The most prevalent fish species were damselfish, surgeonfish, and anthias. In the deeper, sloping area next to the shallow area (impact area) of MPY, damsels and anthias were seen congregating. Planktivorous damsels and anthias favored the deeper portion, but omnivore damsels were more prevalent in shallow areas (Figure 9). Small, herbivorous surgeonfish were also numerous and were seen aggregating in the shallow area. The impact area in MPY is characterized by small patches of corals, sand, and rubble, which are favored by surgeonfish as they feed on filamentous algae and detritus (Nguyen and Nguyen 2006; Domeier and Colin 1997). Surgeonfish and damselfish were also the major sources of fish biomass at the MPY grounding site. Benthic invertebrates like wrasses (Labridae) and goatfishes (Mullidae) flourished in shallow waters and were observed to forage on sand and debris. Big pelagic fish like unicornfish and fusiliers also influenced the biomass.

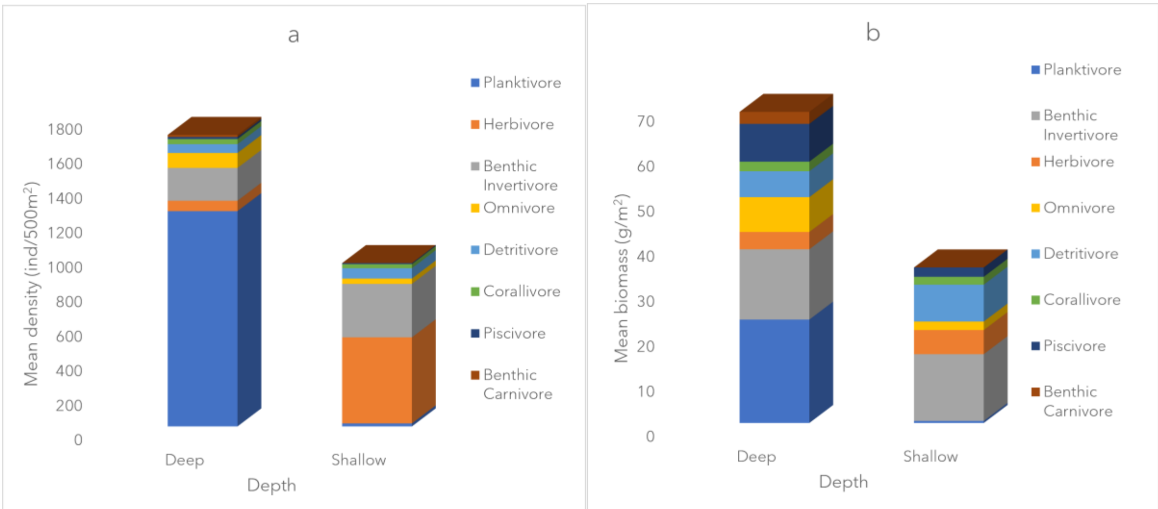


Figure 9. Mean density (a) and biomass (b) in the Min Ping Yu grounding site classified according to trophic levels.

Temporal patterns

The only consistent available data since the start of the monitoring in 2014 was in the adjacent deeper portion of the impact site of each grounding site. For the USS Guardian, the adjacent site was the immediate ~10m depth located in the drop-off. Meanwhile, MPY is characterized by gently sloping terrain before a drop-off; hence the ~10m adjacent site is situated 50 meters away from the impact site. For the purpose of analysis, we used the data from the adjacent site of the impact area as proxies for the grounding areas.

Despite the fluctuating trend in biomass and density values over the years, the two grounding sites did not show a significant decline in average biomass and density yield over the years (Figure 10).

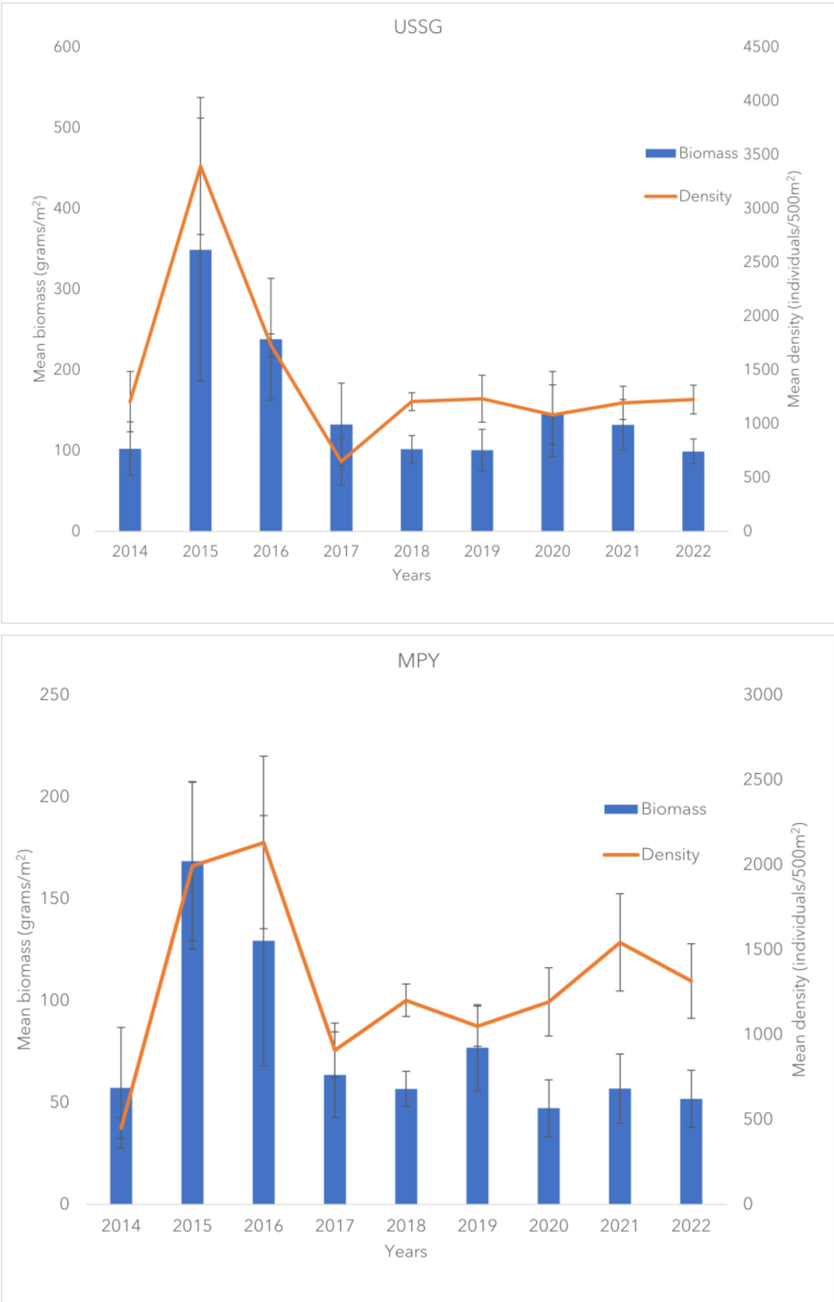


Figure 10. Temporal pattern of mean density (ind/500m^2) and biomass (g/m^2) in the USS Guardian and Min Ping Yu grounding sites. Vertical bars denote the standard error of the mean.

DISCUSSIONS

Present condition

This year's mean biomass (118 g/m^2) was almost similar to the 2021 estimate (119 g/m^2). Unicornfish was the predominant species in 2021, and large parrotfish (Scaridae) were more frequently encountered this year. Additionally, the mean density from 2021 (1,512 ind/500m^2) decreased slightly, most likely influenced by the substantial decrease in anthias (Anthiinae) and wrasse counts (Labridae).

Site 1 and Jessie Beazley both had lower biomass than the previous year. The decrease was caused by fewer encounters of pelagic species in Site 1, including barracuda (Sphyraenidae), fusiliers (Caesionidae), jacks and trevallies (Carangidae). The shallow area of the reefs is rarely visited by pelagic species, that favor relatively deeper areas. However, they cause a massive increase in the total mean biomass when encountered. Despite the decline in Site 1, larger reef-associated fish, including triggerfish and parrotfish, had higher biomass this year.

The main factor that contributed to the decline in mean biomass in Jessie Beazley was the fewer encounters with unicornfish (Nasinae), damselfish, and triggerfish. The decrease in damselfish (Pomacentridae) was more prominent in Jessie Beazley A. Foliose *Montipora* corals dominated the shallow area of Jessie Beazley A, where damsels were observed to aggregate in hundreds. Typhoon Odette in December 2021 caused significant damage to most of the foliose corals in the station and fewer damsels and triggerfish were observed in the area this year.

Figure 11. Among the catch of the apprehended vessel in October 2021 were Humphead wrasse, Red-toothed triggerfish, and several other demersal fish.

Jessie Beazley is located 12nm from the ranger station, thus, patrols in the area are less frequent due to rough sea conditions during most of the year. This makes it more vulnerable to illegal fishing activities than other monitoring sites in TRNP. The manager of the dive boats Discovery Palawan and Solitude reported the presence of suspicious vessels in the area during the diving season, but these fishing boats leave Jessie Beazley at the approach of other vessels.

Marine park rangers apprehended a fishing vessel carrying explosives for dynamite fishing in October 2021. Although they were caught before they could dynamite fish on that day, they are suspected of being responsible for the triggerfishes that the rangers found dead in the reef a week earlier. This suggests that the five (5) fish tubs (180-200kgs) of triggerfishes found onboard the vessel, along with other reef fish (Figure 11), were from the park. Illegal taking of fish in Jessie Beazley may have contributed to the decrease in biomass this year.

Sites 2 and 4 displayed higher fish biomass values than last year due to more encounters with surgeonfish, triggerfish, and parrotfish. Site 4 increased by 21%, with Station 4B having the most notable improvement (27%). Site 2 increased by 11%, while Site 3 slightly decreased by 0.08% compared to the 2021 biomass output.

The biomass and density values between 2021 and this year had no significant difference (t-test, $p>0.05$). The outputs for biomass, mean density and species richness were significantly higher than the established "healthy" values for reef fish in the Philippines (Nañola et al. 2004, Hilomen et al. 2000) for biomass (>40 g/m^2), mean density (>1,113 ind/500m^2), and species richness (>50 sp/500m^2) (Appendix 2).

Temporal patterns

The significant decline in biomass of fusiliers, parrotfish, jacks, trevallies and unicornfish mainly influenced the decline in fish biomass in the deep stations. The biomass of fusiliers (Caesionidae) declined at a rate of - 8.18% every year (LR $p<0.001$, ANOVAR $p<0.001$), parrotfish (Scaridae) at -3.29% (LR $p<0.001$, ANOVAR $p<0.001$), jacks and trevallies at -2.74% (LR $p<0.001$, ANOVAR $p<0.05$), and unicornfish (Nasinae) at -1.8% per year (LR and ANOVAR $p<0.05$) since 2013.

In shallow stations, the biomass of jacks and trevallies showed a significant annual decrease of -2.3% (Carangidae) (LR and ANOVA $p<0.05$). Along with parrotfish and unicornfish, this family was one of the significant contributors to fish biomass in shallow waters. In contrast to the deep stations, parrotfish (Scaridae) and unicornfish (Nasinae) biomass increased significantly in the shallow stations with yearly rates of 1.49% (LR and ANOVA $p<0.05$) and 1.11% (LR and ANOVA $p<0.05$), respectively.

All sites exhibited a significant decline in biomass from 2013-2022 (Table 1). The overall decline is generally influenced by the decrease in the biomass of the fish groups mentioned above.

Pelagic fish also appeared to be declining at a rate of -2.29% per year. Fusiliers, unicornfish, jacks, and trevallies, are larger fishes that often prefer the deeper part of the reef and rarely visit shallower areas. They commonly aggregate for efficient hunting and protection against predators (Ritz et al. 2011), and because their presence is unpredictable in the wild (Kaundra-Arara and Rose 2004), they cause variability in the data when recorded in the transect.

Overfishing is the primary reason for the global drop in fisheries production. It affects over 70% of the Philippine fishing grounds, according to USAID FishRight Project (2019). However, Tubbataha is a protected area where fishing is prohibited. In the last ten years, only three (3) illegal fishing incidents (in 2013, 2015, and 2021) were recorded in TRNP. Nevertheless, undetected illegal fishing activities might be occurring inside the park and contributing to the decline in the fish populations.

The absence of fish in the reef may also be one source of the decline in TRNP. The presence or absence of fish is frequently linked to factors affecting their movements, such as predator avoidance and food source (Helfman et al. 2009). Large migration patterns related to spawning season, availability of food, and mortality risks may also occur (Bone and Moore 2008). For instance, fishes are involved in diel vertical migration, one of the largest and most common synchronized migrations in terms of biomass. During this migration, fish spend daylight in the deeper portions of the reefs (e.g., up to 150 meters for jacks and trevallies) and ascend to the surface at night to feed (Helfman 1986).

Fish could also move with the tides to take advantage of current-driven food, safety, or reproductive transport (Gibson 1992; Gibson 2003; Choat and Robertson 1975). The lunar cycle could also affect the behavioral movements of some reef fish (Takemura et al. 2004; Johannes 1978; Lobel 1978). Since the survey time was regardless of tidal state or moon phase, these factors might have also affected the biomass outputs in Tubbataha.

Fish are also known to escape the warm surface by migrating to deeper waters where the temperature is colder (Currey et al. 2015). According to Currey et al. (2015) and Thompson et al. (2022), the ongoing rise in ocean temperature may drive fish species to migrate from shallow water (where warming would be greatest) to deeper water. This could also be a contributing factor to the decline in biomass since schooling fish (e.g., jacks and trevallies, snappers) were noted in the area, but beyond the depth (>10m) that we monitor.

A considerably bigger seasonal migration, illustrated in oscillatory movement, may also occur (Bone and Moore 2008; Dahlgren and Egglestone 2000; Sale 2002; Sale 1978) in Tubbataha. This migration, along with other factors cited above, may be influencing the declining yearly biomass estimates of the park. Another cause of variations in the yearly mean reef fish biomass in Tubbataha is observer bias in size and count estimates, as seen by the comparatively high standard error bars in Figure 7 in some years.

Grounding sites

The mean biomass at the USS Guardian was lower this year (97.60 g/m^2) than in 2021 (132 g/m^2), but the difference was not statistically significant (t-test, $p>0.05$). The biomass was slightly lower despite the mean density being identical to the value in 2021 because there were fewer encounters with large-bodied pelagic species, mainly jacks and trevallies (Carangidae), and unicornfish (Nasinae). Large demersal fishes had nearly the same mean biomass as last year.

The biomass estimate in the Min Ping Yu site (52 g/m^2) was almost similar to 2021 (54 g/m^2), with no notable decreases except for the jacks and trevallies (Carangidae). In contrast, the biomass outputs of surgeon and unicornfish (Acanthuridae) and fusiliers (Caesionidae) increased from last year.

It is especially significant to note the presence of fishes that consume algal mat in coral areas that suffered damage (Green and Belwood 2009), such as these grounding sites. The density and biomass estimates of herbivorous fishes of different functional groups steadily increased over time in the USS Guardian (density +0.66%; biomass +0.07 %) and the Min Ping Yu (density +2.41%; biomass +0.19%) grounding sites. Among them were large-bodied species of parrotfish (*Bolbometopon muricatum*, *Scarus* sp. and

Chlorurus sp.), unicornfish *Naso* sp., and rabbitfish *Siganus* sp. The presence of this group may have contributed to the improvements in coral recruits (see Chapter 3) and hard coral cover (see Chapter 2) in these sites over the years.

According to the values established by Hilomen et al. (2000) and Nañola et al. (2004), the biomass and density output in the grounding sites over the years were above the minimum standard for healthy reef fish communities. One of the factors in the recovery of the damaged area may be the "healthy" areas surrounding the grounding sites, which could seed the damaged areas.

OTHER OBSERVATIONS

We also noted species of interest outside the transects. A total of 17 individuals of various sizes (up to 110cm) of Humphead wrasse *Cheilinus undulatus* were observed throughout the survey in all sites. Green sea turtles *Chelonia mydas* were noted in all sites, except in Site 2, and Hawksbill turtles *Eretmochelys imbricata* were noted in Site 4 (2 individuals). Schools (in hundreds) of individual big-eye trevallies *Caranx sexfasciatus* were also recorded in Sites 1 and 2. Meanwhile, a school (>300 ind) of Humpback red snapper *Lutjanus gibbus* was noted in Site 3. Bumphead wrasses *Bolbometopon muricatum,* some in schools, were noted in Sites 2, 4, and 5. There were schools with 85 individuals noted in Station 2B and 17 individuals in Station 5B. Blacktip reef sharks *Carcharhinus melapterus* were recorded in Site 1.

CONCLUSION

Tubbataha's biomass output is declining particularly in the deep stations, which may be influenced by feeding and spawning patterns and observer biases. Biomass at the shallow sites' remained stable, with a notable increase in some fish groups. The grounding sites are also showing declines. Protected species and schooling large-bodied fish groups were still observed in the park, which is an indication of the positive impacts of a strictly enforced protected area. Despite the significant declines, Tubbataha estimates still far exceed the set minimum yields for protected areas in the country.

Park authorities have no control over the natural factors that may influence the decline as cited above. However, stringent enforcement must be continued and strengthened to ensure that no anthropogenic activities within the park would further the deterioration of the biomass of reef-associated fish and the habitat they live in.

RECOMMENDATIONS

1. Maintain standardization of assessment methods in the conduct of the fish visual census among the observers to prevent observer bias.
2. Investigate causes of decreasing fish biomass, e.g., seasonality, fishing inside park boundaries, etc.

REFERENCES

Johannes RE (1978) Reproductive strategies of coastal marine fishes in the tropics. Environ Biol Fish 3:65–84. https://doi. org/10.1007/BF00006309

Lobel, Phillip. (1978). Diel, Lunar, and Seasonal Periodicity in the Reproductive Behavior of the Pomacanthid Fish, Centropyge potteri, and Some Other Reef Fishes in Hawaii. Pac. Sci.. 32.

Takemura, A., Rahman, M.S., Nakamura, S., Park, Y., Takano, K. (2004) Lunar cycles and reproductive activity in reef fishes with particular attention to rabbitfishes. 5(4) 317-328. DOI: 10.1111/j.1467-2679.2004.00164.x

Bone, Q. and R.H. Moore.(2008). Biology of Fishes. 3rd edition. Taylor and Francis Group. ISBN 0-203- 88522-8.

Campos, W. and Belida, P. (2008) Ichthyoplankton Assemblages in Atolls Along Cagayan Ridge, Sulu. Sea, Philippines. 11th International Coral Reef Symposium;

Currey, Leanne M., Heupel, Michelle R., Simpfendorfer, Colin A., Williams, Ashley J.. Assessing environmental correlates of fish movement on a coral reef. Coral Reefs, 2015; DOI: 10.1007/s00338-015-1318-7

Dantis, A., Nañola, C., Castrence, F., Cabansag, J., Valles, D., Rañola, C., Campos, W., Hilomen, V., Hernandez, H. & Aliño, P. Distribution patterns and community structure of fishes in some offshore and shelf reefs of the Philippines. Proceedings of the symposium on marine biodiversity in the Visayas and Mindanao. University of the Philippines, Visayas, 1999. 86-93.

David A. Ritz, Alistair J. Hobday, John C. Montgomery, Ashley J.W. Ward, Chapter Four - Social Aggregation in the Pelagic Zone with Special Reference to Fish and Invertebrates, Editor(s): Michael Lesser, Advances in Marine Biology, Academic Press, Volume 60, 2011, Pages 161-227, ISSN 0065-2881, ISBN 9780123855299, https://doi.org/10.1016/B978-0-12-385529-9.00004-4.

Domeier, M.L. and P.L. Colin, 1997. Tropical reef fish spawning and aggregations: defined and reviewed. Bull. Mar. Sci. 60(3):698-726.

English, S., Wilkinson, C., and Baker, V. (1997) Survey Manual for Tropical Marine Resources, ASEAN-Australia Marine Science Project: Living Coastal Resources. Townsville: Australian Institute of Marine Science.

Froese, R., and Pauly, D. (2021) Fishbase. World Wide Web electronic publication.: http://fishbase.org.

Gibson, R. N., 1992. Tidally-synchronised behavior in marine fishes. In Ali, M.A. (ed.), Rhythms in Fishes. Plenum Press, New York: 63–81.

Gibson, R.N. (2003). Go with the flow: tidal migration in marine animals. In: Jones, M.B., Ingólfsson, A., Ólafsson, E., Helgason, G.V., Gunnarsson, K., Svavarsson, J. (eds)

Migrations and Dispersal of Marine Organisms. Developments in Hydrobiology, vol 174. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-2276-6_17

Green AL and DR Bellwood. 2009. Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience – A practical guide for coral reef managers in the Asia Pacific region. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland.

Hilomen, V.V, C.L. Nañola and A.L. Dantis, 2000. Status of Philippine reef fish communities. In Licuanan, W.Y. and E.D. Gomez. 2000. Philippine Coral Reefs, Reef Fishes and Associated Fisheries: Status and Recommendations to Improve Their Management. GCRMN Report. Appendix B.

Kulbicki, M., Mou Tham, G., Thollot, P. & Wantiez, L. 1993. Length-weight relationships of fish from the lagoon of New Caledonia. *Naga, the ICLARM Quarterly,* 16, 26-30.

Nguyen, N.T. and V.Q. Nguyen, 2006. Biodiversity and living resources of the coral reef fishes in Vietnam marine waters. Science and Technology Publishing House, Hanoi.

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sale, P. F. 2002. Coral reef fishes: dynamics and diversity in a complex ecosystem, Academic Press.

Thompson, P. L., Nephin, J., Davies, S. C., Park, A. E., Lyons, D. A., Rooper, C. N., Peña, M. A., Christian, J. R., Hunter, K. L., Rubidge, E., & Holdsworth, A. M. (2022). Groundfish biodiversity change in northeastern Pacific waters under projected warming and deoxygenation. BioRxiv, 2022.05.04.490690. https://doi.org/10.1101/2022.05.04.490690

CHAPTER II. REEF BENTHOS

Giannina Nicole Feliciano[1], Rhiana Angelita Parr[1], Maria Michelle Cadiz[1], Maria Retchie Alaba[2], Jeffrey David[2], Noel Bundal[2] and Wilfredo Licuanan[1]

[1] Br. Alfred Shields FSC Ocean Research Center,

De La Salle University, Manila

[2] Tubbataha Management Office, Puerto Princesa City

OVERVIEW

Spanning 970 km^2 in area, the Tubbataha Reefs Natural Park (TRNP) is the largest no-take marine protected area (MPA) in the Philippines (Dygico et al. 2013). Protected under national law and declared a UNESCO World Heritage Site, the TRNP is also the best-managed MPA in the country (ADB 2014). TRNP is a foremost dive tourism destination globally because of its rich marine biodiversity (Dygico et al. 2013). The coral reefs of TRNP have also been used as a benchmark for relatively pristine reefs in the country (Licuanan et al. 2017).

Coral reefs provide refugia for millions of marine species, income from tourism and recreation, and are important indicators of ecosystem health (IUCN 2017). Regular monitoring of the coral reefs in Tubbataha is integral to its management. The reefs of TRNP are therefore well-studied, with long-term data sets of reef benthic cover and composition collected and analyzed over the past 20 years.

While hard coral cover (HCC) in TRNP remained stable from 2012 to 2015 (Licuanan et al. 2017), monitoring from more recent years revealed that some reefs are experiencing statistically significant declines in HCC and increases in non-coral benthos such as sponges, turf algae, and cyanobacteria (Licuanan and Bahinting 2021). The continuation of monitoring efforts in the coral reefs of TRNP is essential to detecting changes and diagnosing drivers of change, as this will improve management response and ensure that the reefs continue to thrive. This report presents the status of the coral reefs of TRNP and the spatio-temporal patterns of reef benthos in the park since 2012.

METHODS

Data collection

Surveys on the shallow areas were performed on 75m x 25m regular monitoring stations on the upper reef slope, at a depth range of 2 to 6 meters, following the hierarchical sampling scheme described in van Woesik et al. (2009). Twelve regular monitoring stations were surveyed this year, ten of which were monitored annually since 2012, one station monitored since 2021 (Station 5A), and a new station established and surveyed this year (Station 5B). However, the deep areas were not surveyed in Stations 5A and 5B because the deeper portion (10 meters) of the reef was too far from the shallow areas, which made it logistically difficult.

Reef benthos in the shallow areas of each monitoring station were sampled using the methods detailed in Luzon et al. (2019). The deepest limit of each station was demarcated by a 75-m belt transect (transect 1) following the reef's contour. Randomized x,y-coordinates (in meters) were used to deploy four 50-m transects (transects 2 to 5) at least 1-m apart from the preceding transect and parallel to one another. The same randomization was used to identify the starting point for photographs in transect 1. The benthos was sampled by taking photographs at 1-m intervals along the shallow side of each transect using Canon G7 X cameras, in underwater housings, mounted on 1-m x 1-m aluminum monopods. A total of 250 transect photographs were processed from each monitoring station. Additional photos of the reef, coral colonies, non-coral benthos, and abiotic substrates were taken to aid in the description and documentation of the monitoring stations.

Reef benthos in deep areas of the monitoring stations were also sampled by deploying four 20-meter transects, 5 meters apart from each other, along the same depth of 10-m. Photographs were taken at 1-m intervals on the shallower side of each transect using the same camera-monopod set-up. A total of 80 images were processed from the deep area of each monitoring station.

Two ship grounding sites have been monitored annually since 2014, after two separate grounding incidents (i.e., USS Guardian naval ship in the South Atoll and Min Ping Yu fishing vessel in the North Atoll) occurred in 2013. Three fixed 4-m x 4-m quadrats were established in each ship grounding site in areas directly impacted by the ship grounding and adjacent control areas that were not directly affected. These quadrats were photographed using the same camera-monopod set-up. Each quadrat was photographed entirely, with images having at least 50% overlap with one another. Of the ≥90 images per quadrat, 30 images were randomly selected for processing and analysis.

Data processing

Transect and quadrat images were processed using Coral Point Count with Excel extensions (CPCe) 4.1 (Kohler and Gill 2006). Ten random points were overlaid on each image, and the benthos beneath each point was identified and scored into one of six reef bottom types: hard coral (HC), algal assemblage (i.e., recently dead coral or carbonate rock overlain with thin layers of turf algae or coralline algae; AA), abiotic material (i.e., sand, silt, or rubble; AB), macroalgae (MA), *Halimeda* (HA), and other biota (OB). Hard corals were further classified into 59 hard coral Taxonomic Amalgamation Units (TAUs), which consist of genus-growth form combinations that are optimized for the resolution of transect images. Percent cover of benthos was recorded, and coral TAU density (i.e., the average number of hard coral TAUs recorded in each station; referred to as "coral generic diversity" in Licuanan et al. 2019) was computed.

Data analysis

Hard coral cover (HCC) and coral TAU density categories (see Licuanan et al. 2019; Table 2) were identified at the station, site, atoll, and location level. Simple linear regression (LR) and one-way repeated measures analysis of variance (ANOVAR) were performed to identify significant changes in benthic cover over time. LR was also used to determine the direction and rate of change (i.e., slope) of HC, AA, and sponge (SP) cover from 2012 to 2022. ANOVAR was used to identify significant differences in HCC among the 2012 to 2022 monitoring periods. RStudio (RStudio Team 2020) and PAST 3.26 (Hammer et al. 2001) were used to perform statistical analyses. The data were visualized using RStudio (RStudio Team 2020) and QGIS (QGIS.org 2022).

Table 2. Hard coral cover and TAU density (referred to as "coral generic diversity") categories in Licuanan et al. (2019).

Category	Average hard coral cover (%)	TAU density (Average number of hard coral TAUs)
Category A	> 44	> 26
Category B	> 33 to 44	> 22 to 26
Category C	> 22 to 33	> 18 to 22
Category D	0 to 22	0 to 18

RESULTS

Present conditions

Shallow areas

At the location level, the reefs of Tubbataha (Sites 1 to 4), had an average HCC of 26.8% ± 1.9 SE, and a TAU density of 19.8 TAUs ± 0.8 SE (Table 3) in 2022. The HCC value is less than the average HCC (28.4% ± 2.4 SE) and similar to the average TAU density (20.8 ± 0.9 SE) reported for fringing reefs in the Sulu Sea bioregion (Licuanan et al., 2019).

At the atoll level, the North Atoll (Sites 1 and 2) had higher HCC and more TAUs compared to the South Atoll (Sites 3 and 4) (Table 3). At the site level, Site 5 and Jessie Beazley had the highest HCC, and both sites qualified as Category B reefs in terms of HCC. Site 5 had higher HCC (40.4% ± 1.9 SE) and higher TAU density (22.6 TAUs ± 1.3 SE) compared to the rest of the Tubbataha Reefs (Table 3). Site Jessie Beazley also had higher HCC (33.4% ± 3.4 SE) compared to the rest of the Tubbataha Reefs, but a lower TAU density (17.4 TAUs ± 2.6 SE) (Table 3). At the station level (Figure 12), Station 1B was the only one to qualify as Category A in 2022 based on HCC (44.8% ± 0.5 SE). Station 1B also had the highest TAU density (25 TAUs ± 1.0 SE), thus belonging to TAU density Category B. Compared to 2021, both Station 1A and Station 1B improved in both HCC and TAU density.

Station 1A moved from Category D to Category C in terms of HCC, and from Category C to Category B in terms of TAU density. Station 1B moved from Category B to Category A in terms of HCC but remained in Category B in terms of TAU density.

Table 3. Summary table for hard coral over (HCC), TAU density, rates of change in HCC, and differences in HCC among years in the shallow areas. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated. ns = not significant (p>0.05).

	Average % HCC (± SE) 2022		Average TAU Density (± SE) 2022		Rate of Change in HCC (Linear Regression) 2012-2022	Difference Among Years in HCC (ANOVAR; p<0.05 is significant) 2012-2022
	% HCC	Category	TAU Density	Category		
TUBBATAHA (without JB, Site 5)	26.8 ± 1.9	C	19.8 ± 0.8	C	⬇ (-0.9%)	p < 0.0001
ATOLL level						
North Atoll	29.0 ± 2.6	C	21 ± 0.9	C	ns	p < 0.0001
South Atoll (without Site 5)	24.7 ± 2.7	C	18.7 ± 1.3	C	⬇ (-1.9%)	p < 0.0001
SITE level						
Site 1	34.1 ± 3.7	C	23.6 ± 0.8	B	ns	p < 0.01
Site 2	23.8 ± 3.1	C	18.4 ± 1.2	C	⬆ (+0.7%)	p < 0.0001
Site 3	23.1 ± 4.7	C	16.1 ± 2.3	D	⬇ (-3.4%)	p < 0.0001
Site 4	26.3 ± 2.9	C	21.2 ± 0.8	C	ns	ns
Site 5	40.4 ± 1.9	B	22.6 ± 1.3	B	N/A	N/A
Jessie Beazley	33.4 ± 3.4	B	17.4 ± 2.6	D	⬇ (-3.4%)	p < 0.0001
STATION level						
Station 1A	23.4 ± 1,.8	C	22.2 ± 1.0	B	⬇ (-1.4%)	p < 0.0001
Station 1B	44.8 ± 0.5	A	25 ± 1.0	B	⬆ (+0.8%)	p < 0.001
Station 2A	15.6 ± 1.8	D	16 ± 1.6	D	ns	p < 0.001
Station 2B	32.1 ± 2.4	C	20.8 ± 1.2	C	⬆ (+1.1%)	p < 0.0001
Station 3A	30.4 ± 5.0	C	15.8 ± 3.1	D	⬇ (-2.1%)	p < 0.0001
Station 3B	15.9 ± 6.8	D	16.4 ± 3.9	D	⬇ (-4.6%)	p < 0.0001
Station 4A	18.6 ± 2.2	D	19.4 ± 0.4	C	⬇ (-1.0%)	p < 0.0001
Station 4B	34.0 ± 1.5	B	23 ± 1.0	B	ns	p < 0.05
Station 5A	41.2 ± 3.8	B	19.8 ± 1.6	C	N/A	N/A
Station 5B	39.7 ± 1.4	B	25.4 ± 1.0	B	N/A	N/A
Jessie Beazley A	25.5 ± 3.4	C	10.2 ± 2.1	D	⬇ (-4.1%)	p < 0.0001
Jessie Beazley B	41.4 ± 2.9	B	24.6 ± 0.7	B	ns	p < 0.001

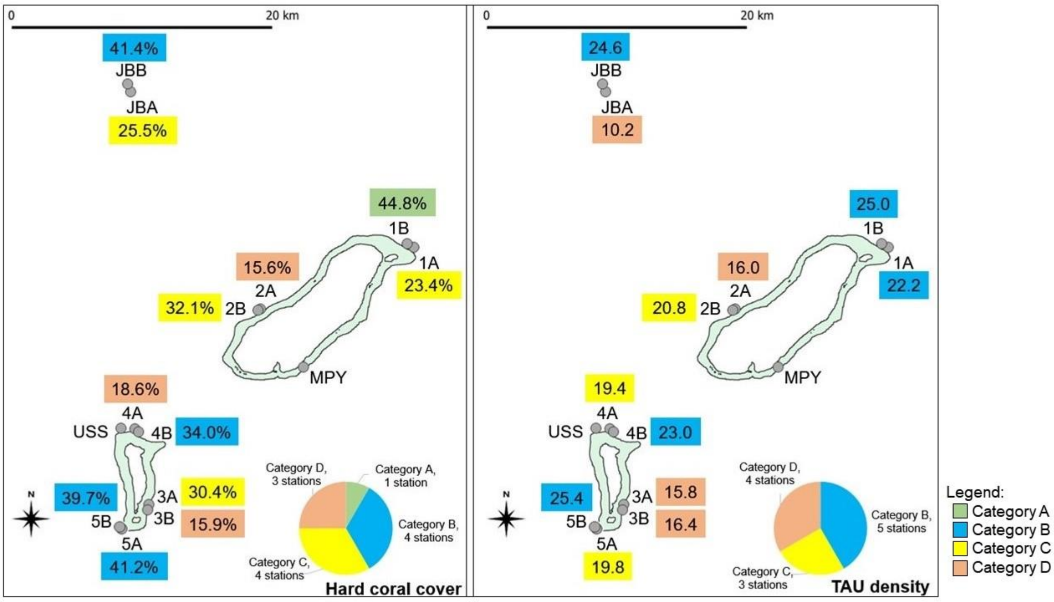


Figure 12. Map of Tubbataha monitoring stations labeled according to hard coral cover (HCC) category and TAU density category (see Licuanan et al. 2019). Average HCC and TAU density categories of each station are indicated.

Three stations moved down at least one category from 2021 to 2022 in terms of HCC. Station 5A went from Category A to Category B, and Jessie Beazley A went from Category B to Category C. Meanwhile, Station 3A moved down two categories in terms of HCC, going from Category A in 2021 to Category C in 2022. Station 3A also moved down one category in terms of TAU density, going from Category C in 2021 to Category D in 2022.

Non-coral benthos such as soft corals, cyanobacteria, and sponges were also observed in the TRNP monitoring stations. In 2022, soft coral cover ranged from 0.3% ± 0.1 SE (Stations 3A and 3B) to 15.1% ± 2.0 SE (Station 1B). Jessie Beazley B had the second-highest soft coral cover at 13.1% ± 3.6 SE. Soft corals in these stations mostly consisted of large, leathery alcyoniids (Figure 13). Average soft coral cover in Tubbataha was at 3.5% ± 1.5, though the soft coral cover was variable among stations.

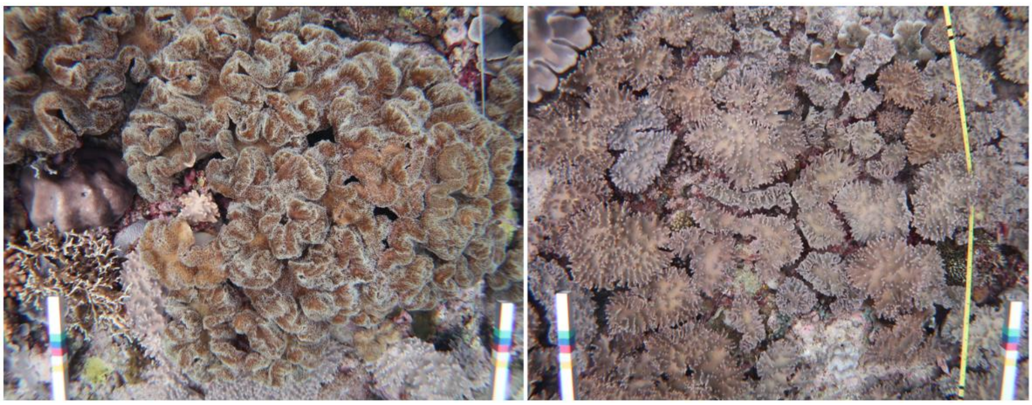


Figure 13. Soft corals in transect images in Station 1B (Transect 2), with 1-m monopod arms for scale

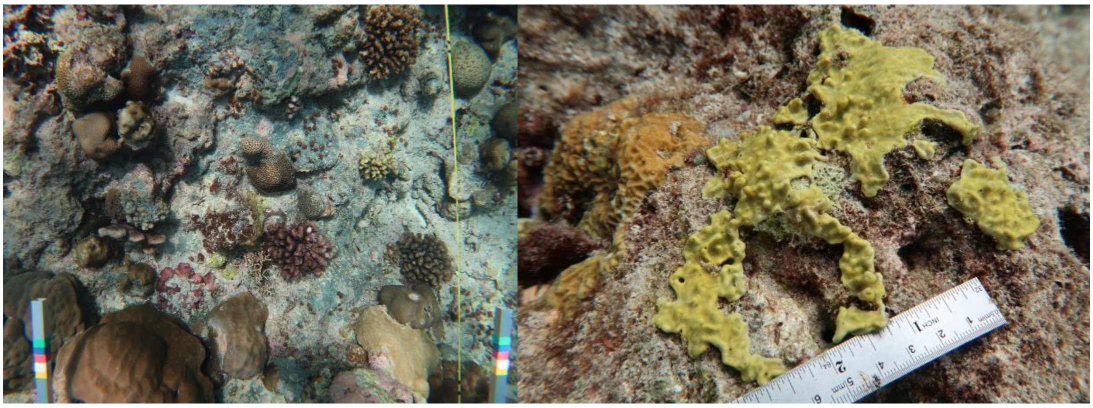


Figure 14. Encrusting sponges in Station 4B.

In 2022, the average sponge cover in the Tubbataha monitoring stations was 6.0% ± 0.9 SE, ranging from 0.3% ± 0.1 SE (Jessie Beazley A) to 11.4% ± 1.9 SE (Station 4B). More than half the stations had between 3 to 7% sponge cover, and the predominantly observed sponges had encrusting growth forms (Figure 14). Notably, the coral-killing cyanobacteriosponge, *Terpios*, was observed in at least two monitoring stations (Stations 1A and 3A) and was scored at least once (Figure 15). The *Terpios* patches were previously reported in Site 3, outside the monitoring stations, in deeper reef areas. *Terpios* patches had an average diameter of 3 to 5cm, although a patch of approximately 20cm was also noted.

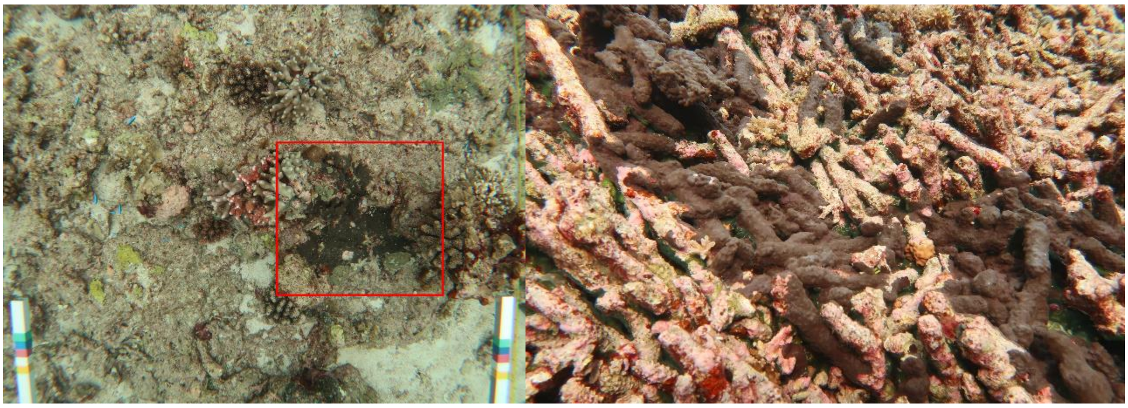


Figure 15. (a) encrusting Terpios captured in a transect image in Station 1A (Transect 5). (b) Terpios encrusting over rubble fields in Station 3A.

Among the transects where cyanobacteria were scored, cyanobacteria cover ranged from 2.6% ± 0.4 SE (Station 2A) to 10.1% ± 1.4 SE (Station 3A) in 2022 (Figure 15). Station 3B had the second-highest cyanobacteria cover at 10. 0% ± 1.9 SE. On average, cyanobacteria cover in the Tubbataha monitoring stations is at 6.8% ± 0.8 SE in transects where cyanobacteria were scored. At the site level, Site 1 had the second-highest average cyanobacteria cover at 9.1% ± 0.7 SE. Cyanobacterial mats were observed to grow over large rubble patches in Site 3, while in Site 1, it grew on unoccupied carbonate substrate (Figure 16).

