TRNP

ECOSYSTEM RESEARCH AND MONITORING REPORT 2021

TUBBATAHA REEFS NATURAL PARK WORLD HERITAGE SITE

DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES 1987

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Ecosystem Research and Monitoring Report 2021

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Cover Photo: Yvette Lee

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EXECUTIVE SUMMARY

Endangered Napoleon wrasse *Cheilinus undulatus* swims freely over the reef. Photo: Yvette Lee

Reef fish. A total of 321 fish species were identified during the survey. Species richness was estimated at 59.76 species per 500m^2, categorized as very high based on the modified criteria set for Philippine reef fish (Hilomen et al., 2000). This year's biomass estimate was 119 grams/m^2, slightly higher than in 2020 (117g/m^2). The increase was mainly due to larger-sized Acanthuridae: Nasinae (unicornfish). Demersal fishes, such as Acanthuridae (surgeonfish) and Scaridae (parrotfish) constituted about 70% of the total biomass value.

The average density estimate was 1,512 individuals/500m^2, considered high based on the modified criteria for a healthy reef fish community (Hilomen et al., 2000). Fish density was contributed by species from Pomacentridae (damselfish) and Serranidae: Anthiinae (fairy basslets). More fishes were recorded in deep stations (60%) than in the shallow.

The fish biomass of commercially targeted species constituted at least 70% of the total mean fish biomass in the Tubbataha Reefs. Several protected species, including the Endangered Napoleon wrasse and Bumphead parrotfish, listed as Vulnerable, were also observed during the survey.

Reef benthos. We followed the categories for hard coral cover (HCC) and coral generic richness (TAU) introduced by Licuanan et al. in 2019 and DENR-BMB Technical Bulletin No. 2019-04.

The average hard coral cover (HCC) in the shallow areas of the reefs was 32.3%. Its average generic (TAU) richness was 20 TAUs. The monitoring stations in Jessie Beazley had an average HCC of 41.3% and an average TAU richness of 16.4 TAUs. The HCC in the shallow area is decreasing at a rate of 0.91%. The decrease in HCC were evident in two sites in the South Atoll and in Jessie Beazley Reef. The average algal assemblage cover was 54.3%, while Jessie Beazley had lower algal cover. Sponges were also observed in all monitoring stations with the highest sponge cover observed in Site 1.

In the deep areas, the average HCC was 27.4%, with an average of 28 coral TAU richness. A decline of 1.2% in HCC was recorded in the deep monitoring stations. At the site level, a significant decline was only observed in Site 4. The average algal assemblage cover (mostly encrusting coralline algae) was higher than the hard coral cover. All the stations, except JBA, were dominated by AA, ranging from 26% to 70% of the benthic cover.

The fixed plots in the ship grounding sites were showing signs of improvement in terms of HCC. The high HCC and TAU richness in the newly established Station 5A highlight areas in Tubbataha, yet to be explored, that may harbor well-developed and diverse coral communities.

Coral recruitment. In the shallow areas, the average coral recruit density was 53 individuals/m^2 dominated by the brooder type of corals under the families Poritidae, Pocilloporidae, Acroporidae and Agariciidae. The average coral recruit density in the deep areas was 87.89 ind/m^2. Encrusting corals from the genus *Pavona*, *Porites,* and branching *Pocillopora* dominated all the stations.

The USS Guardian grounding site had a higher density of coral recruits than the Min Ping Yu (MPY) grounding site. The lower coral recruit density in MPY may be attributed to the unstable substrate of rubbles and sand.

Seabirds. A total of 13 species of birds were identified during the inventory. The total number of all avifauna species, including migratory species, recorded in TRNP over time is 119. In May 2021, a minimum of 28,178 adult individuals of seven breeding seabird species were recorded.

Young Great Crested Terns line the edge of Bird Islet during high tide. Photo: Kymry Delijero

Bird Islet hosted almost 71% of the breeding population (89% in 2020) and South Islet 29% of the population (11% in 2020). Compared to the 2020 inventory, the May 2021 count result is 14% lower, mainly due to a decrease in the numbers of Brown Noddy by 48%, and of Great Crested Tern by 25%.

Water Quality. Generally, all parameters monitored in 2021 were within the water quality guidelines of the DENR except for phosphates, the concentration of which exceeded 0.1 mg/L in six (6) stations. The results of total coliform, fecal coliform, and oil and grease showed the lowest values measured for the first time in all stations in TRNP, which is likely due to the absence of dive boats.

Sharks. A total of 414 reef sharks were encountered during the survey, with an overall mean density of 10.4 individuals/hectare. Grey reef shark had the highest density followed by whitetip reef shark. These two species were encountered in all the dives. One (1) tiger shark was recorded in Shark Airport. Eighteen (18) rays were recorded, 17 of which were spotted eagle rays and one (1) reef manta ray. This year's mean density of reef sharks was relatively higher than the surveys conducted in 2015, 2016, and 2017.

Tectus niloticus. A total of 829 individuals were recorded resulting to an average density of 18 individuals/200m^2, much lower compared to the 31 individuals/200m^2 recorded in 2017. The average basal diameter of *T. niloticus* this year was 92mm. This value is larger compared to the average basal diameter recorded in 2006, 2008, and 2017. Majority of the *T. niloticus* measured from 71 to 100mm in basal diameter, the size at which the species reach sexual maturity.

Tectus niloticus camouflaged under the table corals. Photo: Anthea Valenzuela

Seagrass. Five seagrass species were recorded this year: *Halophila ovalis, Halodule pinifolia, H. uninervis, Cymodocea rotundata,* and *Syringodium isoetifolium*. As in 2017, *H. ovalis* and *H. pinifolia* were the most dominant seagrass species in all the sites, while *S. isoetifolium* was only recorded in Site 4. The average seagrass cover recorded in Tubbataha this year was 29.9%, categorized under fair condition. The overall macroalgae and epiphyte cover in the seagrass beds were 9.8% and 47.3%, respectively.

INTRODUCTION

The United Nations proclaimed 2021-2030 as the 'Decade of the Ocean', which highlights the opportunity to reverse declining ocean health despite challenges such as climate change and biodiversity loss. This initiative provides a common framework for "nations to work together to generate global ocean science" which aims to strengthen the management of our coasts and oceans for the benefit of humanity (IOC 2020). It highlighted the need to improve the interdisciplinary research efforts and the development and implementation of a science-based solution to achieve resilient oceans.

Marine World Heritage Sites (WHS), such as the Tubbataha Reefs Natural Park (TRNP), are some of the world's iconic protected areas recognized for their outstanding universal values – biodiversity, natural habitats, and intrinsic beauty, among others. They contribute around 88% of ocean research data in various disciplines – biophysical, socio-economic, and applied science, to name a few (UNESCO 2021). Thus, WHS play an important role in the Ocean Decade by generating ocean science to advance our knowledge and direct our research focus on the challenges of our seas.

TRNP is the largest no-take marine protected in the Philippines, and its management relies heavily on research and monitoring results to formulate science-based management actions and policies. The results of these studies are also important in assessing the degree to which the outstanding universal value of TRNP is maintained. The Tubbataha Management Office conducts regular research and monitoring activities to:

1) determine ecosystem health;
2) generate sound scientific information;
3) serve as basis for formulating proactive strategies;
4) measure biophysical indicators of management effectiveness.

This year, despite significant increases in the cost of conducting research due to health protocols, we pursued efforts to monitor the condition of fish and benthic communities of Tubbataha. We conducted coral recruitment studies, now on its fifth year, and the seabird monitoring and inventory. For two years in a row, while tourism was at a standstill due to Covid 19, we did the water quality study and can now compare pre- and post-pandemic conditions. We continued the regular shark study with the assistance and guidance of our partner, LAMAVE. The study on *Tectus niloticus* and seagrass, last conducted in 2017, were also done this year.

We wanted to know whether the management strategies in place are still efficient for conserving Tubbataha. We aimed to compare the condition of the various biophysical and physical attributes of the park to determine trends and fine tune approaches. Finally, detecting issues before they become unmanageable was another aim for the studies.

CHAPTER 1. REEF FISH

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OVERVIEW

Large marine protected areas (>100km^2), such as the Tubbataha Reefs, are scientifically proven to be ecologically effective in protecting marine flora and fauna, and threatened species due to the provision of larger refuges (Savage et al., 2020; Lewis et al., 2017; and Edgar et al., 2014). The healthy reef fish community in TRNP has been validated by years of monitoring, and by national and international recognitions afforded to the park. The status of the fish community is also one of the management bases for decision-making and is one of the biological indicators in gauging the effectiveness of managing the park (TRNP MEE 2020).

This year, TMO was assisted by Dr. Hazel Arceo from the University of the Philippines – Cebu in the conduct of the regular monitoring of the reef fish community. Fish biomass, density, and species richness are some of the parameters used to gauge the condition of the reef. This chapter discusses the status of the fish community using these three parameters.

METHODS

Study Sites

TMO regularly monitors five sites located in the North Atoll, South Atoll and the Jessie Beazley Reef (Figure 2) to describe the status of the fish and benthic communities. In each site, two replicate stations, approximately 200 meters apart, were established. One additional station (5A) was established this year in the southwest tip of South Atoll. The geographic location of each monitoring station is provided in Appendix 2. In each station, shallow (~5meters) and deep (~10meters) areas were assessed to acquire a better understanding of the condition of the reefs at varying depths. This hierarchical sampling design is presented in Figure 1. The two ship grounding sites, USS Guardian (USSG) and Min Ping Yu (MPY) have been monitored since 2013 to assess the changes through time.

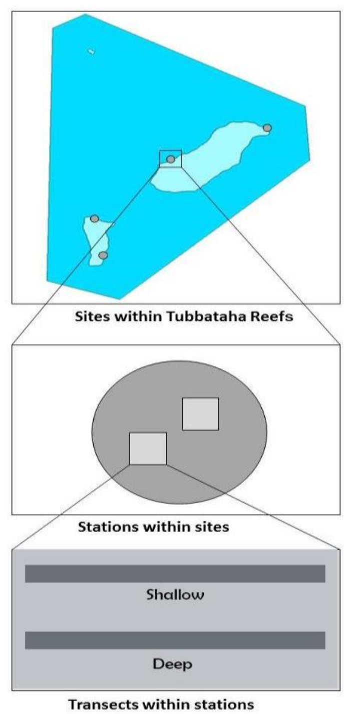

Figure 1. Hierarchical sampling design (Modified from Licuanan et al., 2016).

Field survey

Three (3) 50-meter replicate transects, separated by a 10-meter buffer, were laid in deep (~10m) and shallow (~5m) areas of each station. Each transect has an imaginary 5-

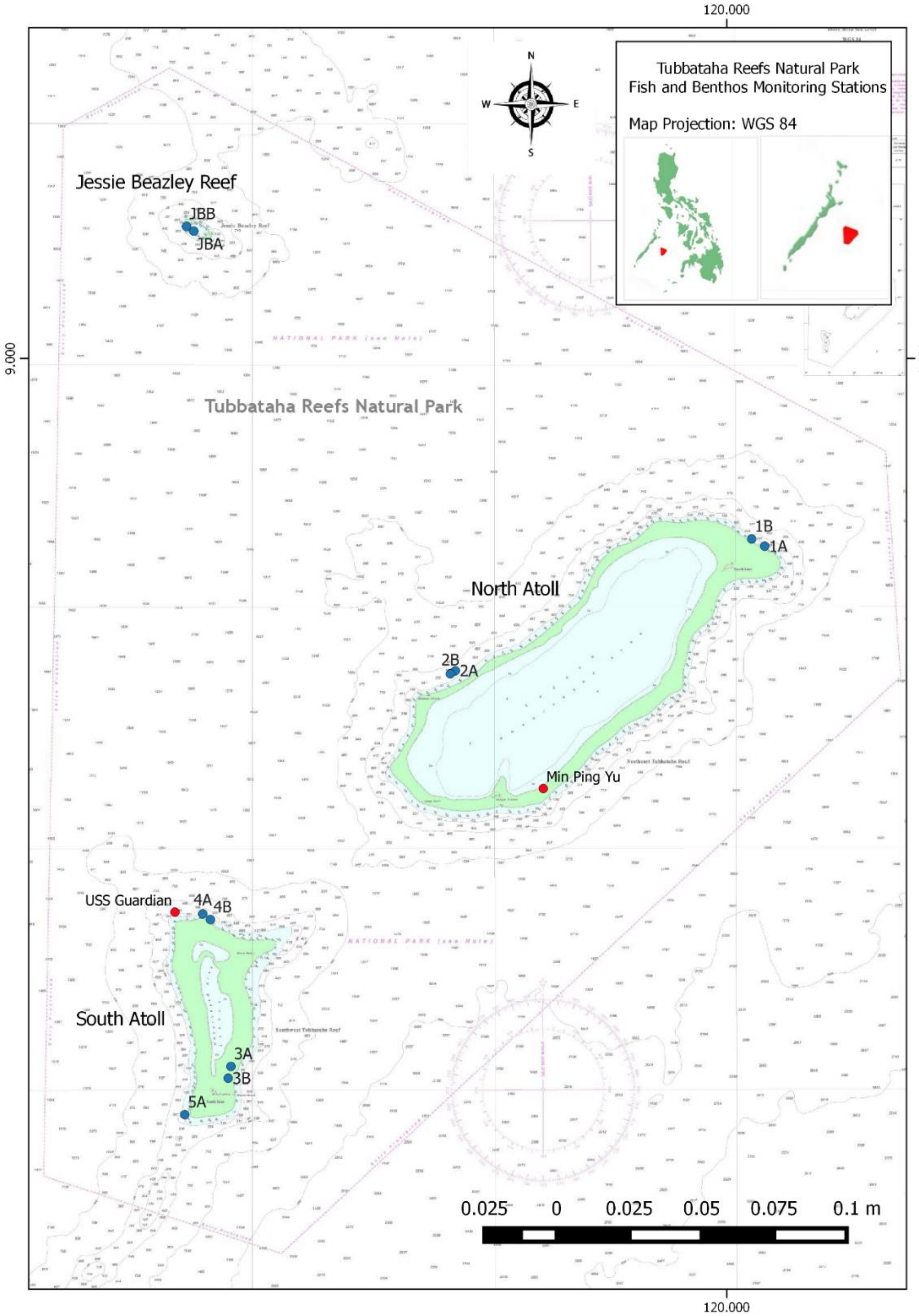

Figure 2. Location map of the fish and benthos monitoring stations.

meter coverage on both sides, establishing a 10 x 50-meter corridor. We further segmented the transect into 5-meter stops along its length and was surveyed one segment after another. Daytime Fish Visual Census (FVC) described by English et al. (1997) was employed to determine the attributes of the fish community such as biomass, density, and species richness.