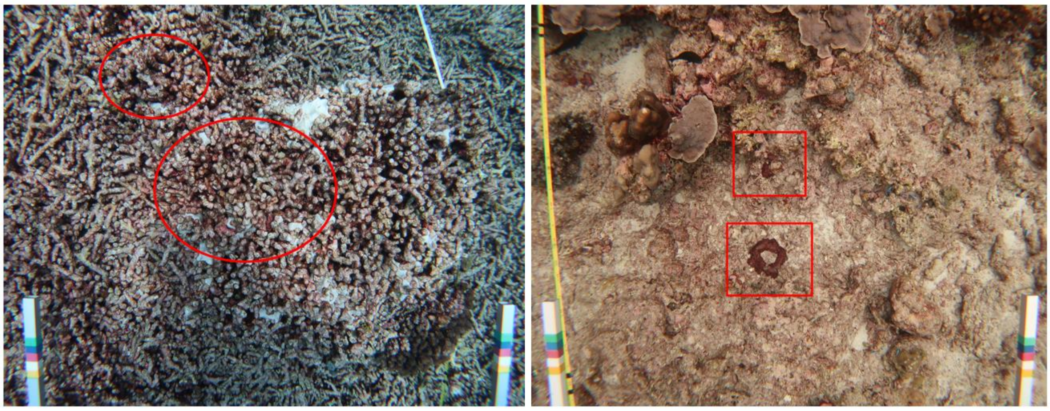


Figure 16. Filamentous cyanobacteria in Station 3A (Transect 2, left) and Station 1A (Transect 4, right)

Deep areas

At the location level, the deep areas of Tubbataha (Sites 1, 2, 3 and 4) had an average HCC of 23.0% ± 2.2 SE, and a TAU density of 14.5 TAUs ± 0.7 SE (Table 5). At the atoll level, the North Atoll (Sites 1 and 2) had lower HCC compared to the South Atoll (Sites 3 and 4) (Table 4).

Table 4. Summary table for hard coral over (HCC), TAU density, rates of change in HCC, and differences in HCC among years in the deep areas. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated. ns = not significant (p>0.05).

	Average % HCC (±SE) 2022	Average TAU density (±SE) 2022	Rate of change in HCC (Linear Regression) 2017-2022	Difference Among Years in HCC (ANOVAR; p<0.05 is significant) 2017-2022
TUBBATAHA (without JB)	23.0 ± 2.2	14.5 ± 0.7	⬇(-1.3%)	p<0.01
ATOLL Level				
North Atoll	21.8 ± 3.2	14.4 ± 0.9	⬇(-1.5%)	P<0.01
South Atoll	24.3 ± 3.0	14.5 ± 1.1	ns	ns
SITE Level				
Site 1	31.3 ± 4.2	17.4 ± 0.6	ns	ns
Site 2	12.3 ± 1.6	11.4 ± 0.7	⬇(-1.7%)	p<0.001
Site 3	23.3 ± 5.0	14.4 ± 1.2	ns	ns
Site 4	25.2 ± 3.7	14.8 ± 1.9	⬇(-2.3%)	p<0.05
Jessie Beazley	23.3 ± 3.7	11.3 ± 1.3	ns	ns
STATION Level				
Station 1A	23.2 ± 1.1	16.5 ± 0.6	⬇(-2.3%)	p<0.05
Station 1B	39.5 ± 6.1	18.3 ± 0.8	ns	ns
Station 2A	11.4 ± 1.5	12 ± 0.9	⬇(-2.4%)	p<0.01
Station 2B	13.3 ± 3.0	10.8 ± 1.0	ns	ns
Station 3A	28.2 ± 8.5	14.3 ± 1.7	ns	ns
Station 3B	18.3 ± 5.4	14.5 ± 2.0	ns	ns
Station 4A	20.7 ± 6.5	12.3 ± 3.4	⬇(-2.9%)	ns
Station 4B	29.8 ± 2.7	17.3 ± 1.3	⬇(-1.7%)	p<0.05
Jessie Beazley A	17.9 ± 4.6	10 ± 2.5	ns	p<0.001
Jessie Beazley B	28.6 ± 4.6	12.5 ± 0.3	ns	p<0.05

At the site level, Site 1 had the highest HCC (31.3% ± 4.2 SE) and TAU density (17.4 TAUs ± 0.6 SE). At the station level, Station 1B had the highest HCC (39.5% ± 6.1 SE) and TAU density (18.3 TAUs ± 0.8 SE). The lowest HCC was recorded in Station 2A (11.4% ± 1.5 SE), while the lowest TAU density was recorded in Jessie Beazley A (10.0 ± 2.5 SE).

Soft corals made up 48.1% ± 8.4 SE of Jessie Beazley A and 28.9% ± 9.4 SE of Station 1A, both values higher than the HCC of the two stations (Figure 17). Rubble made up 29.8% ± 9.5 SE of Station 3A and 50.3% ± 11.5 SE of Station 3B, while corallimorphians made up 21.25% ± 4.67 SE of Jessie Beazley B. Jessie Beazley B had the highest sponge cover at 14.1% ± 2.9 SE in 2022.

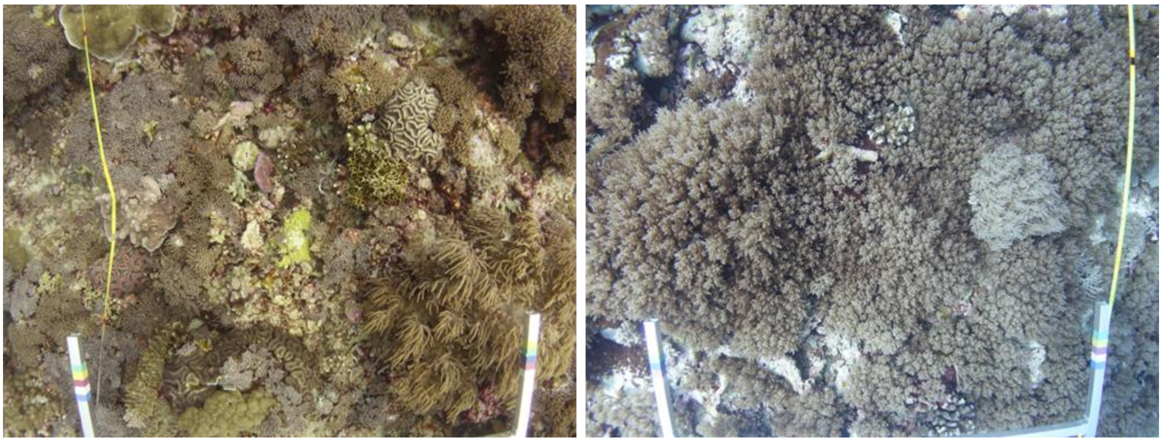


Figure 17. Soft corals in Station 1A (left) and Jessie Beazley A (right).

Temporal patterns in Benthic Composition

Shallow areas (2012 to 2022)

At the location level the HCC of Tubbataha has been declining at a rate of -0.9% yearly from years 2012 to 2022 (See Table 2). At the site level, three out of five monitoring sites exhibited statistically significant changes in HCC (Figure 18). Only Site 2 exhibited an increase in HCC over time at a rate of roughly 0.7% per year. Site 3 HCC on the other hand is decreasing at an annual rate of -3.4%. This significant loss in HCC over time within Site 3 likely contributed to the overall decline observed in the South Atoll, where HCC decreased at an annual rate of -1.9%. Out of all the shallow monitoring sites, Jessie Beazley reefs appear to be experiencing the most rapid decline in HCC at rate of -3.6% HCC lost annually.

At the station level, only Stations 1B and 2B exhibited increasing trends in HCC from years 2012 to 2022 at annual rates of 0.8% and 1.1%, respectively (Table 3). HCC is decreasing over time in a total of five monitoring stations, namely: Station 1A at -1.4%, 3A at -2.1%, 3B at -4.6%, 4A at -1.0%, and Jessie Beazley A at -4.1% annually (Figure 19).

A statistically significant increase in AA cover over time was observed at the location level at a rate of 0.7% per year (LR p<0.05, ANOVAR p<0.0001). At the site level, the decrease in HCC observed in both Site 3 and Jessie Beazley was accompanied by an increase in AA at annual rates of 1.7% (LR p<0.001, ANOVAR p<0.0001) and 3.0% (LR p<0.0001, ANOVAR p<0.0001), respectively (Figure 18). Positive trends in AA cover were also observed at the station level at annual rates of 2.7% in Station 3B (LR p<0.0001, ANOVAR p<0.0001), 1.2% in Station 4A (LR p<0.05, ANOVAR p<0.0001), and 3.5% in Jessie Beazley A (LR p<0.0001, ANOVAR p<0.0001).

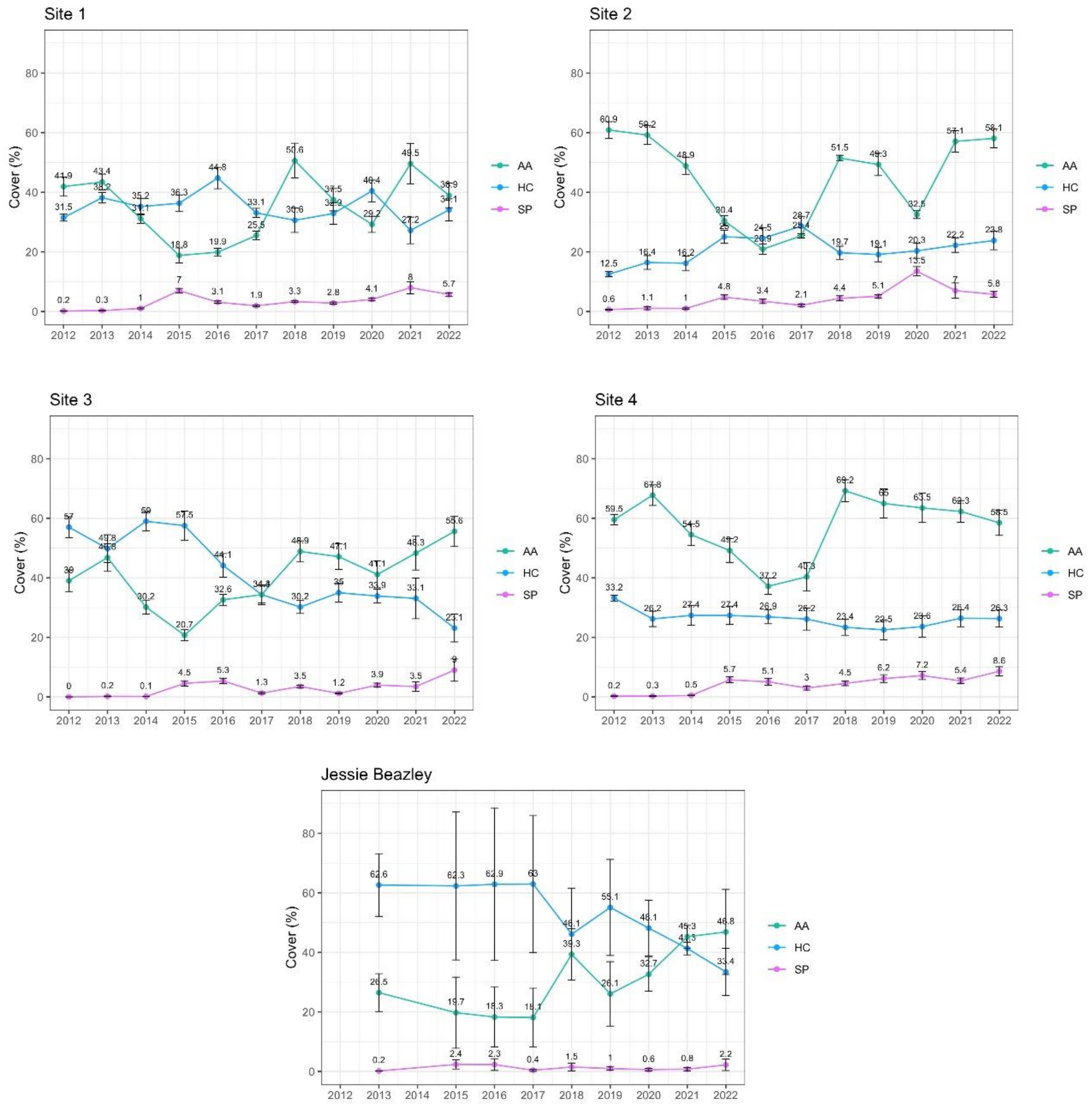


Figure 18. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring sites from 2012 to 2022. Error bars represent +/- one standard error.

Sponge cover continues to slowly increase over time within Tubbataha (0.7% annually; LR $p<0.0001$, ANOVAR $p<0.0001$) with significant trends observed across Sites 1 to 4 and within their respective monitoring stations (Figure 19). The monitoring site with the most rapid spread in SP cover remains to be Site 2, with SP cover now observed to be increasing at 0.8% per year (LR $p>0.0001$, ANOVAR $p<0.0001$). Site 3 has the highest sponge cover among all sites at 9.0% ± 3.7 SE in 2022. Similar to the results reported in the 2021 Benthos Report, stations 2B and 4B exhibited the highest rates of increase in SP cover. However, the rate of SP cover growth within Station 4B at 1.1% per year (LR $p>0.0001$, ANOVAR $p<0.0001$) has surpassed that of Station 2B, which is currently at 1.0% increase per year (LR $p>0.0001$, ANOVAR $p<0.0001$).

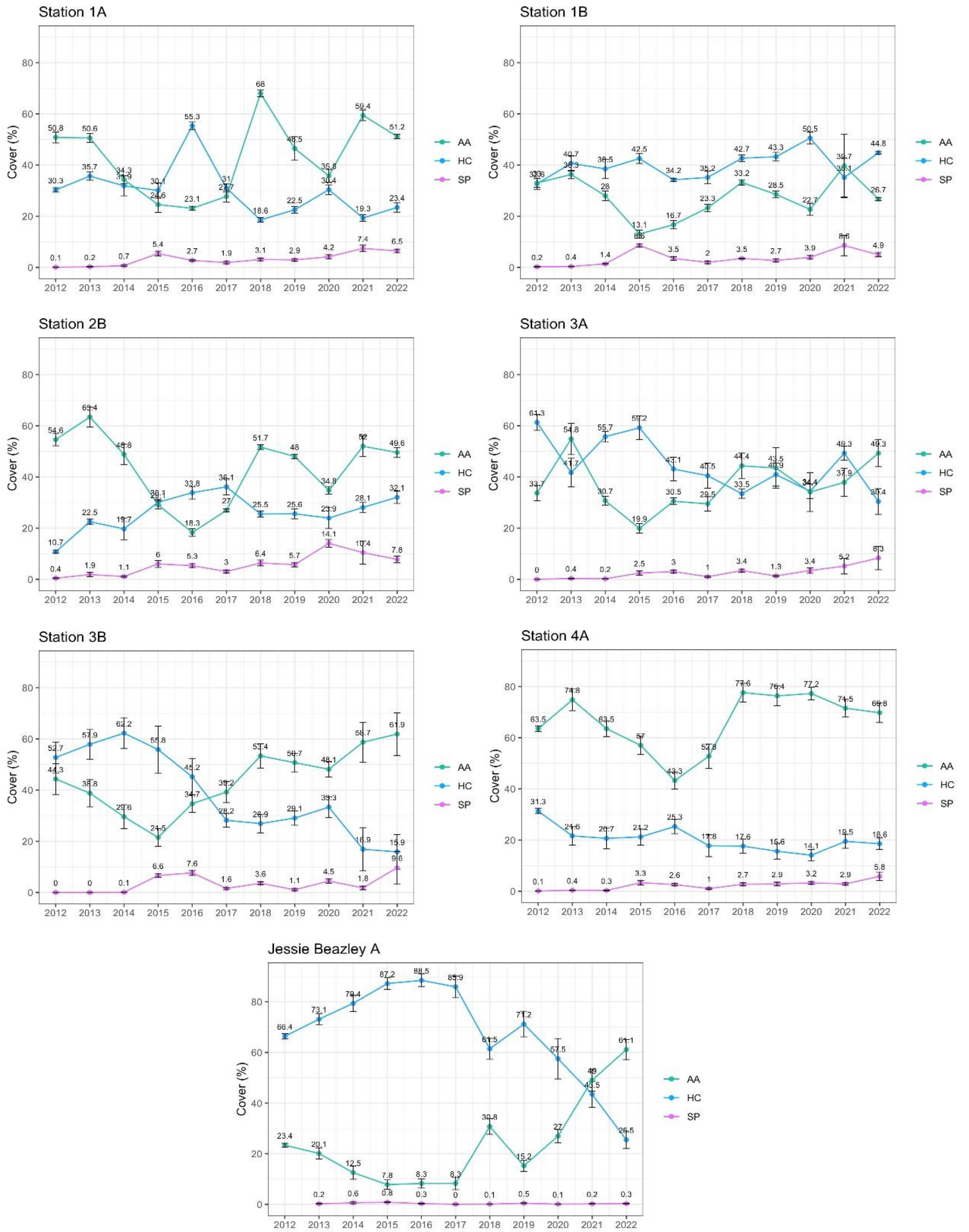


Figure 19. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in Stations 1A, 1B, 2B, 3A, 3B, 4A, and Jessie Beazley A from 2012 to 2022.

Deep areas (2017 to 2022)

The HCC of Tubbataha at the location level is declining at a rate of -1.3% yearly from 2017 to 2022 (Table 3). The deep areas of the North Atoll experienced a significant decline of 1.5% in HCC from 2017 to 2022, with significant difference among years. HCC in the South Atoll did not change significantly from 2017 to 2022 (Table 4).

At the site level, two out of five monitoring sites exhibited statistically significant changes in HCC. Site 2 is declining at an annual rate of -1.7% and Site 4 at -2.3%. HCC in Sites 1, 3 and Jessie Beazley did not change significantly from 2017-2022 (Figure 20).

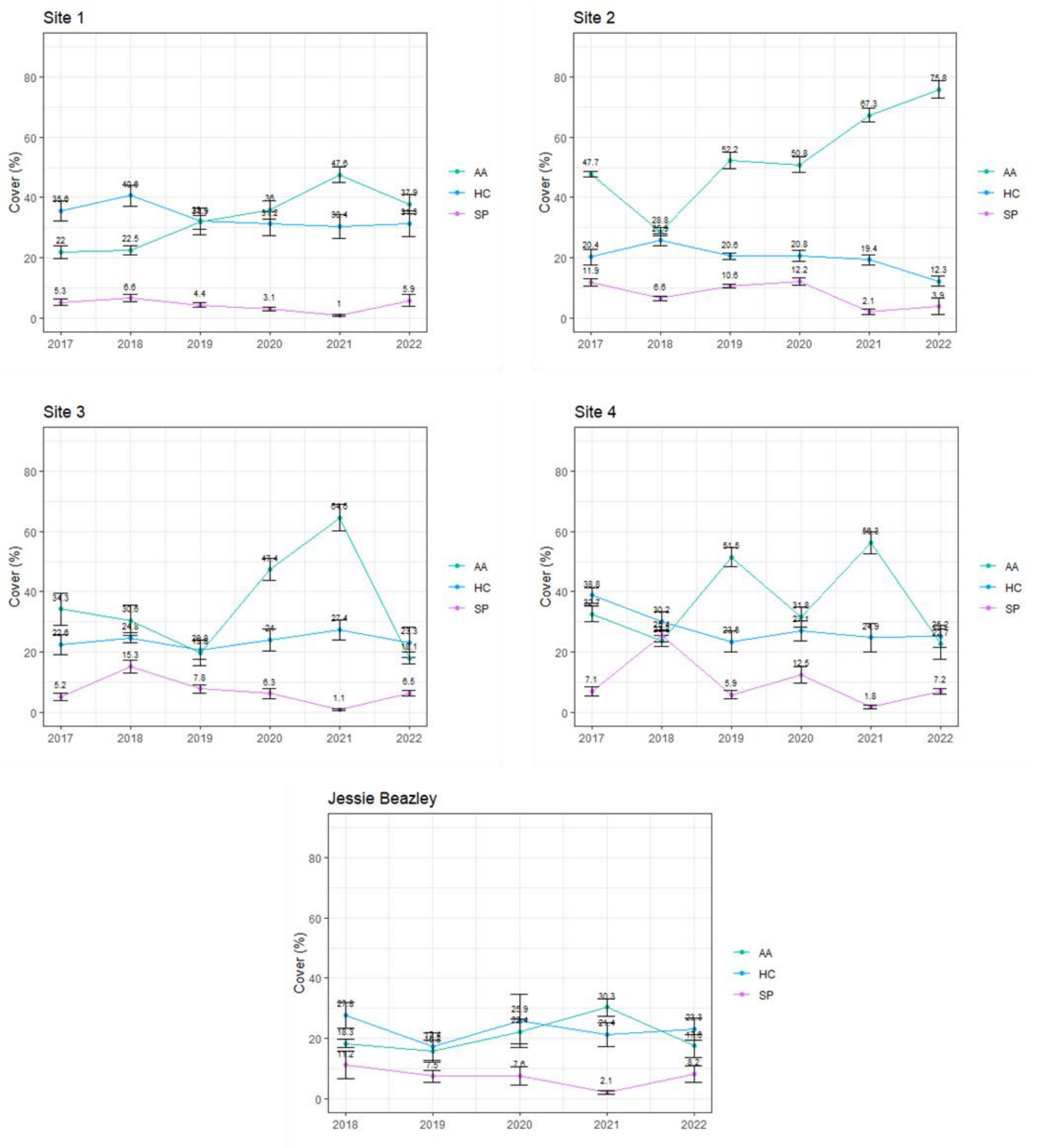


Figure 20. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the deep areas of the monitoring sites from 2017 to 2022. Error bars represent +/- one standard error.

At the station level, none of the sites exhibited a significant increase in HCC over time. Annual declines were recorded for the HCC of Stations 1A at -2.3%, 2A at -2.4%, 4A at -2.9%, and 4B at -1.7% (Figure 21).

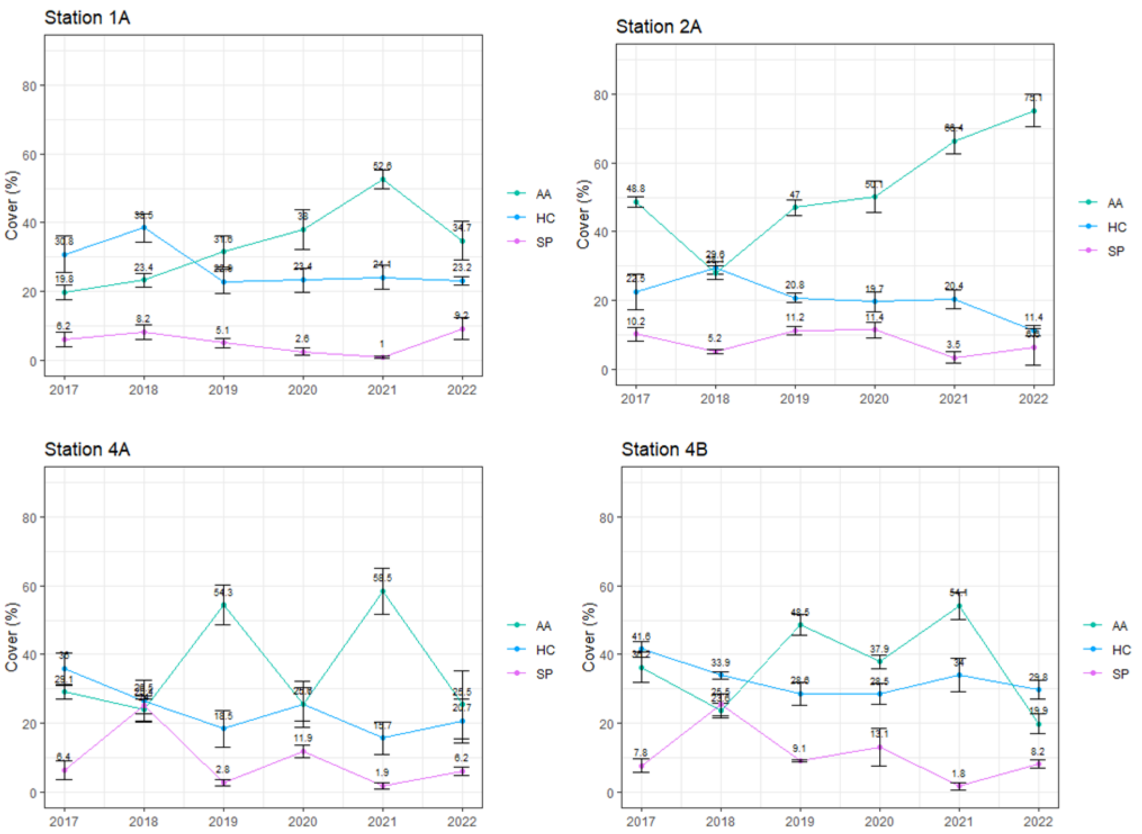


Figure 21. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the deep areas of Stations 1A, 2A, 4A, and 4B from 2017 to 2022.

A statistically significant increase in AA cover over time was observed at the location level at a rate of 3.5% per year (LR $p<0.001$, ANOVAR $p<0.001$). AA cover in the North Atoll (Sites 1 and 2) significantly increased over the years at a rate of 5.8% (LR $p<0.001$, ANOVAR $p<0.001$), while no significant change occurred in the South Atoll.

At the site level, an increase in AA cover was recorded in Site 1 at 4.5% (LR $p<0.001$, ANOVAR $p<0.001$) and Site 2 at 7.2% (LR $p<0.001$, ANOVAR $p<0.001$). This was also evident at the station level where significant increases were recorded for AA in Stations 1A (4.8%, LR $p<0.001$, ANOVAR $p<0.001$), 1B (4.2%, LR $p<0.001$, ANOVAR $p<0.001$), 2A (7.1%, LR $p<0.001$, ANOVAR $p<0.001$) and 2B (7.4%, LR $p<0.001$, ANOVAR $p<0.001$).

In contrast to the shallow areas, the sponge cover in the deep areas declined at an annual rate of -1.2% (LR $p<0.001$, ANOVAR $p<0.001$). This decline was evident in Stations 1B at -0.6% (LR $p<0.01$, ANOVAR $p<0.05$) and 2B at -2.3% (LR $p<0.001$, ANOVAR $p<0.001$).

Ship Grounding Sites

Min Ping Yu grounding site

Hard coral cover (HCC) in the small fragments quadrat remains the lowest among the Min Ping Yu plots at 3.7% ± 1.1 SE (Figure 22). The small fragments quadrat was directly impacted by the grounding incident, resulting in a substrate of sand and rubble with patches of remaining carbonate rock after the vessel repeatedly hit the reef. HCC in the large fragments quadrat, where the substrate consists of larger fragments of carbonate rock with some contiguous carbonate substrate, is at 7.1% ± 2.2 SE (Figure 22). The adjacent control quadrat has the highest HCC among Min Ping Yu plots at 24.0% ± 3.0 SE (Figure 22). This year the adjacent control quadrat improved to HCC Category C, after consistently being in Category D (Licuanan et al. 2019).

HCC in the Min Ping Yu grounding site significantly increased in all three monitoring quadrats since the first surveys in 2014 (Table 5; Figure 22). Notably, 2022 is the first year a significant increasing trend in HCC was observed in the small fragments and adjacent control quadrats. HCC in the adjacent control quadrat is increasing at the highest rate (1.4% per year), followed by large fragments (1.3% per year) and the small fragments quadrat (0.3% per year). HCC in the adjacent control quadrat showed a sharp increase from years 2019 to 2022 at a rate of 5.5% per year (LR $p < 0.01$).

Table 5. Summary of linear regression results for % HCC changes in Min Ping Yu and USS Guardian grounding sites. Statistically significant ($p < 0.05$) results are highlighted. ns = not significant ($p > 0.05$).

Plot	Annual rate of change in HCC	p-value	R^2
Min Ping Yu Grounding Site			
Small Fragments	↑ 0.3%	$p < 0.05$	0.49
Large Fragments	↑ 1.3%	$p < 0.05$	0.59
Adjacent Control	↑ 1.4%	$p < 0.05$	0.46
USS Guardian Grounding Site			
Ground Zero	↑ 0.9%	$p < 0.01$	0.67
Impact Border	ns	ns	0.18
Adjacent Control	↓ 2.3%	$p < 0.01$	0.70

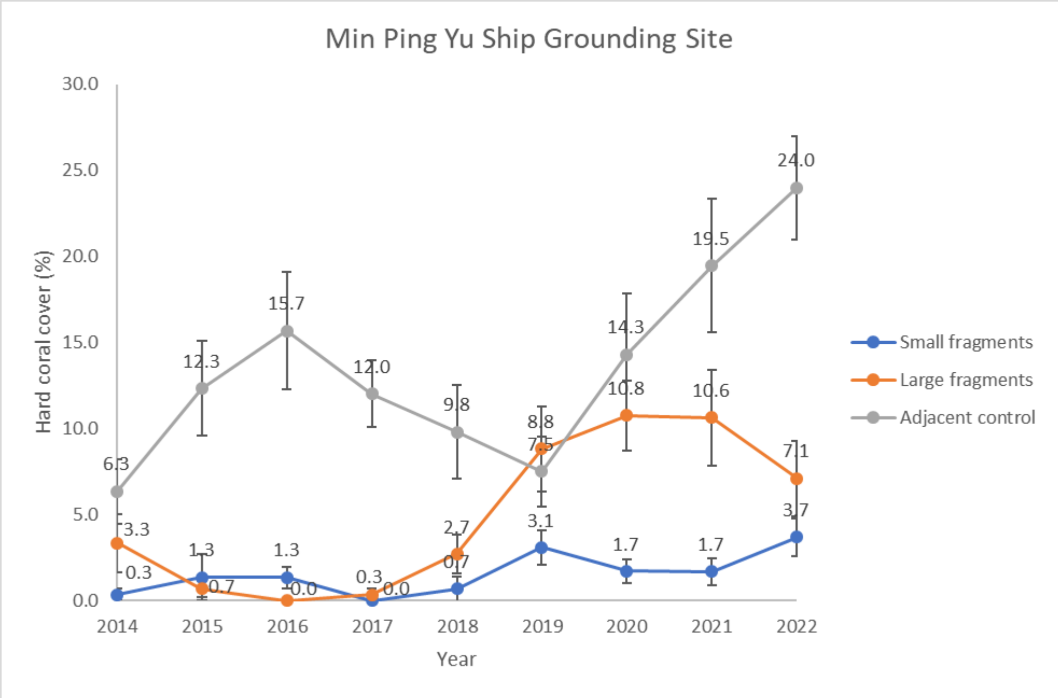


Figure 22. Percent hard coral cover (% HCC) in the Ming Pin Yu ship grounding site. % HCC in three fixed plots is reported: small fragments, large fragments, and adjacent control. Error bars represent +/- one standard error. (Note: values for large fragments and adjacent control HCC were interchanged erroneously in the 2021 TRNP Benthos Report. The values have been verified, and the correct version is displayed in this figure.)

USS Guardian grounding site

In 2022, hard coral cover (HCC) in the USS Guardian grounding site was lowest in the adjacent control quadrat (8.2% ± 1.8 SE; Figure 23), which is located ~55 meters away from the actual impact area. Indeed, the ground zero plot directly hit by the warship had a higher HCC than the adjacent control quadrat, at 9.8 ± 1.9 SE (Figure 23). The impact border quadrat, also damaged by the grounding incident but to a lesser extent, is located 50m east of the ground zero plot. HCC in the impact border quadrat was the highest among the three USS Guardian plots, with an average HCC of 13.2% ± 2.3 SE (Figure 23).

The ground zero plot showed a significant increase in HCC from 2014 to 2022 at a rate of 0.9% HCC per year (Table 5). The largest margin of increase for the ground zero plot occurred from 2015 to 2017 at a rate of 3.6% per year (LR = not significant; Figure 23). Conversely, the adjacent control quadrat showed a significant decline in HCC, at a rate of 2.3% per year, from 2014 to 2022 (Table 5). A steep decline in HCC occurred between 2017 and 2018, where half the HCC was lost. The coral community in the adjacent control quadrat was unable to recover since then (Figure 23).

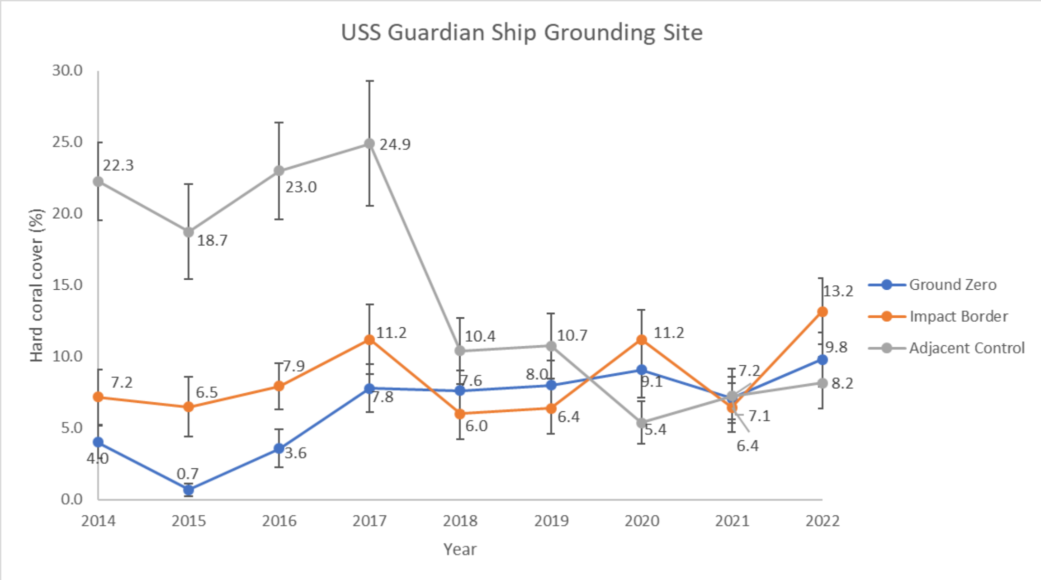


Figure 23. Percent hard coral cover (% HCC) in the USS Guardian ship grounding site. % HCC in three fixed plots is reported: ground zero, impact border, and adjacent control. Error bars represent +/- one standard error.

DISCUSSION

Shallow areas

Present conditions

HCC in TRNP declined by -5.5% from 2021 to 2022, above the level of minimum detectable change reported by Licuanan et al. (2017). The minimum detectable change, identified through the delta value in power analysis, indicates the percent cover change that can be reliably detected by the statistical power of the sampling method (Licuanan et al. 2017). Values above the minimum detectable change implies that the change is ecologically significant. Percent cover variations below the minimum detectable change may not be ecologically significant, since they may be attributed to sampling artifacts, such as the re-randomization of transects within a station throughout the monitoring period. At the site level, HCC decreased from 2021 to 2022 at Site 3 (10%, above level of minimum detectable change), and Jessie Beazley (8%, no level of minimum detectable change reported). Over the same period, HCC increased at Site 1 (7%, above level of minimum detectable change) and Site 2 (1.6%, below level of minimum detectable change).

The decline in Site 3 was driven mostly by loss of hard coral at Station 3A. Although both stations at this site experienced decline, that of Station 3B was much less (1% decline) compared to that of 3A (19% decline). This decline in HCC was accompanied by a concurrent increase in both AA cover and sponge cover at both Station 3A and 3B, which was also reflected at the site level. It should also be noted that the decline in HCC in

Station 3B is lower than the minimum detectable change value reported by Licuanan et al. (2017), and so may not reflect an ecologically significant change.

The decline at the Jessie Beazley site was driven by the decline in Jessie Beazley A, where nearly half of HCC was lost compared to 2021. Comparatively, HCC at Jessie Beazley B increased 1.9%. The decline in Jessie Beazley A was accompanied by a very notable increase in AA.

The declines in Station 3A and Jessie Beazley A may be attributed to Typhoon Odette, which passed through TRNP in December 2021. Station 3A was previously dominated by stands of *Isopora brueggemanni,* a branching species, while Jessie Beazley A was previously dominated by stands of foliose *Montipora.* Both *Isopora brueggemanni* and foliose *Montipora* are more susceptible to damage by strong wave action caused by the typhoon (Darling et al. 2012). In contrast, Station 3B and Jessie Beazley B are both dominated by encrusting and massive forms, with some stoutly-branched colonies also present – colony forms which are less susceptible to typhoon damage (Darling et al. 2012). The difference in the impact of Typhoon Odette on the two paired stations may therefore be the result of differences in coral community composition between them.

The increase in HCC at Site 1 can be attributed to an increase in HCC at both stations, however, only Station 1B displayed an increase greater than the minimum detectable amount reported by Licuanan et al. (2017). This increase in HCC was accompanied by a proportional decrease in AA, and a slight decrease in sponge cover. It is likely that the coral community in Station 1B is continuing to grow and recruit, covering more of the habitable space (i.e., AA).

Results from this year's monitoring suggest that benthic cover of sponge, cyanobacteria, and soft corals vary spatially at different scales. For instance, soft coral cover in the Tubbataha monitoring stations appears to vary at the station-level. The two stations with the highest soft coral cover, Station 1B and Jessie Beazley B have five times and more than 10 times the soft coral cover of their replicate stations, respectively. In contrast, cyanobacteria cover appears to vary at the site-level, where highest cyanobacteria cover was observed in Site 1 in the North Atoll and Site 3 in the South Atoll. Lastly, sponge cover appears to vary at the atoll-level, where sponge cover in the South Atoll is 3% higher than that of the North Atoll and four times that of Jessie Beazley.

Monitoring the benthic cover of selected non-coral taxa such as sponges and cyanobacteria was recommended to determine possible eutrophication in Tubbataha, particularly in the South Atoll (Licuanan and Bahinting 2021). The spatial variation noted in the 2022 data for non-coral benthos may reinforce previous hypotheses (Licuanan and Bahinting 2021) about eutrophication from drainage of South Atoll lagoon waters, causing the higher rate of increase in sponge cover over time (Figure 14) in South Atoll stations compared to North Atoll stations. Notably, *Terpios* was observed in both North and South Atoll stations. To better assess the spread and behavior of *Terpios* on the reefs, fixed plots (4x4meters) were established in two areas – one outside the monitoring station in 3B and another one in front of the Ranger Station. The site-level and station-level variations in cyanobacteria and soft coral cover, respectively, suggest that underlying environmental conditions and possible disturbance conditions may vary in these smaller spatial scales.

While it has been reported that soft corals may gain competitive advantages over hard corals in eutrophication and ocean warming scenarios (Vollstedt et al. 2020), and these same processes may lead to the increase in frequency and severity of cyanobacterial blooms (O'Neil et al. 2012), the complexity of these processes and their impacts on the taxa require further study. To further investigate the role of these non-coral benthos in shaping the reef communities in Tubbataha, spatial variability must be examined along with temporal trends to diagnose changes and determine baselines and thresholds useful for management (Flower et al. 2017).

Temporal Patterns (2012 to 2022)

Site 3 experienced the highest rate of HCC loss over time among the five monitoring sites. With HCC decreasing at an annual rate of -3.4%, the *Isopora brueggemanni*-dominated site has dropped by 33.9% since 2012. Station 3B, which exhibited the highest rate of decline among all stations at 4.6% lost per year, started with 52.7% ± 6.0 SE HCC in 2012 and is now only at 15.9% ± 6.8 SE HCC.

It is worth noting that Site 3 has experienced several disturbances since the year 2016, all of which have resulted in accelerated declines in HCC and the expansion of *Isopora* rubble fields. The declines observed in both 2016 and 2017 were attributed to the mechanical damage caused by the grounding of payaw floats (Eneria and Licuanan 2017). The reef then experienced both bleaching in July (Narida et al. 2020) and likely experienced damage from Tropical Storm Vicky, which made its way across the Sulu Sea in December 2020. Whilst still recovering from the disturbances from the prior year, Site 3 reefs then likely suffered further damage from aforementioned Typhoon Odette in December 2021, which had a similar pathway as Tropical Storm Vicky (PAGASA 2022). Algal turf overgrowing the dead coral and fields of rubble fragments could have caused the increase in algal assemblage (AA) cover recorded within the site from 2016 onwards.

Jessie Beazley reefs experienced the second highest rate of HCC decline at -3.3% per year. The most drastic drop in HCC was observed within Jessie Beazley A, a station dominated by foliose *Montipora* corals, wherein HCC dropped from 88.5% ± 2.5 SE to 25.5% ± 3.4 SE in a span of six years. Jessie Beazley A is primarily composed of competitive foliose colonies that are highly susceptible to storm damage, as well as bleaching due to thermal stress (Darling et al. 2012). The succession of typhoons crossing the Sulu Sea from the southeast direction over the years (PAGASA 2022) may have damaged this *Montipora*-dominated station.

The decline in TAU density over time may be indicative of decreasing coral diversity. This could be a consequence of the decreasing suitability of habitat conditions for corals with competitive life-history strategies. As demonstrated by the loss in HCC in foliose *Montipora*-dominated Jessie Beazley A, disturbances such as strong wave action from typhoons and thermal stress can cause increased levels of mortality among corals with more delicate growth gorms (Darling et al. 2013; Harii et al. 2014). The loss in highly sensitive competitive corals that thrive in pristine habitats and the subsequent rise in dominance of stress-tolerant species may suggest a decrease in diversity due to stressors in the environment (Darling et al. 2012).

The trends of increasing proportions of stress-tolerant genera coupled with decreasing proportions of competitive genera were observed in several monitoring stations (data not shown). Three stations in particular exhibited significant increases in coral cover of stress-tolerant genera ($p < 0.05$, $R^2 > 0.45$), based on LR, namely: Stations 1A, 3B, and 4B. A significant decline in HCC was also observed in Stations 1A and 3B (LR $p<0.05$, ANOVAR $p<0.01$).

AA cover, particularly within the South Atoll and Jessie Beazley has steadily increased since 2012. Significant trends in increasing AA cover (LR) at the station level were driven by high turf algae cover as opposed to crustose coralline algae. Dead corals are typically overgrown by turf algae, which are short (<2cm) hair-like, fleshy, and productive network formed by algal and cyanobacteria species (Smith et al. 2016). The overgrowth of thick layers of tall turf algae and macroalgae over time may be indicative of ecological imbalances such as the loss of herbivorous fish, increased concentrations of organic nutrients in the water, and high coral mortality rates that provide more colonizable space (Fong and Paul, 2010; Smith et al. 2016).

In reef environments that have experienced recent acute disturbances (i.e., typhoon or bleaching event), proliferation of tall, thick layers of turf algae may inhibit coral recruitment (reduced settlement and recruit survival) and subsequently hinder the recovery of coral populations. Moreover, conditions that are not ideal for coral survival can influence the outcome of coral-algal interactions in favor of turf algae survival (McCook et al. 2001; Vermeij et al. 2009). This is likely what has been occurring within Site 3 with *Isopora*-rubble fields continuously expanding, increasing AA cover, and decreasing HCC. Overgrowth of turf algae may directly affect coral recruitment negatively and thus cause a decrease in coral cover over time through mechanical damage and spatial competition on substrate suitable for settlement; as well as indirectly via allelopathy, disease, and hypoxia due to increased microbial activity (Vermeij et al. 2009).

In a study by Price et al., in the Central Pacific, turf algae, fleshy macroalgae, and sponges were recorded to be more abundant in areas with pH levels lower than average seasonal lows (2012). Sponge communities are also known to tolerate thermal anomalies. Reefs that suffered coral mortality after a disturbance would consequently provide more habitable space for sponges to proliferate (Bell et al. 2013). This was exemplified with observations in Site 4 where declining HCC coupled with relatively higher temperatures and turbidity during ebb tide - unsuitable conditions for corals - coincided with higher sponge and cyanobacteria cover (Licuanan and Bahinting 2021).

Sponge cover is increasing in both the North and South Atoll, but only the latter is experiencing simultaneous declines in HCC. There are several possible reasons for the increasing sponge cover. One theory is that thermal stress causes coral mortality, allowing the more resilient sponges to colonize the resulting available space. It is unlikely that the increase in sponge cover within the North Atoll is due to thermal stress given that HCC has been increasing within the atoll (Licuanan and Bahinting 2021).

Licuanan and Bahinting (2021) hypothesized that South Atoll waters may be becoming increasingly eutrophic. Nutrient-rich atoll waters draining through channels may be facilitating the increase in nutrient load within nearby stations. It is hypothesized that increases in organic nutrients in areas with prevailing currents but low water turbulence may be a factor in enhancing sponge abundance (Wilkinson and Evans 1989). This phenomenon seems to be occurring within the stations where sponge cover growth rate was highest, namely Stations 2B and 4B, as these stations are also situated next to a channel.

Although HCC decline over time within Tubbataha is below the level of minimum detectable change (Licuanan et al. 2017), the loss of more than 1% but less than 10% per year indicates the presence of a possible chronic stressor (Flower et al. 2017). To assess nutrient overload, Flower et al. (2017) suggests examining herbivorous fish abundance data for declines. The absence of declines in the population of herbivorous fish in combination with increasing turf algae height over time provides strong evidence of chronic disturbance in the form of nutrient increases or possible eutrophication.

Given strong evidence of chronic nutrient increase or eutrophication (positive trends in turf algae height over time without decreases in herbivorous fish abundance), the resulting prognosis for a reef would depend on several factors according to Flower et al. Firstly, analyzing recruitment data would provide insight as to whether heightened levels of turf algae cover are restricting the available substrate for juvenile corals (Flower et al. 2017). A reef that is progressively dominated by domed corals with large corallites would suggest that conditions are becoming selectively suitable for stress-tolerant corals with high reproductive success (Darling et al. 2012; Flower et al. 2017). These stress-tolerant and slow growing corals would be outcompeted for space by fast reproducing turf algae because the corals prioritize allocating energy for defense mechanisms rather than tissue growth (Flower et al. 2012; Swierts and Vermeij 2016). Finally, an increase in macroalgae cover denotes an unfavorable prognosis for the reef as this would further inhibit coral recruitment, directly cause juvenile mortality through physical damage, thereby strongly hindering recovery of coral populations (Vermeij et al. 2009; Flower et al. 2017).

Deep areas

Present conditions

Between 2021 and 2022, HCC declined by -2.5%, more evidently in the North Atoll (-3.1%) than in the South Atoll (-1.8%). The decline in HCC in the North Atoll was attributed to the -7.1% decline in Site 2, while in South Atoll, a decrease of -4.1% was recorded in Site 3.

The decline in both stations of Site 2 contributed to the decline in the HCC cover of the site. Along with this decline, an increase in AA by 8.7% (Station 2A) and 8.2% (Station 2B) was recorded between 2021 to 2022. In Site 3, the decline in HCC between 2021 to

2022 was also influenced by the changes in both stations, -2.9% decline in Station 3A and -5.4% in Station 3B. This decline in HCC corresponded with an increase in SP cover in both stations (6.3% in Station 3A and 4.4% in Station 3B). The changes may be attributed to Typhoon Odette which passed through the Sulu Sea in December 2021 (PAGASA 2022). Tubbataha marine park rangers and divers reported several areas where damages to the corals were most likely due to the typhoon.

This year, corallimorphs made up 21.3% of Jessie Beazley B, not far from last year's 26.6%. Corallimorphs were also observed in the vicinity of the monitoring station, as they occupy the empty spaces of the reefs (Figure 24). One 4x4 meter fixed quadrat was established outside of the monitoring station to monitor the growth of corallimorphs in the area. The fixed quadrat is located a few meters away from the start of Transect 1 (shallow transect), towards the deeper part of the reef. This plot will be monitored annually to further study the changes in the corallimorphs in the area.

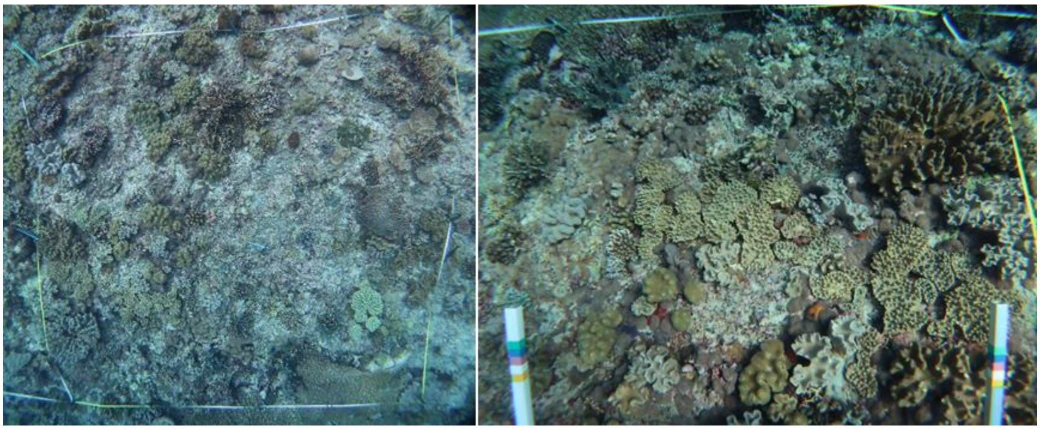


Figure 24. Fixed quadrat established in Jessie Beazley B (left) and a frame showing corallimorphs occupying the empty spaces of the reef (right). Note the abundance of soft corals in the area.

Temporal Patterns (2017 to 2022)

Previously not significant, the linear regression (LR) models for Stations 1A, 2A, and 4B now reveal significant declines in HCC from 2017 to 2022. It should be noted that the HCC in these three stations also declined between 2021 to 2022, which might be an effect of Typhoon Odette in December 2021. In Stations 1A and 2A, the decline in HCC coincided with an increase in AA cover. An increase in SC cover between 2021 and 2022 was also noted in Station 1A. Although not reflected in the data, soft corals were also observed to be occupying Station 2B. In Station 4B, the decrease in HCC did not correspond to an increase in AA or SP, but an increase in SC between 2021 to 2022 was observed.

In other locations, drivers of the proliferation of sponges and soft corals in hard coral-dominated reefs include disturbances (e.g., typhoons, Crown-of-thorns starfish infestation, exposure to extreme low tides) (Chadwick-Furman and Spiegel 2000), poor water quality (Baum et al. 2016), and high turbidity (Fabricius and Dommisse 2000). This year's water quality monitoring in TRNP revealed that almost all parameters adhere to the highest classification given to protected marine waters. It is possible that the recent disturbances in Tubbataha, i.e., coral bleaching in 2020 and Typhoon Odette in 2021, provided space for soft corals to proliferate in these stations.

AA cover in the two stations of Sites 1 and 2 significantly increased over the years. The annual increase was larger in Site 2 (7.2%) than in Site 1 (4.5%). This increase in AA cover may be correlated with the decrease in herbivorous fishes in the two sites. A larger decrease in the annual biomass of herbivorous fishes was recorded in Site 2 (-4.2%) compared to Site 1 (-0.9%). The presence of herbivorous fishes in a coral reef is critical to the ecosystem. Herbivores consume algae, which can otherwise overgrow corals or compete for space. Collapses in the population of herbivorous fishes may result in regime shifts to algae-dominated reefs that may be difficult to reverse (Mumby et al. 2007).

HCC in Station 4A continues to decline at a rate of 2.9% (2017 to 2022), an improvement from last year's 4.1%. It should be noted that the condition in Station 4A improved as suggested by the 5% increase in HCC between 2021 to 2022.

Ship Grounding Sites

The quadrats of both sites directly impacted by ship grounding (i.e., small fragments quadrat in the Min Ping Yu site and the ground zero quadrat in USS Guardian site) are showing significant trends that suggest recovery, though at a rate of less than 1% HCC per year (Table 4). In the case of the USS Guardian grounding site, the hard, contiguous carbonate substrate of the ground zero quadrat is a suitable substrate for coral settlement and recruitment, where recovery can occur at a decadal timescale (Precht et al. 2001). In the case of Min Ping Yu, the increasing trend in HCC in the small fragments plot is a favorable sign, especially since unstable surfaces such as small fragments and rubble are not suitable for coral recruitment (Fox et al. 2005).

At the site level, the Min Ping Yu and USS Guardian grounding sites exhibit contrasting trends. Min Ping Yu exhibited significant increase in HCC over the nine-year monitoring period (Table 5; Figure 22). In contrast, the two other quadrats in the USS Guardian grounding site either do not display a significant trend (impact border) or show a significant decline in HCC (adjacent control) since 2014 (Table 5; Figure 23). These findings show contrasting trends from initial reports on HCC recovery in the two ship grounding sites from 2014 to 2017, where USS Guardian site quadrats were recovering much faster than those in the Ming Pin Yu sites (Raymundo et al. 2018).

The significant recovery of hard corals in the Min Ping Yu site and the decline in the control plots of the USS Guardian site may be attributed to other factors that are not directly related to the grounding incidents. The Min Ping Yu grounding site is located in a relatively wave-sheltered portion of the North Atoll, while the USS Guardian grounding site is on the wave-exposed northern tip of the South Atoll, less than 2km away from Site 4 (Figure 2). On the atoll scale, HCC in the South Atoll exhibits a significant declining trend in terms of HCC (Table 3). This decline has been reported in Site 4 (Licuanan and Bahinting 2021) and attributed to possible eutrophication from lagoon waters draining into the reefs. The steep decline in HCC of the adjacent control plot between 2017 and 2018 suggests an acute disturbance (>10% decline in HCC over consecutive sampling points; Flower et al. 2017), and this portion of the reef does not appear to have recovered since then. To further understand the stressors that may drive these trends and develop appropriate management strategies, auxiliary sampling and analyses may be performed in these quadrats to focus on indicators of disturbance such as juvenile coral density and coral growth rate (Flower et al. 2017).

CONCLUSIONS

There is continuing decline in HCC for both shallow and deep monitoring stations. However, the decline was more apparent in the shallow areas of the South Atoll and in the deep areas of the North Atoll. These declines, coupled with increases in algae, sponges, soft corals, and corallimorphs in various sites, pose concerns and indicate the need for further analyses and studies. The patches of *Terpios* sp. in Station 3B has expanded to the deeper portions of the reef this year. The sponge was also documented within Station 3A and in front of the Ranger Station. The typhoons that recently passed the Sulu Sea, thermal stress, and possible eutrophication require actions that may be beyond the control of park authorities. Thus, vigilant patrols to safeguard the reefs from illegal fishers and ensuring that divers leave minimal impacts on the reefs must be prioritized to ensure that anthropogenic activities do not worsen the current condition.

RECOMMENDATIONS

1. Collect and/or process auxiliary data and conduct integrated analyses to diagnose possible chronic stressors that impact the South Atoll and Jessie Beazley, adapting the framework presented in Flower et al. (2017), specifically:

- Turf algae height
- Density of juvenile corals
- Fish biomass data
- Coral growth rate
- Coral cover according to functional groups (e.g., slow-growing, fast-growing, life-history strategy; see Edinger and Risk 2000, Darling et al. 2012)

2. Limit possible acute stressors in stations or sites exhibiting a decline in condition, for example, by continuing to limit diving activities near stations where HCC is declining.

3. Develop rapid-assessment or simplified monitoring protocols that will allow rangers to collect data or information on the status of the coral reefs immediately and more systematically after known and/or predicted acute disturbances (e.g., typhoons, bleaching events).

4. Utilize bathymetric maps and wave exposure data to glean more insights into how these affect the reefs' susceptibility to disturbance and its potential to be a refugia from chronic and acute stressors.

5. Explore substrate stabilization for stations with large rubble patches (e.g., Station 3B, Min Ping Yu grounding site) with the goal of enhancing successful recruitment and survival of juvenile corals.

REFERENCES

Asian Development Bank. 2014. State of the Coral Triangle: Philippines. ISBN 978-92-9254-518-5

Baum G, Januar I, Ferse S, Wild C and Kunzmann A. 2016. Abundance and physiology of dominant soft corals linked to water quality in Jakarta Bay, Indonesia. PeerJ 4:e2625; DOI 10.7717/peerj.2625

Bell JJ, Davy SK, Jones T, Taylor MW, Webster NS. 2013. Could some coral reefs become sponge reefs as our climate changes?. *Global Change Biology* 19(9), 2613–2624.

Chadwick-Furman N.E., Spiegel M. 2000. Abundance and clonal replication of the tropical corallimorpharian *Rhodactis rhodostoma*. Invertebrate Biology 119: 351-360.

Darling ES, Alvarez-Filip L, Oliver TA, McClanahan TR, Cote IM. 2012. Evaluating life-history strategies of reef corals from species traits. *Ecology Letters* 15(12):1378-1386.

Darling ES, McClanahan TR, Côté IM. 2013. Life histories predict coral community disassembly under multiple stressors. *Global Change Biology* 19(6), 1930–1940.

Dygico M, Songco A, White AT, Green SJ. 2013. Achieving MPA effectiveness through application of responsive governance incentives in the Tubbataha reefs. *Marine Policy* 41:87-94.

Edinger EN, Risk MJ. 2000. Reef classification by coral morphology predicts coral reef conservation value. *Biological Conservation* 92:1-13.

Eneria JA, Licuanan WY. 2017. Annual Monitoring Report 2017: Tubbataha Reef Benthos. Br. Alfred Shields FSC Ocean Research Center. De La Salle University: Manila.

Fabricius K and Dommisse M. 2000. Depletion of suspended particulate matter over coastal reef communities dominated by zooxanthellate soft corals. Marine Ecology Progress Series. Vol. 196: 157-167. DOI: 10.3354/meps196157

Flower J, Ortiz JC, Chollett I, Abdullah S, Castro-Sanguino C, Hock K, Lam V, Mumby PJ. 2017. Interpreting coral reef monitoring data: a guide for improved management decisions. *Ecological Indicators* 72:848-869

Fong P, Paul VJ. 2011. Coral Reef Algae. In Dubinsky A, Stambler N (Eds.), *Coral Reefs: An Ecosystem in Transition,* (pp. 241-272).

Fox HE, Mous PJ, Pet, JS, Muljadi AH, Caldwell RL. 2005. Experimental assessment of coral reef rehabilitation following blast fishing. *Conservation Biology* 19(1):98-107

Hammer Ø, Harper DAT, Ryan PD. 2001. PAST: Paleontological Statistics software package for education and data analysis. *Palaeontologica Electronica* 4:9pp.

Harii S, Hongo C, Ishihara M, Ide Y, Kayanne H. 2014. Impacts of multiple disturbances on coral communities at Ishigaki Island, Okinawa, Japan, during a 15 year survey. *Marine Ecology Progress Series* 509:171-180.

IUCN. 2017. International Union for the Conservation of Nature Issues Brief November 2017. Accessed at https://www.iucn.org/sites/dev/files/coral_reefs_and_climate_change_issues_brief_final.pdf

Kohler KE, Gill SM. 2006. Coral Point Count with Excel Extensions (CPCe): a visual basic program for the determination of coral and substrate coverage using random point count methodology. Computers and Geosciences 32:1259-1269

Licuanan WY, Bahinting SED. 2021. Changes in benthic cover in the South Atoll of Tubbataha Reefs due to possible eutrophication. *Philippine Journal of Science* 150:139-143

Licuanan WY, Robles R, Dygico M, Songco A, van Woesik R. 2017. Coral benchmarks in the center of biodiversity. *Marine Pollution Bulletin* 114:1135-1140

Luzon KS, Verdadero FXD, Mendoza YF, Licuanan WY. 2019. *A Handbook of Protocols for the Conduct of Reef Assessments in the Philippines*. Manila: De La Salle University Publishing House

McCook L, Jompa J, Diaz-Pulido G. 2001. Competition between corals and algae on coral reefs: a review of evidence and mechanisms. *Coral Reefs* 19(4): 400–417.

Mumby, P. J., A. Hastings, H. J. Edwards. 2007. Thresholds and the resilience of Caribbean coral reefs. Nature 450:98–101.

O'Neil JM, Davis TW, Burford MA, Gobler CJ. 2012. The rise of harmful cyanobacteria blooms: the potential roles of eutrophication and climate change. *Harmful Algae* 14:313-334

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). 2022. Annual tropical cyclone tracks – 2020 – Tropical Storm Vicky. *Philippine Department of Science and Technology (DOST) PAGASA.* Accessed at https://www.pagasa.dost.gov.ph/information/annual-cyclone-track.

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). 2022. Annual tropical cyclone tracks – 2021 – Typhoon Odette. *Philippine Department of Science and Technology (DOST) PAGASA.* Accessed at https://www.pagasa.dost.gov.ph/information/annual-cyclone-track.

Price NN, Martz TR, Brainard RE, Smith JE. 2012. Diel variability in seawater pH relates to calcification and benthic community structure on coral reefs. PLoS ONE 7(8): e43843.

Precht WF, Aronson RB, Swanson DW. 2001. Improving scientific decision-making in the restoration of ship-grounding sites on coral reefs. *Bulletin of Marine Science* 69(2):1001-1012

QGIS.org. 2022. *QGIS Geographic Information System*. QGIS Association. http://www.qgis.org

Raymundo LJ, Licuanan WY, Kerr AM. 2018. Adding insult to injury: ship groundings are associated with coral disease in a pristine reef. *PLoS One* 13(9):e0202939

RStudio Team. 2020. *RStudio: Integrated Development for R*. RStudio, PBC, Boston, MA URL http://www.rstudio.com/.

Smith JE, Brainard R, Carter A, Grillo S, Edwards C, Harris J, Lewis L, Obura D, Rohwer, F, Sala E, Vroom PS, Sandin S. 2016. Re-evaluating the health of coral reef communities: baselines and evidence for human impacts across the central Pacific. *Proceedings of the Royal Society B: Biological Sciences,* 283(1822), 20151985–.

Subade RF. 2005. Mechanisms to capture economic values of marine biodiversity: The case of Tubbataha Reefs UNESCO World Heritage Site, Philippines. *Marine Policy* 31:135-142.

Swierts T, Vermeij MJ. 2016. Competitive interactions between corals and turf algae depend on coral colony form. *PeerJ* 4:e1984.

van Woesik R, Gilner J, Hooten AJ. 2009. Standard operating procedures for repeated measures of process and state variables of coral reef environments. Melbourne: Coral Reef Targeted Research and Capacity Building for Management Program, The University of Queensland

Vermeij MJA, Smith JE, Smith CM, Vega Thurber R, Sandin SA. 2009. Survival and settlement success of coral planulae: independent and synergistic effects of macroalgae and microbes. *Oecologia* 159(2): 325–336. -7

Vollstedt S, Xiang N, Simancas-Giraldo SM, Wild C. 2020. Organic eutrophication increases resistance of the pulsating soft coral *Xenia umbellata* to warming. *PeerJ*, 8,e9182.

Wilkinson CR, Evans E.1989. Sponge distribution across Davies Reef, Great Barrier Reef, relative to location, depth, and water movement. *Coral Reefs,* 8(1), 1–7.

CHAPTER III. CORAL RECRUITMENT

Rowell Alarcon[1], Ma. Retchie Alaba[1], Joan Pecson[2]
Jeffrey David[1], Noel Bundal[1], and Kymry Delijero[2]

[1]Tubbataha Management Office
[2]World Wide Fund for Nature – Philippines

OVERVIEW

Coral recruitment and juvenile abundance are important indicators of reef resilience (Graham et al. 2015). Disturbances such as frequent coral bleaching events have been the cause of major losses of live corals globally, which may lead to changes in coral reef structure and functioning (Hughes et al. 2018). A healthy coral reef has the natural ability to recover from such disturbances.

Coral recovery is dependent on the survival and growth of remnant coral colonies and on coral recruitment. Understanding the dynamics of early life stages of corals can provide valuable insights on the effects of disturbances on coral community composition (Graham et al. 2011). Estimating coral recruitment on spatial scales particularly after perturbation could shed light on reef dynamics, hence the importance of monitoring that detects and predicts patterns of change on coral reefs.

METHODS

Data collection

A set of pre-determined random numbers generated in Excel was used as guide to determine the placement of the quadrats in the transect. In each transect, a diver randomly placed a 34 x 34 cm (0.12 m2) quadrat on the substrate to obtain representative samples of each station. The quadrat was marked with scale bars (2 and 5 cm) on both sides for size reference (Figure 25b).

Five photos were taken (four close-up shots at each corner and one full quadrat shot) in each quadrat, to provide more detailed images of juvenile corals (Figure 25c). Images were taken using a 20-megapixel camera with an underwater casing. A total of 40 quadrats per station were processed – 20 in the shallow and 20 in the deep areas.

For the grounding sites of the USS Guardian and Min Ping Yu, permanent monitoring plots measuring 4 x 4 meters (Figure 26) were laid following the method described by Licuanan et al. (2014). They were strategically positioned to capture the impacts of the ship groundings on the reefs. Of the three plots that were stablished in the USS Guardian grounding site, one quadrat was positioned in the impact zone (Quadrat 1), one in the buffer zone (Quadrat 2), and another in the control zone (Quadrat 3). While for the Min Ping Yu grounding site, the plots were set up on the fragments of corals left behind by the vessel. Quadrat 1 was established on the piles of small fragments (20-50 cm diameter), Quadrat 2 was placed on the large fragments (~1m diameter) of corals shattered by the rudder, and Quadrat 3 was positioned adjacent to the impact zone. A total of 10 quadrats were sampled in each plot. The quadrat was placed in the middle, at the four corners, and haphazardly (five spots), on each plot.

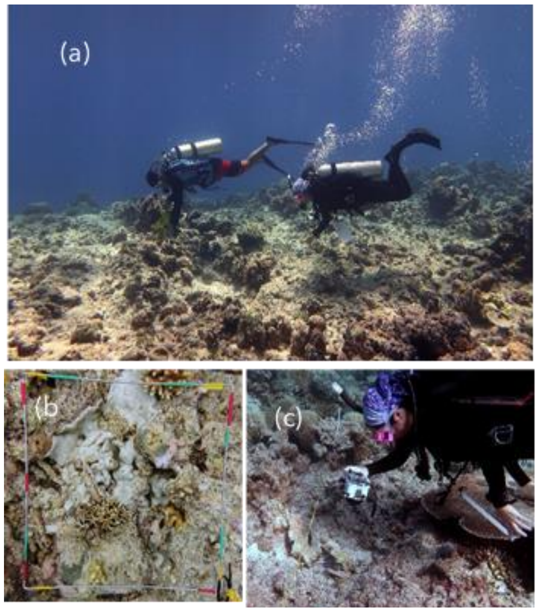


Figure 25. Coral recruitment sampling: (a) quadrat placed randomly within the transect; (b) close-up shot of the quadrat with scale bars, and (c) multiple photos taken using underwater camera.

Data processing

All photos were downloaded, grouped, and labeled according to transect and quadrat per site. Coral Point Count with Excel Extension® (CPCe) software was used for post-processing and scoring. Only coral colonies measuring <5cm were considered recruits (Burgess et al. 2009). In the CPCe software, each photo was calibrated using the 5cm scale bar located on each side of the quadrat. This scale bar provided an adequate size estimate of the coral recruits. The recruits were classified to the closest possible taxonomic level, usually the genus level. The Indo-Pacific Coral Finder version 3.0 and the Corals of the World were used as references for coral identification. Small coral fragments that were deemed remnants of adult corals were excluded.

Figure 26. Permanent quadrats of the two grounding sites established in 2014 (Licuanan et al. 2014).

Data analysis

The percentage of each hard coral (TAUs) was computed for every station and were plotted using Microsoft Excel. Estimates of coral recruit density were calculated for each quadrat as the number of recruits per 0.12m2. Differences in the densities of recruits across sites, depths, grounding plots, and years were tested using Analysis of Variance (ANOVA: Two-factor without replication, $p<0.05$). In addition, a paired t-Test (two sample of the mean, $p<0.05$) was performed to compare the differences of the recruit density across depths and its corresponding value from the previous year. The size frequency distribution of recruits was plotted for each site. A chi-square contingency table analysis was used to test whether the size frequency distribution of recruits differed among sites.

RESULTS

Shallow Areas

Percentage Cover

A total of 42 genera belonging to 15 coral families were recorded in the shallow area. The coral recruits in the shallow areas were dominated by brooder type of corals - Agariciidae (22.4%), Poritidae (19.8%) and Pocilloporidae (18.7%). Broadcast spawning corals from the family Acroporidae and Faviidae constituted 14.1% and 12.1% of the percentage cover, respectively (Figure 27). From 2018 to 2022 there was a decrease in the percentage cover of coral recruits in the shallow area.

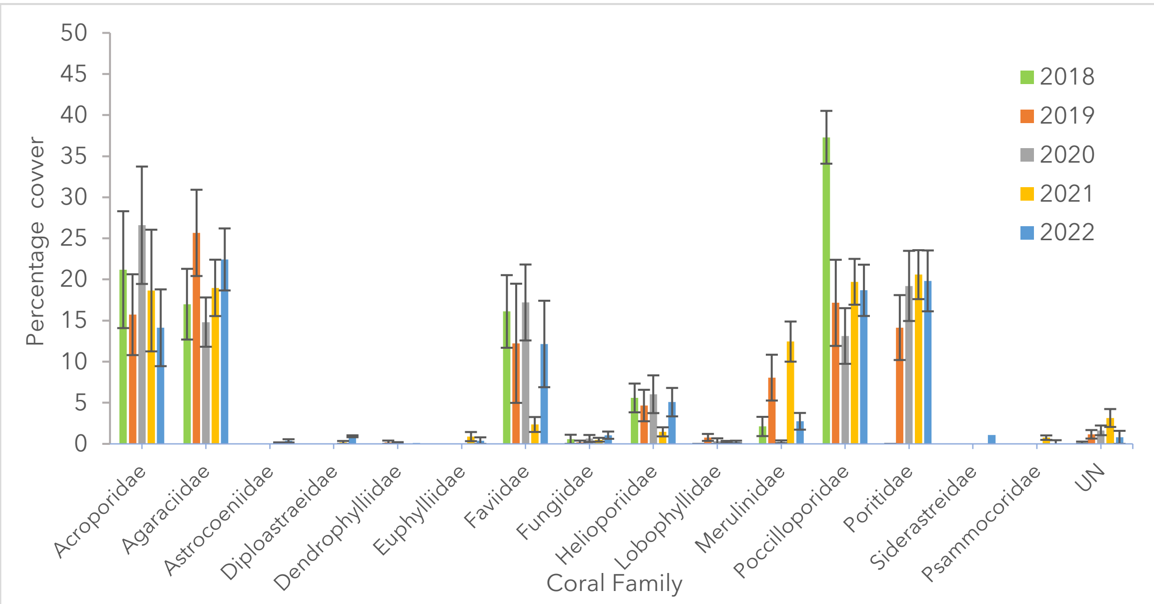


Figure 27. Mean percentage cover per family of all coral recruits in the shallow areas. Error bars represent standard error of the mean. Unidentified corals were group under the category UN.

Density

The average mean density of recruits was 52.9 ind/m^2 (±7.1 SE), lower than the 91.6 ind/m^2 (±9.8 SE) in 2021 (Table 6). Site 3 had the highest coral recruit density of 74.6 ind/m^2 (±1.8 SE) and Site 1 had the lowest density of 36.7 ind/m^2 (±0.9 SE). Most of the coral recruits belonged to the genus *Pavona*, *Porites*, and *Pocillopora*. The broadcast spawning corals e.g., *Acropora* branching, *Hydnopora* and *Favites,* as well as the rarely encountered genus *Acanthastrea* and *Galaxea,* were also observed this year. In Jessie Beazley, there was an increase in recruit density of the genus *Montipora* compared to the previous year. A large portion of *Montipora* beds in this area were likely damaged, providing space for coral recruits to attach to the substrate.

Table 6. Coral recruit density in the shallow areas

SITE	2018	2019	2020	2021	2022
Site 1	39.2 ±1.1 SE	99.2 ±3.2 SE	72.1 ±.04 SE	129.6 ±2.6 SE	36.7 ±0.9 SE
Site 2	50.0 ±1.1 SE	93.3 ±3.1 SE	62.5 ±.05 SE	60.0 ±1.1 SE	56.7 ±1.1 SE
Site 3	14.2 ±0.5 SE	59.2 ±2.0 SE	77.5 ±.03 SE	95.4 ±2.0 SE	74.6 ±1.8 SE
Site 4	19.2 ±0.7 SE	79.2 ±2.7 SE	50.8 ±.05 SE	81.7 ±1.6 SE	51.7 ±1.1 SE
Site 5					52.1 ±1.2 SE
Jessie Beazley	30.0 ±1.0 SE	28.3 ±0.9 SE	59.6 ±.02 SE	91.3 ±2.4 SE	45.4 ±1.0 SE
Mean Density	30.5	71.8	64.50	91.58	52.85

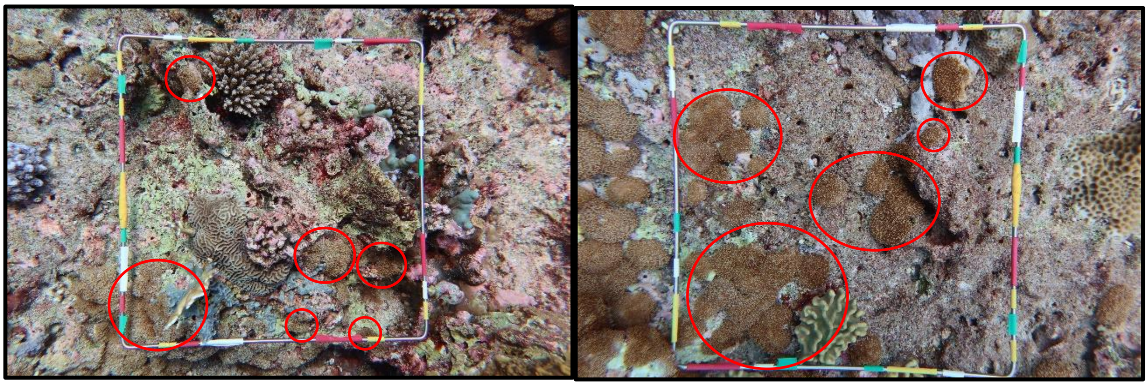


Figure 28. Images showing the presence of corallimorphs (in red circles) inside the quadrat (left image). There are more corallimorphs than coral recruits in Jessie Beazley B (right image).

Site 5 in South Atoll, the latest addition to the monitoring sites, had a coral recruit density of 52.1 ind/m^2 (±1.2 SE), where genus *Porites*, *Isopora*, *Pavona* and *Hydnopora* thrived. Overall, the coral recruit density in the shallow areas increased from 2018 to 2022. The coral recruitment density was statistically significant between years (ANOVA, $p<0.05$) but did not show significant difference between sites. In addition, corallimorphs (*Rhodactis sp.*) had a density of 99.2 ind/m^2 at Jessie Beazley B (Figure 28). Corallimorph is a type of anemone which typically thrives in coral areas that suffered from environmental degradation, usually man-made disturbances (Work et al. 2018).

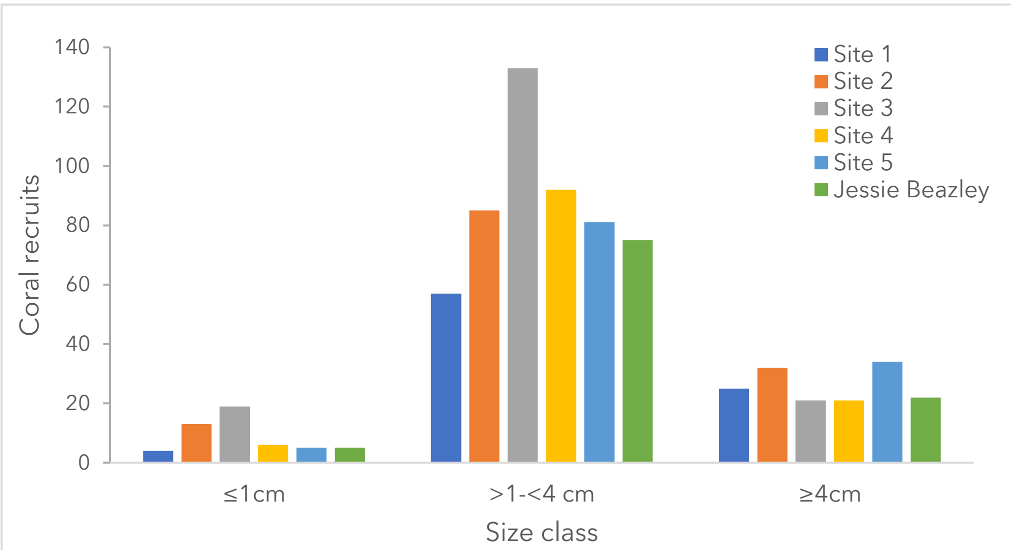


Figure 29. Size frequency distribution of coral recruits in the shallow areas.

Size-frequency distribution

Of the 730 individual recruits recorded across all sites, the frequency of newly settled corals (<1 cm in size) was the lowest at 7% (52 coral recruits). Most coral recruits (72%) were juveniles, while the mature recruits constituted 21%. As recruits mature (>4cm), only 20-30% would survive to become adults (Richmond 1997). Overall, the proportion of newly settled, juvenile, and mature coral recruits in TRNP follows the same pattern since 2018.

Deep areas

Percentage Cover

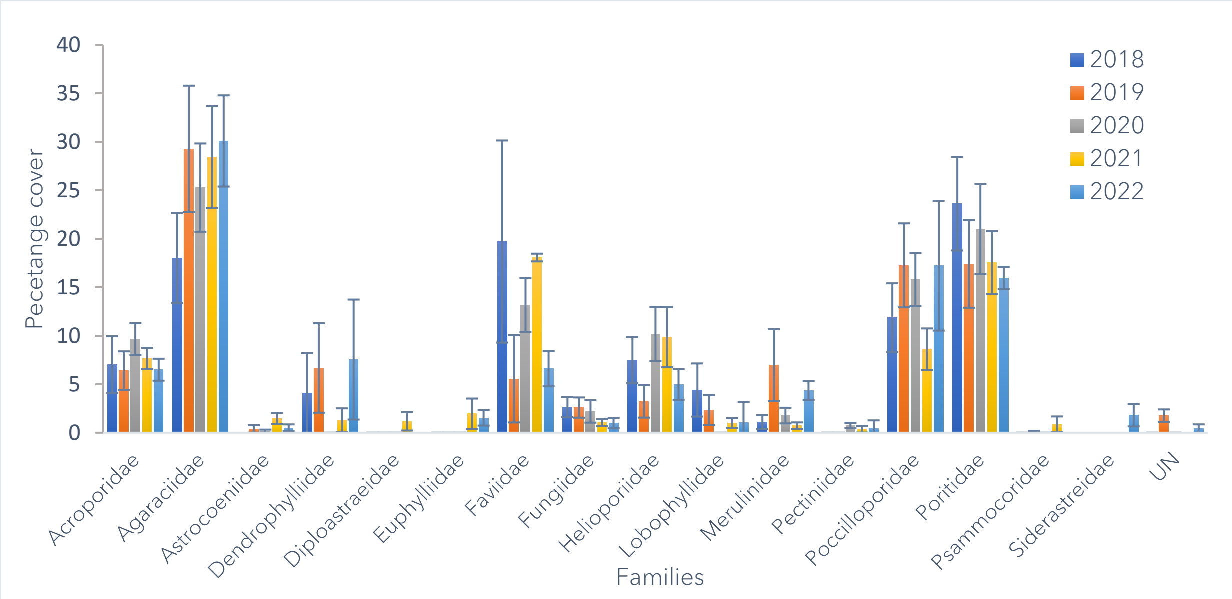


Figure 30. Mean percentage cover per family of all coral recruits at 10 meters. Error bars represent standard error of the mean. Unidentified corals were group under the category UN.

In the deep area, 37 genera belonging to 15 families were recorded. Since 2018, three coral families – Agariciidae, Poccilloporidae, and Poritidae – were the most dominant. Consistently, family Agariciidae had the highest percentage cover at 30.1%, followed by Pocilloporidae and Poritidae at 17.2% and 15.7%, respectively (Figure 30). Dominance of these families mimicked the shallow areas. Coral families recorded in the park changes every year (ANOVA $p<0.05$). For example, in 2021 and 2022, we observed Genus Stylocoeniella, which is rarely recorded in Tubbataha.

Density

The mean recruitment density of 52.7 ind/m^2 mirrored the density in the shallow areas. However, this value is lower compared to 105.6 ind/m^2 of 2021. Encrusting type of corals from genus *Pavona* and *Porites,* and branching *Pocillopora* dominated all the sites. This was followed by the genus *Acropora* and *Seriatopora*. It was noted that *Tubastrea,* which was rarely observed in other sites, outcompetes with sponges in Jessie Beazley. Site 3 remains with the highest density at 89.2 ind/m^2 (±2.1 SE) while Site 2 had the lowest density recorded at 30 ind/m^2 (± 0.7 SE) (Table 7). The deeper transect of Jessie Beazley B was mostly covered with corallimorph which was proliferating since 2018. Since 2021, the occurrence of corallimorphs at the deeper transect has rapidly increased and begun to seriously compete for space with coral recruits even in shallow area.

Table 7. Coral recruit density of all stations at 10 meters.

Ind/m²	2018	2019	2022	2021	2022
Site 1	45.0 (±1.3 SE)	45.8 (±1.0 SE)	72.5 (±1.6 SE)	82.5 (±1.4 SE)	47.9 (±0.9 SE)
Site 2	34.2 (±0.4 SE)	43.8 (±0.6 SE)	44.2 (±0.9 SE)	62.1 (±1.1 SE)	30.0 (±0.7 SE)
Site 3	72.5 (±2.1SE)	73.3 (±2.5 SE)	103.8 (±2.8 SE)	137.5 (±2.9 SE)	89.2 (±2.1 SE)
Site 4	53.3 (±1.5 SE)	59.6 (±1.6 SE)	86.3 (±2.1 SE)	117.1 (±2.7 SE)	47.9 (±0.9 SE)
Jessie Beazley	36.3 (±1.0 SE)	57.1 (±1.2 SE)	63.3 (±1.4 SE)	128.8 (±2.2 SE)	48.8 (±1.1 SE)
Mean Density	48.3	55.9	74.0	105.6	52.8

A total of 265.8 ind/m² of corallimorphs were recorded in Jessie Beazley B. They were observed to be competing against the coral recruits for space at the deeper areas of the reef. The density of corallimorphs in the deep is three times higher compared to the shallow area, posing a potential threat to the population of coral recruits at this station. Comparison of coral recruit density between years and across the sites shows significant difference (ANOVA, $p<0.05$).

This difference might be attributed to factors such as open spaces providing refuge to coral recruits. Brooder corals e.g., the genus *Porites*, *Pavona* and *Pocillopora,* dominated both depths. These types of corals have different life histories (Turner et al. 2017). They form fully developed larvae which are ready to settle on the substrate within days, unlike the planula production of broadcasting corals, which usually takes longer to settle (Ritzon-William 2009). The brooders corals also have extended spawning pattern (Goodbody-Gringley et al. 2021) compared to other coral genus that are not frequently observed, e.g., genus *Favites* and other massive forming coral genus in Tubbataha.

Juvenile corals constituted 62% of the recruits recorded across all stations, while the newly-settled and mature corals comprised 6% and 32%, respectively (Figure 31). The Chi-square test for size-frequency distribution showed a significant difference only in Jessie Beazley (ANOVA, $p<0.05$), where fewer coral recruits were observed this year compared to the previous year. The deeper areas may be affected by the proliferation of competitors such as the corallimorphs in Jessie Beazley B and soft corals in Jessie Beazley A. These faster growing organisms hinder the survival of coral recruits.