Three (3) divers completed Sites 1, 2 and 3, while two (2) divers completed the rest of the sites. We assessed the deep transects first and the shallow afterward.

Data Analysis

Data were collated and organized using the format adapted from Coral Reef Visualization and Assessment (CoRVA) system introduced by the DENR in 2014.

Species richness was determined using the actual number of species identified during the survey, while fish density was expressed by the number of individuals per given area (individuals per $500m^2$). We simplified the biomass in grams per square meter (grams per m^2) and was calculated with the existing length and weight model (Kulbicki et al., 1993), using the formula:

$$W = aL^b$$

> where *W* is derived weight (g), **L** is the estimated total length (cm), and **a** and **b** are regression parameter values obtained from CoRVA and FishBase database (www.fishbase.org).

A paired t-test was applied to calculate significant variations in the density and biomass of reef fishes in varying depths, and between this year and the previous year's estimates at $p=0.05$. We also applied the same statistical analysis in the density and biomass outputs between the depths of each grounding site.

Two-factor analysis of variance (ANOVA) in Microsoft Excel 2016 was used to detect if there were significant differences in the overall biomass between sites and between years, from 2013-2021. Take note that we only applied this analysis from 2013 due to the change in the number of monitoring sites from seven (1999-2012) to five (2013-present).

We also categorized the fish populations based on their commercial and ecological importance (target, indicator, and major) and their associations with the reefs (demersal or 'fishes that dwells in the reef bottom' and pelagic or 'fishes that prefer deeper part of the reef').

RESULTS

Regular monitoring sites

A total of 321 fish species were identified during the survey. Site 3 had the highest number with 198 species. Site 4 had 194 species, Site 2 with 191, JBR with 173, and Site 1 with 154. Species richness was estimated at 59.76 species per $500m^2$, categorized as very high based on the modified criteria set for Philippine reef fish (Hilomen et al., 2000). Most of the species identified were from Labridae (wrasses, 52 spp), Pomacentridae (damselfish, 38 spp), and Chaetodontidae (butterflyfish, 31 spp).

This year's biomass estimate was 119 g/m^2, slightly higher than in 2020 (117g/m^2), but the difference was not significant. The increase was mainly due to larger-sized Acanthuridae: Nasinae (unicornfish) encountered this year. Also, the team encountered a school (24 individuals; ~100 cm size) of Blackfin barracuda *Sphyraena qenie* in Station 1A, contributing to the station's higher biomass value compared to other stations and the overall biomass value.

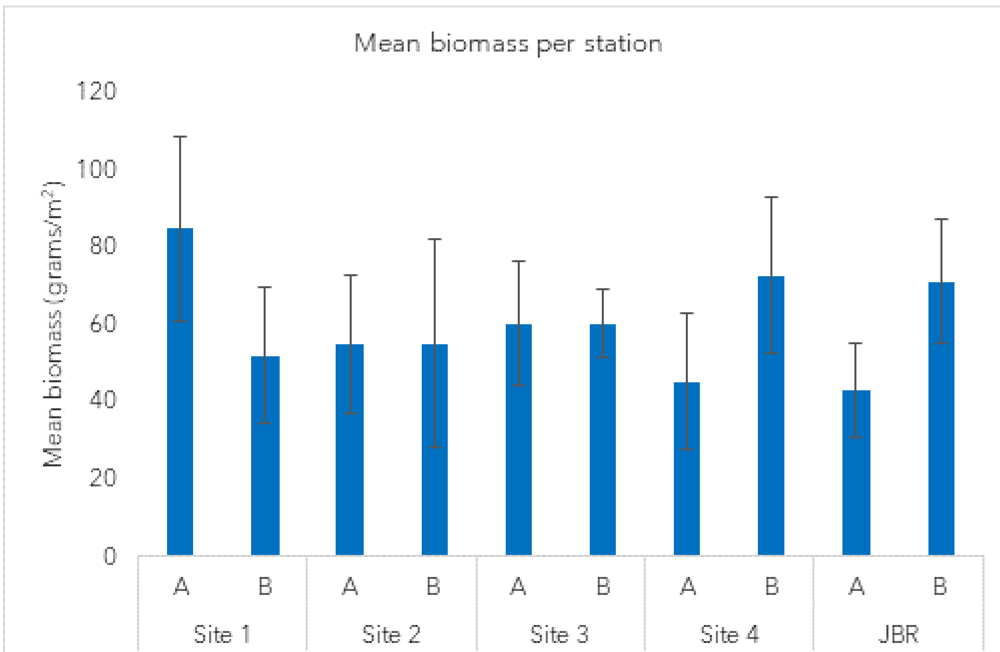

Figure 3. Mean biomass of each station in varying depths (shallow and deep).

Demersal fishes, such as Acanthuridae (surgeonfish) and Scaridae (parrotfish) constituted about 70% of the total biomass value. Demersal fish is highly associated with coral reefs, hence more reliable in determining reef health than its pelagic counterpart.

The average density estimate was 1,512 individuals/500m^2, considered high based on the modified criteria for a healthy reef fish community (Hilomen et al., 2000). Although lower than 2020 (1,681 individuals/500m^2), the difference was not significant.

Fish density was contributed by species from Pomacentridae (damselfish) (620 individuals/500m^2) and Serranidae: Anthiinae (fairy basslets) (443 individuals/500m^2). Both families are often observed in schools of hundreds of individuals. More fishes were recorded in deep stations (60%) than in the shallow (Figure 3). Demersal fishes were the most recorded group, which were mainly species from families Pomacentridae, Serranidae: Anthiinae, and Labridae (wrasse).

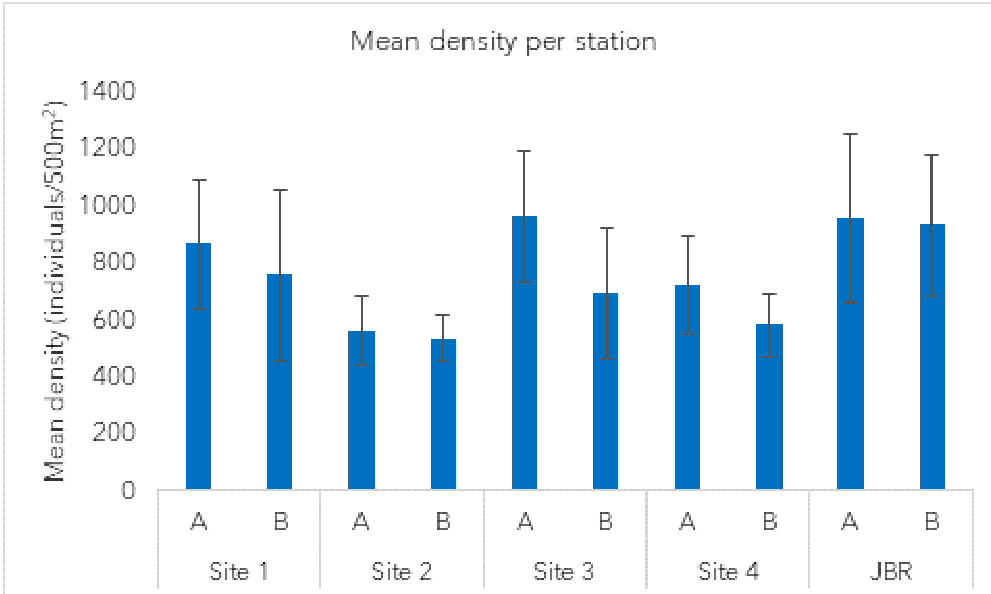

Figure 4. Mean density of each station in varying depths (shallow and deep).

New monitoring station

A total of 98 species were identified in the newly-established monitoring station with species richness of 52 sp/500m^2 – a very high value for reef fish community (Hilomen et al., 2000). The biomass estimate was at 35.24 g/m^2. Scaridae (parrotfish) were the largest fishes recorded in the area. The estimated density was 350 individuals/500m^2. Pomacentridae (damselfish) was the most abundant group recorded in the station. No pelagic fish species were recorded in the station.

Unlike most of the monitoring sites that are located near the drop off, this new site is characterized by a gently sloping terrain more than 40 meters from the reef edge. Pelagic species are often found in the deeper part of the reef and seldom visit the shallow part; hence, it might be the explanation for their absence.

Although not inside the transects, we noted an aggregation (>20 individuals) of Yellow margin triggerfish *Pseudobalistes flavimarginatus* in the area. They congregated in about 6x30m sandy bottom flat. This might be related to the spawning of the species where males establish territories and wait for the arrival of the females (Gladstone 1994).

Patterns of fish community

Figure 5 shows the fluctuating biomass in Tubbataha Reefs since the survey in 1999. Mean fish biomass in TRNP ranged from 95 to 298 g/m^2, which were considered "very high" (i.e., >40 g/m^2; Nañola et al., 2006) over the course of the monitoring years. A decreasing trend (depicted in blue dash line) in biomass estimates below the long-term average has been observed for five years now.

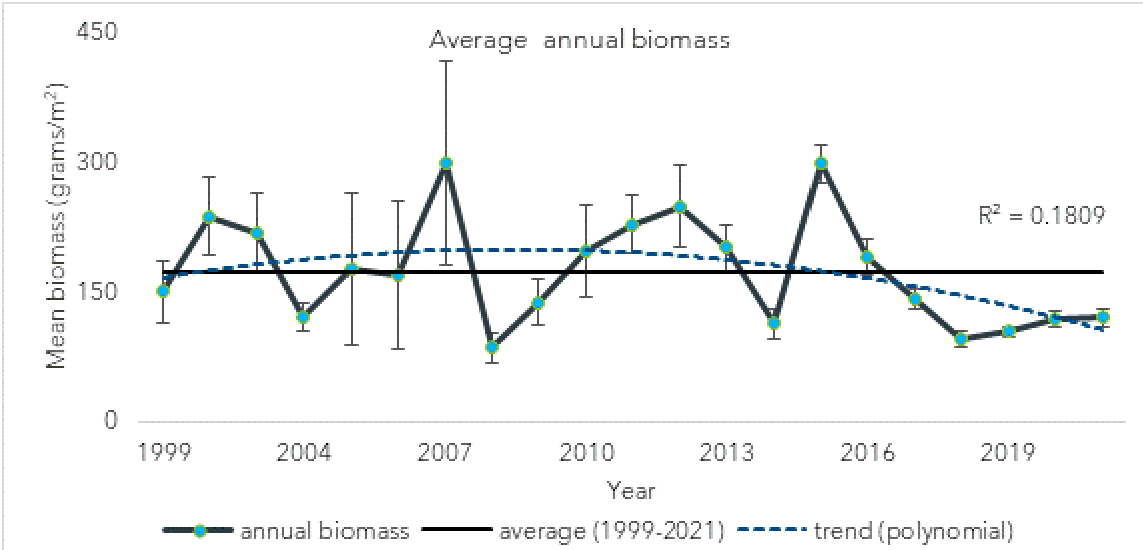

Figure 5. Biomass estimates from 1999-2021 showing a decreasing trend from 2016 (dash lines) and the annual average (straight line). Vertical bars denote standard error of the mean.

Since 2016, large-bodied fishes, e.g., Carangidae (jacks and trevallies), subfamily Nasinae (unicornfish), Scaridae (parrotfish), Serranidae (groupers), were observed to be declining. A school of large individuals (>30cm) of red snapper *Lutjanus bohar* was encountered in 2016 but only occurred in fewer numbers from 2017-2021. An abrupt increase in biomass was observed in 2015 which was influenced by the unusual number of Scaridae (parrotfish) encountered that year.