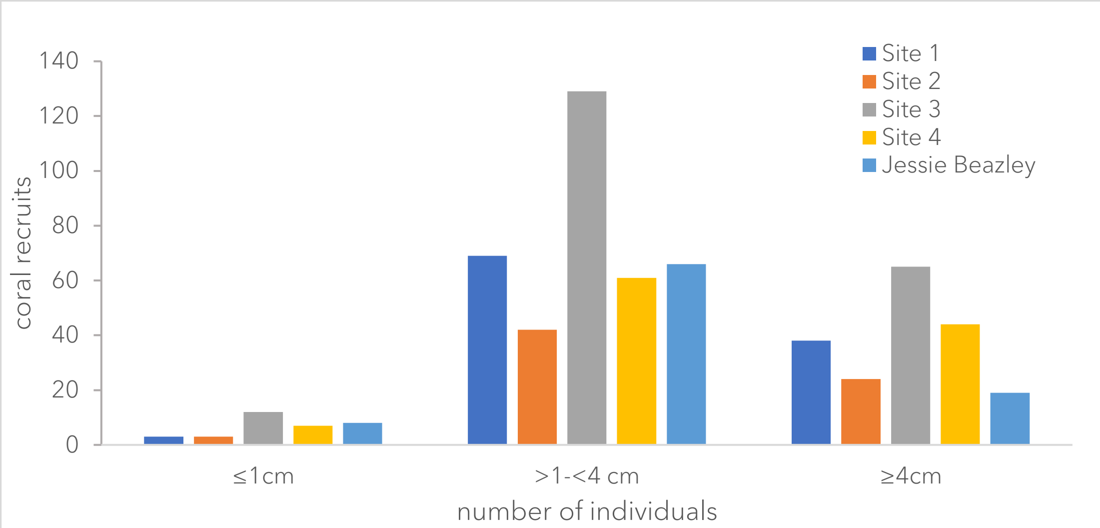


Figure 31. Size-frequency distribution of coral recruits in the deep areas.

Ship Grounding Sites

Density in USSG

The overall mean density recorded at the USS Guardian grounding site was 35.6 ind/m^2 which was 20% lower than in 2021 (40.8 ind/m^2). The highest density was recorded in the control zone (54.2 ind/m^2), while the buffer zone and impact zones had 35 ind/m^2 and 17.5 ind/m^2, respectively. The density of coral recruits in the

monitoring plots were generally lower than the previous year, particularly in the impact and buffer zones, although the difference between plots is not significant. The plots were mostly dominated by genus *Pocillopora*, *Porites* and *Pavona*. Generally, recruit densities at the USSG grounding site shows an increasing trend over the years.

Density in MPY

The average density in the MPY grounding site (29.4 ind/m^2) was lower than in the USSG grounding site (35.6 ind/m^2). In the large fragments plot, an increase by 76% from 27.50 ind/m^2 (2021) to 48.33 ind/m^2 (2022) was observed, while both small fragments and adjacent plots decreased by 50% and 35%, respectively. Most of the plots were dominated by genus *Porites, Pocillopora, Pavona,* and *Isopora*, while some plots were also observed to have more branching *Acropora*. This is expected, as it mimics the coral composition of the area adjacent to the grounding site. There is significant difference in the coral recruit densities between years (2014 to 2022) (ANOVA, $p<0.05$), but not between plots.

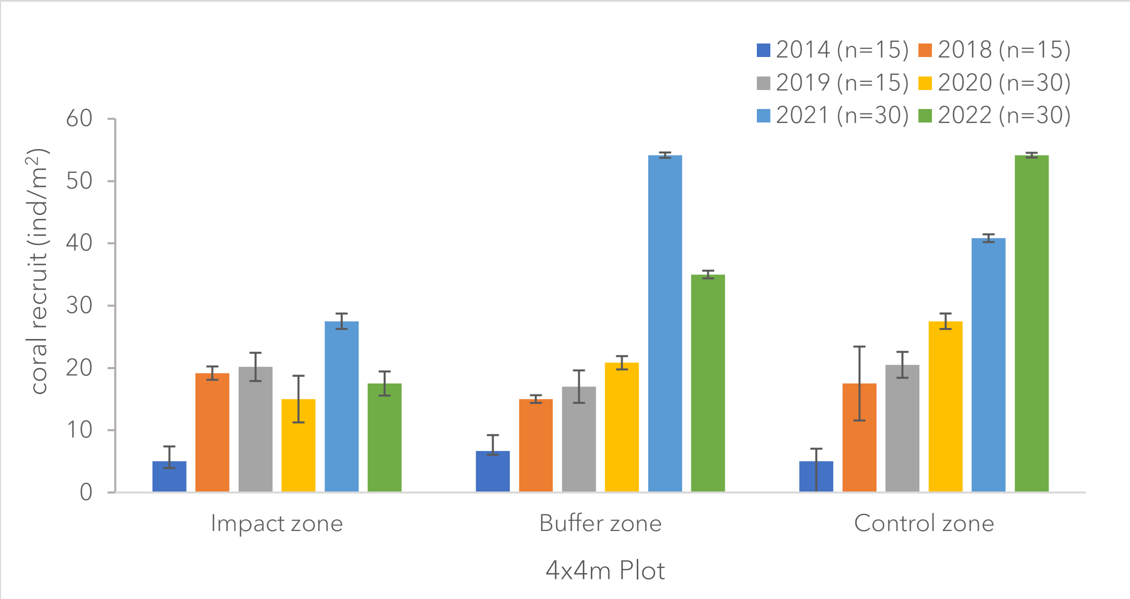


Figure 32. Coral recruit density of the three plots at USSG grounding site. Error bars represent standard error of the mean.

DISCUSSION

An overall mean density of 52.85 ind/m^2 was recorded in the shallow areas, significantly lower than in 2021 (91.58 ind/m^2) (paired *t*-Test, $p<0.05$). The deep area had a mean density of 52.75 ind/m^2, two times lower compared to 2021 (105 ind/m^2)(paired *t*-Test, $p<0.05$). The density of coral recruits in Tubbataha was higher compared to other tropical countries employing similar sampling methods. This year's recruit density was two times higher at the same the depth than in Tioman Island in Malaysia (25.92 ind/m^2) (Muhhanmad et al. 2017).

The average coral recruit densities in the shallow and deep areas this year are within the range of values from 2018 and 2020. In 2021, the coral recruit density at both depths were particularly high, possibly due to the disturbances in the second half of 2020, e.g., bleaching incident in July 2020 and Typhoon Vicky in December 2020. Although typhoon Vicky did not directly hit Tubbataha (PAGASA 2020), its intensity exacerbated the monsoon winds, bringing strong waves that battered the reefs. As the waves continuously struck the reef, corals and other benthos may have been broken or removed, leaving open spaces for coral recruits to occupy. This could have created opportunities for coral recruits to double their population, thus a high density of recruits was recorded in the 2021 survey. This may be viewed as a positive development, showing the reef's capability to replenish its population after disturbances.

Shallow Areas

In the shallow areas, the brooder coral families of Agariciidae, Poritidae, and Pocilloporidae were the most dominant. In the previous years, the broadcast spawning coral from the family Acroporidae consistently dominated the monitoring sites, as expected in shallow reef areas. The change in dominance of coral family this year is a possible representation of the healthy fecundity of brooder corals this year.

Over the years, the trend in coral recruit density appears to be increasing, influenced by the consistently high recruit density observed in Sites 3 and 4. These areas in South Atoll often have open spaces with compacted rubbles, a favorable substrate condition for opportunistic brooder corals. Some brooder type of corals, e.g., genus Pavona and Pocillopora, have extended spawning behavior (Edmunds et al. 2011). Their recruits tend to have high survival rates in disturbed reefs than broadcast spawning corals (Glynn and Colley 2008).

Deep Areas

In the deep areas, coral recruits were likewise dominated by brooder corals, *e.g.,* genus *Porites*, *Pocillopora* and *Pavona*. This type of corals tends to reflect the local abundance of fecund colonies (Edmund et al. 2011). They reproduce multiple times a year in contrast to broadcast spawning corals, which usually spawn only once a year (Harrison and Wallace 1990). Other factors such as water circulation (Oprandi et al. 2019), dominance of parent colonies within the area, or self-recruitment also affect coral recruitment (Koester et al. 2021). This year, coral recruit densities in Site 3 was almost twice the value of the other sites. This area is mainly composed of compacted rubbles, a suitable substrate for the coral recruits to thrive.

Jessie Beazley A has the lowest coral recruit density because a large portion of its deep site was covered in soft corals, dominating the substrate suitable for coral recruitment. Nevertheless, from 2018 to 2022, both depths showed an increasing trend, suggesting continuous coral propagation in the area.

Density: Shallow vs Deep

The average density and coral genera pattern observed this year in the deep and shallow areas were almost similar. The dominance of coral recruits in an area may be influenced by a wide range of ecological processes such as competition, succession, and disturbance (Harrison and Wallace 1990). In general, the brooder type of corals (genus *Porites* and *Pavona*) consistently overtook the broadcast type e.g., genus *Acropora* and *Favites*, which may be related to succession and competition among corals (Adjeroud et al. 2016). During its early life stage, a coral is more sensitive to environmental factors compared to when it becomes an adult (Moore 1974). The high succession and competition rates of some brooder type of corals, e.g., *Pocillopora acuta,* can be the reason why they dominate this year. They appear to be more robust and can maintain high recruitment under climatic threats (Barh et al. 2020). On the other hand, some broadcast type of coral, e.g., genus *Acropora,* are dependent on high-light conditions but do not thrive well in strong current (Hancock et al. 2021).

Size Distribution Pattern

A similar size frequency distribution pattern was observed at both depths across the years. Newly-settled coral recruits comprised around 6-7%, the juvenile coral recruits ranged between 62-72%, and 21-32% of the population were mature recruits. This proportion supports findings that suggest that the frequency of coral recruit decreases as the size class increases (Moulding 2005). From the total recruit population accounted each year, we can presume that about 30% are likely to develop into adult colonies. Survival rates of coral recruits may vary depending on several factors. The coral recruits that reached maturity stage (≥4cm) were mostly sexually mature, capable of reproducing asexually or through fusion (Raymundo and Maypa 2004). Furthermore, the chance of survival is higher amongst mature coral recruits as they became more tolerant to stressor than the smaller recruits (dela Cruz and Harisson, 2020). This may be related to the 30% mature population observed in Tubbataha in terms of survival of coral recruitment. In-depth studies that identify coral genus among size classes, as well as coral genus classification that contributes to recruitment success rates may provide insights to determine the capacity of the reef to recover. These studies will also generate understanding of ecological changes in hard coral communities under continuous environmental stress.

Density in the Grounding Sites

The average density in the MPY grounding site (29.4 ind/m^2) was lower than in the USSG grounding site (35.6 ind/m^2). The lower coral recruit density in MPY was attributed to the movement and accumulation of sand and rubbles particularly at the small and large fragments plots. The presence and movement of sand and rubble likely inhibited the survival of recruits at the impact zone (Bak & Engel 1979). The adjacent plot was in the shallower portion of the reef, which is occasionally exposed to strong waves compared to the other two plots. This hinders coral recruits from thriving and developing into bigger colonies. This was further confirmed by thriving stress-tolerant coral genus, e.g., encrusting *Pavona*, *Porites* and *Isopora,* which were observed dominating portions of the plots with favorable surface areas, e.g., metal pegs and sheltered crevices.

An overall decrease in density was also observed in the USSG grounding site. The impact zone had the lowest recruit density recorded among the three plots, which may be attributed to the larger-sized dislodged coral rubbles that damaged the coral recruits. This year, the control zone had the highest density. This plot continued to show an increasing trend in coral recruit density from 2014-2022. The variation of recruit densities at each plot did not show a significant difference.

CONCLUSION

Consistent patterns of coral recruitment were observed throughout the years. Coral recruitment densities showed an increasing trend in the monitoring sites and grounding sites in Tubbataha. Despite the major disturbances which took place in most of the sites, the reefs may have a high potential to recover, as indicated by the continuous propagation of corals in the natural substratum. The combination of high turnover of coral recruit population of the brooder type combined with habitat-forming broadcast type of corals are important to reshape the coral population in the park. Thus, brooder and broadcast types of corals play an important role in replenishing the coral population in Tubbataha.

RECOMMENDATIONS

1. Continue employing randomized quadrat sampling to provide quality data of the actual recruit population in an area

2. Identify coral recruits to the genus level and among size classes to determine the success rate and proportion of brooder and long-lived coral recruits

3. Tag five to 10 coral recruits per plot, particularly coral recruits belonging to the mature size class (≥4cm) in the fixed plot of the grounding sites. This will be monitored every year to provide data recovery and growth rate of corals found in the grounding sites.

REFERENCES

Adjeroud M, Kayal M, Penin L. 2016. Importance of Recruitment Processes in the Dynamics and Resilience of Coral Reef Assemblages. In: Rossi S., Bramanti L., Gori A., Orejas C. (eds) Marine Animal Forests. Springer, Cham. https://doi.org/10.1007/978-3-319-21012-4_12

Bak, RPM, Engel MS. 1979. Distribution, abundance, and survival of juvenile hermatypic corals (Scleractinia) and the importance of life history strategies in the parent coral community. Mar. Biol. 54, 341–352 . https://doi.org/10.1007/BF00395440

Bahr KD, Tran T, Jury CP, Toonen RJ 2020. Abundance, size, and survival of recruits of the reef coral *Pocillopora acuta* under ocean warming and acidification. PLoS ONE 15(2): e0228168. https://doi.org/10.1371/journal.pone.0228168

Burgess SC, Osborne N, and Sfiligoj KB. 2010. Environ Monit Assess. 171: 345. https://doi.org/10.1007/s10661-009-1282-1

dela Cruz DW, Harrison PL (2020) Enhancing coral recruitment through assisted mass settlement of cultured coral larvae. PLoSONE 15(11): e0242847. https://doi.org/10.1371/journalpone.0242847

Edmunds, Peter & Cumbo, Vivian & Fan, Tung-Yung. 2011. Effects of temperature on the respiration of brooded larvae from tropical reef corals. The Journal of experimental biology. 214. 2783-90. 10.1242/jeb.055343.

Gardner TA, Cote IM, Gill JA, Grant A, Watkinson AR. 2005. Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. Ecology. 2005;86:174–184. doi: 10.1890/04-0141. [CrossRef] [Google Scholar]

Graham N, Jennings S, MacNeil MA, Mouillot D, Wilson SK. 2015. Predicting climate-driven regime shifts versus rebound potential in coral reefs. Nature 2015;518:1–17. pmid:25607371.

Graham N, Nash KL, Kool JT. 2011. Coral reef recovery dynamics in a changing world. Coral Reefs 2011; 30:283–94. https://doi.org/10.1007/s00338-010-0717-z

Goodbody-Gringley G, Scucchia F, Ju R, Chequer A, Einbinder S, Martinez S, Nativ H and Mass T (2021) Plasticity of Porites astreoides Early Life History Stages Suggests Mesophotic Coral Ecosystems Act as Refugia in Bermuda. Front. Mar. Sci. 8:702672. doi: 10.3389/fmars.2021.702672

Hancock, JR, Barrows AR, Roome TC, Huffmyer AS, Matsuda SB, Munk NJ, Rahnke, SA, Drury C. 2021. Coral husbandry for ocean futures: leveraging abiotic factors to increase survivorship, growth, and resilience in juvenile *Montipora capitata*. Mar. Ecol. Prog. Ser. 657, 123–133. https://doi.org/10.3354/meps13534.

Harrison P L and Wallace C C. 1990. Reproduction, dispersal and recruitment of scleractinian corals pp 133–207 in Z. Dubinsky, editor. Coral reefs. Elsevier Science, Amsterdam,the Netherlands.

Hughes TP, Kerry JT, Baird AH, Connolly SR, Dietzel A, Eakin CM, et al. 2018. Global warming transforms coral reef assemblages. Nature 2018; 556:492–6. https://doi.org/10.1038/s41586-018-0041-2 PMID: 29670282

Koester A, Ford AK, Ferse SCA, Migani V, Bunbury N, Sanchez C. 2021. First insights into coral recruit and juvenile abundances at remote Aldabra Atoll, Seychelles. PLoS ONE 16 (12): e0260516. https://doi.org/10.1371/journal. pone.0260516

Moore S, Dwyer R. 1978. Effects of oil on marine organisms: a critical assessment of published data. Water Research. 1974; 8(10):819–27.

Moulding AL. 2004. Coral Recruitment Pattern in Florida Keys. Rev. Biol. Trop. (Int. J. Trop. Biol. ISSN-0034-7744) Vol. 53 (Suppl. 1): 75-82, May 2005 (www.tropiweb.com)

Muhammad F, Mohd H, Saad S, Mukai Y and Zuhairi A. 2017. Relationship between adult abundance and successive coral recruitment density in the Tioman Island Marine Park, Malaysia, Zoology and Ecology, 27:3-4, 328-334 https://doi.org/10.1080/21658005.2017.1396793

Oprandi A, Montefalcone M, Morri C, Benelli F, and Bianchi CN. 2019. Water circulation, and not ocean acidification, affects coral recruitment and survival at shallow hydrothermal vents, Estuarine, Coastal and Shelf Science, Volume 217, Pages 158-164, https://doi.org/10.1016/j.ecss.2018.11.017.

Turner, JA, Thomson DP, Cresswell AK., Trapon, M, and Babcock, RC. 2018. Depth-related patterns in coral recruitment across a shallow to mesophotic gradient. Coral Reefs 37, 711–722. doi: 10.1007/s00338-018-1696-8

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). 2022. Annual tropical cyclone tracks – 2020 – Tropical Storm Vicky. Philippine Department of Science and Technology (DOST) PAGASA. Accessed at https://www.pagasa.dost.gov.ph/information/annual-cyclone-track.

Richmond RH. 1997. Reproduction and recruitment in corals: critical links in the persistence of reefs. Life and death of coral reefs Chapman & Hall, New York. 1997:175–97.

Veron JEN, Stafford-Smith MG, Turak E. and DeVantier LM. 2016. Corals of the World. Accessed 18 Oct 2022. http://www.coralsoftheworld.org/page/home/

Work, TM, Aeby, GS, Neal, BP. 2018. Managing an invasive corallimorph at Palmyra Atoll National Wildlife Refuge, Line Islands, Central Pacific. *Biol Invasions* **20**, 2197–2208 (2018). https://doi.org/10.1007/s10530-018-1696-1

CHAPTER IV. SEABIRDS

Arne Erik Jensen[1], Angelique M. Songco[2], Ma. Retchie Alaba[2]

[1]Wild Bird Club of the Philippines[1]
[2]Tubbataha Management Office[2]

OVERVIEW

Objectives

The objectives of the seabird monitoring and inventories at Tubbataha Reefs Natural Park (TRNP) are:

- Determine developments and trends in seabird populations, the condition of habitats, and emerging threats;
- Identify management actions to respond to emerging threats to seabirds;
- Enhance the method and skills of TMO staff and partners in seabird monitoring;
- Prepare the annual monitoring and inventory report on the seabirds and their habitats;
- Formulate recommendations to improve the conservation and management of the seabirds.

Fieldwork

The field work was divided into two periods as avifauna inventory was part of other biodiversity surveys. The team arrived at the Ranger Station on 25 April and inventories were conducted from 26 April to 27 April at Bird Islet and on 30 April, from 9:00am to 12 noon (high tide) at South Islet. Distance counts were carried out at Bird Islet on 3 May.

Prior to the fieldwork, an online discussion was held between TMO staff and Mr. Arne Jensen on actions taken in response to the 2021 recommendations. TMO Research Officer, Ma. Retchie Alaba, reviewed the inventory methods and assigned tasks for the field work. The marine park rangers' (MPR) monitoring and inventory reports from June 2021 to May 2022 were also evaluated.

Weather

The weather was dominated by limited northeasterly wind but occasionally strong wind associated with thunderstorms and rain showers (26-27 April). On 30 April there was no wind and no cloud cover. Daytime temperatures averaged 29° Celsius.

Seabird Inventory Team

The 2022 constituted of 14 participants headed by the Park Superintendent (PASu) of TRNP including six TMO staff and MPRs, two researchers from WWF-Philippines, one researcher from University of the Philippines – Cebu, and four local volunteers (Annex 1). The team of MPRs consisted of three from the Philippine Coast Guard, one from the Philippine Navy, one from the Municipal Government of Cagayancillo, and four from TMO. Due to the economic constraints of TMO, the avifauna consultant and volunteers from outside of Palawan were unable to join the survey. Headed by Captain Ronald de Roa, M/Y Navorca of WWF Philippines transported the team to Tubbataha.

METHODS

The fieldwork followed methods for distance count monitoring and for inventories of breeding seabirds established and used since 2004 (Jensen 2004). For details of methodologies, see the 2020 inventory report.

The counts of the breeding bird populations represent a combination of different count methods. These include direct day-time inventories of adults, immatures, juveniles, pulli, eggs, and nests. To determine the total seabird population, an afternoon count of boobies flying in to roost was conducted from 4:30pm to 6:30pm on 26 April at Bird Islet (Annex 5) and on 30 April at South Islet (Annex 6). Standardized measurements of the Bird Islet and vegetation development were also carried out.

Major equipment used were handheld binoculars (10 x 50), spotting scopes (20-60 x), GPS, and cameras. The patrol boat and dinghy were also used to conduct the distance counts.

Taxonomic treatment and sequencing follow the IOC World Bird List Version 12.2 (10 July 2022) and Wild Bird Club of the Philippines Checklist of Birds of the Philippines 2022.

Calculation of land area and vegetative cover

Photos of permanent photo documentation sites in Bird Islet and South Islet were taken (Annex 8). These sites were established in 2004 to measure changes in land area and in vegetation. GPS readings were taken measuring the land area of Bird Islet at high tide.

Vegetative cover was monitored by conducting a census of the condition of trees and other vegetation on the islets. Trees, all planted saplings mostly of *Pisonia grandis* (Anuling, Bird-catcher Tree, Lettuce) were almost all gone due to and impacts from the population of Red-footed Booby *Sula sula.* The condition of trees is classified as either in optimal (good), moderately deteriorating (fair) or severely deteriorating (bad) condition, and lastly, as dead. For photos of beach forest species, see Jensen et al. 2019. The vegetation inventory of 2022 was carried out using the same methodology as all other years and the trend over time is therefore comparable.

Calculation of breeding populations

The methods used to calculate the seabird populations followed the previous years' approach:

- Day time direct counts of birds, nests, and eggs;
- In-flight data of Red-footed Booby and, Brown Booby *Sula leucogaster*;

- Dawn count (5 am) of Brown Booby and Red-footed Booby populations at the 'Plaza';
- Count of Great Crested Tern *Thalasseus bergii* and Brown Noddy *Anous stolidus* along the shoreline at high tide.
- Assessment of the MPRs quarterly inventory results enabling calculations and estimations of the annual breeding populations of the seabirds.

The result of the fieldwork was compared with several data sets: the WWF Philippines data from 1998 to 2004; the annual inventory results from 2004 to 2021; and data gathered by MPRs from June 2021 to May 2022. The data from 1981 to 2013 were analyzed in detail by Jensen and Songco (2016) and published in the Journal of Asian Ornithology (FORKTAIL 32 (2016): 72–85). Other analyses are found in the 28-year seabird population development report published in 2009, in 2004 to 2006, and in the 2010 to 2020 seabird field reports (see Jensen 2004 to 2006 and 2009 to 2016, and Jensen *et al.* 2017-2021).

RESULTS AND DISCUSSION

Monitoring of Changes in Land Area

Independent sets of measurements were taken using two GPS units. The measurements were taken at high tide along the shoreline as the vegetation line previously used as a reference has disappeared. Due to this shift in methodology, data sets from 2016 onwards are not comparable to the previous years'. Measurements in May 2021 were taken during a springtide of 1.6 meters compared to measurements taken during high tides of around 0.9 meters the previous years. Therefore, a comparison of the land area is only indicative.

Bird Islet. The land area has decreased by 4.8% - from 14,009 m2 in 2021 to 13,334 m2 in 2022. Compared to the 18,760 m2 land area in 1981, (Kennedy 1982), the decrease is to about 6,750 m2 or 29% (Table 8). The circumference of the islet measured along the high tide line was 494 meters compared to 513 meters in 2021, or a decrease by 4%. As in 2021, erosion was observed particularly at the northeast part of the islet. The 'Plaza', defined as the central area of the islet dominated by compacted barren soil with very limited vegetation (Figure 33), was measured to be 7,014 m2 representing a more than 100% increase compared to 2021 (3,253 m2). The circumference of the 'Plaza', however, is not demarcated and there are uncertainties in the measurement data.

Table 8. Approximate changes in the land area of Bird Islet from 1911 to 2022. Source: Worcester 1911, Kennedy 1982, Heegaard and Jensen 1992, Manamtam 1996, WWF Philippines 2004 and Tubbataha Management Office 2004 to 2022.

Year	Land area (length x width)/ circumferenc (m)	Land area (high tide) (m^2)	Open area ("Plaza") (m^2)	Major sandbars position and condition	Erosion area
1911	400 x 150	60,000	No data	>40,000 m^2 (?)	No data
1981	268 x 70	18,760	18,000	NW, SE	South coast
1991	>220 x 60	> 13,200	>8,000 (est.)	NW, SE	South coast
1995	265 x 82	21,730	8,000 (est.)	NW, SE	South coast
2004	219 x 73	17,000	>1,100 (est.)	NW: Stable SE : Decrease	South coast
2005	No data	15,987	>4,000 (est.)	NW, SE: Stable	South coast
2006	No data	14,694	7,900 (est.)	NW, SE: Stable	South coast
2007	No data	13,341	8,000 (est.)	NW, SE: Stable	South coast
2008	No data	12,211	< 8,000	NW: Decreasing SE : Stable	South coast
2009	No data	10,557	< 7,000	NW: Eroded SE : Decreasing	West coast
2010	No data	11,038	4,367	NW: Eroded SE : Stable	South coast
2011	No data	12,968	4,000 (est.)	NW: Stable SE : Stable	Northeast coast

2012	590	12,494	3,892	NW: Stable SE : Stable	Northeast coast
2013	548	10,955	4,840	NW: Decreasing SE : Stable	Northeast coast
2014	503	>10,220	4,124	NW: Decreasing SE : Stable	Northeast coast
2015 [1]	<561	<13,408	3,279	NW: Stable SE : Stable	Northeast coast
2016 [2]	590	15,649	4,513	NW: Disappeared SE : Decreasing	Northeast coast
2017 [3]	588	15,307	6,704	NW: Disappeared SE : Decreasing	Northeast coast
2018 [4]	568	15,373	2,572	NW: Two small sandbars off the coast SE : As above	Northeast Coast
2019 [5]	574	17,987	6,202	NW: Two small sandbars off the coast SE: Three sandbars off the coast	None compared to 2018
2020	610	19,297	5,826	NW: Two stable sandbars SE: One stable and one expanding sandbar	No erosion
2021 [6]	>513	>14,009	3,253		Erosion of NE-part
2022	494	13,334	7,014		

		NW: stable sandbars SE: Stable sandbars NW: one stable sandbar SE: One stable sandbar	Erosion of northern coast

Note 1: In 2015, new GPS equipment were used. Detailed comparison with previous year's data is therefore not possible.

Note 2: Measurement approach changed from measurement along shore vegetation line to measurement along the high tide line. Data can therefore not be compared.

Note 3: Expansion in area of Plaza is due to inclusion of former forested areas.

Note 4: Reduction in area of Plaza is due to expansion in grass areas.

Note 5: Expansion in area of Plaza is due to reduction in grass areas. Change in land area may have been caused by the variation in the route walked as this is not physically demarcated.

Note 6: Reduction in area of Plaza is due to expanding grass areas. Change in land area may have been caused by measurements taken during springtide of 1.6 meters.

Figure 33. Landscape of 'Plaza', Bird Islet, May 2022. Photo: Rowell Alarcon/TMO

The land area development over 111 years at Bird Islet since Dean C. Worcester's assessment in June 1911 shows a continued decline from approximately 60,000 m^2 to 18,760 m^2 in 1981, a time span of 71 years (Kennedy 1981). The average decline in land area per year by 420 m^2. Over the past 41 years, from 1981 to 2022, there has been a further loss to about 13,334 m^2 square meters or about 132 square m^2 meters per year. Bird Islet shrunk by 76% and using a linear prognosis, it may take only about 70 years before Bird Islet disappears, Figure 34. A visible signs of the decline are eroded coastlines and increased areas of eroded cemented calcite guano sandstone that used to be the core area at the center of the islet ('Plaza').

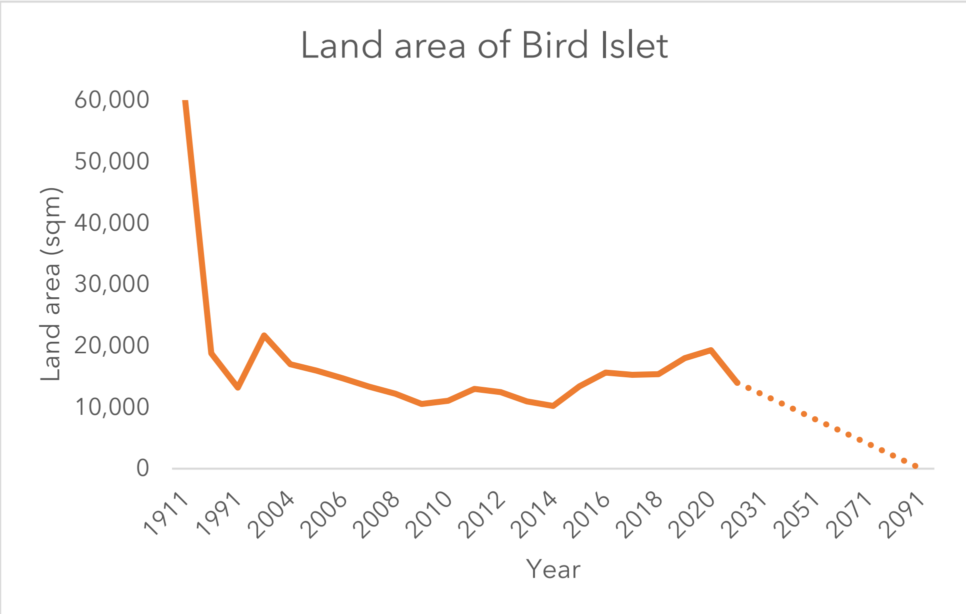


Figure 34. Land area development of Bird Islet from 1911 to 2022, and projected development until 2091.

South Islet. South Islet was originally part of a large sandbar until a circumferential concrete seawall was constructed in the 1980s (Kennedy 1982) to accommodate a lighthouse. In 2019 an embankment and construction of a new seawall and lighthouse changed the size of the islet, Figure 35. The circumference of the islet in 2020 was 307 meters (292.3 meters in 2019) compared to 230 meters in 2018, or an increase by 33.4%. The land area is 5,222 m^2 (5,585 m^2 in 2019) compared to 2,884 m^2 in 2018. The 81% variation represents the reclamation of additional marine areas. Typhoon Odette in December 2021 caused at the northwestern portion of the islet the new seawall to disassociate from the old wall.

Figure 35. Aerial photo of South Islet in 2002. Photo: Bo Mancao.

Monitoring of Changes in Habitats

The total number of beach forest trees at Bird and South Islets from 2006 to 2016 was around 354 trees, classified as being in very good condition (229 trees on Bird Islet and 125 trees on South Islet). Since 2016 all trees have died.

As part of reforestation efforts, beach forest saplings were planted in small numbers from 2017 to 2019 on Bird Islet. In June 2020, TMO planted a total of 430 saplings, 329 in Bird Islet and 101 in South Islet. By April 2022, on Bird Islet, there was only eight saplings left, all enclosed in protective bamboo guards. On South Islet, all saplings died due to salt spray during rough weather, a phenomenon not previously observed in South Islet. Extreme heat and drought during the latter half of 2021 in combination with lack of shade and frequent de-leafing by Red-footed Booby, may be among the causes. For further details, see the 2021 inventory report, Annex 3. In 2022 the TMO started its own nursery in Puerto Princesa based on stem-cut Abok-abok *Heliotropium foertherianum* and Anuling *Pisonia grandis* imported from Cagayancillo to Puerto Princesa.

Bird Islet. The baseline was 229 beach forest trees recorded in 2006. In June 2019, 12 saplings of Anuling were planted and 329 saplings in June 2020.By April 2022 eight saplings had survived in protective bamboo guards, Appendix 8 and Appendix 14, and Figure 36.

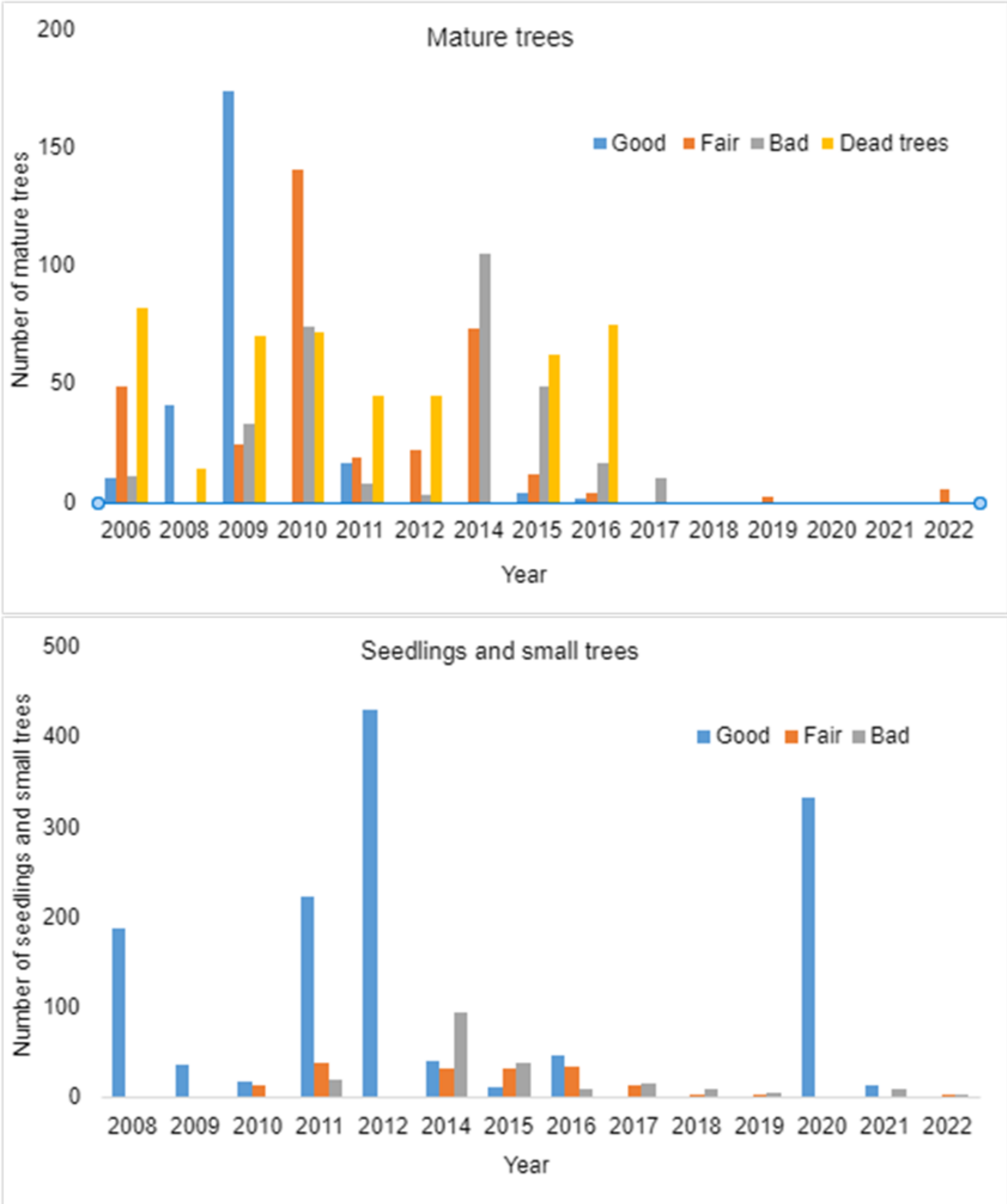


Figure 36. Status of vegetation in Bird Islet from 2006 to 2022.

South Islet. Until 2009, the beach forest comprising about 125 trees was in optimal condition, with several trees as high as about 30 feet. By 2014, trees in bad condition dominated the vegetative cover of the islet. In 2019, five remaining dying trees were removed during the reconstruction of the islet. In June 2020, 101 Anuling saplings were planted of which no one was alive by April 2022. Nineteen samplings were sent to TRNP and planted on South Islet after the inventory ended in April 2022. (Figure 36, and Appendix 8).

Avifauna Inventory Results

A minimum of 17 species of birds including two new species to TRNP, the Grey-capped Emerald Dove *Chalcophaps indica* and a gull species (possible Vega Gull *Larus vegae*) were identified during and outside of the inventory period until June 2022 May (Appendix 13). The total number of all avifauna species, mostly migratory species, recorded in TRNP over time is 122 species.

Ten of the observed species can be classified as pelagic seabirds. Of these, seven species breeds in TRNP: Brown Noddy *Anous stolidus,* Black Noddy *Anous minutus,* Great Crested Tern *Thalasseus bergii*, Sooty Tern *Onychoprion fuscata*, Masked Booby *Sula dactylatra,* Red-footed Booby *Sula sula*, and Brown Booby *Sula leucogaster*. Of three other breeding species, the Pacific Reef Egret *Egretta sacra* breeds annually; the Barred Rail *Gallirallus torquatus* occasionally and the Eurasian Tree Sparrow *Passer montanus* that may now have become locally extinct in TRNP.

Of the breeding seabird species, the Masked Booby is listed as Critically Endangered, the Brown Booby and Black Noddy as Endangered, and the Brown Noddy, Great Crested Tern, and Sooty Tern as Vulnerable species (DENR 2019). Further, the Black Noddy is included in Appendix II of the Convention of Migratory Species as a species that will benefit from international protection and management agreements.

Overall, the booby species of TRNP breed throughout the year and the tern species around nine months annually (Heegaard and Jensen 1992, Manamtam 1996, Kennedy *et al*. 2000, Jensen 2009, Jensen and Songco 2016). The April inventory results, therefore, represent only the breeding population present during the time of the inventory. The data analysis and conclusions, however, takes into consideration MPR data prior to the inventory period in 2022.

In April 2022, 39,202 adult individuals of seven breeding seabird species were recorded; 26,906 on Bird Islet and 11,636 on South Islet (Table 9). Bird Islet hosted almost 70% of the breeding population (71% in 2021) and South Islet more than 30% of the population (29% in 2021). Compared to the inventory in 2021, the population on Bird Islet increased by 36% but still substantially lower than in 2020 (6.3%). The number of seabirds on South Islet has increased by 43% compared to the inventory result of May 2021. On this islet, the population of Brown Noddy is now at the same level as before 2019, the year of the new lighthouse construction, and the Black Noddy population 9% higher.

Compared to the 2021 inventory, the April 2022 count result is higher by more than 10,000 birds or by 38% (Table 9, Appendix 9). The total of adult seabirds in May 2022 is at the same level as the population in 2015 (38,911 individuals) but almost 188% higher than in the baseline year of 1981 (Kennedy 1982). If the population breeding numbers of Sooty Tern is based on eggs laid in February 2022 (3,814 eggs) and eggs present during the April inventory, the population of this species would be 19,076 adults, or 2,828 breeding individuals, if the 744 actively breeding individuals with eggs in February 2022 are added.

For Brown Noddy, if breeding birds with eggs and off-springs in February are added (1,066 individuals), the population is 3,200 adults and for Black Noddy 3,026 breeding individuals, if 812 actively breeding February birds are included. In total, the breeding seabird population by April 2022, if February active breeding birds with eggs and offspring's are included, would be around 48,860 breeding individuals.

The difference in result for April 2022 compared to May 2021 is mainly due to an increase in the breeding populations of Great Crested Tern, Sooty Tern and Brown Booby with a continued decrease in the numbers of Black Noddy noted.

Table 9. Total count numbers of adult resident seabirds present on Bird Islet and South Islet from 26- 27 and 30 April 2022 compared to the inventory result of May 2020 and May 2021.

Species / Number	2020			2021			2022 Bird Islet	2022 South Islet	Total	% change 2019-2020	% change 2020 - 2021	% change 2021 - 2022
	Bird Islet	South Islet	Total	Bird Islet	South Islet	Total						
Brown Noddy	2,134	1,128	**3,262**	>798	904	1)>1,702	638	1,446	4) 2,084	+52	- 48	+22
Black Noddy	1,974	676	**2,650**	1,414	1,462	2) 2,876	976	1,238	5) 2,214	+28	+ 8	-23
Great Crested Tern	16,762	1,048	**17,810**	7,644	5,732	13,376	11,718	6,094	17,812	+5	- 25	+ 30
Sooty Tern	>5,272	0	**> 5,272**	6,000	0	3) 6,000	8,790	2,658	6) 11,448	+21	+13	+91
Masked Booby	2	0	2	2	0	2	2	0	2	0	0	0
Red-footed Booby	430	230	660	321	101	422	410	326	736	-39	-36	+74
Brown Booby	>2,528	449	> 2,977	3,710	90	3,800	4,732	174	7) 4,906	-5	+28	+29
Total	29,102	3,531	32,633	19,889	8,289	28,178	26,906	11,636	39,202	+ 18	-14	+38

1) Represent change in phenology. February 2021 count was 2,728 adults
2) Total 3,636 breeding individuals, if 760 actively breeding individuals in February 2021 are added
3) Total 8,063 individuals, if 2,063 individuals actively breeding in February 2021 are added
4) Represents change in phenology. Total 3,200 breeding individuals, if 1,116 actively breeding individuals with eggs and off-springs in February 2022 is added.
5) Total 3,026 breeding individuals, if 812 actively breeding individuals with eggs counted in February 2022 is added. Change in phenology.
6) If the population breeding numbers is based on eggs laid in February 2022(3,814 eggs) and eggs and pulli present during the April inventory, the population of this species would be18, 506 adult individuals.
7) 5,130 individuals, if 224 actively breeding birds with juveniles, pulli and eggs in February 2022 is added.

Review of Marine Park Rangers Data

Since the inventory in May 2021, MPRs made three inventories on Bird Islet and 11 on South Islet until 31 March 2022. The inventories on Bird Islet included in-flight counts of booby species. Only one in-flight count was conducted on South Islet (August 2021).