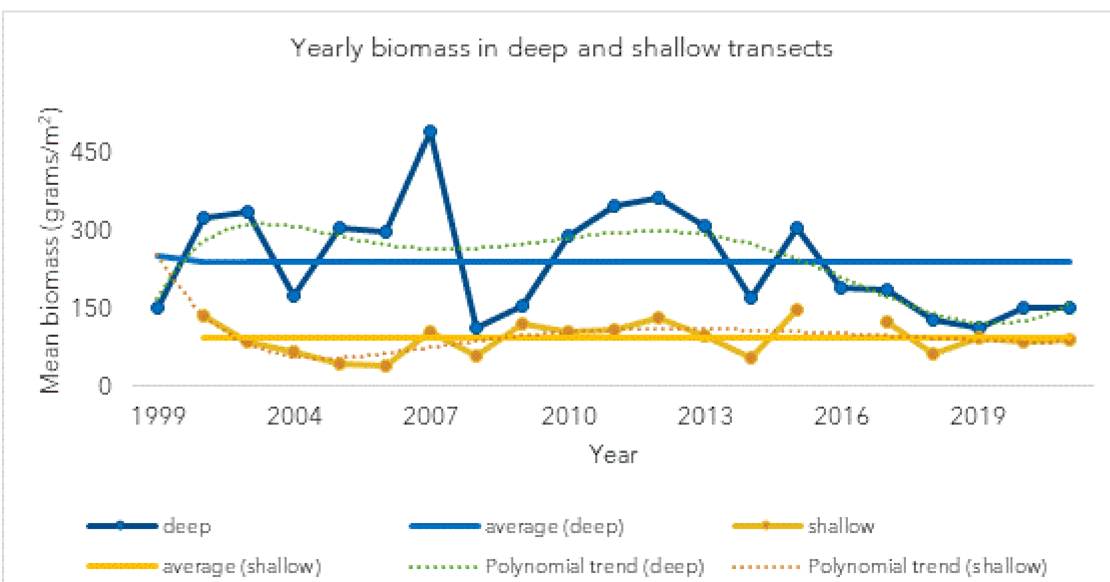

Figure 6. Average biomass outputs in deep (~10m) and shallow (~5m) transects since 1999 to present.

The ANOVA results confirmed that there was a significant variability in the biomass outputs of TRNP since 2013 in terms of fish community among the sites ($p<0.05$) and over the years ($p<0.001$). The presence of large-sized fishes, such as Acanthuridae: Nasinae, Carangidae (jacks and trevallies), followed by Balistidae (triggerfish), and Scaridae (parrotfish) plays a major role in the differences in biomass outputs of each site and year. Since the two major contributors of the biomass are both pelagic species and often occur in schools, their presence (or absence) influences the fluctuating biomass year after year.

The biomass values since 1999 in the two depths (Figure 6), fall under the 'very high' category (>40g/m^2; Hilomen et al., 2000). Deep transects have remarkably greater fish biomass outputs than its shallow counterpart. This year, around 64% of the total biomass was recorded in deep areas.

Despite the generally declining trend depicted in Figure 6, the biomass in deep transect showed an increasing trend from 2020. Meanwhile, shallow transects showed a more stable trendline closer to the annual long term average biomass output (91.7g/m^2).

Over the years, the fish biomass of commercially targeted species constituted at least 70% to 85% of the total mean fish biomass in the Tubbataha Reefs (Figure 7). This year, the biomass estimates for the target fish group were mainly contributed by large-sized fish species from the subfamily Nasinae (unicornfish), families Scaridae (parrotfish), and Acanthuridae (unicornfish).

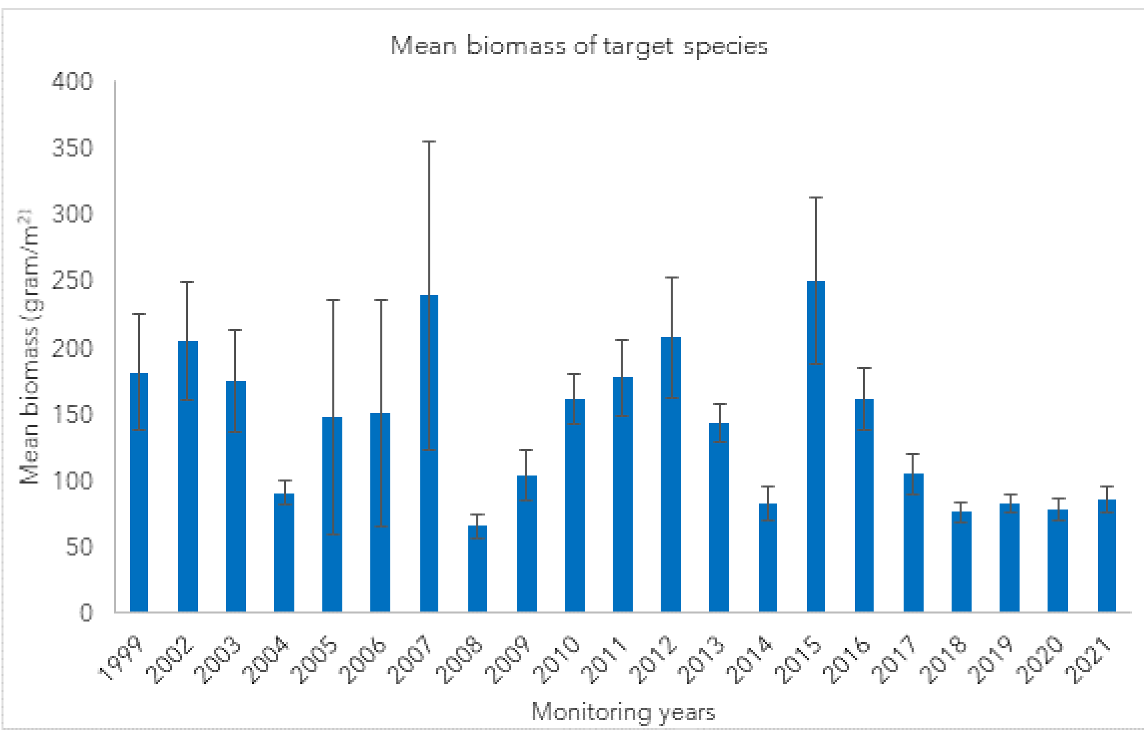

Figure 7. Average biomass of commercially targeted species in TRNP since 1999. Vertical bar denotes standard error of the mean.

Indicator species, those that rely on corals for food, constituted 2-4% of the total annual biomass. Notable indicator species are from the families Chaetodontidae (butterflyfish) and Pomacanthidae (angelfish).

The major group, the fishes that do not belong to the two mentioned, contributed 20-30% to the total biomass annually. The group was represented mainly by Pomacentridae (damselfish), and Serranidae: Anthiinae (fairy basslets). These fishes serve as food to other fishes. Both indicators and major groups exhibited an increasing trend during the two-decade monitoring.

Grounding sites

Over the years of monitoring, the two grounding sites remained at the best category per national standard for reef fish community (Hilomen et al., 2000; Nañola et al., 2006). The biomass and density outputs in these sites always exceeded the minimum value for a very healthy reef fish community.

In the Min Ping Yu grounding site, 153 fish species were chanced upon this year with species richness of 53 sp/500m^2. This falls under the very high category (>50sp/500m^2) (Hilomen et al., 2000). The biomass estimates in the Min Ping Yu grounding site this year was 57g/m^2, slightly lower than the previous year (59 g/m^2). Fish biomass was mostly contributed by Scaridae (parrotfish), Acanthuridae (surgeonfish), and Holocentridae (squirrelfish).

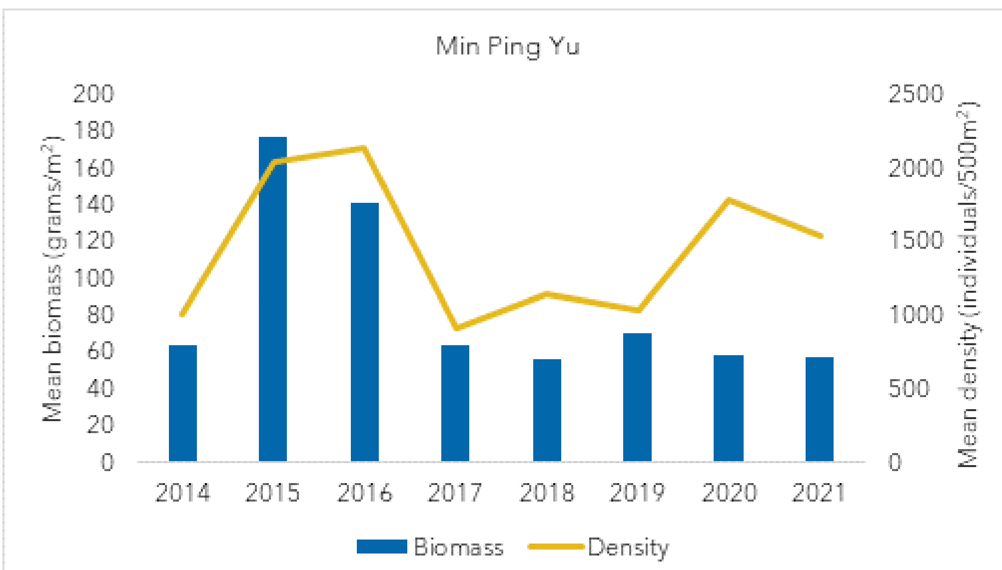

Figure 8. Temporal pattern of mean biomass and density of the Min Ping Yu grounding site.

Commercially targeted fish species contributed 68% to this biomass. Meanwhile, 3% belonged to indicator species and 29% were from the major group of fishes. The fish density in this site decreased slightly. The demersal fishes constituted about 98% of the total mean density, mainly due to the families Pomacentridae (damselfish) and subfamily

Anthiinae (fairy basslets). These two families were again the most abundant fishes recorded on the site.

In the USS Guardian grounding site, a total of 137 species of fish were recorded with species richness of 52 sp/500m^2, also considered 'very high' (Hilomen et al., 2000). Similarly, the fish community in the USS Guardian grounding site showed a slight decrease from the 2020 estimate (Figure 9). Last year's biomass was largely contributed by more than 60 large (>50cm) Bumphead parrotfish *Bolbometopon muricatum*, which were not encountered this year.

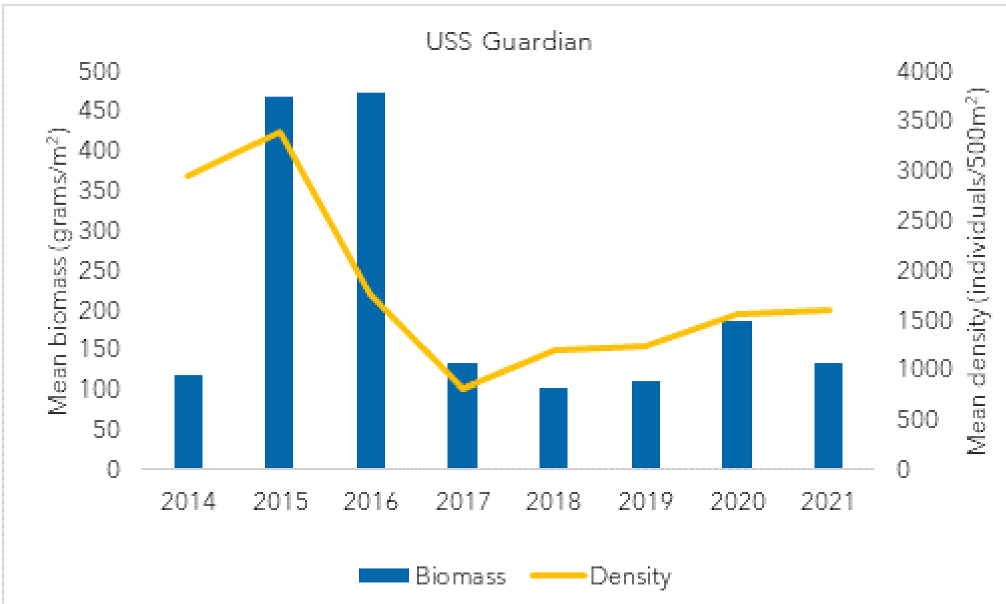

Figure 9. Temporal pattern of mean biomass and density of the USS Guardian grounding site.

Demersal fishes composed 82% of the total mean biomass, mainly due to the prominence of species from families Balistidae (triggerfish) and Scaridae (parrotfish). Target fishes were about 60% of the total mean biomass, 2% indicator species, and 36% were from the major fish group. Fish density was slightly higher this year. Demersal fishes were the most abundant group (99%), due to the abundance of Pomacentridae (damselfish) and subfamily Anthiinae (fairy basslets).

The biomass estimates for both sites were considered 'very high' while the mean density was 'high' (Nañola et al., 2006; Hilomen et al., 2000).

Other observations

The Napoleon wrasse *Cheilinus undulatus*, an Endangered species, was observed in all monitoring sites except in the newly established station. Two (2) of the individuals noted measured ~100cm. A school (>45 individuals) of Bumphead parrotfish, listed as

Vulnerable, was noted in Site 4 while one (1) individual was recorded in the USS Guardian grounding site. Whitetip and grey reef sharks were also noted in Site 2 and in all the stations of Jessie Beazley Reef. The Endangered Green Sea turtle *Chelonia mydas* was recorded in Site 2, 3, and 4, grounding sites, and in the newly established monitoring site. Meanwhile, the Critically Endangered Hawksbill turtle *Eretmochelys imbricata* was noted in Site 3.

Figure 10. A school of Bumphead parrotfish swims above the reef crest. Photo: Retch Alaba

DISCUSSIONS

Deep transects consistently showed higher fish biomass values, mainly because of large-sized pelagic fishes, such as subfamily Nasinae (unicornfish) and Carangidae (jacks and trevallies), that prefer the deeper portions of the reef, occasionally form schools, and seldom visit shallow reef areas. Large-sized (>37cm; >1kg) Scaridae (parrotfish) have also significantly influenced the biomass estimates in the deep transects over the years. Meanwhile, in the shallow transects, Scaridae (parrotfish) and Balistidae (triggerfish) primarily influence the biomass estimates, followed by Carangidae (jacks and trevallies) and Acanthuridae (surgeonfish).