Until April 2022, the MPRs also conducted 10 monthly distance monitoring counts around Bird Islet and South Islet. Because of sometimes substantial numbers of Black Noddy roosting at the sandbar of the Ranger Station, five counts were carried out here. No counts were carried out at Jessie Beazley Reef.

The data gathered revealed several important observations, Table 10 .

Table 10. Selected results of MPR distance and direct counts from June 2021 to March 2022.

Species	Bird Islet	South Islet
Brown Noddy	Indicating a new phenology, part of population has been overwintering since 2017. Early start of breeding in February 2022 with > 1000 adults based on nest count including 34 juveniles/pulli and 178 eggs.	Contrary to normal absence from November to February, present every month in 2021 which is the new normal pattern for this species. Breeding every month with more than 1,400 adults with 176 juveniles/pulli and 495 eggs, e.g., in January 2022.
Black Noddy	Following distance count data, present throughout the year since 2017, but lowest numbers in January 2022 (295 individuals). Has become regularly roosting at the sandbar at the Ranger Station (e.g. 1,600 on August 2021).	Now present throughout the year with lowest numbers in January (220 individuals). Used to be absent from November to February .Outside of the inventory period, up to 220 adults observed on the ground without nests from June to August 2022.
Great Crested Tern	Absent only in October 2021 and near- absent in November 2021 (110 individuals) and in January 2022 (45 individuals) Breeding season 2022 started in March.	As in the 2020 breeding season, absent from September 2021 to March 2022. Breeding started in April 2022, similar to 2021.
Sooty Tern	Near-absent in October 2021 and absent in January 2022. Main breeding periods include August 2021 (9,460 adults), February 2022 (7,044 adults). A new breeding cycle started in April 2022.	For the first time since 2002 found breeding from 13 February 2022 and in March in large numbers of 3,162 adults. Originally, the species only bred at South Islet (1981 data).

Masked Booby	Two adults present from June 2021 to May 2022. Had one egg in August 2021 which was lost in September. In June 2022 a nest monitoring camera was installed, an egg hatched on 23 June 2022.	No breeding population
Red-footed Booby	Low number of adults, less 300 individuals since May 2021. Numbers of nests also remained low, <100, and in general with very few off-springs. A total of 71 empty nests were removed since August 2021.	An average of 170 adults since August 2021 with highest number 395 individuals in September 2021.Nesting rate low as empty active nests are removed, 172 nests since August 2021. Very few nests had egg and of these just five juveniles and pulli were reported over the eight-month period.
Brown Booby	In August 2021 a very high number of 4,384 adults were breeding with 1,042 juveniles and pulli and 1,039 eggs. In November 2021 only about 1,244 adults which is much lower than previous years (about 3,000 adults from 2017 to 2020) In February 2022 also lower numbers compared to February 2021, 1,090 adults of which only 111 birds were actively breeding.	Breeding since August 2021 with up to 14 pairs in September 2021. Previously documented breeding is from 2016, and 2019 to 2021.
Pacific Reef Heron	Reported with maximum of eight individuals	Maximum 12 individuals in September 2021 and February 2022 Otherwise low numbers, and lower than the average from 2004 to 2019. May have been impacted by habitat change with fewer breeding options due to reclamation in 2019.
Barred Rail	No birds observed	One bird in November 2021

Eurasian Tree Sparrow	Not observed	Not observed

Species Account of Breeding Birds

The combined results of the adult populations and their development over time at Bird Islet and South Islet are shown in Appendix 9. Data on the number of immature, juvenile, and pulli and on the number of eggs and nests recorded since 2004 on the two islets are presented in Appendix 10. Percentages of in-flight populations of Brown Noddy, Black Noddy, Red-footed Booby and Brown Booby are shown in Appendix 11 (Bird Islet) and Appendix 12 (South Islet). A complete list of non- breeding avifauna records is found in Appendix 13.

Brown Noddy (Conservation Status - Philippine Red List: Vulnerable): Fluctuating population. Total estimated annual population:> 3,200 individuals (in 2022 until April).

The breeding population in April 2022, 2,084 individuals, is 22% higher than in May 2021, but at the same level then as in the baseline inventory year in 1981, 2,136 individuals (Kennedy 1982) (Table 9, Figure 37 and Figure 38, and Appendix 9.) The population on Bird Islet is declining; on South Islet it is still recovering from the man-made habitat changes made in 2019. The substantial population found in January and February 2022 of up to 1,980 adults, represent a change in phenology with the same number of birds breeding at the beginning of the calendar year compared to April 2022. On South Islet where 1,446 individuals were counted in April, the population has increased by 60%. Of the breeding population on Bird Islet, 52% of the adults had nests, on South Islet 71%.

The species was normally absent from TRNP from November to February, but on Bird Islet it has overwintered since 2017,and on South Islet, it is present all month and breeding at least from January 2022.

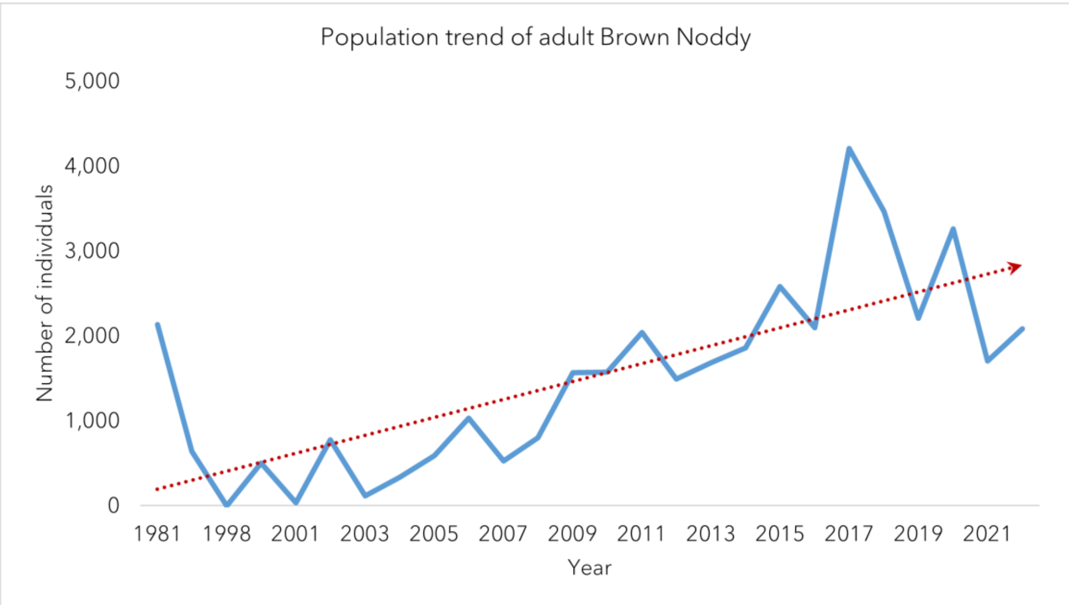


Figure 37. Population trend of adult Brown Noddy from 1981 to 2022.

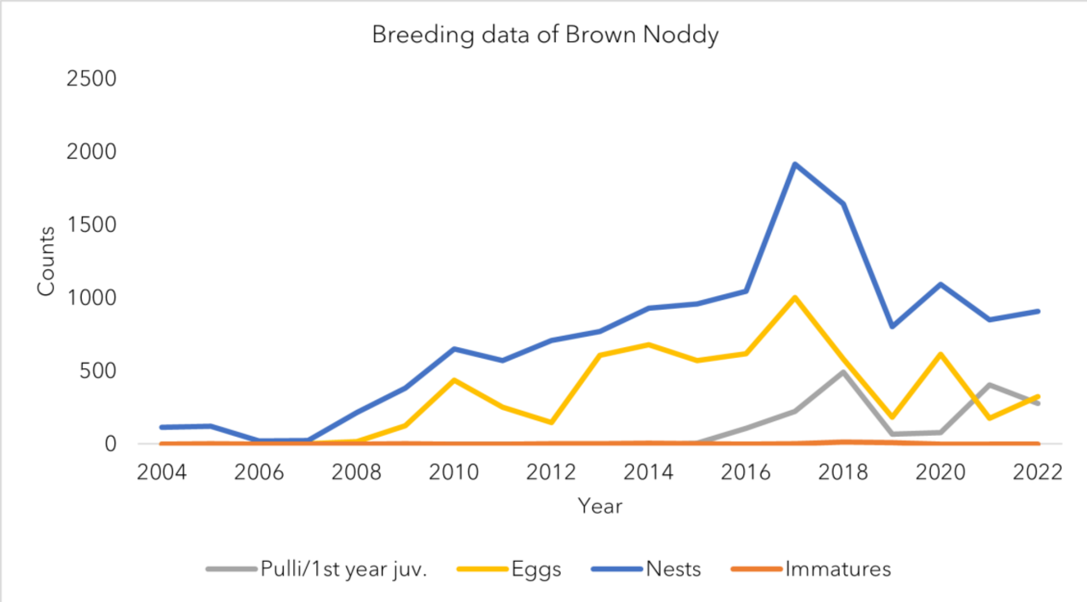


Figure 38. Breeding data of Brown Noddy from 2004 to 2022.

Black Noddy (Conservation Status – Philippine Red List: Endangered): Declining population. Total estimated annual population: 3,100 - 4,000 adult individuals

Black Noddy is classified as Endangered by the Department of Environment and Natural Resources (DENR, DAO 2019-09) and is included as a conservation management-dependent species under the Convention for Migratory Species (Appendix II).

Of the original population of 10,656 adult birds (2013), minimum about 30% remain, Annex 3.The continued population decline is correlated to the loss of its natural breeding habitat over time.

A total of 2,214 adults individuals were counted in April 2022. There were 2,876 adult birds in May 2021 and 2,650 individuals in 2020. However, due to change in phenology at least 26.8 % or 812 birds were breeding in February 2022. The overall result suggests a decrease by 23% with the largest decline, 31%, occurring on Bird Islet Table 9, Figure 39. On South Islet the decline was 15%.

The species was present at Bird Islet and South Islet every month since May 2021. TRNP had about 3,400 birds present in August 2021, and 1,060 individuals in January 2022. The February and April 2022 inventory data represent a minimum of 3,026 breeding birds.

Of 1,852 nests found in April 2022, 541 nests or 29.2% contained either juveniles, pulli or egg (37% in 2021 and 27% in 2020). It represents a considerable increase in nest numbers compared to the May 2021 inventory (1,438 nests or 28.8%), Figure 40, Appendix 10. On Bird Islet only about 26% of the population had nests. Of these, only 249 nests had eggs or off-springs.

From 2013 to 2017, the species was found to have produced a very low number of eggs and offspring equivalent to an average of 6.6% compared to the adult population present, Table 11, Figure 39 and Appendix 9. The average percentage was substantially higher from 2019 to 2022 at 27.9 % with 2022 at the highest, 34.1% and at the same level as in 2021. The positive trend is correlated with the artificial breeding structures established on both Bird Islet and South Islet.

Table 11. Comparison of numbers of adult Black Noddy and numbers of their eggs, pulli and juveniles found from February to November 2013 to 2021, and February to May 2022 at Bird Islet and South Islet

Year/Numbers	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Adult population	10,656	7,556	8,226	8,716	5,191	4,473	2,072	3,128	3,636	3,026
Eggs, pulli and juveniles	>700	>351	>329	>384	>412	623	534	568	1,223	1,033
Percentage of population	6.6	4.6	4.4	9.5	7.9	13.9	25.8	18.2	33.6	34.1

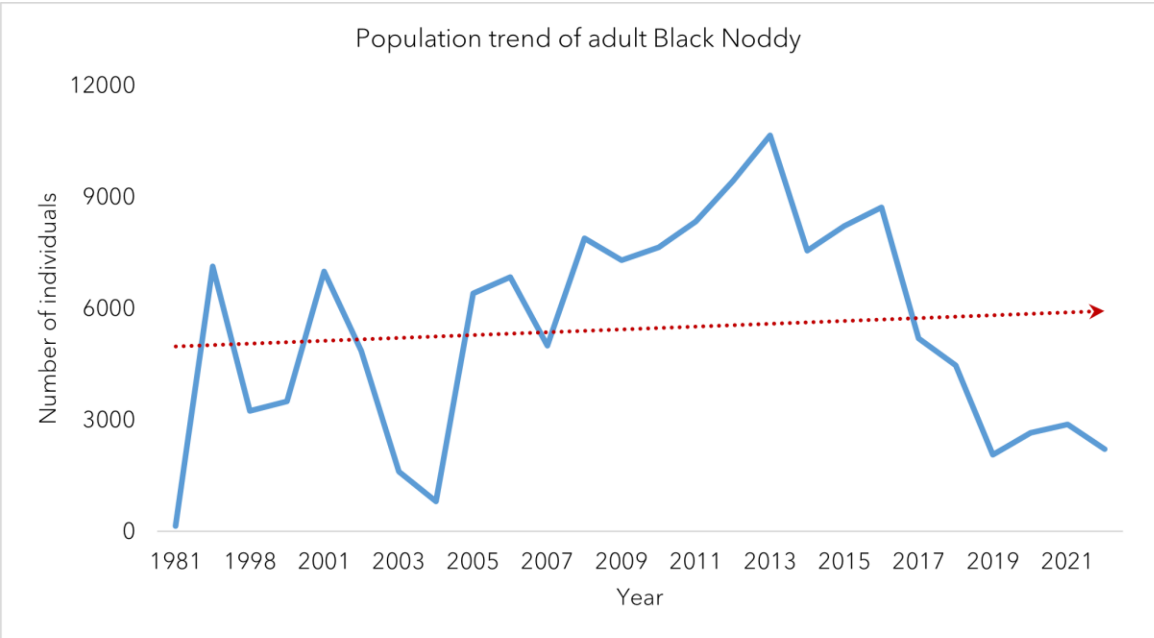


Figure 39. Population trend of adult Black Noddy from 1981 to 2022.

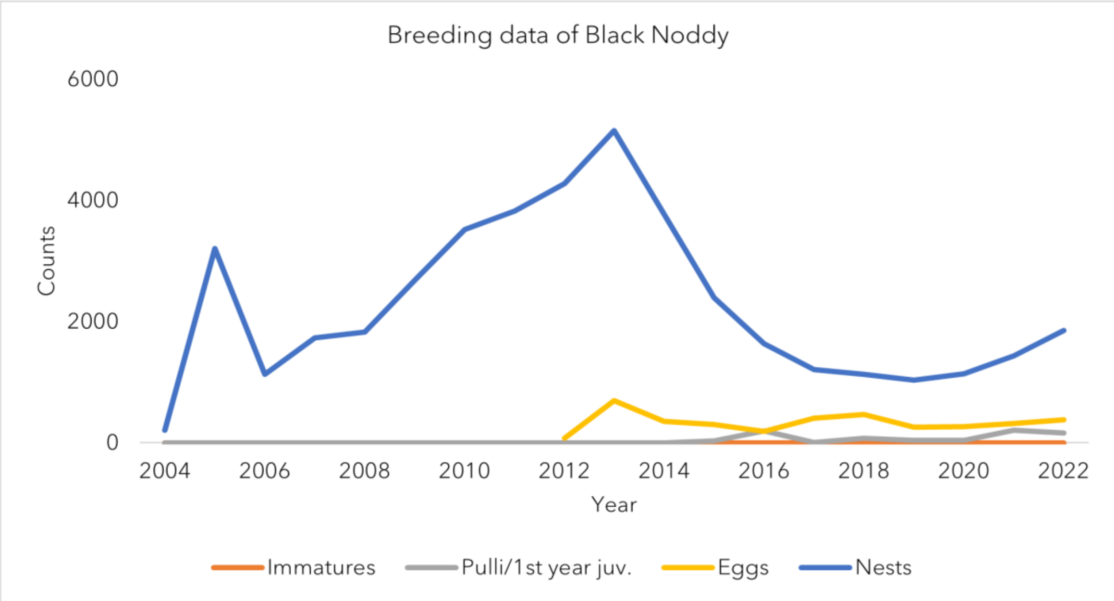


Figure 40. Breeding data of Black Noddy from 2004 to 2022.

Breeding Structures for Black Noddy

In 2022, there are 13 breeding structures on Bird Islet (5 PVC and 8 bamboo structures) in Bird Islet. Two of 8 structures were built in February 2022. Of the 6 old bamboo structures, one is deteriorating. In South Islet, there are 10 structures (2 PVC and 8 bamboo structures). All five old bamboo structures are deteriorating but still used by breeding birds. To compensate for loss of breeding area the MPRs constructed one additional bamboo structure in April 2022 and two in August 2022.

Given the continued decline in the population, detailed monthly data on the breeding population has been collected since June 2020 on South Islet. On this islet TMO has recorded how the recolonization of seabirds including Black Noddy happened. Since June 2021 the breeding monitoring took place every two weeks, or a total of 11 times. In addition there is a very detailed dataset per structure at South Islet for the period May 2022 to end September 2022. As it falls outside of the period for this report it still has to be analyzed.

Original structures were all made of bamboo, but in September 2020 and in February 2021 three designs with experimental PVC structures were installed. As of October 2022, there are 13 structures (5 PVC and 8 bamboo) in Bird Islet of which two were built in February 2022. Three of the oldest structures have deteriorated and are not used by the noddies (February 2022). In South Islet, there are 10 structures (2 PVC and 8 bamboo). All five old bamboo structures are deteriorating but are still used for breeding. The rangers constructed one additional structure in April and two in August 2022 as replacement and nesting materials (mainly cut grasses, leaves, and seaweeds) were also provided February, April, June, and August.

Initial analysis from 2021 (Jensen, Songco, Pagliawan, 2021) showed a significant difference in the use of the PVC structures and the bamboo structures with a clear preference for structures made of bamboo. Samples analyzed from 17 February 2022 (Bird Islet) and from 15 May 2022 (South Islet) showed a population on Bird Islet with 467 nests, of which more than 654 individuals bred on bamboo structures and more than 121 individuals on PVC structures. Of the PVC breeding birds 96 birds 0r 78.7% had nests of which 66.7% contained either juveniles, pulli or eggs during the time of data gathering. In comparison, of the 654 birds breeding on bamboo structures 522 birds or 79.8% had nests of which 249 nest or 95 % contained either juveniles, pulli or eggs.

On Bird Islet of 308 nests found, 47 nests were placed at PVC structures or 15.2%. Of these nests 68% either had juveniles, pulli or eggs. The full structure dataset over time may needs to be analyzed as the birds preference is not clear based on the sampling sets analyzed. More important, however, would be an analysis of pullus survival rate to juvenile stage and beyond.

The species is only breeding on artificial nesting structures. Despite the success of the artificial breeding structures in increasing the reproduction rate, the rate is still too low to maintain the breeding population as it needs to produce enough offspring to replenish the population over time.

Great Crested Tern (Conservation Status - Philippine Red List: Vulnerable): Fluctuating annual population 18,000 adult individuals. Compared to May 2021 the population in April 2022, 17,812 adults increased by 31% and is at the highest level ever (Table 9, Figure 42 and Figure 42, Appendix 10). The result for April 2022 is more than 8 times higher than the baseline count of 2,264 individuals in 1981 (Kennedy 1982), Appendix 9.

Adult birds were present at Bird Islet from Mid-February 2022 and at South Islet from mid-March. During the April inventory, on Bird Islet 1,398 pulli and 4,461 eggs were found. It equals 11,718 adult birds, an increase by 50 % compared to 2021 but still lower than 2020 where more than 16,000 birds were breeding on the islet. On South Islet, the species had continued increasing its breeding numbers but at a more modest rate of 6% compared to the population size in 2021 (Table 12).

Table 12. Breeding data from 1981 to 2021 of Great Crested Tern at South Islet

Number/Year	1981	1985	2000	2002	2003	2020	2021	2022
Adults	2,264	135	50	560	64	1,026	5,732	6,094
Eggs	1,132	+	12	145	7	512	1,790	2,638
Pulli	0	0	0	25	19	2	872	409
Juveniles	0	0	0	0	0	0	256	0

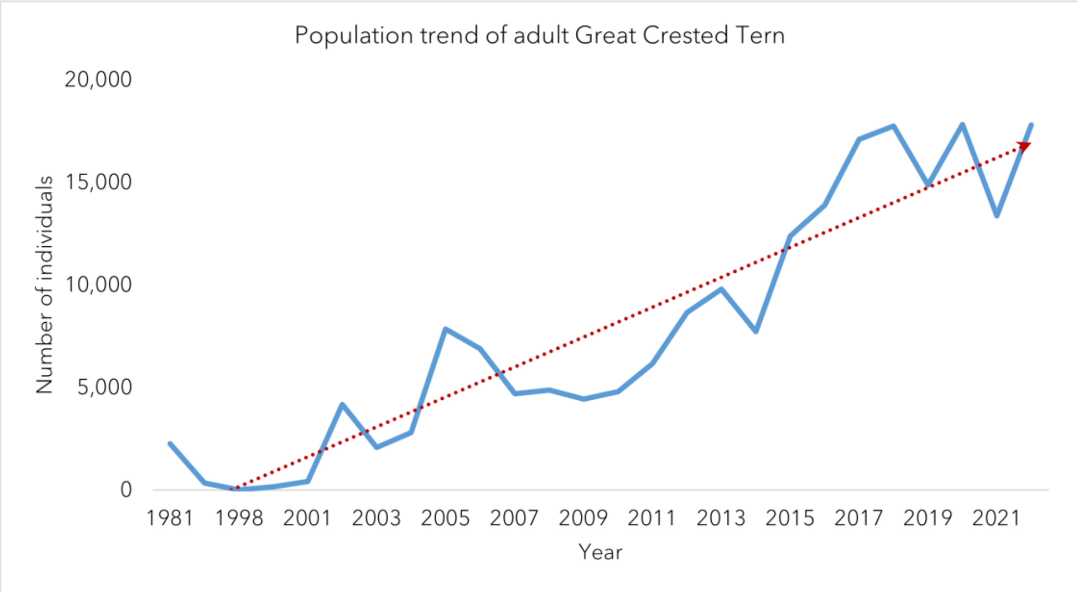


Figure 42. Population trend of adult Great Crested Tern from 1981 to 2022

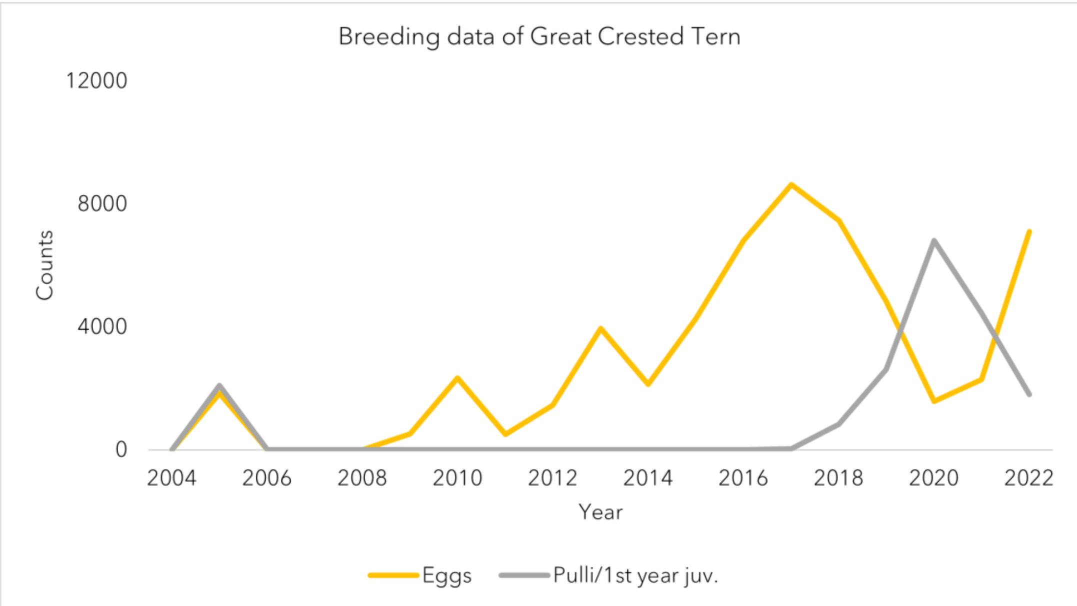


Figure 42. Breeding data of Great Crested Tern from 2004 to 2022

Sooty Tern (Conservation Status – Philippine Red List: Vulnerable): Stable population. Total estimated annual population: <u>11,500 – 19,000 adults.</u>

The breeding population at Bird Islet in April 2022 was about 8,790 adults or nearly 47% higher than in May 2021. Compared to the number of birds breeding at both islets, it is 130% higher than in the baseline inventory year of 1981 (5,070 individuals), Table 9, Figure 44 and Figure 44, and Appendix 9. For the first time since 2002, the species bred on South Islet (2,658 individuals). Originally Sooty Tern only bred on this islet.

Sooty Terns were present from June 2021 although near absent in October and November 2021 and absent in January 2022.On South Islet it was present from February 2022.

MPR data shows that at least 7,044 individuals were breeding on Bird Islet on 17 February 2022 (3,522 eggs) and 594 individuals on South Islet (13 February) or a total of 7,638 individuals. Surprisingly, two months later, in April 2022, 10,868 individuals had 3,284 eggs and 2,150 pulli and juveniles. It suggests that as many as 18,506 adults were breeding in the first and second quarter of 2022.

TMO data from 2017 to 2021 indicate that the Sooty Tern has a sub-annual breeding cycle (Jensen, Songc0, Paliawan 2021). There may also be two separate sub-populations with breeding cycles that tend to shift over time, e.g., one population generally breeds from November to February and another population from May to August, Table 13. However, there are some data gaps to more precisely determine all months when off-springs are present. Based on data available, sub-annual breeding intervals may translate to breeding peaks at different months of the year, as suggested in Table 13. Distance counts and inventory data over time need to be analyzed to reach reliable conclusions.

Table 13. Breeding months of Sooty Tern 2017 to 2022 on Bird Islet. Egg laying periods indicate a sub-annual breeding cycle or breeding cycles composed of two sub-populations (yellow and red fond).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017				EGGS	Pulli			EGGS			Juv/P	
2018					EGGS			Juv/P			EGGS	
2019		Juv/P						EGGS				
2020		EGGS			Juv/P	?					EGGS	
2021		Juv/P		?	EGGS			Juv/P	Juv/P			
2022		EGGS	Juv/P	EGGS/P					?			

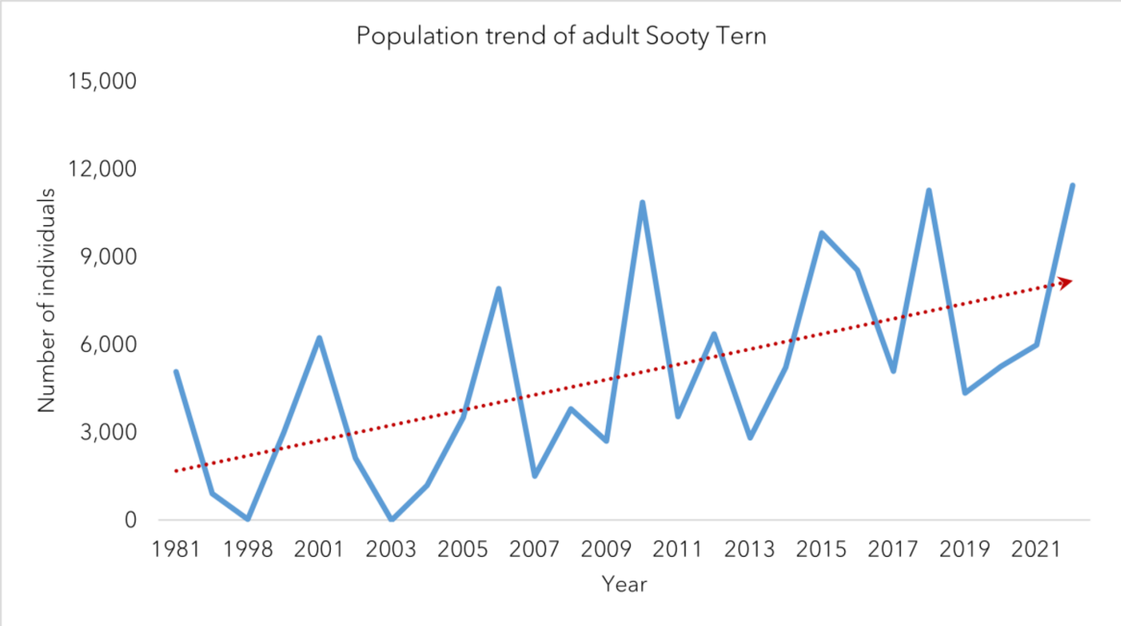


Figure 44. Sooty Tern population trend from 1981 to 2022.

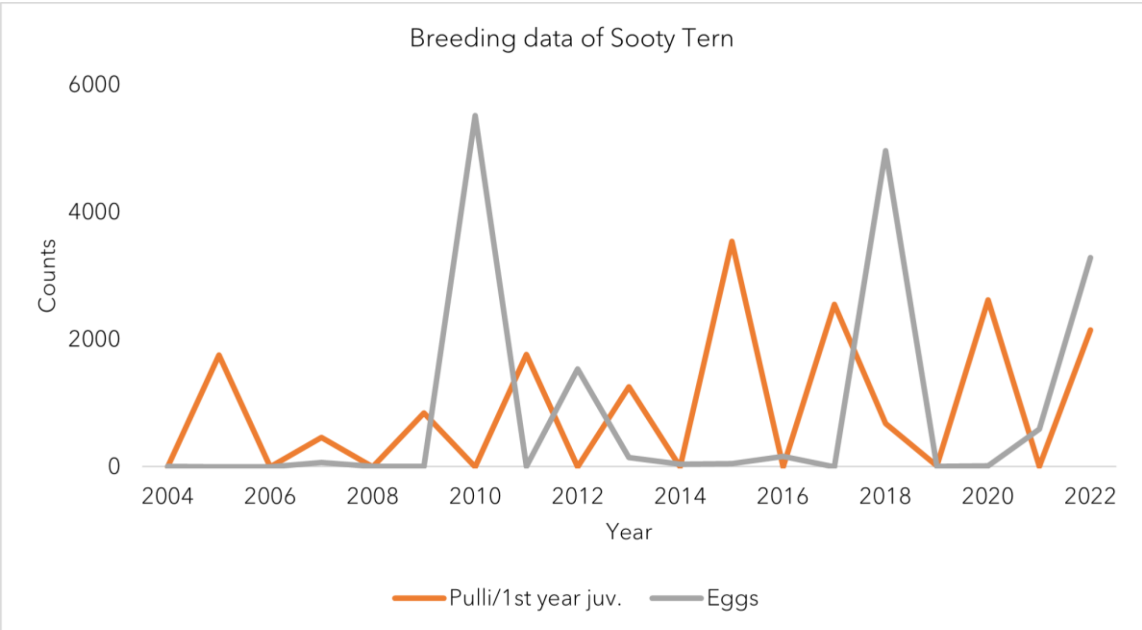


Figure 44. Sooty Tern breeding data from 1981 to 2022.

Masked Booby (Conservation Status - Philippine Red List: Critically Endangered): Two adults present from June 2021 to May 2022. Had one egg in August 2021, which was lost in September. On June 2022, a nest monitoring camera was installed, revealing that an egg hatched on 23 June 2022.(Figure 45).

Figure 45. Masked Booby with off-spring, July 25, 2022. Photo Jeffrey David/TMO

Red-footed Booby (Conservation Status - Philippine Red List: Least Concern): Overall declining population. Total estimated annual population: 750 - 800 adult individuals.

The adult population in April 2022 was 736 individuals compared to 422 individuals in May 2021, higher by 74% (Table 9, Figure 47 and Appendix 9). Compared to the baseline inventory year in 2004 (2,435 adult individuals), the population is lower by more than 70%. MPR data shows that from June 2021 to March 2022 the average number of adult birds was around 300 individuals, with the highest number present in September 2021, 685 individuals. The number of nests is very low, in April 2022 only 68 nests (Figure 47 and Appendix 10). Only 14% of the population at Bird Islet had nests while 33% were actively breeding on South Islet.

The declining population is a result of population management through nest removal by the MPR. From August 2021 until April 2022 about 340 nests under construction were removed. However, MPRs have noted four pairs that had nests placed directly on the ground, Figure 48. This new breeding strategy may allow the species to again increase its population size.

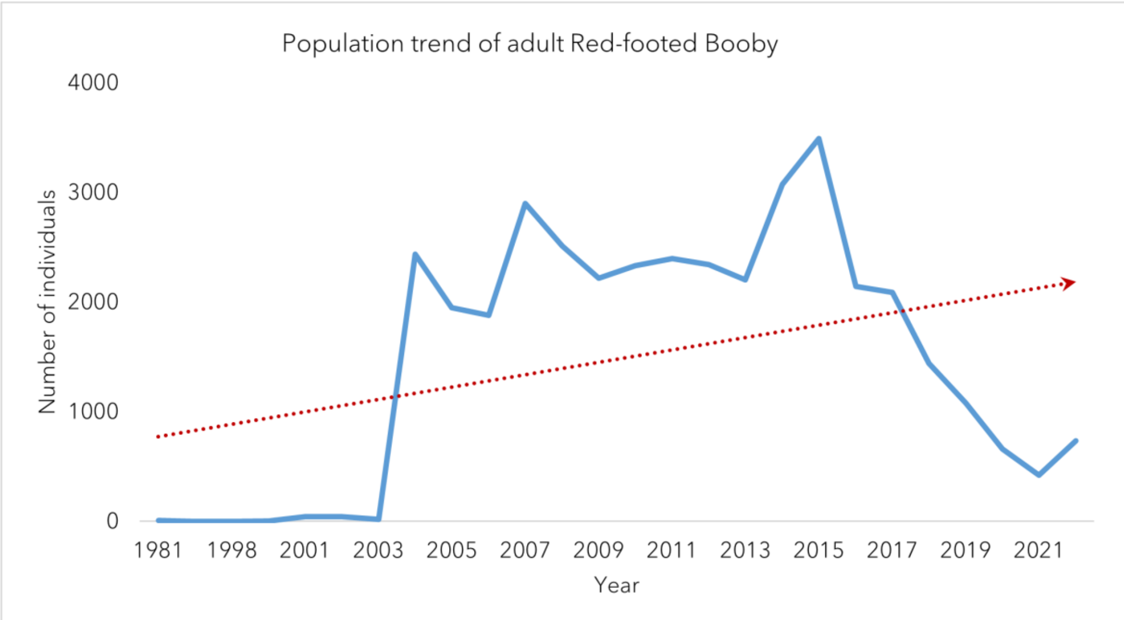


Figure 47. Population trend of adult Red-footed Booby from 1981 to 2022.

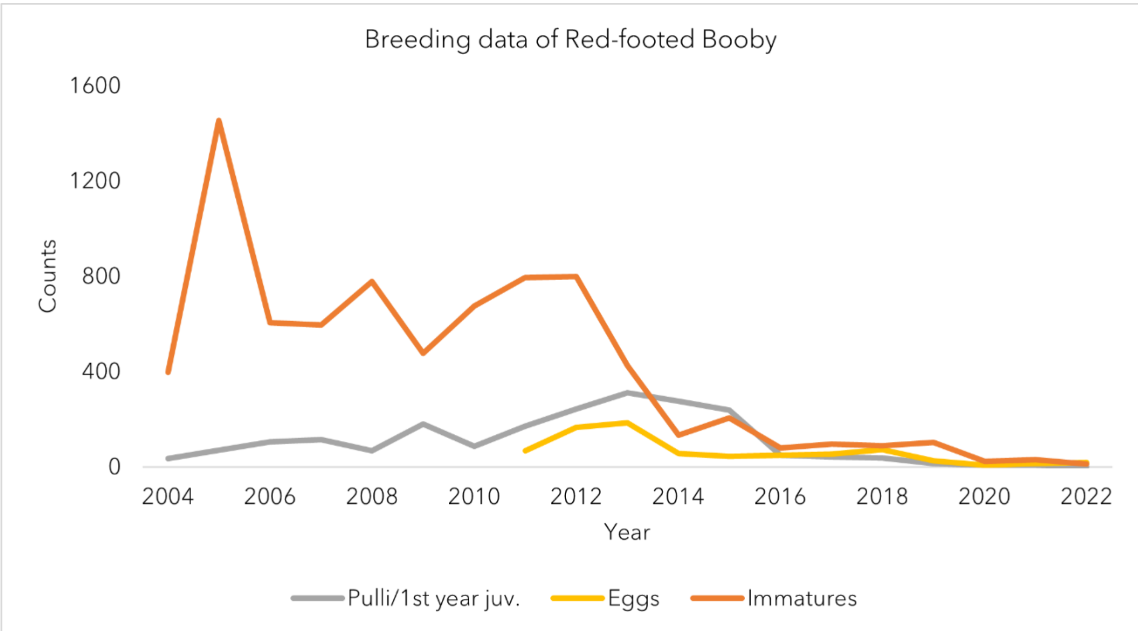


Figure 47. Breeding data of Red-footed Booby from 2004 to 2022.

Figure 48. Red-footed Booby breeding on the ground for the first time at TRNP in 2022. Photo: Rowell Alarcon/TMO

Brown Booby (Conservation Status - Philippine Red List: Endangered): Increasing population. Total estimated annual population: 5,200 adult individuals. The population is now about 30% higher than the baseline inventory year of 1981 (3,768 adults), Appendix 9 and 29% higher than in 2021, Table 9, Figure 50.

The increase in nests found in April 2022 compared to the count in May 2021, 27.2% or 508 nests, represents a continued increase since 2018, from 376 nests to 2,369 nests (Figure 50, Appendix 10). Of the nest found in April 2022, 1,792 contained eggs and 360 pulli and juveniles representing an extraordinary high breeding rate of about 90%. In 2021, 75% had either eggs or offspring. On South Islet, of 174 adult birds only three pairs had nests.

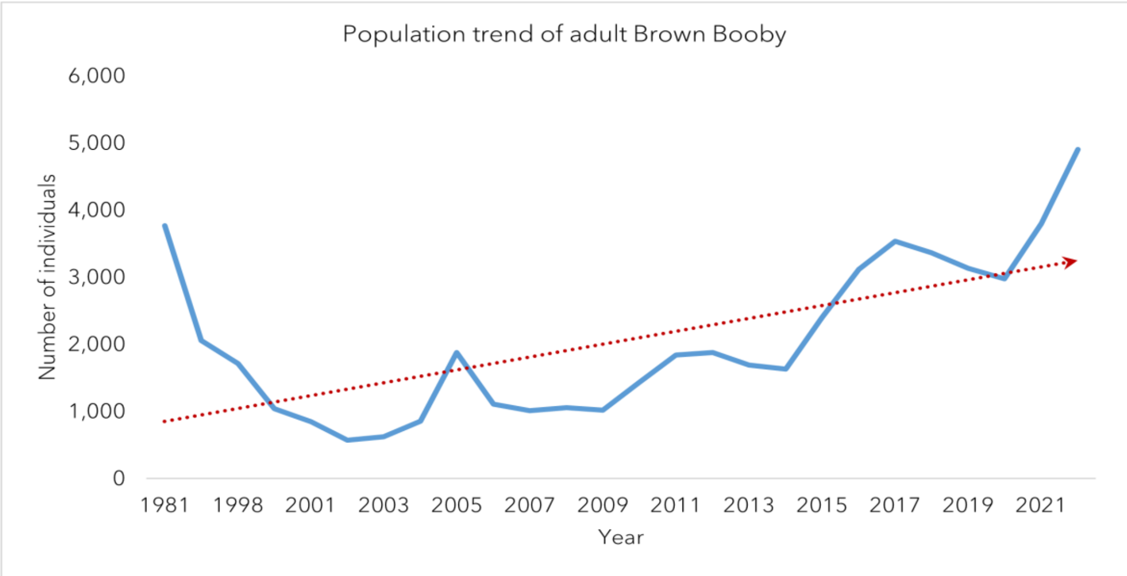


Figure 50. Population trend of adult Brown Booby from 1981 to 2022.

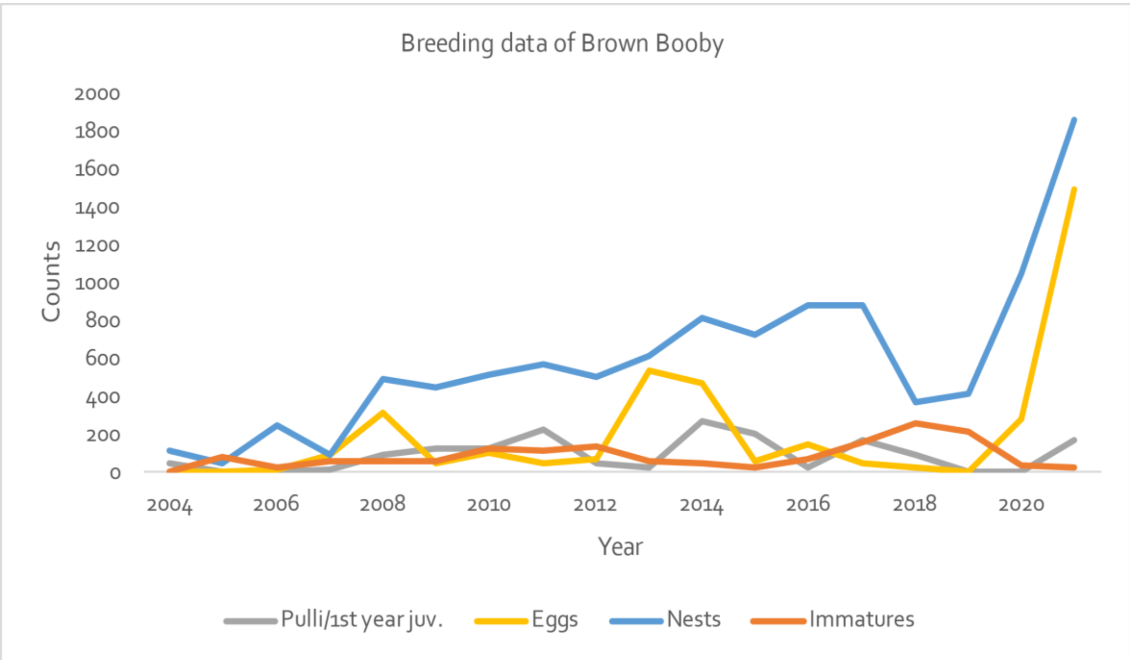


Figure 50. Breeding data of Brown Booby from 2004 to 2022.

Banded birds: In August and November 2021 and in April 2022, a total of 116 birds, color banded and steel ringed between 2006 to 2009 on Bird Islet, had their bands and rings read. Of these, 62 were banded as adults and 52 individuals as pulli, Table 14. The birds banded as pulli are now from 13 to 16 years old. Adults banded in 2006 are at least 20 years old and have lived around 80% of their lifespan.

Table 14. Results of ring reading on Bird Islet August and November 2021 and April 2022.

Year of Banding	Adults	Juvenile	Unaged	Total
2006	14	5	2	21
2007	21	21		42
2008	12	22		34
2009	15	4		19
Total	62	52	2	116

Pacific Reef Heron: The total adult population in April 2020 may have been 10 individuals, four at Bird Islet and six at South Islet with one possible nest. This is below average numbers since 2004.

RECOMMENDATIONS

Habitats

1. **Restoration of Beach Forest:** The reforestation is not successful and its encouraged to fully implement guidance on growing the trees provided in Appendix 6 of the 2021 report.

2. **Land area at Bird Islet:** Areas in Bird Islet that are eroding should be mapped out and the map updated annually. If erosion increases to the extent where it starts to cause reduction in seabird breeding populations, consider sand nourishment through in-pumping of sand from nearby sandbars.

4. Species

Black Noddy: To limit possible disturbance on South Islet, reduce the number of breeding monitoring to only one per month. Inventories to the normal standard of once per quarter.

b) As a conclusion has not been made on the reproduction rate expressed as the number of juveniles produced at PVC structures versus bamboo structures, continue to replace deteriorated bamboo structures until it is documented that the species is reproducing in sufficient numbers at the PVC structurers. An analysis of overall pullis survival rate to juvenile stage, and beyond, is needed.

c) There is a need to maintain about 10 structures per islet and with sufficient breeding materials to provide at least the up to 4,000 noddies with breeding opportunities.

d) The artificial structurers do not protect the species from exposure to strong winds and rainfall. It is recommended that protective shields be installed for the structures. This may increase the reproduction rate, which is still too low to secure the population.

5. Methodology

Recommended improvements on data collection and reporting includes:

a) Data on pulli to be separated from data on juveniles, which are birds living in their first calendar year;

b) Immatures (birds in their second calendar year or more) of Sooty Tern, Great Crested Tern and the two noddy species cannot be easily distinguished from adult birds, or at all. Hence, do need to try to report them except for species of boobies.

REFERENCES

Heegaard, M. and Jensen, A.E. 1992. Tubbataha Reef National Marine Park – a preliminary ornithological inventory. Enviroscope Vol. VII, 7: 13-19. *Haribon Foundation*.

DENR Administrative Order No 2019 – 09. Updated National List of Threatened Philippine Fauna and Their Categories

Jensen, A. E. 2004. Monitoring and inventory of the seabirds of Tubbataha Reef Marine National Park and Cawili Island, the Sulu Sea. With notes on the population development and habitat status. May 2004. *Tubbataha Protected Area Management Board and WWF- Philippines*. Unpublished Report.

Jensen, A. E. 2005. Monitoring and Inventory of the Seabirds of Tubbataha Reef Marine National Park, Cagayancillo, Palawan, the Philippines, May 7-11, 2005. *Tubbataha Protected Area Management Board*. Unpublished Report.

Jensen, A.E. 2006. Monitoring and Inventory of the Seabirds and their Breeding Areas in Tubbataha Reef Marine National Park, Cagayancillo, Palawan, the Philippines, April 27 - May 1, 2006. *Tubbataha Protected Area Management Board and WWF-Philippines*. Unpublished Report.

Jensen, A. E. 2009 a. Conservation of seabirds and threatened avifauna in the Cagayan Ridge Marine Biodiversity Conservation Corridor, the Sulu Sea, Philippines. Conservation International Philippines. Retrieved on 5 Sept. 2019 from http://www.conservation.org.ph/sss/.

Jensen, A. E. 2009 b. Population development of the breeding seabirds from 1981 to 2009 in Tubbataha Reefs Natural Park & World Heritage Site, Palawan, the Philippines. *Tubbataha Management Office*, Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A. E. 2010. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2010. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A. E. 2011. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2011. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A. E. 2012. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2012. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A. E. 2013. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2013. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A. E. 2014. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2014. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A. E. 2015. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2015. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A.E. and Songco, A. 2016. Population development of the breeding seabirds and a systematic list of birds recorded from 1981 to 2009 in Tubbataha Reefs Natural Park and World Heritage Site, Palawan, the Philippines. *FORKTAIL-Journal of Asian Ornithology* 32: 2016.

Jensen, A. E. 2016. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines May 2016. *Tubbataha Management Office,* Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A.E., Songco, A.M., Pagliawan, M.R . 2017. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2017. Tubbataha Management Office, Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A.E., Songco, A.M., Pagliawan, M.R . 2018. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2018. Tubbataha Management Office, Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A.E., Songco, A.M., Pagliawan, M.R . 2019. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2019. Tubbataha Management Office, Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A.E., Songco, A.M., Pagliawan, M.R. 2020. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2020. Tubbataha Management Office, Puerto Princesa City, Philippines. Unpublished Report.

Jensen, A.E., Songco, A.M., Pagliawan, M.R. 2021. Monitoring and inventory of the seabirds and their breeding areas in Tubbataha Reefs Natural Park & World Heritage Site, Cagayancillo, Palawan, Philippines, May 2021. Tubbataha Management Office, Puerto Princesa City, Philippines. Unpublished Report.

Kennedy, R. S. 1982. The last of the Seabirds. The Filipinas Journal of Science and Culture, Filipinas Foundation Vol III: 40 – 49.

Manamtam, A.S. 1996. Survey of Seabirds in Tubbataha, Cavili and Cagayancillo, the Sulu Sea. Haribon Foundation, Danish Ornithological Society, BirdLife International and DENR.

Wild Bird Club of the Philippines (2022). Checklist of Bird of the Philippines. Version 2022.

Worcester, D.C. 1911. Newly Discovered Breeding Place of Philippine seabirds. Philippines Journal of Science 6: 167-177.

CHAPTER IV. WATER QUALITY

OVERVIEW

The water quality monitoring in the Tubbataha Reef Natural Park (TRNP) is part of the annual ecosystem research and monitoring activities of the Tubbataha Management Office (TMO). It aims to assess the prevailing water quality in the park, track the changes and trends, and identify the possible sources and impacts of these changes.

Twenty (20) monitoring stations were established in TRNP based on the location, anthropogenic activities, and regular monitoring stations. These are located in the core zone (17) and buffer zone (3) of the park. Water quality monitoring started in April 2014, undertaken during the dive season from March to May. Parameters were determined on-site using multiparameter digital water quality meter. Water samples were then collected and brought to the environmental laboratory for analysis.

This is the third water quality monitoring conducted in TRNP since the onset of COVID-19 pandemic in 2020. This report presents the trends of water quality from 2014 to 2017, before the pandemic, and from 2020-2021, when there were no tourism activities due to pandemic, until 2022, when tourism resumed.

METHODS

Water Quality Monitoring Stations

There are twenty (20) established water quality monitoring stations since 2014, strategically located in North Atoll, South Atoll and Jessie Beazley Reef (Figure 51). As the monitoring activity progressed, the stations were adjusted based on the relevance and association with tourism activities and regular biophysical monitoring in the Tubbataha Reefs. In 2020, adjustments were made to move some stations closer to the dive sites and monitoring stations for fish and benthos components. In 2021, WQ07 was moved closer to South Islet, WQ13 was moved closer to Bird Islet, and WQ17 was moved to the Ranger Station. Appendix 16 presents the geographical location and description of the water quality monitoring sites in TRNP.

Figure 51. Water quality monitoring stations in Tubbataha Reefs Natural Park, May 2022.

Collection of Water Samples

The water quality monitoring was conducted on 10-13 May 2022 by the Tubbataha Management Office and the Palawan Council for Sustainable Development Staff. Grab water samples were collected in three separate containers: wide mouth glass with 1 liter capacity for oil and grease and 2.5-liter capacity-HDPE for physicochemical parameters such as color, total suspended solids, nitrates and phosphates. Samples for total and fecal coliform analyses were collected in a 150 ml sterilized glass bottle.

Sample collection was done by holding the sample container near its base and plunging the neck downward, below the surface. The sample bottle was turned until its neck pointed slightly upward and its mouth directed toward the direction of the current. Water samples were collected from the upstream side of the patrol boat. Grab samples of surface water were collected for oil and grease analysis.

All collected samples were sealed, labelled, packed properly, and kept with ice in an ice chest. As preservative, 5 ml of 1:1 Hydrochloric acid was added to samples of oil and grease. All water samples were taken to PCSD Environmental Laboratory for analysis.

Figure 52. Collection of water samples in Tubbataha Reefs Natural Park (May 2022)

Water Quality Parameters and Guidelines

Physico-chemical and microbiological parameters were analyzed to determine the trends and prevailing water quality in TRNP. Parameters such as pH, temperature, dissolved oxygen, salinity and total dissolved solids were measured *in situ* using Horiba Multiparameter Probe. Other parameters such as color, total suspended solids, nitrates, phosphates, oil and grease and fecal coliform were analyzed in PCSD Environmental Laboratory.

Table 15 shows the water quality analyzed in the PCSD Environmental Laboratory. Appendix 17 shows the complete list and general description of parameters analyzed in TRNP since 2014.

Table 15. Water quality parameters monitored in the Tubbataha Reefs Natural Park

Parameter	Description	Method of Analysis
A. Physico- chemical parameters		
Total Suspended Solids (TSS)	Particles that remain suspended in water, thereby causing turbidity or increase the color of the water. Higher TSS, the higher the turbidity.	Gravimetric dried at 103 - 105^{0}C
Color	Caused by the presence of dissolved organic matter, metallic salts, or suspended solids	Visual Comparison Method (Platinum Cobalt Scale)
Nitrogen as Nitrates	Indicates the presence of nutrients in the water bodies. High concentration can cause severe illness to animals	Colorimetric using Hach Nitrate Powder Pillows
Phosphorus as Phosphates	Indicates the presence of one of the primary nutrients in the water bodies. High concentration fuels the growth of algae and other microorganisms	Colorimetric using Hach Phosphate Powder Pillows
Oil and Grease (O&G)	Fats, oils, waxes, and other related constituents found in water that are recovered in the solvent.	Gravimetric Method (Petroleum Ether Extraction)
B. Microbiological Parameters		
Fecal Coliform (FC)	FC are members of the Total Coliform group that originate in the intestinal gut of warm-blooded animals.	Multiple Tube Fermentation Technique

Reference: Standard Methods for the Examination of Water & Wastewater, APHA-A4WWA 21st Ed, 2005.

An updated Water Quality Guidelines (WQG) was issued through the DENR Administrative Order (DAO) 2021-19. It provided new guideline values for fecal coliform and phosphates, while the WQG for other parameters were still based on DAO 2016-08 (Table 16). In the absence of water classification conducted by DENR in TRNP, the beneficial usage of sea waters surrounding TRNP was considered as a basis to identify WQG, determined under the classification Class SA (DAO 2016-08).

Table 16. Water quality guidelines for primary parameters for marine and coastal waters under Class SA.

Parameters	Unit	Water Quality Guidelines
pH	-	7.0-8.5
Temperature	°C	26-30
Dissolved Oxygen	mg/L	6.0
Color	PCU	5
Total Suspended Solids	mg/L	25
Oil and Grease	mg/L	1
Fecal Coliform	MPN/100mL	20*
Phosphates	mg/L	0.1*
Nitrate as NO_3-N	mg/L	10

Class SA: Protected waters or waters designated as national or local marine parks, reserves, sanctuaries, and other areas established by law (Presidential Proclamation 1801 and other existing laws), and/or declared as such by appropriate government agency, LGUs, etc. (DAO 2016-08). * Based on DAO 2021-19.

RESULTS

2022 General Water Quality

Generally, the 2022 WQ monitoring showed that all parameters analyzed in the laboratory are within the WQ guidelines except for phosphates. On-site parameters such as dissolved oxygen were all within the WQ guideline (above 6 mg/L) while pH levels above 8.5 and temperature beyond 30°C were measured in some stations (Table 17).

Visually, all stations appeared to be very clear, with color <5 PCU. This corroborates results of total suspended solids that ranged from <1 mg/L to 14 mg/L, or way below the 25 mg/L WQ guideline (DAO 2016-08). The oil and grease in all WQ stations was below the minimum detection limit of <1 mg/L and WQ guideline of 1 mg/L (DAO 2016-08). Similarly, fecal coliform concentration was <1.8 MPN/100 mL, way below the WQ guidelines of 20 MPN/100 mL (DAO 2021-19). The improvement in water quality in TRNP recorded in April 2020 was maintained even after tourism slowly resumed in March 2022.

Table 17. Results of water quality monitoring conducted in Tubbataha Reef Natural Park (May 2022)

WQ Monitoring Stations		Color PCU	Phosphates mg/L	Nitrates mg/L	Fecal Coliform MPN/ 100 mL	Total Suspended Solids mg/L	Oil and Grease mg/L	Temperature °C	pH	Dissolved Oxygen mg/L
South Atoll	WQ01	<5	0.1097	1.2429	<1.8	<1	<1	29.4	8.50	7.23
	WQ02	<5	0.1082	1.7791	<1.8	4	<1	29.25	8.39	7.51
	WQ03	<5	0.1219	1.4926	<1.8	<1	<1	29.44	8.45	7.29
	WQ04	<5	0.0983	1.642	<1.8	<1	<1	29.39	8.48	7.01
	WQ05	<5	0.1091	1.5155	<1.8	<1	<1	29.38	8.41	8.4
	WQ06	<5	0.1082	2.0003	<1.8	9	<1	29.76	8.42	7.88
	WQ07	<5	0.1183	1.8011	<1.8	2	<1	29.25	8.39	7.51
North Atoll	WQ09	<5	0.154	2.2451	<1.8	6	<1	29.43	8.52	7.1
	WQ10	<5	0.1206	2.2206	<1.8	4	<1	29.46	8.57	7.97
	WQ11	<5	0.1153	1.7309	<1.8	2	<1	30.05	8.65	8.87
	WQ12	<5	0.1083	1.4885	<1.8	<1	<1	29.57	8.65	7.2
	WQ13	<5	0.1683	2.4312	<1.8	5	<1	33.05	8.76	9.92

	WQ14	<5	0.1108	1.8338	<1.8	<1	<1	31.37	8.57	6.31
	WQ15	<5	0.1186	2.1178	<1.8	<1	<1	30.81	8.55	6.19
	WQ16	<5	0.3401	2.4997	<1.8	10	<1	30.54	8.65	7.39
	WQ17	<5	0.1127	2.3561	<1.8	14	<1	29.17	8.32	7.65
JBR[1]	WQ19	0.152	2.6882	<1.8	<1.8	5	<1	29.3	8.60	7.98
Buffer Zone	WQ08	<5	0.2369	2.037	<1.8	<1	<1	29.48	8.46	6.62
	WQ18	<5	0.1189	2.3332	<1.8	12	<1	30.65	8.65	6.07
	WQ20	<5	0.254	2.4581	<1.8	3	<1	29.53	8.61	6.71
	WQG*	**5**	**0.1**	**10**	**20**	**25**	**1**	**26-30**	**7-8.5**	**6.0**

*Based on DAO 2018-06 and DAO 2021-19 (for Fecal Coliform and Phosphates). Abbreviations: MPN - Most Probable Number; WQG – Water Quality Guidelines;
[1]Jessie Beazley Reef

Trends of Water Quality from 2014 - 2022

Tourism slowly resumed in 2022 after the closure of TRNP due to COVID-19 pandemic in March 2020. In this discussion, the trends of WQ parameters are presented in four (4) groups based on the location of WQ monitoring stations; South Atoll, North Atoll, Jessie Beazley Reef, and the buffer zone.

The first WQ monitoring activity was conducted in 2014, with fourteen (14) parameters measured *in situ* and analyzed in the laboratory. Due to limited resources, WQ monitoring was not conducted in 2018 and 2019. It was resumed in June 2020, three months after TRNP closed for tourism activities. Out of eleven (11) parameters monitored in May 2022, this discussion focuses on nine (9) parameters with WQ guideline as per DAO 2016-08 and DAO 2021-19.

The water quality monitoring data from 2014 – 2022 for all parameters measured in water quality monitoring stations are shown in Appendix 17.

South Atoll

There are seven (7) WQ monitoring stations in South Atoll, a shallow platform surrounded by sandy lagoon and with a small islet. The South Islet serves as roosting and nesting site of seabirds. Four (4) WQ stations are located on top of the reef (WQ01 to WQ04), two (2) inside the lagoon (WQ05 and WQ06), and one (WQ07) in South Islet.

Figure 53 shows the trends of water quality parameters monitored on site in South Atoll from 2014 to 2022. On-site measurement showed that the highest temperature monitored in South Atoll was 31.8°C (WQ04) in 2014 and while the lowest was 25.4°C (WQ02) also recorded in 2014.

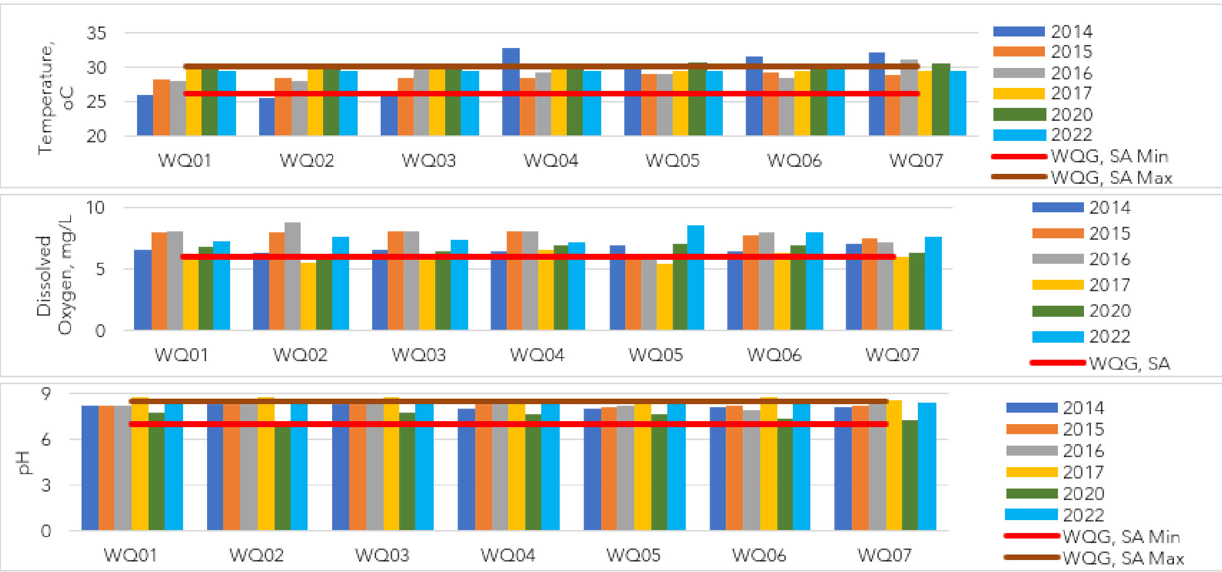


Figure 53. Trends of water quality parameters measured on site in South Atoll from 2014 to 2022

Figure 54 shows the results of WQ parameters analyzed in the laboratory. All parameters that refers to physical appearance or aesthetic quality of seawater in the South Atoll are below the WQ guidelines from 2014 to 2022. The color (clarity) concentration ranged from <5 to 10 PCU, with recent results (2020-2022) within the WQ guideline of 5 PCU. Similarly,

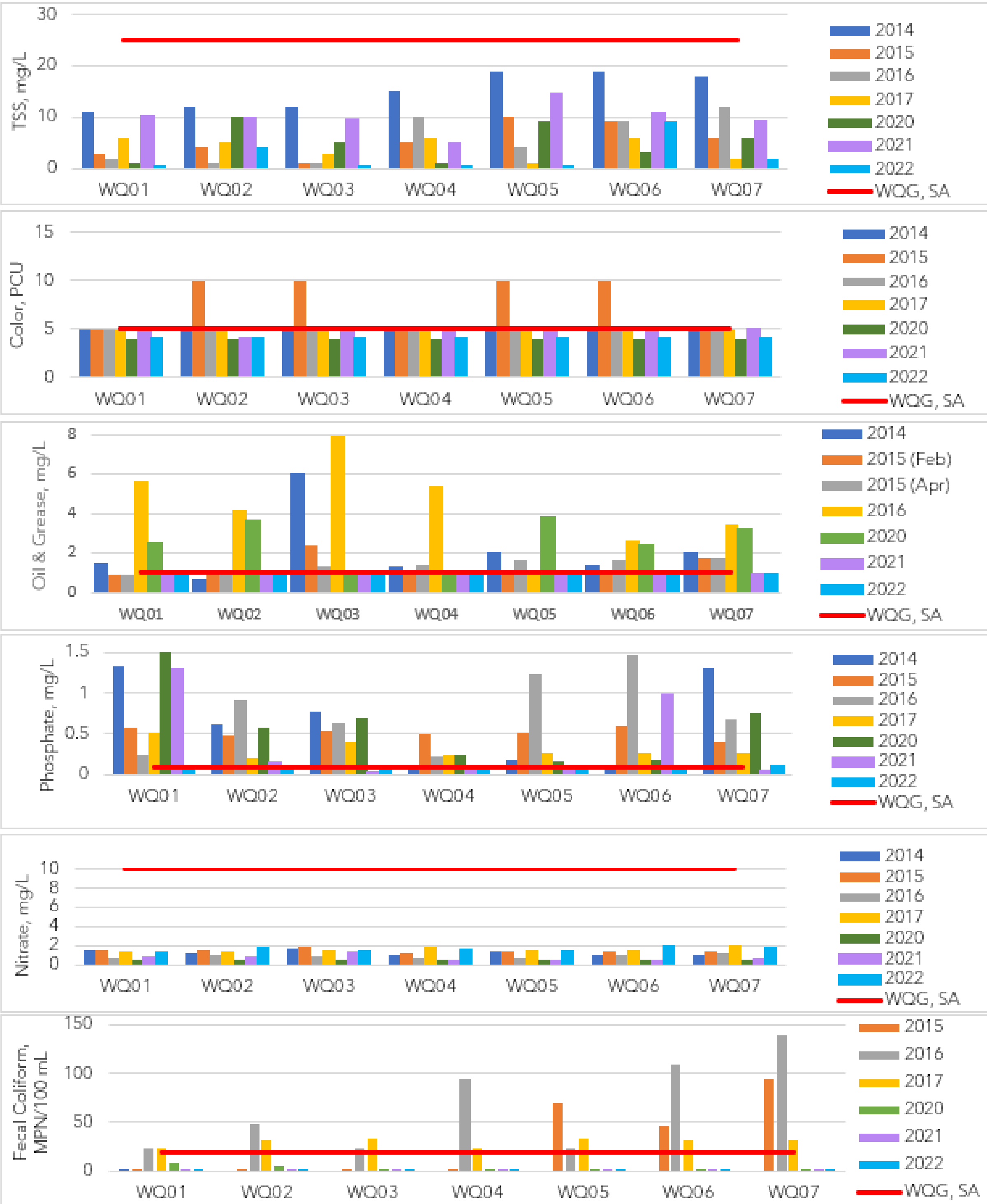


Figure 54. Trends of water quality parameters monitored in South Atoll from 2014 to 2022

the total suspended solids (TSS) ranged from <1 mg/L to 19 mg/L, all below the water quality guidelines (25 mg/L, Class SA).

The recorded excess in the concentration of oil and grease in almost all stations in South Atoll from 2014 to 2017 was attributed to tourism activities. The highest concentration was 7.9 mg/L (WQ03) in 2016. As cited in the previous reports, the monitoring activities conducted from these stations coincided with the dive season when tourism was at their peak. Oil and grease in WQ07 exceeded 1 mg/L until 2020. From 2021, concentration of oil and grease from all WQ stations in South Islet was below 1 mg/L.

Similarly, the highest concentration of fecal coliform (140 MPN/100 mL) was also recorded in South Islet in 2016. Generally, the concentration of fecal coliform in WQ monitoring stations in South Atoll was above 20 MPN/100 mL in 2016 to 2017, as shown in Figure 55. The fecal coliform improved to 7.8 MPN/100 mL (WQ01), 4.5 MPN/100 mL (WQ02), <1.8 MPN/100 mL (WQ03,WQ04, WQ05, WQ06,) 2 MPN/100 Ml (WQ07) , way below the water quality guideline of 20 MPN/100mL (Class SA, DAO 2021-19) during the closed season of 2020 and 2021, and was sustained as of the monitoring conducted in May 2022 when concentration was <1.8 MPN/100 mL in all stations in South Atoll.

Nitrates concentration from 2014 to 2022 ranged from 0.393 mg/L (WQ04, 2021) to 2.00 mg/L (WQ07, 2017), all consistently within the WQ guideline of 10 mg/L (Class SA).

On the other hand, the concentration of phosphate recorded from 2014 to 2022 exceeded the WQ guidelines for protected area (Class SA, 0.1 mg/L). The highest concentration was measured in WQ01 (1.51 mg/L) in 2020 while the lowest 0.0379 mg/L from WQ03 in 2021.

North Atoll

The North Atoll is comprised of nine (9) water quality monitoring stations (WQ09 to WQ17): WQ09 is located in the grounding site of Min Ping Yu, WQ10 to WQ 12 on top of the reef, WQ14 to WQ16 are located inside the lagoon, WQ13 in Bird Islet, and WQ17 is located close to the ranger station.

Figure 56 shows the trends in water quality parameters monitored *in situ* from 2014 to 2022. In 2022, the highest temperature in North Atoll was 33.05°C in WQ13 and the lowest recorded was 29.17^{0}C in WQ 17.

The pH around North Atoll was recorded from 7.05 (WQ17, 2021) to 8.89 (WQ14, 2014). Recent monitoring recorded pH in North Atoll slightly higher than 8.5 except in WQ17.

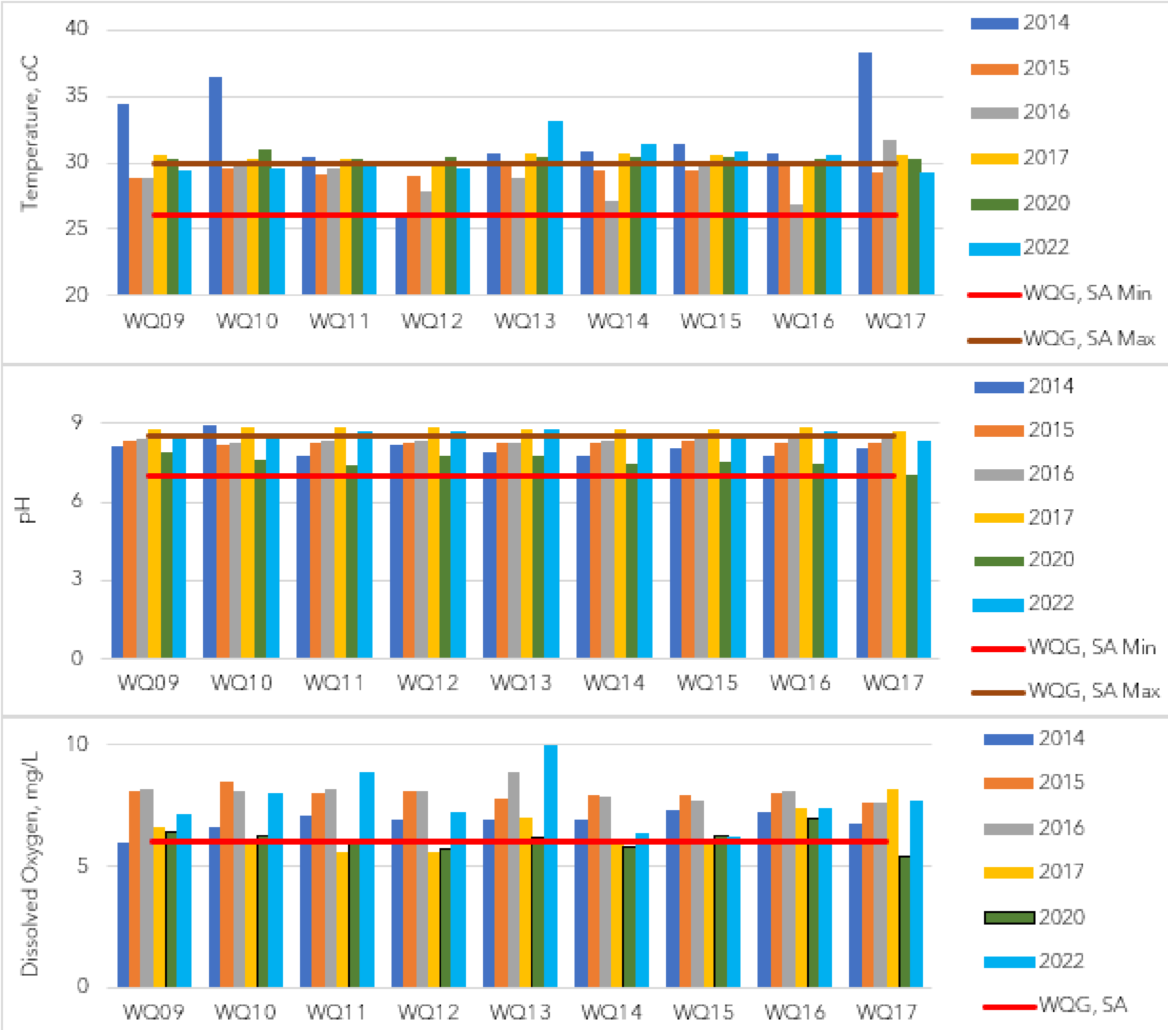


Figure 55. Trends in water quality parameters monitored in situ in North Atoll, Tubbataha Reefs Natural Park from 2014 to 2022.

Figure 56 showed physico-chemical parameters monitored in North Atoll from 2014 to 2022. The concentration of TSS ranged from <1 mg/L to 20 mg/L (WQ10, WQ11) which were all below the water quality guidelines (25 mg/L, Class SA). While exceedance in color was recorded in 2015 (WQ12, WQ16 and WQ17), recent results showed clear waters in all WQ stations in North Atoll at below 5 PCU.

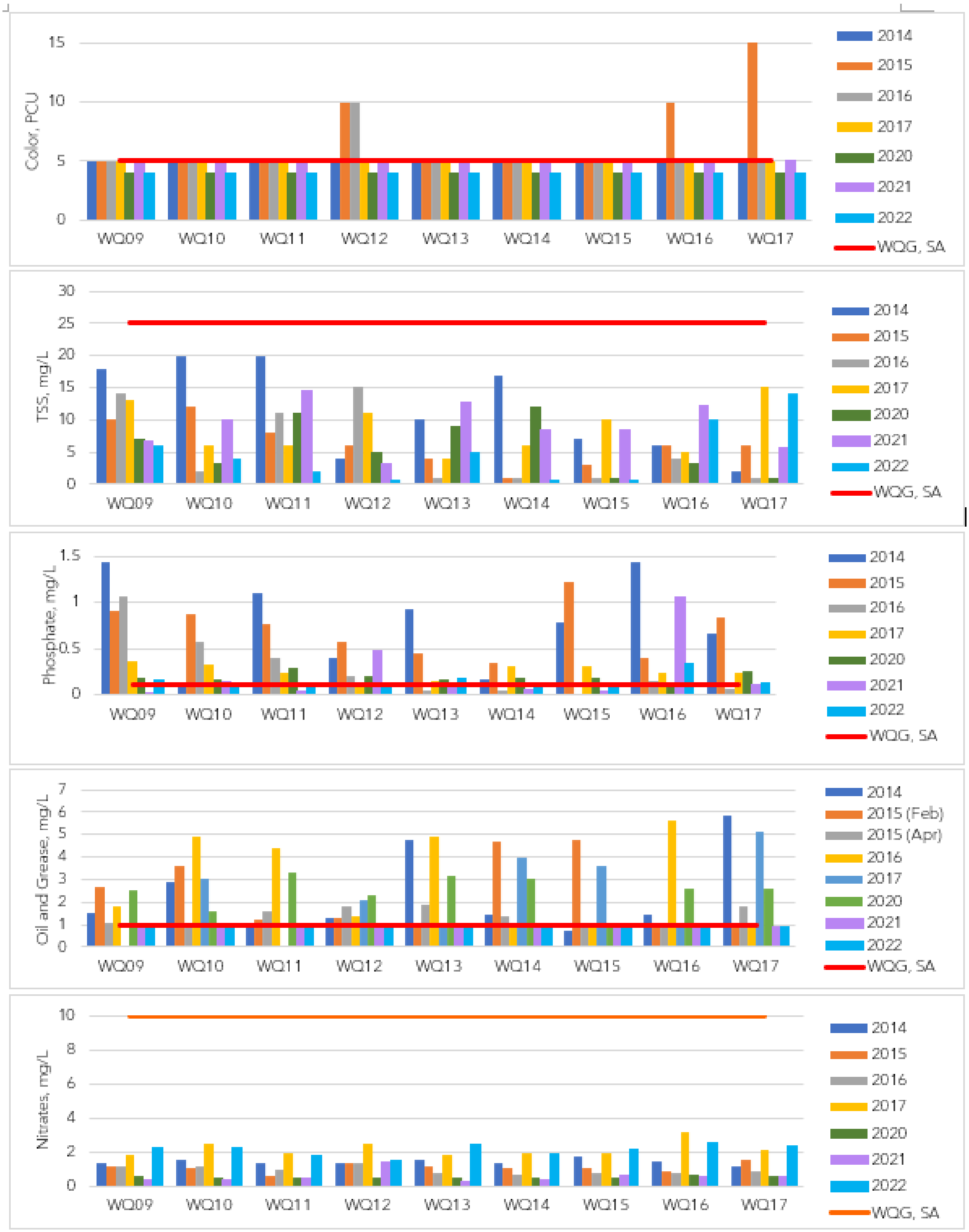


Figure 56. Trends in water quality parameters in North Atoll, Tubbataha Reefs Natural Park from 2014 to 2022. (Abbreviations: TSS – total suspended solids, WQG – water quality guideline; PCU – Platinum Cobalt Unit)

Trends of oil and grease showed that while high concentration was recorded in some stations during the active operation of tourism until 2020, with the highest concentration of oil and grease measured in North Atoll was 5.83 mg/L (WQ17, 2014), concentration of oil grease was <1 mg/L in all WQ stations in 2021 and 2022.

Similar trend was observed for fecal coliform in North Atoll, the highest concentration was recorded at 140 MPN/100 mL at WQ16 (2016). While in exceedance in previous years, results in 2022 showed that the fecal coliform in North Atoll was <1.8 MPN/100 mL, way below the WQ guideline of 20 MPN/100 mL (Class SA, DAO 2021-19).

Nitrates level in North Atoll ranged from 0.279 mg/L (WQ13, 2021) to 3.20 mg/L (WQ16, 2017), way below the WQ guideline of 10 mg/L for Class SA (DAO 2016-08). Phosphate levels exceeded WQ guideline of 0.1 mg/L since 2014 to 2022. The highest concentration of phosphate was recorded in WQ09 and WQ16 at 1.43 mg/L (2014) and the lowest concentration was 0.02 mg/L in WQ09 in 2021.

Jessie Beazley Reef

Located on the top of the reef, the water quality monitoring station in Jessie Beazley Reef is also a dive site and monitoring station for fish and benthos. Figure 57 shows the physico-chemical parameters monitored in Jessie Beazley Reef from 2014 to 2022. Recent monitoring shows temperature ranged from 26-30°C while dissolved oxygen levels qualified

Figure 57. Trends in water quality parameters monitored in situ in Jessie Beazley Reef from 2014 to 2022.

under Class SA. The pH level was recorded to be slightly higher than prescibed range of 7 to 8.5.

Waters surrounding this station remains to be clear as shown by the trends in TSS and color. The concentration of TSS ranged from 1 mg/L to 9 mg/L, way below the guideline (25 mg/L, Class SA) as shown in Figure 58. The color remained at <5 to 5 PCU from 2016 to 2022.

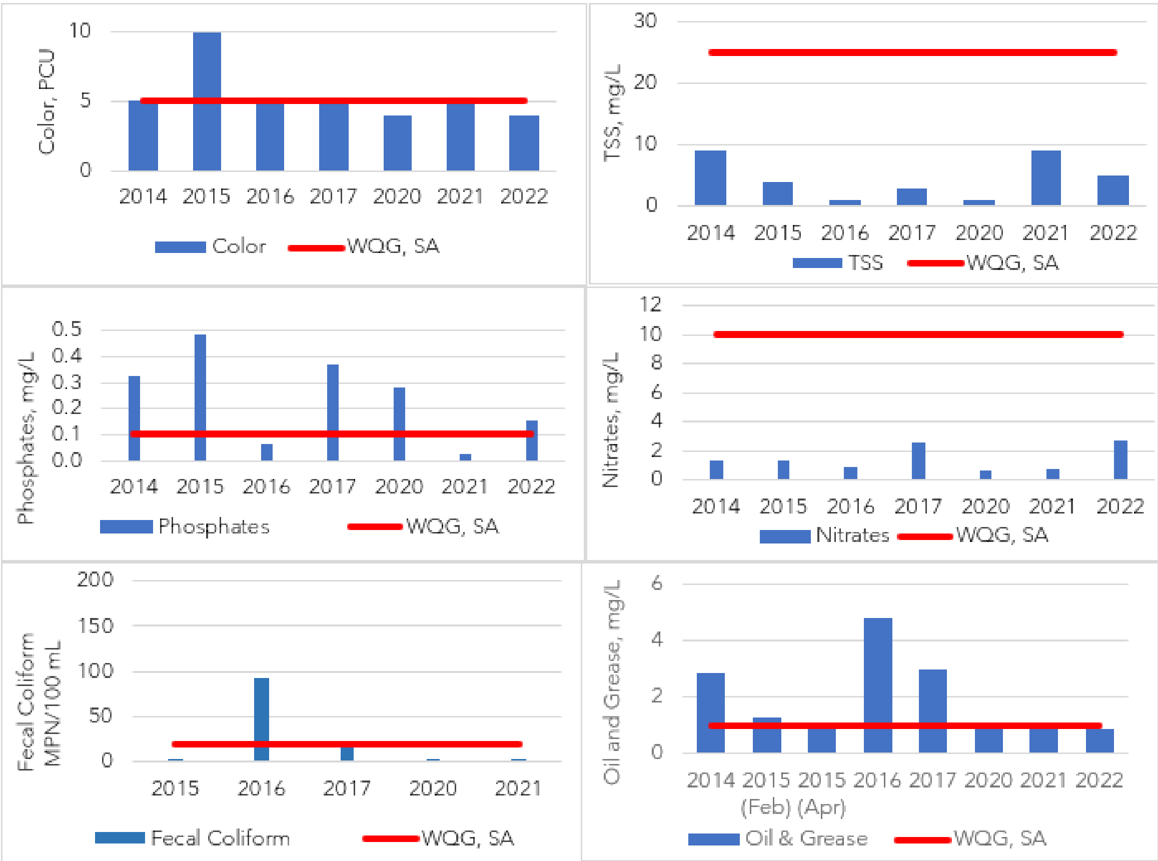


Figure 58. Trends of physico-chemical and water quality parameters monitored in Jessie Beazley Reef,from 2014 to 2022. (Abbreviations: TSS – total suspended solids, WQG – water quality guideline; PCU – Platinum Cobalt Unit; MPN-Most Probable Number)

While high concentrations of oil and grease was measured in the previous years (4.8 mg/L in 2016), levels of oil and grease decreased to concentrations below the water quality guideline (Class SA, 1 mg/L) from 2020 to 2022.

Fecal coliform declined from 94 MPN/100 mL in 2016 to <1.8 MPN/100 mL in 2021 to 2022, which is way below the WQ guideline for protected waters (20 MPN/100 mL for Class SA, DAO 2021-19).

Nitrate levels were within the WQ guidelines (Class SA, 10 mg/L), with a range of 0.50 mg/L (2020) to 2.689 mg/L (20220. On the other hand, the concentration of phosphate ranged from 0.06 mg/L (2016) to 0.152 mg/L (2022), levels that are exceeding the water quality guideline of phosphates for protected waters (Class SA, 0.1 mg/L), except in 2016 and 2021.

Buffer Zone

Three (3) water quality monitoring stations are located in the buffer zone of TRNP, each of which are located adjacent to three reef formations: WQ08 in South Atoll, WQ18 in North Atoll, and WQ20 in Jessie Beazley Reef. Figure 59 shows the trends of parameters monitored *in situ* from 2014 to 2022. While recorded to exceed the WQ guidelines in the previous years, 2022 data of temperature and pH were within the range of 26-30°C and 7 to 8.5, respectively. The pH level ranged from 7.16 (WQ20, 2020) to 8.82 (WQ18, 2017), while temperature ranged from 26.19°C (WQ08, 2014) to 33.60°C (WQ08). Similarly, dissolved oxygen levels were above 6 mg/L.

Results of laboratory analysis showed that concentrations of color and TSS in all station located in buffer zone were within the Class SA WQ guidelines for these parameters (Figure 60). The color ranged from <5 PCU to 5 PCU, while the TSS concentrations were recorded from <1 mg/L to 22 mg/L.