No major difference in the composition of fish families was observed at both depths. Since Tubbataha Reefs is characterized by its wide reef flats which lead to abrupt drop-offs, the distance of 'shallow' and 'deep' transects is not more than 15 meters. Thus, fish groups in the deep transects can easily venture into the shallow part and vice versa, explaining the similarity in the composition of fish families.

Differing biomass values from year to year can be linked to the fact that fishes are highly mobile animals. Various factors drive these movements, which are connected to survival demands correlated with feeding and predator avoidance (Dahlgren and Egglestone 2000; Helfman et al., 2009), mortality risk, and habitat shifting (Dahlgren and Egglestone 2000).

An extensive horizontal migration could also be driven by spawning, feeding, and ontogenetic shifts in habitat requirements (Sale 2002). The different observers since 2013 can also be one of the contributing factors in the differences observed in the biomass estimates. Standardizing size and count estimates among the observers prior to the actual census could minimize this variation as noted in shorter error bars beginning in 2016, when researchers standardized their census technique.

The main objective for conserving Tubbataha is to maintain its biological diversity to contribute to food security. Since commercially important fishes are highly targeted and are first to disappear in exploited reefs, their occurrence (and in large sizes) in Tubbataha indicates that fishing pressure is almost non-existent in the park (FAO 2003a). Over the years, Tubbataha Reefs has proven that stringent protection is a vital factor in securing mature fish populations, evident in the consistent display of high biomass outputs, especially of commercially important fishes. Furthermore, its isolation and remoteness from anthropogenic disturbances and its size appear to be crucial factors in structuring the healthy fish community of the park.

Tubbataha's reef fish community remains one of the highest by Philippine standards. In addition, the presence of threatened and top predator species (e.g., sharks, Napoleon wrasse, marine turtles, etc.) is proof of the conservation benefits of highly effective and successfully managed MPAs. These species are of utmost interest because their population is either declining at an alarming rate or some are on the brink of extinction. Marine Protected Areas are established not only to allow recovery of fish biomass but also to ensure the conservation of vulnerable species and their ecosystems (Hoyt 2018). The presence of threatened species not only implies a healthy environment but also suggests a well-protected reef.

RECOMMENDATIONS

For the succeeding surveys, it is recommended that:

- Observers maintain the practice of standardizing the size and count estimates before the actual survey to diminish huge variations in the data collected;

- Continue to assign one person dedicated to lay the transects in both depths. This does not only minimize the time spent underwater but also ensures that researchers doing the survey have enough air to complete the survey.

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CHAPTER 2. REEF BENTHOS

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OVERVIEW

Coral reefs are among the most diverse yet most threatened ecosystems on the planet. They are refugia to over a million marine species and directly support over 500 million people worldwide (IUCN 2017). Reefs provide food production, coastal protection, water purification, carbon sequestration, tourism, and recreation. Corals are also sensitive to changes in sea temperatures, making them key indicators of global ecosystem health. However, they are also among the fastest to deteriorate (IUCN 2017). Regular monitoring of coral reefs allows managers and scientists to determine the status of the ecosystem and formulate adaptive management measures to conserve this critical habitat better.

TRNP remains the largest and best-enforced marine protected area in the Philippines, and its coral reefs set the benchmark for relatively pristine reef status in the country (Licuanan et al., 2017). TRNP reefs are also well-studied, having been monitored annually for at least twenty years. Thus, TRNP reefs have a detailed long-term dataset of reef benthic cover and composition. Unfortunately, a statistically significant decline in hard coral cover (HCC) was reported in the reefs of Tubbataha over the past three monitoring years. Increases in algal assemblage and other biota, such as sponges, were also documented in several Tubbataha monitoring stations (see Licuanan and Bahinting 2021). Detecting changes in the structure of benthic communities in Tubbataha's upper reef slope is necessary to diagnose reef status and identify possible drivers of change to constantly improve and refine the management of the country's best-kept reefs. This report presents the results of the long-term reef benthos monitoring in Tubbataha and the current status of the reef benthic community.

METHODS

Data collection

The reef benthos monitoring stations were located in the same area where the fish visual census was conducted (see Figure 2). The shallow area monitoring stations were located on the upper reef slope, at a depth range of 2 to 6 meters, and had an area of 75m x 25m. These stations followed the hierarchical sampling scheme described in van Woesik et al. (2009). Fourteen (14) stations have been monitored since 2012, and a new station (Station 5A) was established during the 2021 field survey. The sampling of the reef benthos in each monitoring station was performed using the methods described in Luzon et al. (2019). The deepest limit of each station was demarcated by a 75-m belt transect following the reef's contour. Four 50-meter transects were then deployed at least 1m apart from the preceding transect and parallel to one another. A random number generator was used to determine x,y-coordinates (in meters) where the four 50-m transects would be deployed and which 50m segment the 75m transect would be sampled. Photographs of the benthos were taken at 1-m intervals on the shallow side of each transect using Canon G7 X cameras in underwater housings mounted on 1m x 1m aluminum monopods. Two hundred fifty transect photographs were processed and analyzed from each monitoring station.

In deep areas of monitoring stations, four 20-meter transects are deployed, five meters apart from each other, all at the same depth of 10m. Photographs were taken every meter on the shallower side of each transect. A minimum of 80 images was taken in the deep area of each monitoring station.

Three fixed 4m x 4m quadrats were established in each ship grounding site (i.e., USS Guardian and Min Ping Yu) to represent areas of impact and adjacent control areas that were not directly impacted by the grounding incidents (Figure 11). These quadrats were photographed using the same camera-monopod set-up. The entirety of each quadrat was photographed, with images having at least 50% overlap with one another, corresponding to at least 90 images per quadrat. Thirty (30) images from each quadrat were selected using a random number generator for processing and analysis.

Figure 11. Permanent quadrats of the two grounding sites established in 2014. (Licuanan et al., 2014).

Data processing

Transect 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. The benthos beneath each point was identified and scored into one of six major benthic categories (i.e., hard coral (HC), algal assemblage or micro-algal turfs (AA), abiotic material (AB), macro-algae (MA), *Halimeda* (HA), other biota (OB)). Hard corals were further classified into 59 Taxonomic Amalgamation Units (TAUs), which are combinations of genus and growth form optimized for the resolution of transect images. Percent cover of benthos was recorded, and coral generic richness (i.e., the average number of hard coral TAUs recorded in each station) was computed. Additionally, the major category AA is further classified into specific subcategories, i.e., algal assemblage (AA), crustose coralline algae (CA), dead coral (DC), dead coral algae (DCA), disease (DIS). In this report, AA refers to the major category which includes the five subcategories for both shallow and deep reef areas.

Data analysis

The corresponding hard coral cover (HCC) and coral generic richness categories (see Licuanan et al., 2019; Table 1) were assigned 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 occurring in the benthic cover of the monitoring stations. Simple linear regression was used to determine the direction and rate of change (i.e., slope) of HC, AA, and Sponge (SP) cover from 2012 to 2021.

ANOVAR was used to identify significant differences in HC and AA cover among the different monitoring periods from 2012 to 2021. RStudio (RStudio Team 2020), PAST 3.26 (Hammer et al., 2001), and JMP 16 were used to perform the analyses. The data were visualized using RStudio (RStudio Team 2020), JMP 16, and QGIS (QGIS.org 2021).

Table 1. Hard coral cover and coral generic richness categories introduced in Licuanan et al. (2019).

Category	Hard coral cover (%)	Coral generic richness (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, 2, 3, and 4) had an average HCC of 32.3% ± 4.1 SE and an average generic (TAU) richness of 20.0 TAUs ± 0.1 SE (Table 2). These reported values were higher than the average HCC (28.4% ± 2.4 SE; Licuanan et al., 2019) and similar to the average TAU richness (20.8 TAUs ± 0.9 SE) of fringing reefs in the Sulu Sea bioregion (Licuanan et al., 2019). The monitoring stations in Jessie Beazley had an average HCC of 41.3% ± 2.2 SE and an average TAU richness of 16.4 TAUs ± 6.2 SE (Table 2).

At the site level, Jessie Beazley had the highest average HCC but the lowest average TAU richness among the monitoring sites (Table 2). The high HCC and low TAU richness in Jessie Beazley were due to the monospecific stands of foliose *Montipora* that dominated the Jessie Beazley A station. The lowest average HCC was observed in Site 2 (22.2% ± 5.9 SE), which was dominated by massive *Porites, Isopora* (mostly *I. palifera*), encrusting *Montipora, Goniastrea* spp., and *Platygyra* spp. Site 1 had the highest average TAU richness (22.3 TAUs ± 0.3 SE). The top five most abundant coral TAUs here were *Echinopora* (mostly *E. lamellosa*), encrusting *Montipora*, encrusting *Porites, Platygyra* spp., and *Millepora* spp.

At the station level, the newly added monitoring station 5A had the highest average HCC (54.6% ± 0.5 SE; HCC Category A) among all the monitoring stations (Table 2; Figure 12). Stations 5A and 3A were the only stations belonging to HCC Category A in 2021, with Station 3A having an average HCC of 49.3% ± 2.7 SE (Table 2; Figure 12). Station 2A had the lowest average HCC (16.3% ± 1.9 SE). Among the monitoring stations, only Station 3A showed an improvement in cover from HCC Category B (34.4% ± 2.8 SE) in 2020 to HCC Category A (49.3% ± 2.7 SE) in 2021. Stations Jessie Beazley A and 1B moved down from HCC Category A (57.5% ± 8.0 SE in JBA; 50.5% ± 2.4 SE in 1B) in 2020 to HCC Category B (43.46 % ± 5.1 SE in JBA; 35.1% ± 7.6 SE in 1B) in 2021.

Notably, Station 3B had the largest decline in HCC over one year, moving down two categories from HCC Category D to B, from an average HCC of 33.3% ± 2.8 SE in 2020 to 16.9% ± 8.4 SE in 2021. The rest of the monitoring stations remained in the same cover category from 2020 to 2021.

Table 2. Summary table for hard coral cover (HCC), generic (TAU) richness, rates of change in HCC, anc 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

	Average % HCC (± SE) 2021		Average TAU richness (± SE) 2021		Rate of change in HCC (Linear regression) 2012-2021	Difference among years in HCC (ANOVAR; p <0.05 is significant) 2012-2021
	% HCC	Category	TAU richness	Category		
TUBBATAHA (without JB, 5A)	32.3 ± 4.1	C	20.0 ± 0.9	C	↓ (-0.91%)	p < 0.001
ATOLL Level						
North Atoll	24.7 ± 4.3	C	20.1 ± 1.1	C	ns	ns
South Atoll	29.8 ± 7.4	C	20.0 ± 1.5	C	↓ (-1.98%)	p < 0.001
SITE Level						
Site 1	27.2 ± 7.9	C	22.3 ± 0.3	B	ns	ns
Site 2	22.2 ± 5.9	C	18.7 ± 0.8	C	ns	p < 0.05
Site 3	33.1 ± 16.2	B	18.8 ± 3.2	C	↓ (-3.27%)	p < 0.001
Site 4	26.4 ± 6.9	C	21.1 ± 0.5	C	↓ (-0.70%)	p < 0.05
Jessie Beazley	41.3 ± 2.2	B	16.4 ± 6.2	D	↓ (-3.01%)	p < 0.001
Station Level						
Station 1A	19.3 ± 1.3	D	22.0 ± 1.3	C	ns	p < 0.01
Station 1B	35.1 ± 7.6	B	22.6 ± 3.4	B	ns	ns
Station 2A	16.3 ± 1.9	D	17.8 ± 1.3	D	ns	ns
Station 2B	28.1 ± 1.9	C	19.4 ± 1.1	C	ns	p < 0.01
Station 3A	49.3 ± 2.7	A	22.0 ± 1.3	C	ns	p < 0.01
Station 3B	16.9 ± 8.4	D	15.6 ± 4.1	D	↓ (-4.63%)	p < 0.001
Station 4A	19.5 ± 2.7	D	20.6 ± 0.9	C	↓ (-1.23%)	p < 0.01
Station 4B	33.4 ± 2.3	B	21.6 ± 1.3	C	ns	ns
Station 5A	54.6 ± 0.5	A	25.0 ± 1.4	B	N/A	N/A
Jessie Beazley A	43.5 ± 5.1	B	16.0 ± 1.5	D	ns	p < 0.001
Jessie Beazley B	39.2 ± 3.3	B	22.6 ± 0.9	B	ns	ns

Station 5A also had the highest TAU richness (25.0 TAUs ± 1.4 SE; TAU Richness Category B) among the stations surveyed. Jessie Beazley B was the only station that improved from TAU richness Category C (21.0 TAUs ± 1.0 SE) in 2020 to TAU richness Category B (22.6 TAUs ± 0.9 SE) in 2021. Two monitoring stations, Stations 4B and 3B, had TAU richness categories that moved down from 2020 to 2021. Station 4B moved from TAU richness Category B (22.2 TAUs ± 2.0 SE) in 2020 to TAU richness Category C (21.6 TAUs ± 1.3 SE) in 2021. Station 3B had the lowest average TAU richness among the monitoring stations. This station moved from TAU richness Category C (20.8 TAUs ± 1.2 SE) in 2020 to TAU richness Category D (15.6 TAUs ± 4.2 SE) in 2021. The remaining monitoring stations stayed in the same TAU richness category as the previous year.

The reefs of Tubbataha (Sites 1, 2, 3, 4) had an average algal assemblage (AA; mainly turf algae) cover of 54.3% ± 4.0 SE, with Station 4A having the highest average AA cover at 71.5% ± 3.5 SE. Average AA cover in Station 4A increased by around 8% compared to the previous year (AA cover in 2020 = 63.5% ± 13.8 SE). The reefs of Jessie Beazley had a lower average AA cover than the reefs in the North and South Atolls (AA cover = 45.2% ± 3.8 SE), while the newly added Station 5A had the lowest average AA cover at 37.3% ± 1.2 SE.

Sponges were also observed in all monitoring stations, and the highest sponge cover was observed in Site 1 (SP cover = 8.0% ± 0.6 SE). Site 2 had the highest average sponge cover in 2020 (13.5% ± 0.5 SE). In 2021, Site 2 ranked second for sponge cover (7.0% ± 3.4 SE). At the station level, Station 2B had the highest sponge cover among the monitoring stations at 10.6% ± 4.5 SE.

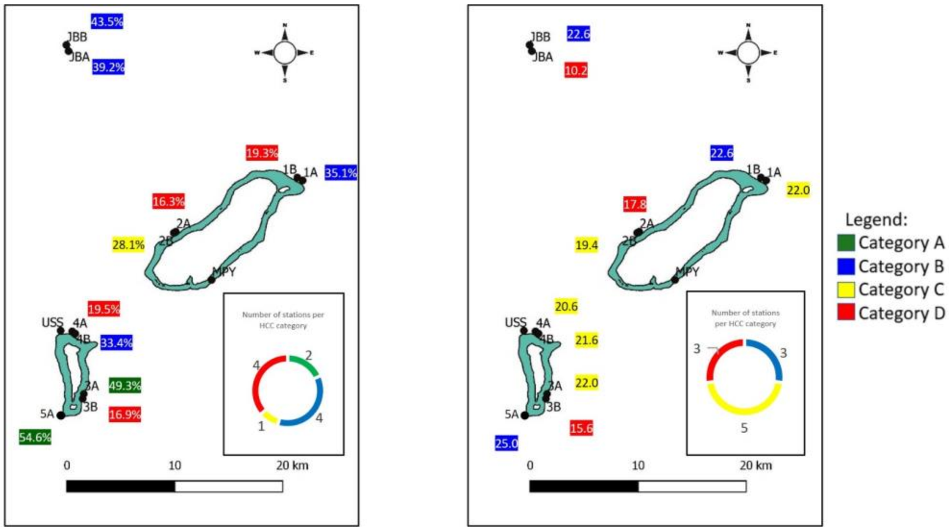


Figure 12. Map of Tubbataha monitoring stations labeled according to (A) Hard Coral Cover (HCC) category and (B) TAU Richness category (Licuanan et al., 2019).

Deep areas

The average HCC in the deep areas (including Jessie Beazley) was 27.4% ± 2 SE, with an average of 28 ± 1.8 SE coral TAU richness. Like last year (2020), Site 1 had the highest HCC of 30.5% ± 6.2 SE and the highest number of coral TAUs of 34. The lowest HCC was recorded in Site 2 (19.4% ± 1 SE), and the lowest number of TAUs was Jessie Beazley (23 TAUs). At the station level, the highest HCC in 2021 was recorded in Station 1B (36.8% ± 5.5 SE), dominated by *Echinopora* and encrusting *Porites,* while the lowest was noted in Station 4A (15.7% ± 4.7 SE), mainly composed of *Echinopora* and *Goniastrea*.

Like last year, the average major category AA cover this year (36.7% ± 5.1 SE) was higher than the hard coral cover. All the stations, except JBA, were dominated by AA, ranging from 26% to 70% of the benthic cover (Table 3). The major AA category this year was composed mostly of encrusting coralline algae. Station JBA was dominated by soft corals. It is also important to note that corallimorphs made up 26.6% of the benthic composition of Station JBB.

Table 3. Summary table for HCC and AA in the deep areas in 2021 and rates of change (2017 to 2021) at 10 m depth. Statistically significant results are indicated as follow: * <0.05, **<0.01, ***<0.001, ns = not significant

	Average % HCC (± SE) 2021	Rate of change in HCC (Linear regression) 2017-2021	Average % AA (± SE) 2021	Rate of change in AA (Linear regression) 2017-2021
TUBBATAHA (without JB)	25.5 ± 0.6	↓ (-1.2%)*	59.0 ± 1.5	↑ (+6.4%)***
ATOLL Level				
North Atoll	24.9 ± 5.5	ns	57.5 ± 9.8	↑ (+6.3%)***
South Atoll	26.1 ± 1.2	ns	60.5 ± 4.1	↑ (+6.6%)***
SITE Level				
Site 1	30.5 ± 6.2	ns	47.6 ± 5.0	↑ (+6.5%)***
Site 2	19.4 ± 1	ns	67.3 ± 0.9	↑ (+6.1)***
Site 3	27.4 ± 3	ns	64.6 ± 5.5	↑ (7.7%)***
Site 4	24.9 ± 9	↓ (-3.1%)**	56.3 ± 2.2	↑ (5.5%)***
Jessie Beazley	21.4 ± 3.9	ns	30.3 ± 4.3	↑ (4.25%)**
STATION Level				
Station 1A	24.2 ± 3.5	ns	52.6 ± 2.7	↑ (+8.0%)***
Station 1B	36.8 ± 5.5	ns	42.6 ± 3.1	↑ (+4.9%)***
Station 2A	20.4 ± 2.8	ns	66.4 ± 3.9	↑ (+5.7%)**
Station 2B	18.3 ± 2.5	ns	68.3 ± 2.5	↑ (+6.5%)**
Station 3A	31.1 ± 4.8	ns	59.0 ± 6.4	↑ (+9.6%)**
Station 3B	23.7 ± 4.3	ns	70.2 ± 5.6	↑ (+5.8%)*
Station 4A	15.7 ± 4.7	↓ (-4.1%)*	58.5 ± 6.7	↑ (+6.0%)*
Station 4B	34.0 ± 4.8	ns	54.1 ± 3.9	↑ (+5.0%)**
Jessie Beazley A	17.4 ± 3.3	ns	34.6 ± 4.9	↑ (+6.1%)*
Jessie Beazley B	25.4 ± 7.3	ns	26.0 ± 1.5	↑ (+2.3%)*

Temporal Patterns in Benthic Composition

Shallow areas (2012-2021)

At the location level, HCC is decreasing at an absolute rate of 0.91% (Table 2; LR p<0.05, R = 0.75; ANOVAR p<0.001) from 2012 to 2021. At the site level, three out of the five monitoring sites exhibited a significant decreasing trend in HCC (Figure 13). Specifically, Jessie Beazley HCC was decreasing at an annual rate of 3.01% (Table 2; LR p<0.01, R = 0.66; ANOVAR p<0.001), while Site 3 and Site 4's HCC were annually decreasing at rates of 3.27% (LR p<0.01, R = 0.74; ANOVAR p < 0.001) and 0.70% (LR p<0.05, R = 0.51; ANOVAR p<0.05), respectively (Table 2). Notably, the HCC of Sites 3 and 4, both located in South Atoll, were decreasing annually at a rate of 1.98% since 2012 (Table 2; LR p<0.01, R = 0.60; ANOVAR p < 0.001). At the station level, HCC in Stations 3B and 4A were decreasing by 4.63% annually (Table 2; LR p<0.001, R = 0.89; ANOVAR p < 0.001) and 1.23% (Table 2; LR p<0.05, R = 0.75; ANOVAR p<0.01), respectively (Figure 14).

Algal assemblage (AA) cover did not significantly change at the location level over time (LR and ANOVAR p > 0.05). At the site level, only Jessie Beazley showed a significant increase in AA cover at a rate of 2.2% annually from 2012 to 2021 (Figure 2, LR p<0.05, R = 0.60; ANOVAR p< 0.001). At the station level, only Station 3B showed a significant increasing trend in AA cover (Figure 14), at a rate of 2.4% (LR $p<0.01$, R = 0.58; ANOVAR $p<0.001$).

Increases in sponge (SP) cover were reported only for Station 4B in the 2020 reef benthos report (Bahinting et al., 2020). The present report shows that sponges are now more widespread and are increasing in cover in the reefs of Tubbataha. At the location level, SP cover was increasing at a rate of 0.65% per year (LR $p<0.01$, R = 0.77), and average SP cover increased 20-fold over the monitoring period (SP cover = 0.3% ± 0.1 SE in 2012; 6.0% ± 1.1 SE in 2021). Three out of the five monitoring sites exhibited increasing SP cover trends (Figure 13), with Site 2 having the highest rate of change at 0.71% per year (LR $p<0.01$, R = 0.74). SP cover in Site 4 was increasing at 0.71% per year (LR $p<0.01$, R = 0.80), while SP cover in Site 1 was increasing at 0.57% per year (LR $p<0.05$, R = 0.59). At the station level (Figure 14), Station 2B was exhibiting the highest

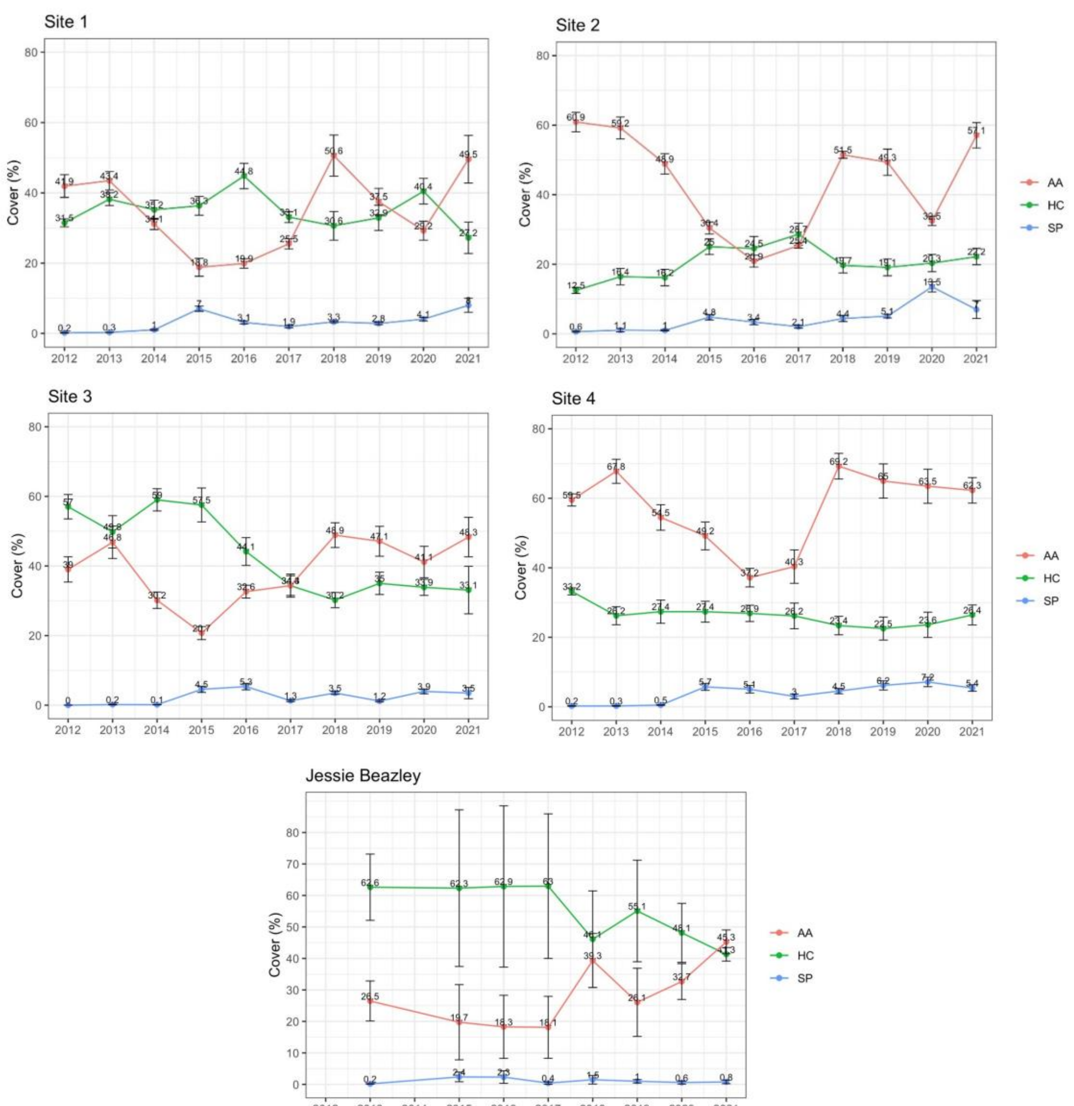


Figure 13. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring sites from 2012 to 2021. Error bars represent +/- one standard error.

rate of change, with SP cover increasing at 1.2% per year (LR p<0.01, R = 0.83), followed by Station 4B, which was increasing at 1.1% per year (LR p<0.01, R = 0.81).