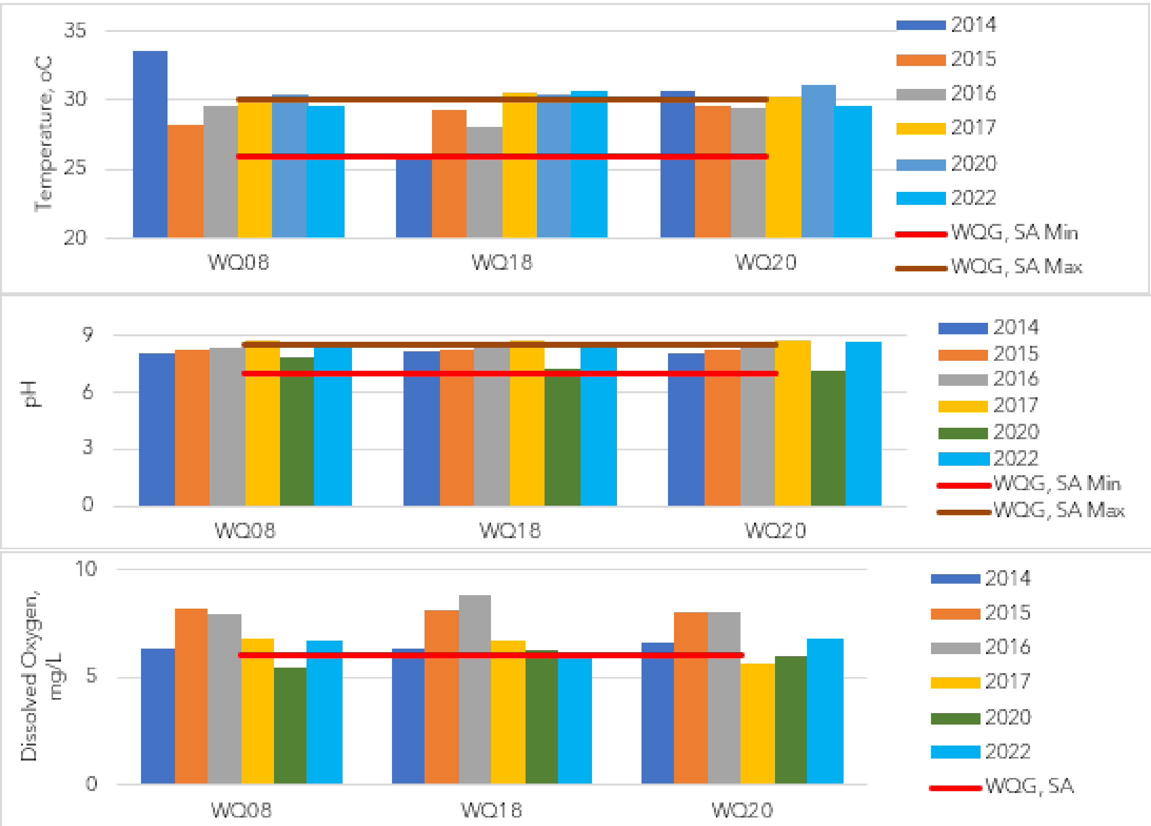


Figure 59. Trends of water quality parameters monitored in situ in buffer zone, Tubbataha Reefs Natural Park from 2014 to 2022.

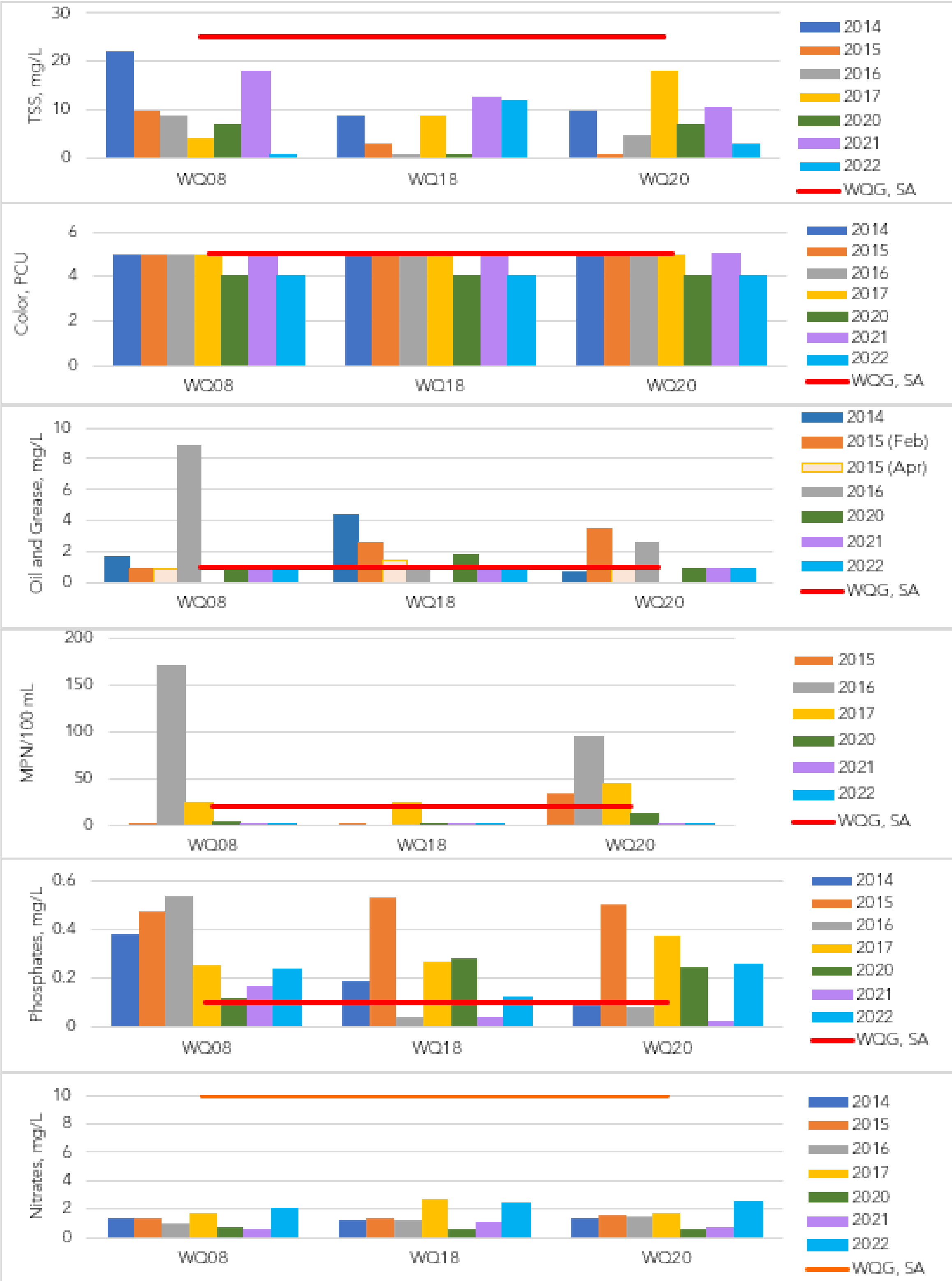


Figure 60. Trends in water quality parameters monitored in the buffer zone of Tubbataha Reefs Natural Park from 2014 to 2022. (Abbreviations: TSS – total suspended solids, WQG – water quality guideline; PCU – Platinum Cobalt Unit; MPN-Most Probable Number)

While the highest concentration of oil and grease in TRNP was measured in WQ08 (8.8 mg/L) in 2016, it started to decrease in 2020 and was within the WQ guideline (1 mg/L) by 2022. Similarly, the highest concentration of fecal coliform was recorded in WQ08 in 2016 at 170 MPN/100 mL. Its concentration gradually decreased to <1.8 MPN/100 mL in all stations from 2021 to 2022.

The phosphate levels in all WQ monitoring stations in the buffer zone ranged from 0.024 mg/L (WQ20, 2021) to 0.54 mg/L (WQ08, 2016), and still exceeded the WQ guideline of 0.1 mg/L for Class SA (DAO 2016-08) in 2022.

On the other hand, the highest concentation for nitrates was 2.70 mg/L, while the lowest was 0.510 mg/L. Nitrate levels recorded from all stations in the buffer zone are all within the WQ guidelines (Class SA, 10 mg/L).

DISCUSSION

There are three parameters in exceedance of water quality guidelines during the pre-lockdown period of 2014 to 2017. These are oil and grease, phosphates, and fecal coliform. Figure 61 shows the changes during pre-lockdown, lockdown, and reopening phases. The high concentrations were observed to decline during the lockdown phase. The recorded concentrations higher than the WQ guideline for these parameters under Class SA were attributed mainly to active tourism activity, when monitoring was conducted.

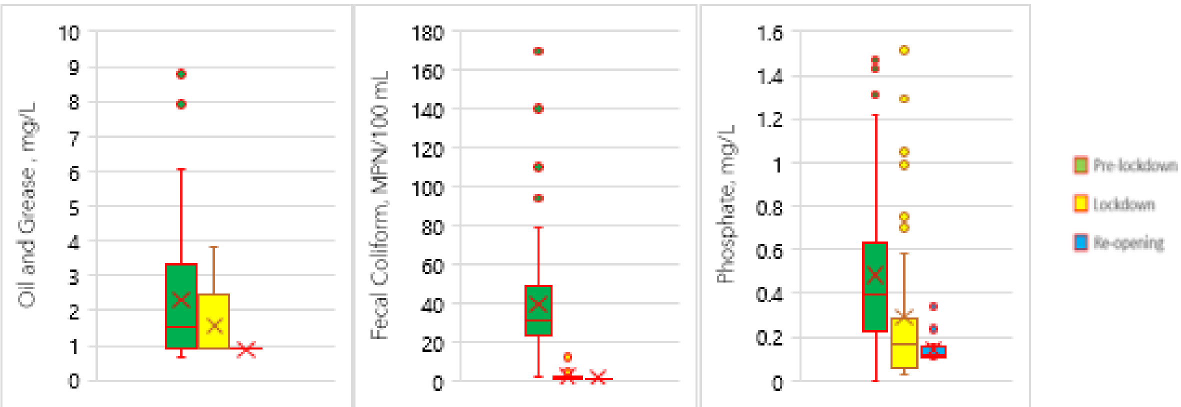


Figure 61. Box and whisker plot of different parameters to measure the physico-chemical and microbiological analysis of samples collected in Tubbataha Reefs Natural Park in three periods from 2014 - 2022.

Data before the pandemic (2014-2017) showed that only 30% of oil and grease data were within 1 mg/L, with exceedance recorded from all water quality monitoring stations. This improved during the 2020 to 2022 monitoring, when 77% of the data were within 1 mg/L, while 2022 data showed 100% of monitoring stations have oil and grease level within the 1 mg/L (Class SA). Similarly, only 24% of data of fecal coliform from 2014-2017 were within 20

MPN/100 mL . It showed improvement during the pandemic, where 100% of fecal coliform data collected in 2022 were all within the WQ guidelines. This improvement in water quality could be attributed to the implementation and compliance of the dive boat operators to Philippine Coast Guard (PCG) Memorandum Circular 10-14 prohibiting the discharge of treated sewage within 4 nautical miles (NM) and untreated sewage within 12 NM from the shoreline and special areas with significant ecological condition and importance such as TRNP.

Table 18 represents the phase-wise mean and standard deviation of nine (9) parameters monitored in TRNP during the pre-lockdown, lockdown, and reopening phase. The results showed that the lockdown allowed improvements of water quality as reflected by the mean concentration of each parameter. The aggregated data shows that the water quality in TRNP complies with the most stringent water quality guideline as per DAO 2016-08 for marine parks, reserves and sanctuaries (Class SA).

Table 18. Descriptive statistics of variables of physio chemical, microbiological parameters monitored in three periods in Tubbataha Reefs Natural Park (+SD).

Parameters	Pre-Lockdown (2014-2017)	Lockdown (2020-2021)	Reopening Phase (2022)	Water Quality Guidelines
Temperature	29.77 ± 1.29	30.41 ± 0.25	29.91 ± 0.94	26-30
pH	8.37 ± 0.28	7.51 ± 0.26	8.53 ± 0.11	7.0-8.5
Dissolved Oxygen	7.63 ± 0.90	6.28 ± 0.47	7.44 ± 0.90	6.0
Color	5.63 ± 1.83	<5	<5	5
Total Suspended Solids	7.69 ± 5.60	6.00 ± 3.82	8.00 ± 4.32	25
Oil and Grease	2.33 ± 1.76	2.19 ± 0.99	<1	1
Phosphates	0.49 ± 0.36	0.31 ± 0.24	0.14 ± 0.06	0.1*
Nitrates	1.38 ± 0.47	0.57 ± 0.22	2.00 ± 0.40	10
Fecal Coliform	39.57 ± 37.95	2.74 ± 2.93	<1.8	20*

Class SA:Protected waters or waters designated as national or local marine parks, reserves, sanctuaries, and other areas established by law (Presidential Proclamation 1801 and other existing laws), and/or declared as such by appropriate government agency, LGUs, etc. (DAO 2016-08). * Based on DAO 2021-19.

While the results of continuous monitoring showed decline or improvement on aggregated data of water quality in TRNP during the lockdown, it is important to note, however, that there are natural factors affecting water quality in the park. Among the monitored parameters, the concentration of phosphates in almost all monitoring stations remained in exceedance of Class SA WQ guideline of 0.1 mg/L. The box and whisker plot of phosphates from water quality monitoring stations is shown in Figure 62.

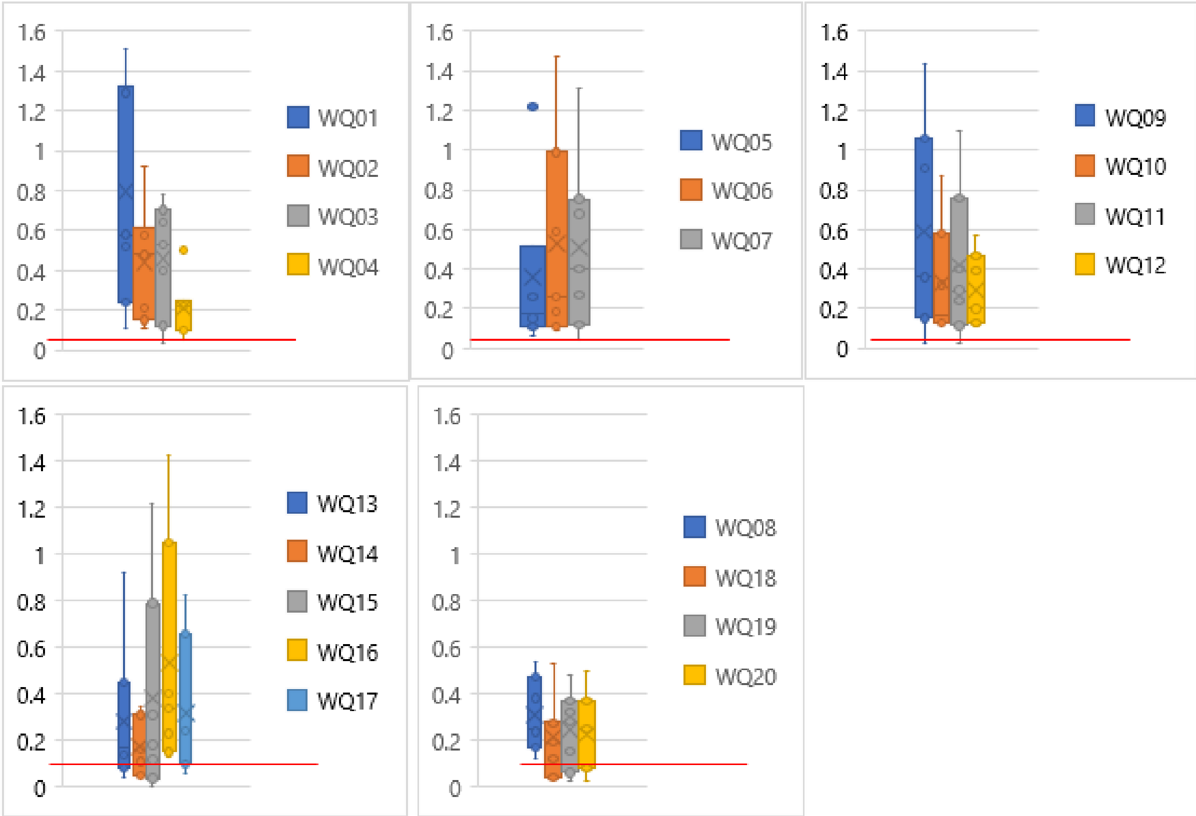


Figure 62. Range of concentration of phosphates recorded in water quality monitoring stations in TRNP from 2014 to 2022. Red horizontal line indicates the water quality guideline for Class SA, 0.1 mg/L (DAO 2016-08).

The droppings of seabirds in the islets of TRNP was identified as a possible cause of elevated concentration of phosphates in the seawater. The 2022 data supports previous water quality reports that show high levels of phosphates and nitrates in the stations close to the rookery and breeding ground of seabirds. The breeding ground has become a point source of nutrients due to bird guano. The increased presence of filamentous cyanobactera was attributed to elevated levels of nutrients in the vicinity of South Atoll (Licuanan and Bahinting, 2021). The elevated concentration of phosphates indicates that the surrounding water is suitable for the filamentous cyanobacteria to continuously thrive in the area.

Another concern is the issue of warming sea surface temperature brought about by climate change. Temperatures higher than 30°C were recorded since 2014 in various monitoring stations (Figure 63). The temperature across the WQ stations ranged from 25.40 °C (WQ02, 2014) to 38.40 °C (WQ17, 2014), although the latter may be an outlier.

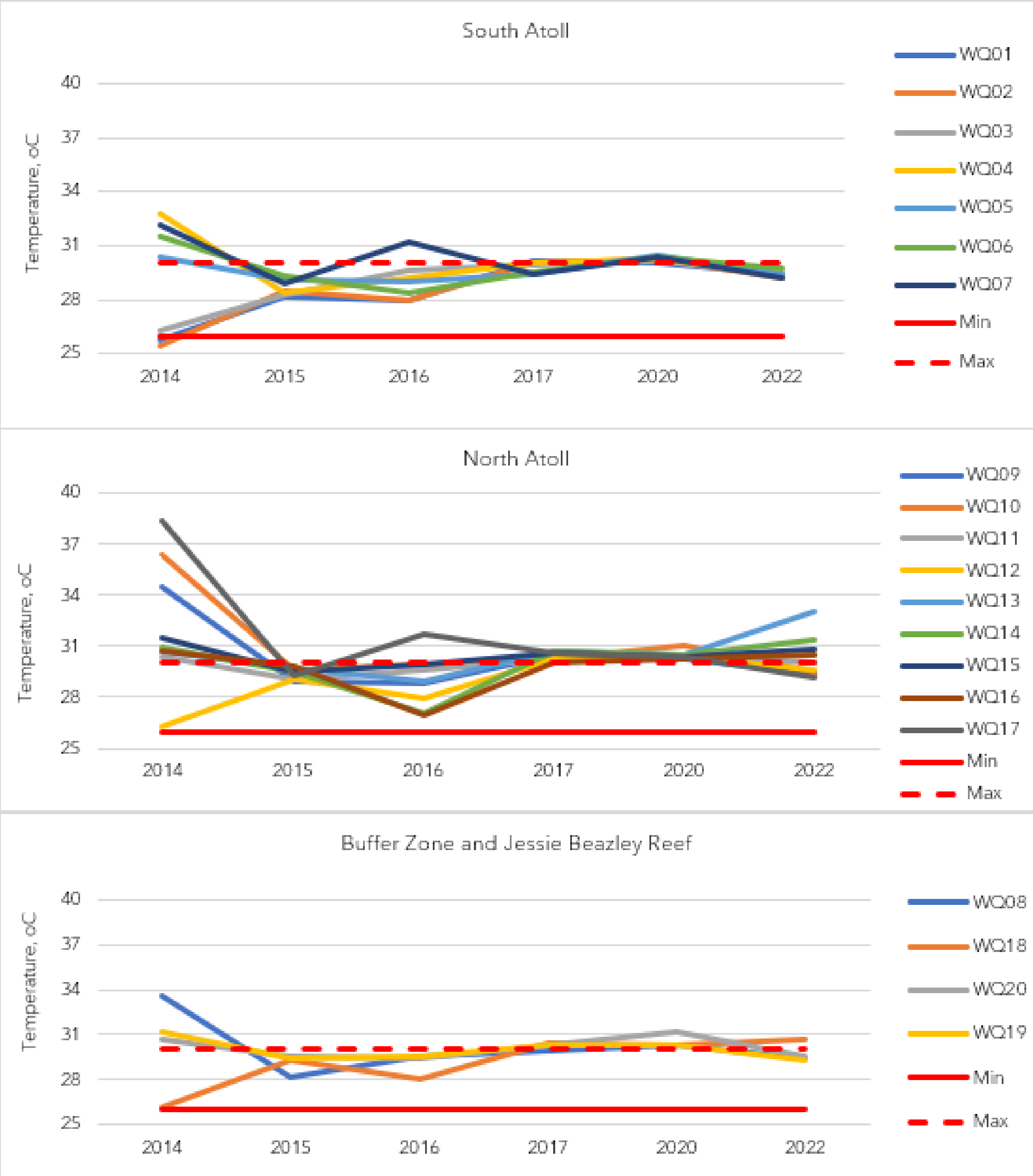


Figure 63. Trends of temperature recorded in water quality monitoring stations in TRNP from 2014 to 2022. Solid red horizontal line indicates the minimum temperature at 25oC while broken red line indicates maximum temperature at 30oC (Class SA, DAO 2016-08).

The average temperature decreased in 2022 to 29.9°C from 30.4°C in 2020. On average, the temperature recorded in North Atoll (30.3°C) was slightly higher than South Atoll at 29.4°C. Five out of nine WQ monitoring stations in North Atoll had temperature above 30°C.

Similarly, the temperature in WQ station located in the buffer zone adjacent to North Atoll (WQ18) was recorded at 30.65 °C.

Figure 64 shows the sea surface temperature recorded from April to May 2022 in areas surrounding TRNP, where the color indicator shows higher intensity (approximately 30°C and above) in 11 May 2022.

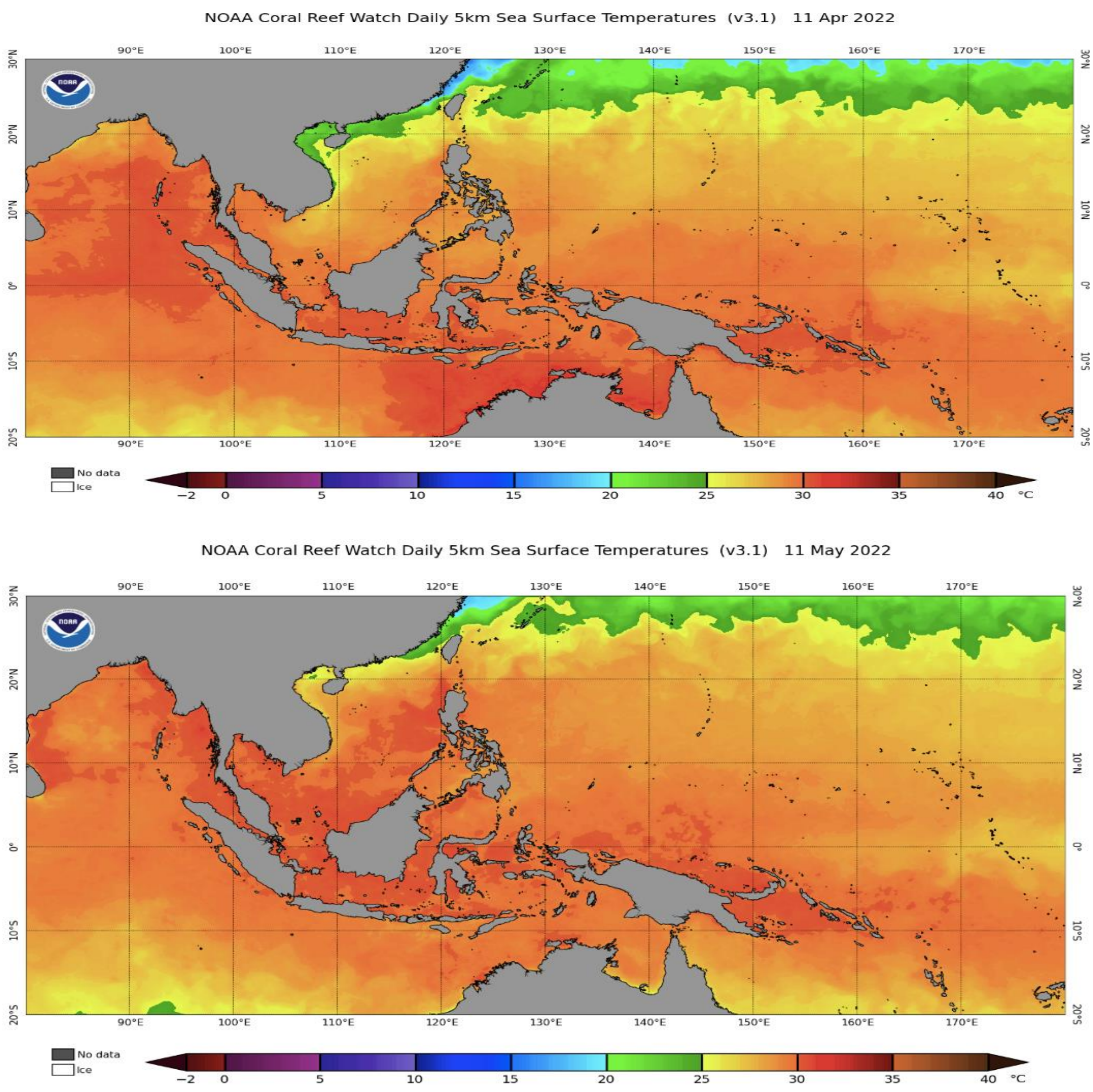


Figure 64. Sea surface temperature recorded in the surroundings of Tubbataha Reefs Natural Park, covering the Coral Triangle and Sulu Sea (encircled in black) from April to May 2022. Source: NOAA Sattelite and Information Service https://coralreefwatch.noaa.gov/product/5km/index.php

Glynn and D'Croz (1990) showed that temperatures of 30-32°C is detrimental to corals and other associated crustacean symbionts after a prolong exposure, while corals at 26-28°C remained alive and healthy. This was evident in the 2020 TMO report where bleached corals were observed in Jessie Beazley Reef, Kook, and Delsan Wreck. No coral bleaching was observed in TRNP in 2022.

The improvements in water quality during the lockdown due to the COVID-19 pandemic showed the importance of a 'closed season' in allowing water bodies to assimilate and recover from pollutants. Assimilative capacity is a natural process that allows bodies of water to absorb and utilize substances or pollutants without affecting quality or harming the aquatic environment. Assimilation occurs through dispersion by wave action and dilution. The assimilative capacity also indicates the amount of pollutants that can be contained, processed, transformed beyond the normal capacity of the water bodies without disturbing its quality (Kulikova et al., 2018). The ability of water bodies to naturally purify and restore itself deteriorates with increasing amounts of pollutants discharged into it (Lee et al., 2017).

CONCLUSION

Improvements have been observed on the water quality in TRNP from pre-lockdown (2014-2017), lockdown (2020-2021), and reopening phase (2022). Consistent with 2021 water quality monitoring, recent concentrations of color, total suspended solids, nitrates, oil and grease and fecal coliform were all within the water quality guidelines for protected waters (Class SA, DAO 2018-06 and DAO 2021-09). It confirms the capacity of waters of TRNP to assimilate pollutants influenced by antropogenic acitivites.

Elevated levels of parameters affected by natural factors in TRNP such as phophates, decreased in some monitoring stations, these levels were still above the Class SA WQ guideline.

RECOMMENDATIONS

To gain better understanding of developments in water quality in TRNP, the following measures are recommended:

1. Continous monitoring of changes and trends in quality of coral reefs or benthic cover to establish the relationship or effects of increased nutrients from seabird guano.
2. Request the classification of waters surrounding the Tubbataha Reefs Natural Park from concerned government agency. Data collected and accumulated through the years of water quality monitoring in Tubbataha may be used as baseline data for assessment and identication of water classification.
3. Continue the annual monitoring of water quality in Tubbataha Reefs Natural Park. Measurement of on-site parameters such as temperature, dissolved oxygen, pH, and turbidity with the use of multiprobe water quality checker should also be done on regular and more frequent interval.

REFERENCES

Arquiza, Y. D. and White, A. T. 1999. Tales from Tubbataha: Natural history, resource use and conservation of the Tubbataha reefs, Palawan, Philippines Bookmark, Philippines, 190 pp.

Chakraborty, B., Bera, B., Adhikary, P. P., & Bhattacharjee, S. (2021). Positive effects of COVID - 19 lockdown on river water quality : evidence from River Damodar ,. Scientific Reports, 1–16. https://doi.org/10.1038/s41598-021-99689-9

Glynn, P.W., D'Croz, L. 1990. Experimental evidence for high temperature stress as the cause of El Niño-coincident coral mortality. *Coral Reefs* 8, 181–191 https://doi.org/10.1007/BF00265009

Kulikova, D.; Kovrov, O.; Buchavy, Y.; Fedotov, V., (2018). GIS- based Assessment of the Assimilative Capacity of Rivers in Dnipropetrovsk Region. J. Geol. Geogr. Geoecol., 27(2): 274-285

Lee, I.; Hwang, H.; Lee, J.; Yu, N.; Yun, J.; Kim, H., (2017). Modeling approach to evaluation of environmental impacts on river water quality: A case study with Galing River, Kuantan, Pahang, Malaysia. Ecol. Modell., 353: 167-173 (7 pages).

Licuanan W.Y. and Bahiniting S.E. (2021) . Changes in Benthic Cover in the South Atoll of Tubbataha Reefs due to Possible Eutrophication. Philippine Journal of Science 150(1): 139 – 143

Ormaza-Gonzaìlez, F. I., Castro-Rodas, D., & Statham, P. J. (2021). COVID-19 Impacts on Beaches and Coastal Water Pollution at Selected Sites in Ecuador, and Management Proposals Post-pandemic. Frontiers in Marine Science, 8(July), 1–16. https://doi.org/10.3389/fmars.2021.669374

APPENDICES

Appendix 1. Fish and benthos monitoring sites

Sites	Stations	Latitude (N)	Longitude (E)
Site 1	1A	8.93532	120.013
	1B	8.93781	120.0085
Site 2	2A	8.89236	119.9063
	2B	8.89128	119.9045
Site 3	3A	8.75591	119.8288
	3B	8.75186	119.8278
Site 4	4A	8.8085	119.8191
	4B	8.80656	119.8217
Site 5	5A	8.7393	119.8129
	5B	8.74064	119.81139
Jessie Beazley	JBA	9.04393	119.816
	JBB	9.04557	119.8135
Grounding sites	USS Guardian	8.80911	119.8095
	Min Ping Yu	8.85174	119.9366

Appendix 2. Categories for evaluating the ecological health of coral reef fish communities in the Philippines according to Hilomen et al. (2000) and Naňola et al. (2004).

Parameter	Measure	Category
Species Richness (Hilomen et al., 2000)	Number of species per 500m^2)	
	<16	Very poor
	13.5-23.5	Poor
	24-37	Moderate
	37.5-50	High
	>50	Very High
Density (Hilomen et al., 2000)	Number of fish per 500m^2)	
	< 100.5 fish	Very Poor
	101-338	Low
	338.5-1,133.5	Moderate
	1134-3,796	High
	> 3,796	Very High
Biomass (Nañola et al., 2004)	g/m^2	
	0-10	Very Low to Low
	11-20	Moderate
	21-40	High
	>40	Very High

Appendix 3. Mean biomass (g/m^2) outputs of fish families in deep (n=30) and shallow (n=30) stations of the regular monitoring sites in the Tubbataha Reefs Natural Park.

Family	Deep (g/m^2)	Shallow (g/m^2)
Acanthuridae	9.27	14.91
Acanthuridae: Nasinae	18.66	10.16
Apogonidae	0.02	0.00
Aulostomidae	0.01	0.00
Balistidae	6.43	23.85
Belonidae	0.00	0.60
Blenniidae	0.00	0.00
Caesionidae	10.13	0.66
Carangidae	4.32	7.25
Carcharhinidae	2.77	0.00
Chaetodontidae	2.10	2.82
Cirrhitidae	0.02	0.06
Diodontidae	0.06	0.00
Ephippidae	0.20	0.47
Gobiidae	0.00	0.00
Haemulidae	0.86	9.92
Holocentridae	8.37	2.81
Kyphosidae	1.30	0.85
Labridae	1.40	1.51
Lethrinidae	9.63	2.25
Lutjanidae	9.35	3.13
Monacanthidae	0.07	0.02
Mullidae	0.23	0.31
Muraenidae	0.36	0.00
Nemipteridae	0.00	0.01
Ostraciidae	0.02	0.05
Pomacanthidae	1.59	2.47
Pomacentridae	4.62	3.99
Pseudochromidae	0.00	0.00
Ptereleotridae	0.01	0.02
Scaridae	10.13	41.87
Serranidae	4.51	5.50
Serranidae/Anthiinae	1.62	1.41
Siganidae	0.36	0.34
Tetraodontidae	0.22	0.23
Zanclidae	1.50	1.48

Appendix 4. Mean density (ind/500m2) outputs of fish families in deep (n=30) and shallow (n=30) stations of the regular monitoring sites in the Tubbataha Reefs Natural Park.

Family	Deep (ind/500m^2)	Shallow (ind/500m^2)
Acanthuridae	56.4	112.4
Acanthuridae: Nasinae	20.2	9.5
Apogonidae	6.7	0.0
Aulostomidae	0.0	0.0
Balistidae	17.6	71.7
Belonidae	0.0	1.5
Blenniidae	0.3	0.1
Caesionidae	47.0	3.7
Carangidae	1.9	2.6
Carcharhinidae	0.1	0.0
Chaetodontidae	18.8	19.5
Cirrhitidae	2.1	4.5
Diodontidae	0.0	0.0
Ephippidae	0.2	0.2
Gobiidae	0.1	0.2
Haemulidae	0.5	1.5
Holocentridae	33.9	2.8
Kyphosidae	0.8	0.6
Labridae	49.5	127.7
Lethrinidae	16.4	3.5
Lutjanidae	8.5	3.0
Monacanthidae	0.0	0.2
Mullidae	0.9	1.4
Muraenidae	0.1	0.0
Nemipteridae	0.0	0.1
Ostraciidae	0.1	0.2
Pomacanthidae	11.5	15.5
Pomacentridae	638.9	745.5
Pseudochromidae	0.2	0.0
Ptereleotridae	5.7	11.2
Scaridae	10.3	20.7
Serranidae	10.3	17.4
Serranidae/Anthiinae	500.0	129.4
Siganidae	0.5	0.5
Tetraodontidae	0.2	0.4
Zanclidae	4.7	5.7

Appendix 5. Mean biomass (g/m^2) and density (ind/500m^2) outputs of fish families in Min Ping Yu grounding site.

Families	Biomass (g/m^2)	Density (ind/500m^2)
Acanthuridae	10.8	111.7
Acanthuridae: Nasinae	5.1	3.8
Apogonidae	0.3	2.7
Balistidae	3.7	6.5
Blenniidae	0.0	0.3
Caesionidae	5.0	20.5
Carangidae	1.5	0.5
Chaetodontidae	2.3	21.0
Cirrhitidae	0.0	1.3
Holocentridae	4.4	26.7
Labridae	1.2	55.5
Lethrinidae	0.9	4.2
Lutjanidae	1.4	1.3
Monacanthidae	0.0	0.8
Mullidae	0.3	3.2
Nemipteridae	0.0	0.3
Pinguipedidae	0.0	0.2
Pomacanthidae	0.3	9.7
Pomacentridae	6.8	940.7
Pseudochromidae	0.0	0.2
Scaridae	4.9	12.3
Serranidae	2.2	6.8
Serranidae/Anthiinae	0.3	83.7
Siganidae	0.0	0.2
Tetraodontidae	0.0	0.2
Zanclidae	0.1	0.8

Appendix 6. Mean biomass (g/m^2) and density ($ind/500m^2$) outputs of fish families in USS Guardian grounding site.

Families	Biomass (g/m^2)	Density ($ind/500m^2$)
Acanthuridae	10.59	53.00
Acanthuridae: Nasinae	2.36	1.33
Balistidae	31.79	109.83
Carangidae	2.02	0.67
Chaetodontidae	2.69	15.17
Cirrhitidae	0.02	2.00
Ephippidae	0.52	0.50
Haemulidae	6.51	3.00
Holocentridae	7.83	23.83
Labridae	1.09	95.17
Lethrinidae	1.69	4.83
Lutjanidae	3.84	3.83
Pomacanthidae	1.46	15.83
Pomacentridae	3.18	434.00
Ptereleotridae	0.00	3.83
Scaridae	13.22	10.17
Serranidae	5.22	13.17
Serranidae/Anthiinae	1.69	429.33
Siganidae	0.37	0.17
Tetraodontidae	0.11	0.33
Zanclidae	1.40	3.83

Appendix 7. 2022 Monitoring Team

TUBBATAHA MANAGEMENT OFFICE

Angelique Songco, Protected Area Superintendent
Noel (Manny) Bundal, MPR
Cresencio Caranay Jr, MPR
Segundo Conales Jr, Researcher/MPR
Jeffrey David, Researcher/MPR
Rowell Alarcon, Researcher
Gerlie Gedoria, Researcher

PHILIPPINE COAST GUARD

CG SN1 Eugene Robert P Atienza
CG SN1 Henerson D Jaranilla
CG ASN Rusty T Velila

PHILIPPINE NAVY - NAVAL FORCES WEST

PO1 Jose J de Castro PN

LGU CAGAYANCILLO

Rex Cayabo

WWF-PHILIPPINES

Ronald de Roa, MY Navorca
Mary Joan Pecson, Researcher
Kymry Delijero, Researcher

UP-CEBU

Hazel Arceo

VOLUNTEERS

Ace Nińo Andew Acebuque
Jomil Rodriguez
Anton Rey Cornel
Benjamin Ted Jimenez

Appendix 8. Condition of vegetation on Bird Islet and South Islet

Condition of vegetation on Bird Islet, May 2006 (baseline year), and 2020 to 2022

Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2006	2020	2021	2022	2006	2020	2021	2022	2006	2020	2021	2022	2006	2020	2021	2022	2006	2016	2018	2019
Dead trees																	82	75	ND	ND
Mature, live trees (> 3 feet)	10	0	0	**0**	49	0	0	**5**	11	0	0	**0**	70	0	0	**5**				
Small, live trees (2- 3 feet)	109	3	13	**0**	0	0	0	**2**	0	0	10	**1**	109	332	23	**3**				
Seedlings (< 1 feet)	50	0 *)	0	**0**	0	0	0	**0**	0	0	0	**0**	50	0	0	**0**				
Total	**169**	**3**	**13**	**0**	**49**	**0**	**0**	**7**	**11**	**0**	**0**	**1**	**229**	**14**	**332**	**8***	**82**	**75**	ND	ND

Notes

Seedlings/small trees 2019 were planted saplings > 1 foot tall, taken from Cagayancillo Municipality. In June 2020, 329 Anuling saplings planted.
In 2021 planting took place only after the May inventory, e.g., 16 mostly Anuling as of August 2021 and in June 2022, 20 saplings
*All plants placed in protective bamboo boxes
Coco Palms: 2018: 3, 2019: 2, 2020: 0, 2021: 0, 2022: 3

Condition of vegetation on South Islet May 2011 (baseline year), and 2020 to 2022

Trees/ Condition	**Good (optimal)**				**Fair (moderately deteriorating)**				**Bad (severely deteriorating)**				**Total (live trees)**				**Dead**				
	2011	**2020**	**2021**	**2022**	**2011**	**2020**	**2021**	**2022**	**2011**	**2020**	**2021**	**2022**	**2011**	**2020**	**2021**	**2022**	**2016**	**2018**	**2019**	**2021**	**2022**
Dead trees															6		16	ND	ND	ND	ND
Mature, live trees (> 3 feet)	70	0	0	**0**	28	0	0	**0**	5	0	0	**0**	103	0	0	0				**0**	
Small, live trees (2- 3 feet)	2	0	51	**19**	0	101	0	**0**	0	0	0	**0**	2	101	35	19				**51**	
Seedlings (< 1 feet)	19	0	0	**0**	0	0	0	**0**	0	0	0	**0**	19	0	0	0				**0**	
Total	**91**	**0**	**0**	**19**	**28**	**101**	**0**	**0**	**x**	**0**	**0**	**0**	**124**	**101**	**35**	**19**	**16**	ND	ND	**51**	

Notes: In June 2020, 101 Anuling saplings > 1 feet tall were planted. In 2021 planting took place only after the May inventory, e.g. 35 mostly Anuling as of August and again in August 2022.
Coco Palms 2011: 13, 2016: 6, 2017:6, 2018:10, 2019:6, 2020:7, 2021: 3, 2022: 5

Appendix 9. Population results and population trend of breeding seabirds in TRNP April to June 1981 – 2022.

Inventory baseline years are underlined. Source: Kennedy 1982, Manamtam 1996, WWF Philippines 1998-2004 and TMO 2004-2022

Species/ Numbers	1981	1995	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ground-breeders Sub-total	**13,388**	**3,949**	**1,744**	**4,695**	**7,529**	**7,635**	**2,804**	**5,200**	**13,825**	**16,957**	**7,746**	**10,534**	**9,721**
Masked Booby	150	1	0	0	0	0	0	0	0	0	0	0	0
Brown Booby	3,768	**1)** 2,060	1,716	1,045	850	577	623	856	1,877	1,108	1,016	1,059	1,018
Brown Noddy	2,136	643	0	500	37	775	115	336	590	1,035	530	800	1,570
Great Crested Tern	2,264	335	0	150	414	4,160	2,064	2,808	7,858	6,894	4,700	4,875	4,433
Sooty Tern	5,070	**1)** 910	28	3,000	6,228	2,123	2	1,200	3,500	7,920	>1,500	3,800	2,700
Tree-breeders Sub-total	**156**	**7,128**	**3,250**	**3,502**	**7,042**	**5,003**	**1,630**	**3,240**	**8,353**	**8,727**	**7,902**	**10,403**	**9,525**
Red-Footed Booby	9	0	0	2	44	43	20	2,435	1,947	1,877	2,902	2,513	2,220
Black Noddy	147	7,128	3,250	3,500	6,998	4,860	1,610	805	6,406	6,850	> 5,000	7,890	> 7,305
TOTAL	**13,544**	**11,077**	**4,994**	**8,197**	**14,571**	**12,638**	**4,434**	**8,440**	**22,178**	**25,684**	**15,648**	**20,937**	**19,246**

Notes: 1) End of March data.
2) Based on Park Rangers distance count 1 June 2014.
3) Based on Park Rangers count 9 August 2014.
4) Based on Park Rangers egg count 14 Feb 2015.