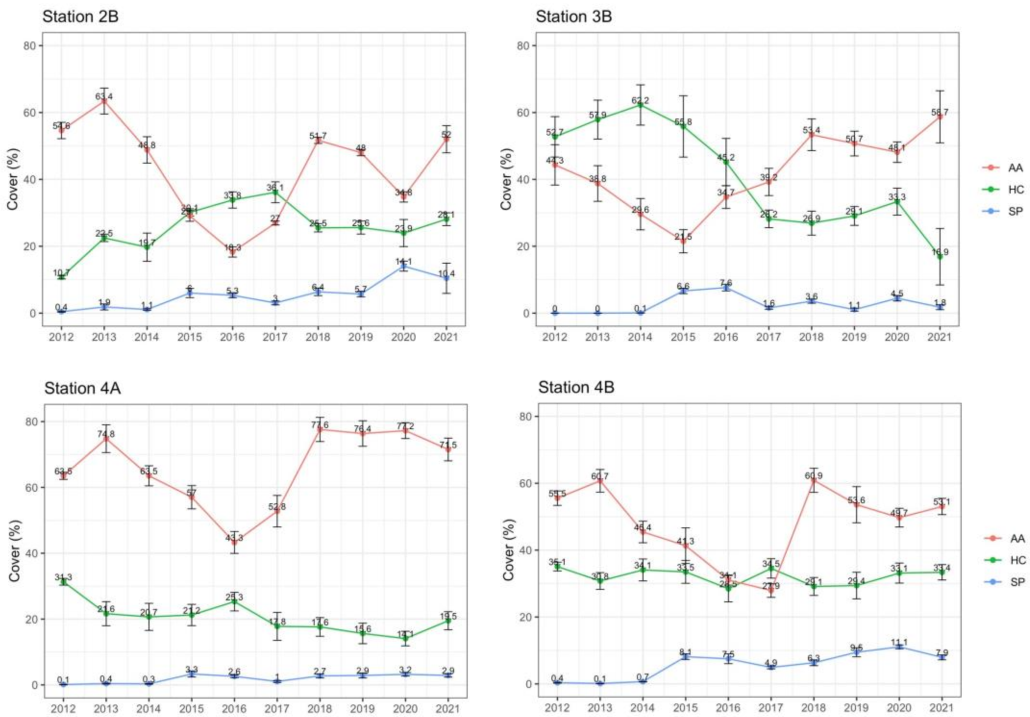
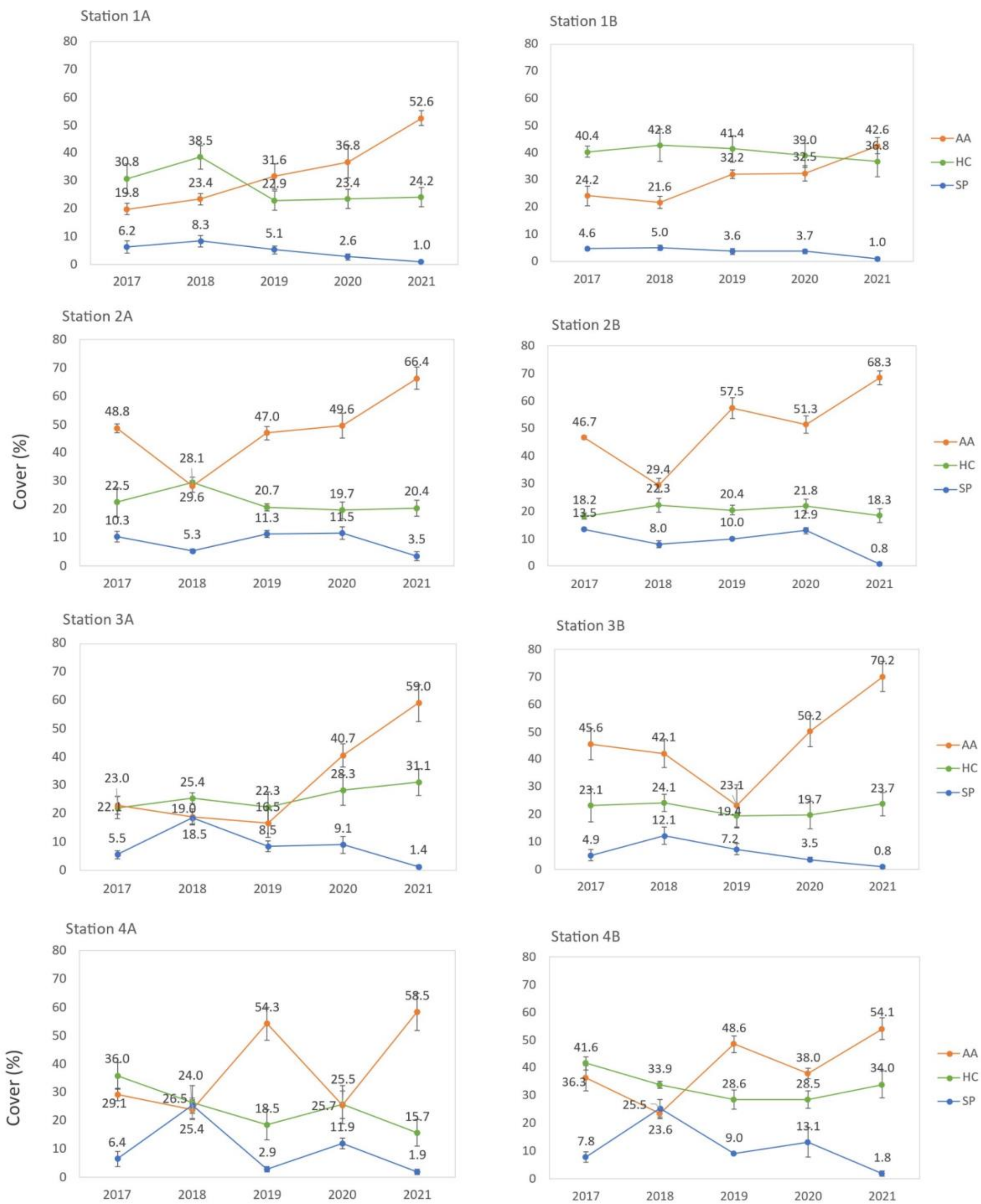


Figure 14. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in Stations 2B, 3B, 4A, and 4B from 2012 to 2021.

Deep areas (2017-2021)

Figure 15 shows the changes in hard coral, algal assemblage and sponge cover per site from 2017 to 2021. An increase in HCC between 2020 and 2021 was observed in Station JBA, while a decrease was recorded in Station JBB. Figure 15 shows that the algal cover increased in all of the stations from 2017 to 2021 at a rate of 6.4% annually (Table 3; LR p<0.001). To determine long-term changes, a linear regression was calculated for the hard coral and AA cover across stations from 2017 to 2021. Significant decrease in HCC was recorded for Station 4A (p<0.05, R=0.49), while significant increases in AA cover were recorded in all the stations: 1A (p<0.001, R=0.85), 1B (p<0.0001, R=0.78), 2A (p<0.05, R=0.61), 2B (p<0.05, R=0.68), 3A (p<0.05, R=0.75), 3B (p<0.05, R=0.45), 4A (p<0.05, R=0.50), 4B (p<0.01, R=0.59), JBA (p<0.05, R=0.53), JBB (p<0.05, R=0.53).


Station 1A
52.6
30.8
38.5
31.6
36.8
19.8
23.4
22.9
23.4
24.2
6.2
8.3
5.1
2.6
1.0
Station 1B
40.4
42.8
41.4
39.0
42.6
36.8
24.2
21.6
32.2
32.5
4.6
5.0
3.6
3.7
1.0
Station 2A
66.4
48.8
47.0
49.6
28.1
22.5
29.6
20.7
19.7
20.4
10.3
5.3
11.3
11.5
3.5
Station 2B
68.3
46.7
57.5
51.3
29.4
18.2
22.3
20.4
21.8
18.3
13.5
8.0
10.0
12.9
0.8
Station 3A
59.0
40.7
23.0
25.4
22.3
28.3
31.1
22.1
19.0
16.5
5.5
18.5
8.5
9.1
1.4
Station 3B
70.2
45.6
42.1
50.2
23.1
24.1
23.1
19.7
23.7
19.4
4.9
12.1
7.2
3.5
0.8
Station 4A
54.3
58.5
36.0
24.0
25.5
29.1
26.5
18.5
25.7
15.7
25.4
6.4
2.9
11.9
1.9
Station 4B
48.6
54.1
41.6
33.9
38.0
34.0
36.3
28.6
28.5
25.5
23.6
13.1
7.8
9.0
1.8
Cover (%)
2017
2018
2019
2020
2021
AA
HC
SP

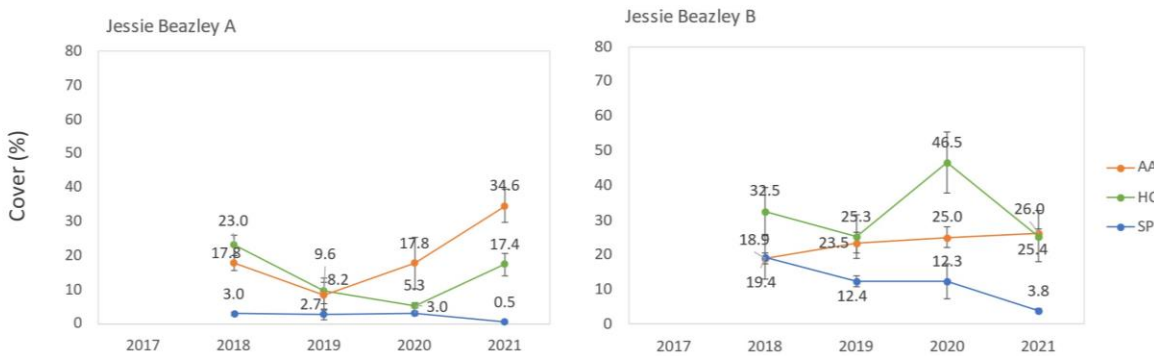


Figure 15. Changes in hard coral (HC), algal assemblage (AA) and sponge (SP) cover at the deep areas from 2017 to 2021. Error bars represent +/- one standard error.

Figure 16 presents the long-term data of TMO, with the percentage cover of hard corals, soft corals, and algae from 1997 to 2021. These data were collected using different methods that evolved over the years. The number of sites also changed. Thus, the results cannot be compared statistically. Despite the limitations, a decline in HCC can be observed since 2013, coinciding with the increasing trend in algae beginning in 2014.

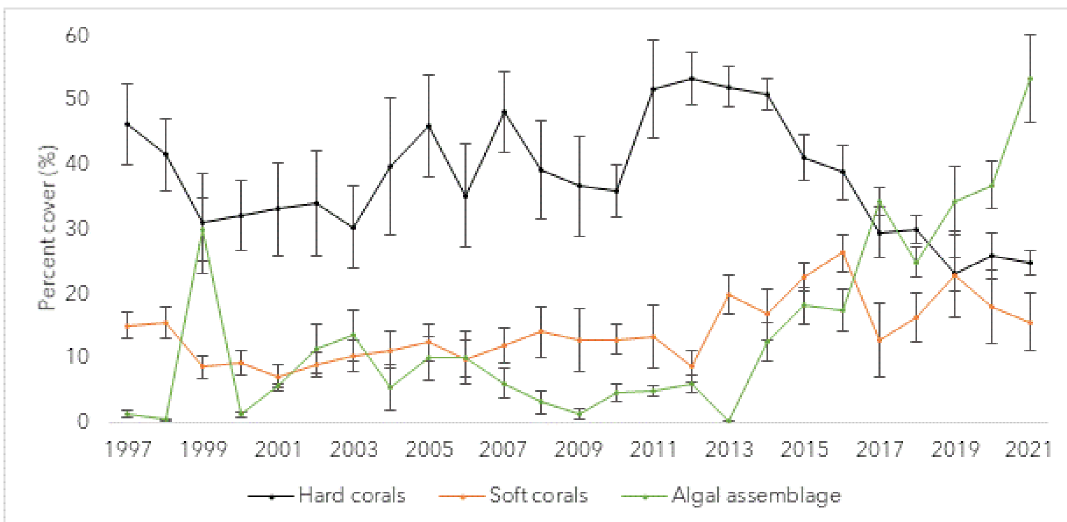


Figure 16. Average hard coral (HC), soft coral (SC), and algal assemblage (AA) cover at monitoring stations at the deep areas from 1997 to 2021. Error bars represent +/- one standard error.

Ship Grounding Sites

The Min Ping Yu vessel ran aground in the southeastern part of the North Atoll (see Figure 2) in 2013. Three 4m x 4m fixed plots were established at different areas in the impact site (Figure 17). The "small fragments" plot was located where the ship repeatedly hit the reef, resulting in small fragments scattered in the area. Around 50m east of the "small fragments" plot, the ship's rudder left large pieces of corals, and a "large fragments" plot was established. A control plot was also established around 95m southwest of the "small fragments" plot.

The fixed plots have been monitored since 2014. The HCC in each plot is shown in Figure 17. The HCC in the "large fragments" plot showed signs of recovery based on a simple linear regression analysis. HCC has increased by 2.29% annually (Table 4; $p<0.05$; $R=0.82$). However, the changes in HCC in "small fragments" and "adjacent control" plots were not statistically significant (Table 4).

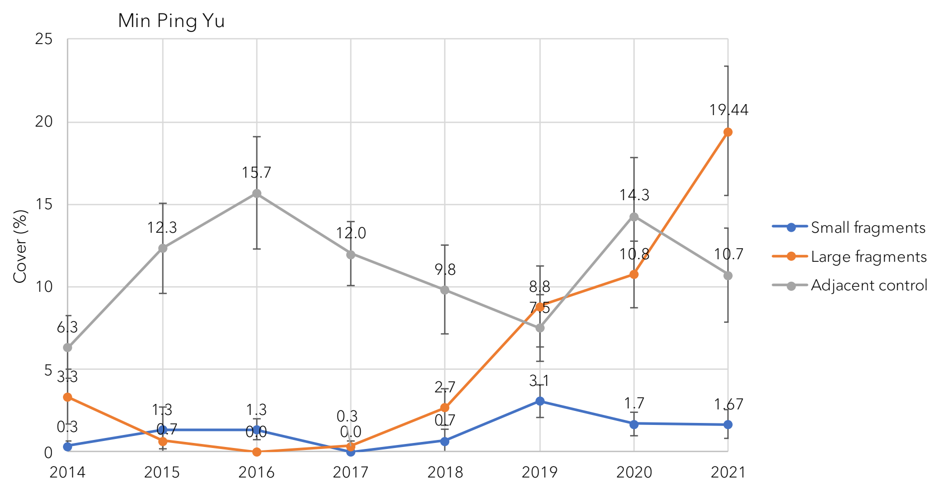


Figure 17. Hard Coral Cover in Min Ping Yu ship grounding site in three fixed plots: Small Fragments, Large Fragments, Adjacent Control. Error bars represent +/- one standard error

Table 4. Summary of statistical parameters for HCC changes in ship grounding sites: Min Ping Yu and USS Guardian from simple linear regression analysis; statistically significant ($p < 0.05$) results from linear regression are highlighted. ns = not significant ($p > 0.05$)

Label	Plot	Annual rate of change in HCC	p-value	R
Min Ping Yu				
Q3	Small Fragments	ns	ns	0.52
Q1	Large Fragments	↑ (2.29%)	p<0.05	0.82
Q2	Adjacent Control	ns	ns	0.13
USS Guardian				
Q1	Ground Zero	↑ (0.92%)	p<0.05	0.78
Q3	Impact Border	ns	ns	0.18
Q2	Adjacent Control	↓ (-2.71%)	p<0.01	-0.85

The USS Guardian warship hit the northwestern tip of the South Atoll in 2013 (see Figure 2). The "ground zero" plot was the area where the reef was most damaged, while the "impact border" plot was located where moderate damage was observed. It was established 50m to the east of the ground zero plot. A control plot was established 200m away in an unaffected part of the reef. The most damaged part of the USS Guardian grounding site showed signs of recovery with an annual increase in HCC of 0.92% (Table 4 ;Figure 18; $p<0.05$; R=0.78). However, the HCC in the control plot has decreased by 2.71% annually (Table 4; Figure 19; $p<0.01$; R=-0.85). On the other hand, the changes in the HCC in the "impact border" plot were not statistically significant.

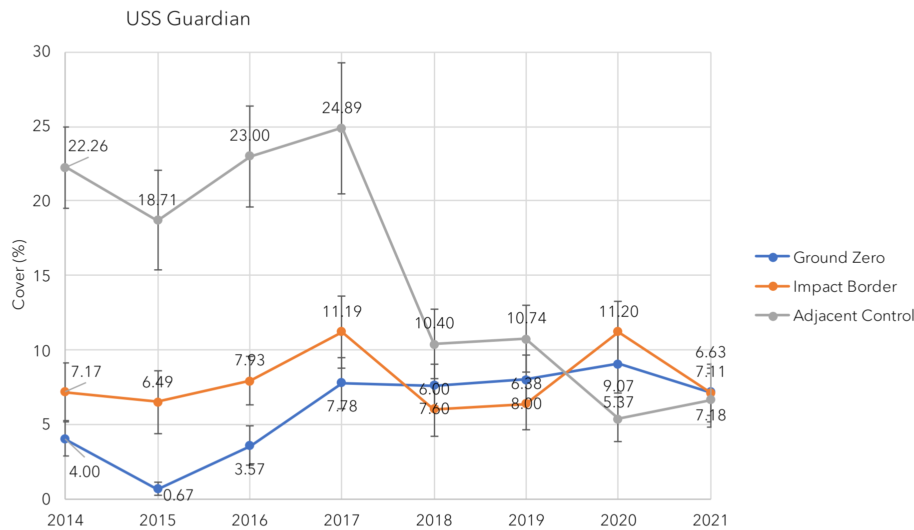


Figure 18. Hard Coral Cover in USS Guardian ship grounding site with three fixed plots: Ground Zero, Impact Border, Adjacent Control. Error bars represent +/- one standard error

DISCUSSION

Shallow areas

Among all the stations, Station 3B had significantly declined in HCC at 4.63% per year since 2012. This station was previously dominated by monospecific stands of *Isopora brueggemanni*, which began to deteriorate in 2017. This decline was attributed to *payaw* floats or logs that likely hit the reefs in 2016 and 2017 (Eneria and Licuanan 2017). The HCC in Station 3B further declined from 33.3% ± 4.0 SE in 2020 to 16.9% ± 8.4 SE this year. This decline may likely be due to the bleaching incident in July 2020, made worse by the impact of Tropical Depression Vicky. This caused wide areas (Transect 1-3) of the reef to become rubble fields. TD Vicky directly hit Tubbataha in December 2020, coming from the southeast direction, possibly creating the most impact on Site 3, located at the southeastern side of South Atoll. It is possible that the present condition in the station is a continuation of the damage that began in 2016. It is possible that the significant decline this year is a result of the cumulative effect of bleaching and possible effects of storms that exacerbated the conditions. It is also worth noting that a wide patch of rubble (14m x 15m) covered by *Terpios* sponge approximately 6m away from the sampling area seems to be growing (Figure 19).

Station 4A also shows significant declines in HCC at a rate of 1.23% per year since 2012. Station 4A also has the highest AA cover among all monitoring stations (71.5% ± 3.5 SE), yet AA cover did not appear to change significantly overall (LR $p > 0.05$) throughout the monitoring period. SP cover has increased significantly since 2012, albeit at a smaller rate of change (0.33% per year, LR $p<0.05$, $R = 0.75$) than in other stations such as 2B and 4B. It is possible that the decline in HCC in Station 4A is due to its coral composition wherein 9.0% of the HCC (relative abundance) is composed of branching acroporiids which are sensitive to coral bleaching events. This is almost five times more than the relative abundance of branching acroporiids in Station 4B (2.6%) which may be why there is no significant decline in HCC in 4B. Declining HCC in Site 4 stations have been reported since 2017 at the transect level and in fixed plots used to measure more minute changes (Licuanan and Bahinting 2021). Monitoring the reef benthos, especially for composition changes in this site, is necessary to detect possible eutrophication in the South Atoll's lagoon (Licuanan and Bahinting 2021).

Figure 19. Rubble fields around Station 3B covered by *Terpios* sponge (these images were taken outside of the sampling area). Photo: Rowell Alarcon

The average HCC in the shallow areas of Tubbataha was lower compared to AA cover. AA in Tubbataha's shallow reef areas was mainly composed of algal assemblages (i.e., thin layers of turf algae on exposed carbonate rock) while AA cover in deeper reef areas is mostly composed of encrusting coralline algae. From the present report, significant trends of decreasing HCC with increasing AA cover were observed at the site level in Jessie Beazley and Station 3B (Figure 13, Figure 14). On the one hand, algal assemblage denotes habitable space for the recruitment and settlement of coral larvae. On the other hand, the excessive growth of algal turf may eventually limit coral recruitment and settlement and allow them to compete with corals for space (Arnold et al., 2010; Roth et al., 2018). Based on the results, the turf algae height did not seem to vary among monitoring stations surveyed.

Sponges were recorded in all the monitoring stations. They compete with corals for space in the reef substrate (Suchanek et al., 1983). Some sponge species have been shown to overgrow corals (Aerts and van Soest 1997), release metabolites that hinder the photosynthesis of zooxanthellae (Pawlik et al., 2007), and aggressively take over broad patches of coral reef (e.g., *Terpios hoshinota*; see Rutzler and Muzik 1993; Licuanan and Bahinting 2021). SP cover increased in stations in both the North and South Atolls, yet the highest rates of change were observed in Stations 2B and 4B (Figure 14), both located close to channels through which nutrient-rich lagoon drain.

Sponge-coral-algae competition is dynamic and complex, where interactions among taxa and the condition of their surrounding environment can determine the structure of benthic communities to favor coral- or algal-dominated states (Gonzalez-Rivero et al., 2011). The detection of increases in sponge cover in stations with decreasing HCC is noteworthy as this may indicate eutrophication (Licuanan and Bahinting 2021). This is especially urgent in Tubbataha since this signal has been reported in the South Atoll, specifically in Site 4 (Licuanan and Bahinting 2021). Prolonged effects of increased nutrient input in reefs may result in irreversible shifts in the composition of the benthic community to favor sponges and cyanobacteria (Knapp et al., 2016; Licuanan and Bahinting 2021).

The grounding sites are showing initial signs of recovery. The HCC in the large fragments plot in the Min Ping Yu grounding site has increased by 2.29% annually since 2012 ($p<0.05$), while the other two plots are not significantly changing. Coral recruits can settle on the surfaces in the "large fragments" plot because it is more stable and favorable for coral settlement. However, for the "small fragments" plot, the coral recruits would find it difficult to settle and grow on the unstable surfaces (Fox et al., 2019) due to constant movement of the pieces of rubble left behind by the rudder of the MPY ship. The most impacted area in the USS Guardian site, ground zero, has increasing HCC. Even though the substrate was impacted the most, it is solid enough for coral recruits to settle and grow. However, the HCC in the control plot in USS Guardian has been declining since 2017. Since the control plot is around 150m away from the ground zero plot, it is possible that the grounding of the USS Guardian is not the cause of the decline of the control plot. There may be other factors causing the decline of the control plot in the USS grounding site.

Deep areas

Coral bleaching was observed in May 2020 during the regular fish and benthos monitoring. In July 2020, all the monitoring sites were reassessed to document how much of the corals were bleached. The bleached HCC at the station level ranged from 3.4% to 16.3% in the deep areas (TMO 2020). This year, the monitoring results showed that overall, the hard coral cover in the monitoring sites' deep areas was stable, except for Station 4A, where a decline was observed beginning in 2017 (Figure 15). The coral bleaching incident may have influenced the decline in Station 4A this year, where a significant decrease in the HCC was recorded (from 25.7% in May 2020 to 12.8% in July 2020; TMO 2020), although it is unlikely for the effects of severe bleaching to be confined only to one station. More likely, the bleaching was more widespread but the bleached corals in Station 4A could not recover after the event, which might be due to its coral composition. In 2020, branching acroporiids composed 7.9% of the hard corals in station 4A, and in 2021, only 1.6% (relative abundance) acroporiids remained. Acroporiids are sensitive to coral bleaching and this could be the reason why station 4A was not able to recover compared to station 4B, which only had 3.1% (relative abundance) acroporiids in 2020, prior to the bleaching event. An increase in soft corals was also recorded in Station 4A from 13.6% in 2020 to 22.0% in 2021 (absolute abundance). The increase in AA on the other stations did not correspond to a significant decrease in HCC from 1997 to 2021. AA in the deep areas of the monitoring stations were mainly encrusting coralline algae, which attracts coral larvae to attach and settle.

Corallimorphs covered 26.6% of JBB this year, and the percentage cover was similar to the station's HCC and AA. Before this, corallimorphs covered 19.6% of JBB in 2018 and 0.9% in 2019. The other monitoring sites recorded negligible values (<3%) since 2017. Corallimorphs were noted in the same station in 2001, colonizing over dead corals (Ledesma et al., 2001). Corallimorphs are a type of invasive anemone-like animal that typically thrives in coral reefs that have been degraded by environmental or man-made disturbances. Their proliferation in an area may be influenced by disturbances, e.g., ship groundings (Work et al., 2008). They reproduce fast through clonal production, making them capable of rapidly monopolizing unoccupied substrate patches on shallow tropical reefs (Chadwick-Furman & Spiegel 2000). They also compete with other hard corals by damaging the latter's tissues and overgrowing them (Langmead and Chadwick-Furman 1999). This was seen primarily on branching Poritidae, Acroporidae, and Pocilloporidae.

CONCLUSIONS

Gradual and incremental changes in benthic cover appear to continue in the reefs of Tubbataha. HCC at the location level continues a downward trend over the 10-year monitoring period. This decline in HCC is especially apparent in the South Atoll and Jessie Beazley. Notably, SP cover also shows a significant increasing trend in South Atoll stations, while Jessie Beazley shows a significant increase in AA cover from 2012 to 2021 and corallimorphs from 2019 to 2021. These changes in the benthic composition may underscore stressors that threaten corals in the reefs of Tubbataha, such as eutrophication and typhoon damage, and the impacts of thermal stress.

However, one-year increases in HCC Category and TAU richness Category were observed in Stations 3A and JBB, respectively. The fixed plots in ship grounding sites are also showing signs of improvement in terms of HCC, suggesting that there is still potential for the reefs of Tubbataha to thrive despite the changing ocean conditions. High HCC and TAU richness in the newly established Station 5A also highlight areas in Tubbataha, yet to be explored, that may harbor well-developed and diverse coral communities. The findings from this report indicate the need to continue and further refine the reef benthos monitoring (see Recommendations section) for better change detection and response to ensure optimal conservation of TRNP.