5) 7,258 individuals based on Park Rangers egg count 16 Feb 2020

Species/ Numbers	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Trend (%)
Ground-breeders														
Sub-total	18,669	13,592	18,383	15,988	16,448	27,193	27,654	29,940	35,878	24,569	29,323	24,880	35,994	+ 44.6
Masked Booby	0	0	0	0	0	0	1	1	1	1	2	2	2	0
Brown Booby	1,438	1,846	1,879	1,690	1,632	2,403	3,122	3,535	3,367	3,138	>2,977	3,800	**10)** 4,906	+ 29.0
Brown Noddy	1,575	2,042	1,492	1,688	1,862	2,583	2,096	4,209	3,470	2,208	3,262	**6)** 1,702	**11)** 2,084	+ 22.0
Great Crested Tern	4,790	6,160	8,653	9,794	**2)** 7,730	<12,387	13,880	17,097	17,752	14,880	17,810	13,376	17, 812	+ 31.0
Sooty Tern	10,866	3,544	6,359	2,816	**3)** 5,224	**4)** 9,820	8,555	>5,098	11,288	4,342	**5)**> 5,272	**7)** 6,000	**12)**11,448	+ 91.0
Tree-breeders														
Sub-total	9,975	10,746	11,776	12,858	10,630	11,718	11,101	7,278	5,916	3,152	3,310	3,298	2,950	-11.5
Red-Footed Booby	2,331	2,395	2,340	2,202	3,074	3,492	2,141	2,087	1,443	1,080	660	422	736	+ 74.0
Black Noddy	7,644	8,351	9,436	10,656	7,556	8,226	8,716	5,191	4,473	2,072	**8)** 2,650	**9)** 2,876	**13)** 2 ,214	-23.0
TOTAL	28,644	24,338	30,159	28,846	27,078	38,911	38,549	37,218	41,794	27,721	32,633	28,178	39,202	+ 38.0

Notes:
1) End of March data.
2) Based on MPR distance count 1 June 2014.
3) Based on MPR count 9 August 2014.
4) Based on MPR Rangers egg count 14 Feb 2015.

5) Annual total 12,530, if 7,258 breeding individuals counted by MPR Feb 2020 is added.

6) May represent change in breeding phenology. February 2021 count was 2,728

7) Annual total 8,063, if 2,063 breeding individuals counted by MPR Feb 2021 is added.

8) Annual total 3,128 breeding individuals, if 478 actively breeding individuals counted by MPR Feb 2020 is added.

9) Annual total 3,636 breeding individuals, if 760 actively breeding individuals counted by MPR Feb 2021 is added.

10) 5,130 individuals, if 224 actively breeding birds with juveniles, pulli and eggs in February 2022 is added

11) Represents change in phenology. Total 3,200 breeding individuals, if 1,116 actively breeding individuals with eggs, pulli and juveniles in February 2022 is added

12). If the population breeding numbers is based on eggs laid in February 2022(3,814 eggs) and eggs present during the April inventory, the population of this species would be 18,506 adult individuals.

13) Total 3,026 breeding individuals, if 812 actively breeding individuals with eggs counted in February 2022 is added

Appendix 10. Seabird breeding data from Bird Islet and from South Islet, 2nd Quarter (mainly May) 2004-2022

Species/Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Red-footed Booby																			
Immatures	398	1,455	606	597	780	477	677	795	799	426	134	206	80	97	89	104	24	30	12
Pulli/1st year juv.	> 35	71	105	116	69	180	88	171	243	312	277	240	49	43	39	14	8	8	0
Eggs	+	+	+	+	+	+	+	68	>166	>185	>57	>46	> 49	55	74	26	>7	14	18
Nests	279	217	225	404	361	367	451	369	739	848	431	379	315	177	223	72	43	73	68
																	Note 1		Note 8
Brown Booby																			
Immatures	0	81	26	55	55	61	126	110	140	62	51	28	66	157	264	218	35	27	13
Pulli/1st year juv.	43	2	7	12	91	126	125	225	46	28	266	200	22	175	95	8	8	172	360
Eggs	1	0	18	95	317	48	106	52	69	532	466	55	144	43	25	6	286	1,496	1,792
Nests	117	43	250	89	497	453	513	575	507	618	816	726	887	886	376	412	1,054	1,861	2,369
																	Note 2	Note 6	Note 9
Brown Noddy																			
Immatures	0	2	0	0	0	4	1	1	2	3	5	2	0	2	14	9	0	0	0
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	0	0	6	109	223	493	68	79	406	279
Eggs	0	0	0	3	17	126	438	253	>147	>607	679	571	620	1,005	581	183	615	177	326
Nests	115	124	20+	25+	218	384	653	571	709	771	931	960	1,048	1,917	1,644	805	1092	851	907
																	Note 3	Note 7	Note 10
Black Noddy																			
Immatures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	0	0	30	193	8	74	d39	40	207	161
Eggs	ND	+	0	+	+	430	+	+	>80	>700	>351	>299	>191	406	468	254	269	323	380
Nests	208	3,203	1,131	1,734	1,824	2,680	3,525	3,827	4,282	5,156	3,778	2,397	1,634	1,205	1131	1036	1,135	1,438	1,852
																	Note 4		Note 11
Great Crested Tern																			
Immatures	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pulli/1st year juv.	0	2,100	0	0	0	0	0	0	0	0	0	0	0	29	832	2610	6,813	4,447	1,807
Eggs	0	1,829	0	0	0	515	2,341	498	1,456	3,939	2,120	4,280	6,800	8,620	7,461	4830	1,568	2,292	7,099
																	Note 5		
Sooty Tern																			
Immatures	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Pulli/1st year juv.	0	1,750	0	458	0	846	0	1,764	0	1,258	0	3,538	0	2,549	680	11	2,622	1	2,150
Eggs	9	0	0	63	2	3	5,515	2	1,534	146	37	52	166	0	4,964	3	14	593	3,284
																			Note 12

Source: WWF Philippines 2004 and TMO 2004 to 2022

Note 1: MPR counted 16 Feb 2020 40 pulli/juv, 17 eggs and 257 nests; on 13 Aug 3 juveniles, 630 pulli, 1,213 eggs and, 1,700 nest
Note 2: MPR counted 16 Feb 2020 51 pulli/juv, 188 eggs and 302 nests; on 13 Aug 254 pulli/juv, 70 eggs and 1020 nests
Note 3: MPR counted 16 Feb 2020 46 pulli/juv, 196 eggs and 367 nests; on 13 Aug 60 pulli/juv, 82 eggs and 356 nests
Note 4: MPR counted on 13 Aug 124 pulli/juv
Note 5: a) MPR counted 16 Feb 2019 3,627 eggs; on 13 Aug 0 pulli/juv and 0 eggs
Note 5: b) 19 -20 May, juveniles and pulli with feathers, c) Many airborne juveniles could not be counted
Note 6: MPR counted on 14 Feb 2021 633 eggs, 67 pulli and 788 nests
Note 7: MPR counted on MPR counted on 14 Feb 2021 92 eggs
Note 8: 13 and 17 Feb 2022 MPR counted 1 juvenile, 1 pullus and 8 eggs = 20 active breeding adults
Note 9: 13 and 17 Feb 2021: MPR counted 1 juvenile, 29 pulli and 114 eggs
Note 10: 13 and 17 Feb 2021: MPR counted 140 juvenile, 46 pulli and 372 eggs = 1,116 active breeding adults
Note 11: MPR counted on 13 and 17 Feb 20221 81 pulli and 325 eggs= 812 active breeding adults
Note 12: MPR counted on 13 and 17 Feb 2022 3,814 eggs, 4 pulli an 1 juvenile = 7,638 adults

Appendix 11. In-flight to roost statistics of boobies and noddies on Bird Islet May 2005 to May 2022

Species/ Numbers	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
	May 10: 17.00-18.15	Apr 28: 16.30-18.25	May 8: 16.30-18.20	May 7: 16.00-18.00	May 7: 16.30-18.30	May 13: 16.30-18.30	May 9: 16.30-18.30	May 10: 16.30-18.30	May 10: 16.30-18.30	May 9: 16.30-18.30	May 9: 16.30-18.30	May 11: 16:30 – 18.30	May 10: 16.30 – 18.30	May 14: 16.30 – 18.30	May15: 16.30 – 18.30	May19: 16.30 – 18.30	May27: 16.30 – 18.30	April 26: 16.30 – 18.30
	Red-footed Booby																	
Adult: Daytime	823	655	631	1,241	686	982	1,011	382	830	950	1,499	248	343	470	362	131	97	279
In-flight	960	1,171	2,082	1,272	1,534	1,259	1,259	1,680	779	813	602	367	527	356	282	309	224	131
Adjusted to 2-hour period	1,012	1,222	2,271	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1,835	1,877	2,902	2,513	2,220	2,241	2,270	2,062	1,609	1,763	2,101	615	870	826	644	430	321	410
%-in-flight population	55%	65%	78%	51%	69%	56%	55%	81%	48%	46%	29%	25%	25%	43%	44%	72%	70%	32%
Average In-flight (%)	**53.8%**																	
Immature: Daytime	514	>205	275	239	179	194	106	174	125	61	111	8	29	24	27	5	5	3
In-flight	588	401	295	541	298	483	483	249	149	5	37	17	40	20	34	16	20	0
Adjusted to 2-hour period	941	419	322	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Total	1,455	>606	597	780	477	677	589	423	274	66	148	25	69	44	61	21	25	3
%-in-flight population	65%	69%	54%	69%	63%	71%	82%	59%	54%	8%	25%	25%	25%	45%	56%	76%	80%	0%
Average In-flight (%)	**51.4%**																	
	Brown Booby																	
Adult: Daytime	629	405	660	691	650	930	1,338	1,060	968	834	1,505	1,920	2,257	1,295	2,212	888	1,556	3,560
In-flight	360	225	326	368	368	508	508	819	722	798	848	1,202	1,278	2,072	727	1,640	1,352	1,172
Adjusted to 2-hour period	576	235	356	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1,205	640	1,016	1,059	1,018	1,438	1,846	1,879	1,690	1,632	2,353	3,122	3,535	3,367	2,939	2,528	2,908	4,732
%-in-flight population	48%	37%	35%	35%	36%	35%	28%	44%	43%	49%	36%	25%	25%	62%	25%	65%	47%	25%
Average In-flight (%)	**36.97%**																	
Immature: Daytime	22	20	21	20+?	22	30+	96	81	30	13	1	25	74	127	187	16	3	0
In-flight	37	6	31	34	39	96	14	59	32	39	25	41	78	105	30	19	18	3
Adjusted to 2-hour period	59	6	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Total	81	26	55	54	61	126	110	140	64	51	26	66	152	232	217	35	21	3
%-in-flight population	73%	23%	62%	63%	64%	76%	13%	42%	50%	76%	96%	62%	51**%**	45%	14%	26%	86%	**0%**
Average In-flight (%)	**51.2%**																	
	Brown Noddy																	
Adult: Daytime							618	607	1,004	1,045	1,031	992	2,953					
In-flight							1,124	525	142	239	378	358	51					
Total							1,742	1,132	1,146	1,284	1,409	1,350	3,004					
%-in-flight population							65%	46%	12%	19%	27%	27%	2%					
Average In-flight (%)	**28.3%**																	
	Black Noddy																	
Adult: Daytime							421	1,098	2,243	1,506	2,412	711	800					
In-flight							1,334	1,124	272	318	132	84	9					
Total							1,755	2,222	2,515	1,824	2,544	795	809					
%-in-flight population							76%	51%	11%	17%	5%	11%	1%					
Average In-flight (%)	**24.6%**																	

Appendix 12. In-flight to roost statistics of boobies and noddies on South Islet May 2014 to 2022

Species/ Numbers	2014	2015	2016	2017	2018	2019	2020	2022	2014	2015	2016	2017	2018	2019	2020	2021	2022
Red-footed Booby									Brown Booby								
	May 8: 16.30 - 17.30	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12: 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	Apr 30 16.30 - 18.30	May 8: 16.30 - 17.30	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12: 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	May 31: 16.30 - 18.30	April 29: 16.30 - 18.30
Adult: Daytime	401	366	508	584	262	154	32	41	7	22	40	31	160	41	73	81	174
In-flight	910	1,020	1,018	633	355	282	198	285	2	28	24	11	144	158	376	20	109
Adjusted to 2-hour period	1,820	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-
Total	2,221	1,386	1,526	1,217	617	436	230	326	11	50	64	42	304	199	449	101	174
% in-flight population	82.0	73.6	66.7	52.0	57.5	64.7	86.1	12.6	18.2	56.0	37.5	26.2	47.4	79.4	83.7	19.8	62.6
Average	61.9								47.9								
Immature: Daytime	68	58	32	27	22	43	5	6	0	2	0	4	32	1	16	3	0
In-flight	1	No count	21	1	23	27	4	2	0	No count	No count	1	0	4	16	2	1
Adjusted to 2-hour period	2	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-
Total	70	> 58	63	28	45	70	9	8	0	>2	0	5	32	5	32	5	1
% in-flight population	2.9	-	33.3	3.6	51.1	38.6	44.4	25.0	0	-	-	20.0	0	80.o	50.0	40.0	50.0
Average	28.4							34.3									

Species	Black and Brown Noddy						
	Year	2015	2016	2017	2018	2019	2022
	(Note 1)	(Note2)	(Note 3)		(Note 4)	(Note 5)	
	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	30 April: 16.30 - 18.30
Adult: Daytime	6,856	> 4,421	4,126	2,179	0	-	-
In-flight	4,678	> 3,500	< 2,066	1,335	o	-	-
Adjusted to 2-hour period	4,678	-	-	-	-	-	-
Total	11,534	7,921	6,192	3,514	0	-	-
% in-flight population	40.6	44.2	33.4	38.0	-	-	-
Average	39.0						
	Brown Noddy						
Adult: Daytime			2,921	1,347	0	427	1,270
In-flight			1,461	681	0	249	176
Adjusted to 2-hour period			-	-	-	-	-
Total			4,382	2,028	0	676	1,446
% in-flight population			33.3	33.6	0	36.8	12.2
Average	29.0						
	Black Noddy						
Adult: Daytime			1,205	832	60	948	1,125
In-flight			605	654	19	171	113
Adjusted 2-hour period			-	-	-	-	-

Total			1,810	1,486	79	1,119	1,238
% in-flight population			33.4	44.0	24.0	15.3	9.1
Average	25.2						

Note 1: Predominantly Black Noddy
Note 2: From 16.30 to 17.30 more birds left the islet compared to the number of birds arriving. From 17.30 to 18.00 more birds arrived than left the islet
Note 3: 578 individuals left the islet while 2,644 flew in = 2,066 in-flight
Note 4: 101 birds did not settle for landing as a results of ongoing construction and reclamation works
Note 5: Black Noddy: flying in to islet 421, flying out 172. Brown Noddy: flying in to islet 464, flying out 293

Appendix 13. Systematic list of non-breeding avifauna observed at South Islet, Bird Islet, and Ranger Station, Tubbataha Reefs Natural Park from June 2021 to 27 to 28 and 30 April and 3 May 2022

Breeding species are indicated in bold letters. Taxonomic treatment and sequence follows IOC/Wild Bird Club of the Philippines 2021. Threat status follows DENR Administrative Order No 2019 – 09: Updated National List of Threatened Philippine Fauna and Their Categories

CR – Critically Endangered, EN – Endangered, VU – Vulnerable, OTS – Other Threatened Species, NT- Near Threatened, LC – Least Concern

Status and Abundance (within Sulu Sea) Threat Status (IUCN and National Red List)	Species name	Number of individuals	Locality	Notes
Resident Common LC	Grey-capped Emerald Dove *Chalcophaps indica*	1	Ranger Station	First record. Caught at Ranger Station May 21 2022 and released same day
Resident Common LC	Barred Rail *Gallirallus torquatus*	1	Bird Islet	On 15 Nov 2021, one bird at South Islet.
Status Unknown Rare LC	Red-legged Crake *Rallina fasciata*	1	Bird Islet	One found dead on 26 April 2022l. 4th TRNP record. Passage Migrant
Migrant (Rare resident) Common LC	Black-winged Stilt *Himantopus himantopus*	5	South Islet	11 September 2021 3rd TRNP record
Migrant Uncommon NT	Grey-tailed Tattler *Tringa brevipes*	7 - 8	Bird Islet	11 Sep and 15 Oct 2021
Migrant Fairly common LC	Ruddy Turnstone *Arenaria interpres*	4	Bird Islet	Outside of the April 2022 inventory period observed in 2021 on 11 Aug: 5, 11 Sep 8, 15 Oct: 6 and 14 Dec: 5

		0	South Islet	On 13 August 2021, 6 individuals
		0	Ranger Station	On 11 Sep 2021, 10 individuals
Accidental	Vega Gull? *Larus vegae*	1	Ranger Station	Species identification needs to be confirmed. One adult photo documented on 12 December 2021
Resident Uncommon LC	Black-naped Tern *Sterna sumatrana*	4	Bird Islet	26- 27 April
		5	Ranger Station	30 April
	Unidentified Frigatebirds *Fregata sp*	2	Bird Islet	26- 27 April, 3 May In 2021, 3 birds on 11 August
		25	South Islet	30 April Highest counts since the May 2021 inventory includes 21 individuals on 13 August and 35 on 15 September 2021
		Adults: 6	South Islet	Outside of the April 2022 inventory period, up to 12 birds on 15 September, 8 birds on 29 November 2021, and 7 on 31 March 2022. In addition, one juvenile individual on 31 October and one pullus on 15 November 2021
Resident Common LC	Eurasian Tree Sparrow *Passer montanus*	0	Bird Islet	The species may be considered local extinct as it has not been observed since May 2020
		0	South Islet	

Appendix 14. Comparison of the landscape and habitats seen from the Permanent Photo Documentation Sites on Bird Islet and South Islet, May 2004 and May 2022

Bird Islet:

Viewing angle for photo: facing NW 180° Comments: panoramic view Photo Doc Site NI No. 01 - 2004

Photo name code: B1 01 Comments: 8 shots (Stitched by Microsoft ICE) Date: 03 May, 2022 Photo Doc Site NI No. 01 - 2022

Photo credit: Rowell Alarcon

Viewing angle for photo: facing NE 038°

Film no: 27, 28

Photo name code: BI 02

Comments: 2 shots good angle

Photo no (camera):

Photo no (negative):

Date: May 7, 2004

Photo name code: BI 02

Comments: 7 shots stitched (Microsoft ICE)

Photo Doc Site NI No. 02 – 2022 Date: 03 May 2022

Viewing angle for photo: facing S 165°
Comments: 3 shots panoramic view
Photo name code: BI 03

Film no: 22, 23, 24
Date: May 7, 2004
Photo no (camera):

Photo name code: BI 03
Comments: 7 shots stitched (Microsoft ICE)
Date: 03 May 2022

Photo no (camera):

Photo Doc Site NI No. 04 - 2004

Viewing angle for photo: facing E 067°

Film no: 14

Photo name code: BI 04

Comments: 1 shot Plaza

Photo no (negative):

Photo no (camera):

Date: May 7, 2004

Photo name code: BI 04

Comments: 6 shots Plaza stitched (Microsoft ICE)

Date: 03 May 2022

South Islet:

Viewing angle for photo: facing S 060º

Comments: shot includes view of the old lighthouse at the background

Photo taken behind the old nipa hut

Photo name code: SI 01

Photo name code: SI 01

Date: 04 May 2022

Comments: single shot including new lighthouse at the background

Coordinates for new photocdoc site was taken in 2019

Photo no (camera): IMG_2705

Appendix 15. Parameters monitored in the Tubbataha Reefs Natural Park

Parameter	Description	Method of Analysis
Physico- chemical parameters		
pH*	A numerical measure of acidity (below 7) and alkalinity (above 7)	Glass Electrode Method
Temperature*	Degree of hotness or coldness of the water. It influences the physicochemical characteristics and the distribution and abundance of marine flora and fauna.	Multi-probe Meter
Dissolved Oxygen (DO)*	Refers to the amount of oxygen available in the water column. It is an important requirement for the maintenance of a balanced population of fish, shellfish, and other marine organisms.	Membrane Electrode Method (DO Meter)
Total Suspended Solids (TSS)	Particles that remain suspended in water, thereby causing turbidity or increase the color of the water. Higher TSS, the higher the turbidity.	Gravimetric dried at 103 - 105^{0}C
Total Dissolved Solids (TDS)**	A measure of the water's content of various dissolved materials	Gravimetric dried at 180^{0}C/ Multiparameter Meter
Salinity	A measurement of the mass of dissolved salts in a given amount of water.	Multiparameter Meter
Color	Caused by the presence of dissolved organic matter, metallic salts, or suspended	Visual Comparison Method (Platinum Cobalt Scale)
Nitrogen as Nitrates	Indicates the presence of nutrients in the water bodies. High concentration can cause severe illness to animals	Colorimetric using Hach Nitrate Powder Pillows
Phosphorus as Phosphates	Indicates the presence of one of the primary nutrients in the water bodies. High concentration fuels the growth of algae and other microorganisms	Colorimetric using Hach Phosphate Powder Pillows
Oil and Grease (O&G)	Fats, oils, waxes, and other related constituents found in water that are recovered in the solvent.	Gravimetric Method (Petroleum Ether Extraction)
Biochemical oxygen demand (BOD)	Measure of the oxygen consumed by microorganisms over time as they degrade organic matter in a water body.	Alkali Iodide Azide (5-day BOD Test)
Chromium hexavalent, Cr(IV)	Cr(VI) compounds may be used as pigments in dyes, paints, inks, and plastics. It also may be used as an anticorrosive agent added to paints, primers, and other surface coatings.	Diphenylcarbazide – colorimetric method
Microbiological Parameters		
Total Coliform (TC)	TC comprises all members of the coliform bacteria group, or the microorganisms from vegetation, soil, and water	Multiple Tube Fermentation Technique
Fecal Coliform (FC)	FC are members of the TC group that originate in the intestinal gut of warm-blooded animals.	Multiple Tube Fermentation Technique

Reference: Standard Methods for the Examination of Water & Wastewater, APHA-A4WWA 21st Ed, 2005.
*Measurement done on site; ** Measured on-site and/or analyzed in the laboratory

Appendix 16. Coordinates and site description of water quality monitoring stations in TRNP, June 2022.

Site	Latitude	Longitude	Site description
South Atoll			
WQ01	N8.80891	E119.81846	Fish and benthos monitoring station 4A; top of reef; dive site
WQ02	N8.76091	E119.81324	top of the reef; not frequently visited by divers
WQ03	N8.74000	E119.81987	top of the reef; near mooring buoy
WQ04	N8.75575	E119.82881	Fish and benthos monitoring station 3A; top of reef; dive site
WQ05	N8.79674	E119.82051	original water quality site; inside lagoon; off limits to tourists
WQ06	N8.78019	E119.82307	original water quality site; inside lagoon; off limits to tourists
WQ07	N8.74841	E119.81892	South Islet; off limits to tourists
WQ09	N8.85182	E119.93669	Min Ping Yu grounding site; shallow reef, not visited by divers
North Atoll			
WQ10	N8.89209	E119.90627	Fish and benthos monitoring station 2A; top of reef; dive site
WQ11	N8.94419	E119.96900	top of the reef; dive site
WQ12	N8.93534	E120.01301	Fish and benthos monitoring station 1A; top of reef dive site; near bird islet
WQ13	N8.93001	E119.99559	Bird Islet; lagoon, off limits to tourists
WQ14	N8.90688	E119.95022	original water quality site; inside lagoon; off limits to tourists
WQ15	N8.89112	E119.94900	original water quality site; inside lagoon; off limits to tourists
WQ16	N8.88922	E119.97076	original water quality site; inside lagoon; off limits to tourists
WQ17	N8.85177	E119.91713	Ranger Station; lagoon, off limits to tourists
Jessie Beazley Reef			
WQ19	N9.04388	E119.81595	Fish and benthos monitoring station JB Reef; top of reef; dive site
Buffer Zone			
WQ08	N8.71722	E119.88998	original water quality site; buffer zone
WQ18	N8.84606	E120.02328	original water quality site; buffer zone; deep waters
WQ20	N9.09834	E119.78648	original water quality site; buffer zone; deep waters

Appendix 17. Water Quality Parameters Per WQ Monitoring Stations in Tubbataha Reefs Natural Park from 2014-2022.

WQ01	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	11	25.8	5	8.24	6.57	1.5	1.32	1.5	33	no data	25,060	-0.0022	2	35.8
2015	3	28.2	5	8.28	7.92	1.5	0.58	<1	23	1.8	25,078	0.0001	0.5	35.5
2016	2	28	5	8.24	8.09	0.75	0.24	5.6	94	23	18,768	0.0001	0.5	34.8
2017	6	30.19	5	8.78	5.9	1.4	0.52	no data	49	23	20,184	<0.003	<1	29.1
2020	<1	30.07	<5	7.75	6.73	0.46	1.51	2.5	23	7.8	30,240	no data	no data	30.07
2021	10	no data	5	no data	no data	0.7908	1.2901	<1	79	<1.8	no data	no data	no data	no data
2022	<1	29.4	<5	8.5	7.23	1.2429	0.1097	<1	<1.8	<1.8	29,600			31.6

WQ02	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	12	25.40	5	8.36	6.32	1.20	0.61	0.69	49	no data	27,640	-0.0028	2.6	35.8
2015	4	28.5	10	8.31	7.89	1.60	0.48	<1	33	1.8	24,720	0.0001	0.5	35.5
2016	<1	28	5	8.29	8.8	1.00	0.92	4.2	49	49	21,200	0.0001	1	34.8
2017	5	30.07	5	8.78	5.5	1.30	0.21	no data	58	31	23,506	<0.003	<1	29
2020	10	30.26	<5	7.05	5.99	0.49	0.58	3.6	23	4.5	30,080	no data	no data	29.88
2021	10	no data	<5	no data	no data	0.8218	0.1534	<1	<1.8	<1.8	no data	no data	no data	no data
2022	4	29.25	<5	8.39	7.51	1.7791	0.1082	<1	4.5	<1.8	27700			

WQ03	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	12	26.27	5	8.32	6.58	1.7	0.78	6.08	23	no data	25778	-0.0034	0.9	34.9
2015	<1	28.3	10	8.33	8.05	1.8	0.53	1.85	46	1.8	24875	0.0001	0.5	35.5
2016	<1	29.6	5	8.4	8.02	0.9	0.64	7.9	33	23	19099	0.0001	0.5	34.5
2017	3	29.91	5	8.81	6.1	1.5	0.4	no data	49	33	22084	<0.003	<1	28.4
2020	5	30.15	<5	7.77	6.44	0.53	0.70	<1	4.5	<1.8	29900	no data	no data	29.67
2021	10	no data	5	no data	no data	1.2502	0.0379	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.44	<5	8.45	7.29	1.4926	0.1219	<1	<1.8	<1.8	29700			31.8

WQ04	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	15	32.8	5	8.09	6.38	1.00	0.11	1.29	23	no data	27,186	0.0008	2.9	35.9
2015	5	28.4	5	8.32	8.04	1.20	0.50	1.15	33	1.8	25,943	0.0001	0.5	35.2
2016	10	29.2	5	8.34	8.09	0.75	0.22	5.4	120	94	19,325	0.0001	0.5	33.4
2017	6	30.1	5	8.67	6.5	1.80	0.25	no data	23	23	23,352	<0.003	<1	29.1
2020	<1	30.29	<5	7.65	6.84	0.48	0.25	<1	7.8	<1.8	30,490	no data	no data	30.33
2021	10	no data	5	no data	no data	0.4504	0.0558	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.39	<5	8.48	7.01	1.642	0.0983	<1	<1.8	<1.8	30200			32.4

WQ05	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	19	30.4	5	8.05	6.95	1.4	0.18	2.03	79	no data	29,788	0.0005	0.9	36.1
2015	10	29.1	10	8.14	6.2	1.3	0.51	1.25	170	70	25,280	0.0001	0.5	35.6
2016	4	29	5	8.27	6.09	0.75	1.22	<1	33	23	19,215	0.0001	0.5	34.9
2017	1	29.46	5	8.64	5.4	1.5	0.26	no data	49	33	24,045	<0.003	<1	29
2020	9	30.52	<5	7.65	7.04	0.47	0.15	3.8	4.5	<1.8	30,390	no data	no data	30.22
2021	15	no data	5	no data	no data	0.3933	0.0614	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.38	<5	8.41	8.4	1.5155	0.1091	<1	<1.8	<1.8	29100			31

WQ06	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	19	31.5	5	8.14	6.47	1	0.09	1.41	23	no data	29436	-0.0046	3.8	36.1
2015	9	29.3	10	8.22	7.65	1.4	0.59	1.25	140	46	26000	0.0001	0.5	35.6
2016	9	28.4	5	7.99	7.95	0.95	1.47	2.6	140	110	20080	0.005	1	34.8
2017	6	29.53	5	8.76	6.3	1.5	0.26	no data	43	31	22552	<0.003	<1	29.2
2020	3	30.34	<5	7.37	6.85	0.53	0.18	2.4	4.5	<1.8	30310	no data	no data	30.25
2021	11	no data	5	no data	no data	0.4186	0.9893	<1	2	<1.8	no data	no data	no data	no data
2022	9	29.76	<5	8.42	7.88	2.003	0.1082	<1	2	<1.8	28900			30.7

WQ07	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	18	32.1	5	8.14	7.01	1	1.31	2.04	44	no data	26096	-0.0034	1.1	35.5
2015	6	28.9	5	8.28	7.48	1.3	0.4	1.7	350	94	26225	0.0001	0.5	35.6
2016	12	31.2	5	8.35	7.07	1.15	0.68	3.4	210	140	24010	0.0001	0.5	34.4
2017	2	29.39	5	8.64	6	2	0.27	no data	43	31	23982	<0.003	<1	29
2020	6	30.36	<5	7.28	6.26	0.44	0.75	3.2	7.8	2	30340	no data	no data	30.17
2021	9	no data	5	no data	no data	0.5631	0.0469	<1	7.8	<1.8	no data	no data	no data	no data
2022	2	29.25	<5	8.39	7.51	1.8011	0.1183	<1	4.5	<1.8	27700			29.6

WQ08	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	11	33.6	5	8.06	6.3	1.40	0.38	1.69	130	no data	26,533	-0.0022	2.5	34.9
2015	3	28.2	5	8.30	8.18	1.30	0.47	0.9	23	1.8	27,728	0.0001	0.5	35.4
2016	2	29.6	5	8.40	7.91	0.95	0.54	8.8	280	170	21,158	0.0001	0.5	34.3
2017	6	29.91	5	8.80	6.8	1.70	0.25	no data	49	23	18,340	<0.003	5	28.9
2020	1	30.36	<5	7.90	5.5	0.69	0.12	<1	7.8	2	28,310	no data	no data	27.9
2021	18	no data	5	no data	no data	0.51	0.1649	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.48	<5	8.46	6.62	2.037	0.2369	<1	6.8	<1.8	29000			30.9

WQ09	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	18	34.5	5	8.1	6	1.3	1.43	1.49	94		33265	-0.0037	1.4	35.1
2015	10	28.9	5	8.31	8.09	1.2	0.91	1.19	23	1.8	28270	0.0001	0.5	35.4
2016	14	28.8	5	8.4	8.18	1.2	1.06	1.8	140	79	22580	0.0001	2	35
2017	13	30.52	5	8.79	6.6	1.8	0.36	no data	23	23	22746	<0.003	5	28.8
2020	7	30.29	<5	7.9	6.42	0.55	0.18	2.5	<1.8	<1.8	30510	no data	no data	30.35
2021	7	no data	5	no data	no data	0.3084	0.0237	<1	<1.8	<1.8	no data	no data	no data	no data
2022	6	29.43	<5	8.52	7.1	2.2451	0.154	<1	<1.8	<1.8	28700			30.8

WQ10	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	20	36.4	5	8.89	6.58	1.5	0.13	2.86	23	no data	34643	-0.0028	0.9	36.4
2015	12	29.6	5	8.21	8.51	1.1	0.87	2.25	23	1.8	26100	0.0001	0.5	35.6
2016	2	29.9	5	8.26	8.13	1.2	0.58	4.9	33	33	23232	0.0001	2	35.2
2017	6	30.25	5	8.8	6.1	2.5	0.32	3	23	23	21688	<0.003	<1	29
2020	3	31.04	<5	7.59	6.25	0.49	0.17	1.6	2	1.1	30760	no data	no data	30.6
2021	10	no data	5	no data	no data	0.3607	0.1315	<1	<1.8	<1.8	no data	no data	no data	no data
2022	4	29.46	<5	8.57	7.97	2.2206	0.1206	<1	<1.8	<1.8	29700			31.8

WQ11	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	20	30.4	5	7.78	7.05	1.3	1.1	1.1	70	no data	29535	-0.0028	1.3	36.6
2015	8	29.1	5	8.25	8.02	0.6	0.76	1.4	23	1.8	27270	0.003	0.5	35.5
2016	11	29.6	5	8.31	8.15	1	0.4	4.4	70	49	20520	0.0001	0.5	35.1
2017	6	30.24	5	8.83	5.6	1.9	0.24	no data	43	31	22091	<0.003	<1	29
2020	11	30.33	<5	7.37	5.92	0.50	0.29	3.3	4.5	<1.8	30640	no data	no data	30.51
2021	15	no data	5	no data	no data	0.3998	0.0267	<1	<1.8	<1.8	no data	no data	no data	no data
2022	2	30.05	<5	8.65	8.87	1.7309	0.1153	<1	<1.8	<1.8	29000			31

WQ12	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	4	26.28	5	8.21	6.93	1.3	0.39	1.3	94	no data	36579	-0.001	0.9	32.1
2015	6	29	10	8.25	8.13	1.3	0.57	1.55	23	1.8	27151	0.0001	0.5	35.5
2016	15	27.9	10	8.29	8.1	1.3	0.2	1.4	70	49	23546	0.009	1	34.7
2017	11	30.23	5	8.83	5.6	2.5	0.13	2.1	23	31	23839	<0.003	<1	29
2020	5	30.44	<5	7.73	5.69	0.52	0.21	2.3	4.5	2	30750	no data	no data	30.62
2021	<3.7	no data	5	no data	no data	1.3694	0.4688	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.57	<5	8.65	7.2	1.4885	0.1083	<1	2	<1.8	29600			31.7

WQ13	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	10	30.7	5	7.92	6.9	1.5	0.92	4.8	23	no data	23910	-0.0025	1.48	36.4
2015	4	29.7	5	8.26	7.8	1.2	0.45	1.4	46	1.8	25366	0.0001	0.5	35.5
2016	0.9	28.9	5	8.28	8.87	0.8	0.04	4.9	120	70	23050	0.0001	2	35.1
2017	4	30.74	5	8.75	7	1.8	0.14	<1	31	31	23091	<0.003	7	29.2
2020	9	30.45	<5	7.78	6.15	0.51	0.17	3.2	17	7.8	30700	no data	no data	30.56
2021	13	no data	5	no data	no data	0.2791	0.082	<1	13	2	no data	no data	no data	no data
2022	5	33.05	<5	8.76	9.92	2.4312	0.1638	<1	<1.8	<1.8	21500			23.7

WQ14	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	17	30.9	5	7.74	6.91	1.3	0.16	1.43	79	no data	35706	-0.0043	<1	30.9
2015	0.9	29.5	5	8.28	7.94	1.1	0.35	3.05	33	1.8	22051	0.0001	0.5	35.6
2016	0.9	27.1	5	8.31	7.87	0.7	0.04	<1	23	23	22428	0.0001	0.5	35.3
2017	6	30.67	5	8.75	6.1	1.9	0.31	4	63	43	23095	<0.003	5	28.7
2020	12	30.48	<5	7.48	5.83	0.48	0.18	3	79	4.5	30610	no data	no data	30.64
2021	13	no data	5	no data	no data	0.2791	0.082	<1	13	2	no data	no data	no data	no data
2022	<1	31.37	<5	8.57	6.31	1.8338	0.1108	<1	<1.8	<1.8	30100			32.2

WQ15	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	7	31.5	5	8.02	7.29	1.7	0.79	0.7	23	no data	35846	-0.0028	0.9	36.5
2015	3	29.5	5	8.29	7.92	1.1	1.22	2.85	49	1.8	22880	0.0001	0.5	35.6
2016	1	29.9	5	8.37	7.73	0.8	0.02	<1	49	33	21128	0.0001	3	35.5
2017	10	30.61	5	8.77	6.1	1.9	0.31	3.6	43	43	18861	<0.003	<1	29
2020	<1	30.42	<5	7.55	6.28	0.49	0.18	<1	2	<1.8	30610	no data	no data	30.46
2021	8	no data	5	no data	no data	0.6161	0.0369	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	30.81	<5	8.55	6.19	2.1178	0.1186	<1	<1.8	<1.8	28800			30.7

WQ16	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	6	30.7	5	7.75	7.28	1.40	1.43	1.45	23	no data	22,228	-0.0037	1.18	36.8
2015	6	29.8	10	8.28	8.05	0.90	0.4	0.90	84	46	23,000	0.0001	0.5	35.6
2016	4	26.9	5	8.39	8.09	0.80	0.15	5.6	170	140	21,906	0.0001	0.5	35.3
2017	5	30.07	5	8.83	7.4	3.20	0.23	0.9	43	43	22,181	<0.003	<1	28.8
2020	3	30.28	<5	7.47	6.97	0.64	0.13	2.6	7.8	2	30,520	no data	no data	30.37
2021	12	no data	5	no data	no data	0.5312	1.0515	<1	<1.8	<1.8	no data	no data	no data	no data
2022	10	30.54	<5	8.65	7.39	2.4997	0.3401	<1	<1.8	<1.8	28900			31

WQ17	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	2	38.4	5	8.06	6.76	1.20	0.66	5.83	110	no data	25,408	-0.0028	1.38	35.9
2015	6	29.3	15	8.24	7.67	1.50	0.83	1.45	170	94	23,611	0.0001	0.5	35.7
2016	1	31.7	5	8.43	7.62	0.90	0.06	<1	23	23	20864	0.0001	0.5	35.1
2017	15	30.65	5	8.70	8.2	2.10	0.24	5.1	23	23	22,818	<0.003	<1	28.9
2020	1	30.36	<5	7.05	5.41	0.54	0.248	2.6	<1.8	<1.8	30340	no data	no data	30.17
2021	6	no data	5	no data	no data	0.5182	0.0963	<1	<1.8	<1.8	no data	no data	no data	no data
2022	14	29.17	<5	8.32	7.65	2.3561	0.1227	<1	<1.8	<1.8	29700			31.8

WQ18	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	9	26.19	5	8.16	6.37	1.2	0.19	4.35	46	no data	22133	-0.0043	0.9	35.7
2015	3	29.3	5	8.27	8.08	1.3	0.53	2	94	1.8	24970	0.003	0.5	35.6
2016	1	28.1	5	8.45	8.8	1.2	0.04	<1	23	no data	21728	0.0001	0.5	34.9
2017	9	30.48	5	8.82	6.7	2.7	0.27	no data	31	23	19595	<0.003	<1	28.8
2020	<1	30.35	<5	7.32	6.22	0.62	0.28	1.8	<1.8	<1.8	30680	no data	no data	30.4
2021	13	no data	5	no data	no data	1.0503	0.0371	<1	<1.8	<1.8	no data	no data	no data	no data
2022	12	30.65	<5	8.65	6.07	2.3332	0.1189	<1	<1.8	<1.8	29600			31.6

WQ19	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	9	31.2	5	7.96	6.93	1.3	0.32	2.88	33	no data	23470	-0.0016	0.9	36.6
2015	4	29.4	10	8.33	8.03	1.3	0.48	1.1	46	1.8	23081	0.005	0.5	35.6
2016	0.9	29.5	5	8.49	7.99	0.8	0.06	4.8	140	94	23229	0.0001	0.5	35.4
2017	3	30.28	5	8.81	7.4	2.5	0.37	3	23	23	19630	<0.003	<1	28.1
2020	<1	30.3	<5	7.34	6.81	0.58	0.28	<1	14	2	30990	no data	no data	30.89
2021	9	no data	5	no data	no data	0.6675	0.0267	no data	<1.8	<1.8	no data	no data	no data	no data
2022	5	29.3	<5	8.6	7.98	2.6882	0.152	<1	<1.8	<1.8	29500			31.5

WQ20	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	10	30.7	5	8.06	6.65	1.4	0.09	0.69	no data	no data	21901	-0.0004	2.67	36.6
2015	1	29.6	5	8.3	8.03	1.6	0.5	2.2	79	33	23701	0.003	0.5	35.6
2016	5	29.4	5	8.43	7.99	1.45	0.08	2.6	140	94	24952	0.0001	3	35.4
2017	18	30.32	5	8.79	5.6	1.7	0.37	no data	43	43	20532	<0.003	<1	29
2020	7	31.14	<5	7.16	5.95	0.56	0.25	<1	41	12	30930	no data	no data	30.81
2021	11	no data	5	no data	no data	0.6488	0.024	<1	<1.8	<1.8	no data	no data	no data	no data
2022	3	29.53	<5	8.61	6.71	2.4581	0.254	<1	<1.8	<1.8	29800			31.9