RECOMMENDATIONS

1. Continue benthos monitoring to detect further changes in benthic composition, with a focus on:
    a. changes in HCC (e.g., decline in Station 3B and 4B, decline in control plot in USS Guardian, increase in MPY and USS Guardian ship grounding sites),
    b. increasing AA cover,
    c. increasing SP cover, especially in stations with decreasing HCC (e.g., South Atoll stations)
    d. trends in cover of other biota such as cyanobacteria, corallimorphs, and rubble
2. Establish a complementary Station 5B following the hierarchical sampling scheme.
3. Carry out further analyses to detect changes in adult hard coral composition through time, since observing hard coral composition can provide more specific information to diagnose drivers of change in benthic composition.
4. Study coral settlement, in addition to coral recruitment, to identify possible bottlenecks for coral growth in the reefs.
5. Monitor specific benthos indicative of different stressors that may affect reef status (e.g., observing sponge-coral interactions in Site 4, tracing the spread of rubble fields in Site 3, trends in turf algae height over time).
6. Monitor additional parameters such as water quality in the monitoring stations may also help diagnose the source of possible eutrophication.
7. Maximize opportunities to map and re-assess the reefs of Tubbataha to detect broader-scale changes and identify other priority areas for monitoring.
8. Prohibit tourist access to dive sites near sampling stations that are declining in HCC e.g., T Wreck, Delsan Wreck, and Triggerfish City, should be considered on an experimental basis, i.e., with adequate controls consistent with the hierarchical monitoring design.
9. Explore low-cost, environment-friendly interventions to stabilize rubble fields in Station 3B and “small fragments” plot in Min Ping Yu.
10. Revisit and adjust current reef management strategies to mitigate reef decline in the face of new ocean conditions and to conserve Tubbataha's reefs for the future.

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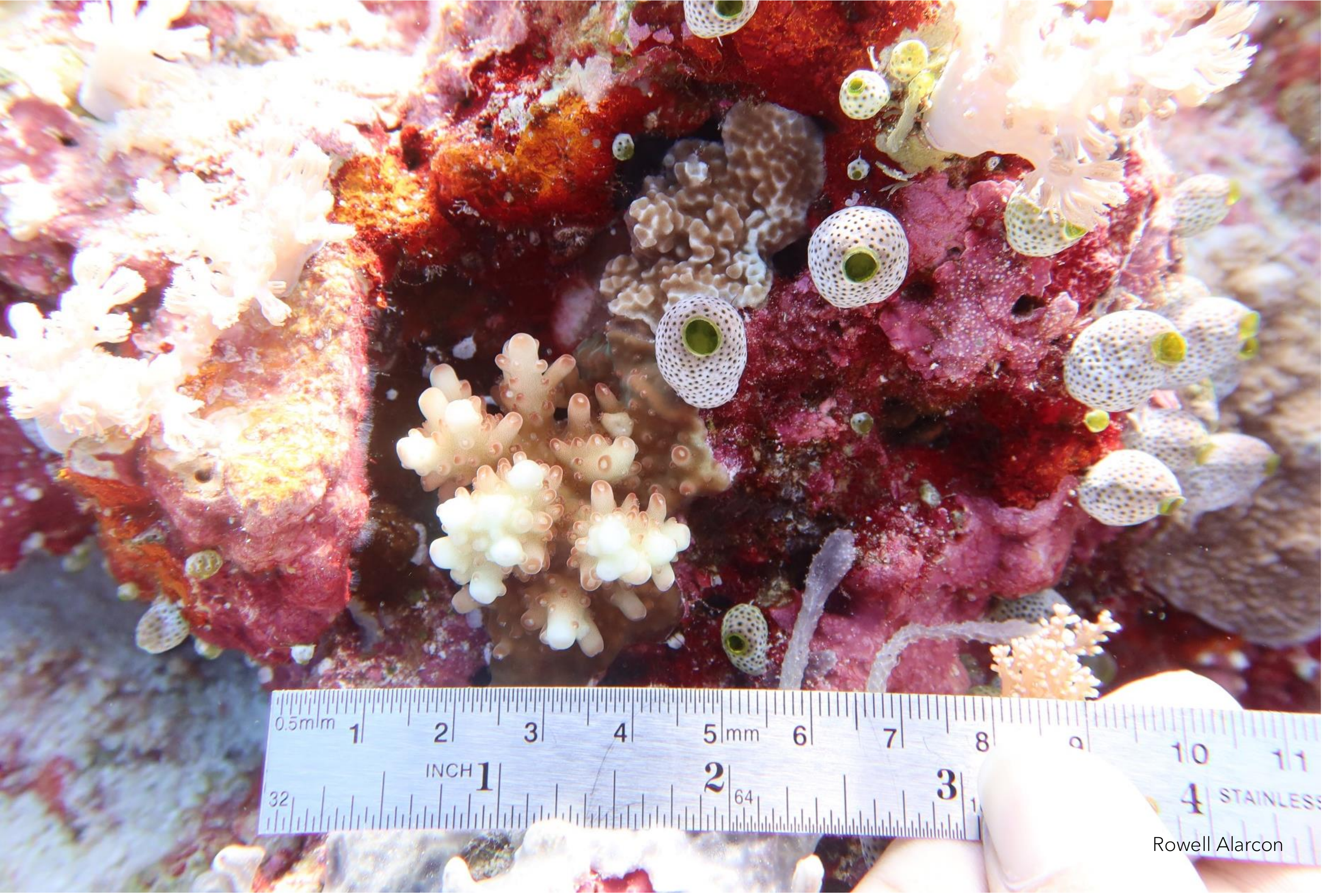

Rowell Alarcon

CHAPTER 3. CORAL RECRUITMENT

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Tubbataha Management Office

OVERVIEW

Coral reefs have decreased significantly due to the impacts of human activities and global climate change (Hughes et al., 2017). The natural recovery of coral reefs can occur if the recruitment process is functioning well. The success of coral recruitment is determined by the availability of coral larvae and favorable substrates and water conditions that support the settlement of coral recruits. The density of young (juvenile) coral colonies is used as a standard to measure the level of coral recruitment in coral reef ecosystems (Munasik et. al., 2014). Studying this cryptic stage of corals provides insight to better evaluate the resilience of reef ecosystems (Doropoulos et al., 2015).

Coral recruitment is a process where a new coral passes through the settlement stage, survives, and reaches the reproductive phase. The success of coral larvae in growing into adult corals, also known as coral recruitment, is critical to the health of coral reef ecosystems. This study intends to continue quantifying coral recruit abundance, recruitment density, and distribution in TRNP. It also aims to identify and understand factors, such as the variability of juvenile corals among sites and depths, that may have implications on the whole coral population.

METHODS

Sampling design

In each transect, a diver randomly placed a 34 x 34 cm (0.12 m^2) 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 20b).

In each quadrat, five photos were taken (four close-up shots at each corner and one full quadrat shot) to provide more detailed images of juvenile corals (Figure 20c). This process was repeated 20 times along the transects at both depths in each of the stations. 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.

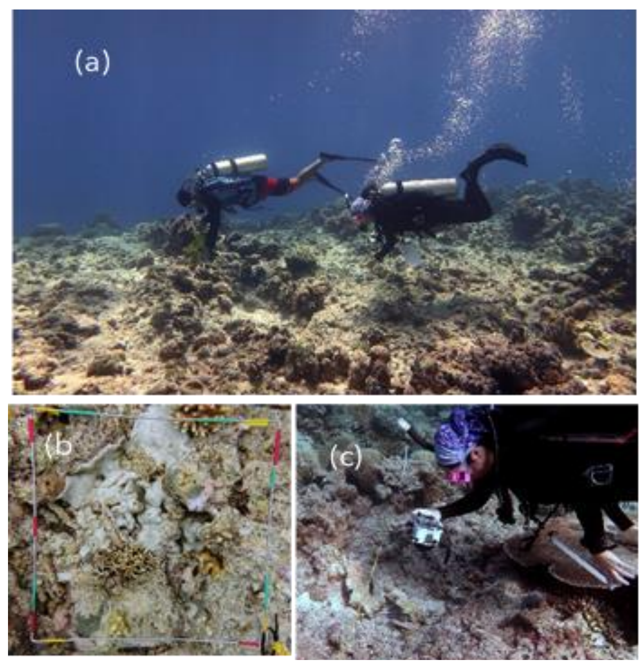

Figure 20. Coral recruitment sampling: (a) quadrat placed randomly within the transect; (b) close-up shot of the quadrat with scale bars, and (c) multiple photos taken using underwater camera. Photos: Rowell Alarcon

For the grounding sites of the USS Guardian and F/B Min Ping Yu, permanent monitoring plots measuring 4 x 4 meters (Figure 11) 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 impact 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 impact 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 based 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 to obtain more robust data. The quadrat was placed in the middle, at the four corners, and haphazardly (five spots), on each plot. A total of 30 quadrats were sampled at each site. All photos were downloaded, grouped, and labeled according to quadrat per site, the 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).

Data analysis

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 Guide to the Corals of Bolinao-Anda Reef Complex were used as references for coral identification. Small coral fragments that were deemed remnants of adult corals were excluded. 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 $0.12m^2$. Differences in the densities of recruits in the grounding site plots across years were tested using Two-way Analysis of Variance (ANOVA). The Chi-square test was used to test the probability of the size-frequency distribution of recruits, juvenile and mature colonies of corals.

RESULTS

A total of 2,367 individual coral recruits from 460 photographs were processed, covering a total of $48m^2$ in the regular monitoring sites and $7.3m^2$ in the grounding sites. This year, 49 genera belonging to 18 families were recorded, the highest since 2018. The average coral recruit density in the deep areas, across all the regular monitoring sites was 87.89 ind/m^2, with values ranging from 0.69 individuals/m^2 to 34.72 ind/m^2. This is relatively higher than in 2020 at 61.67 ind/m^2. This value is higher compared to Malapascua, Philippines at 28.95 ind/m^2 (Dalongeville et al., 2018). In the shallow areas, the average density was 53 ind/m^2, which was almost the same as the previous year. The shallow area had consistently lower density of coral recruits compared to deep areas.

The coral recruit density in the impact zone of the USS Guardian grounding site increased by 21% this year, while a 58% decrease was observed in the impact zone of MPY.

Coral recruitment in the shallow areas

Family and Percentage Cover. This year, a total of 17 coral families were recorded in the shallow area. The coral recruits found in the shallow areas were dominated by families Poritidae (20.58%), Pocilloporidae (19.72%) followed by Acroporidae and Agariciidae at 18.63% and 18.98%, respectively. Brooder type corals (Poritidae, Pocilloporidae, and Agariciidae) were the most dominant. Branching *Acropora* had the highest cover in Stations 3A (27.02%) and 2A (21.05%). Foliose *Montipora* dominated Station JBA at 80.90%.

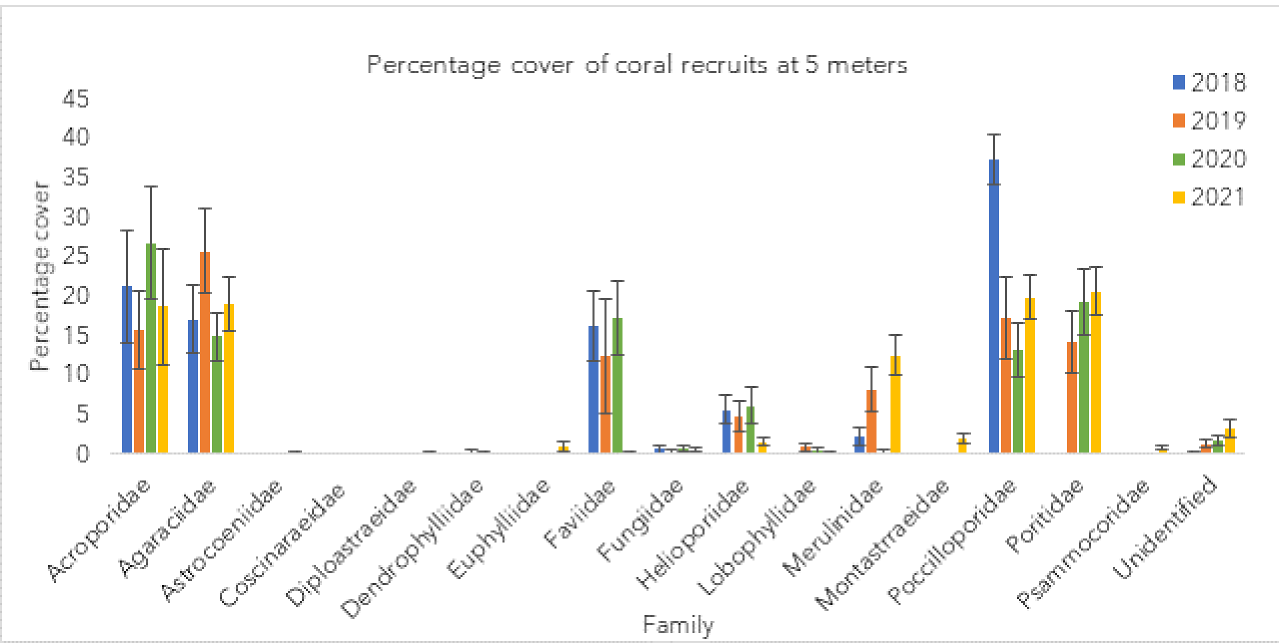

Figure 21. Mean percentage cover of all coral recruits at five meters. Error bars represent standard error of the mean.

Density. Overall, the coral recruit density in the shallow area is higher this year, but the difference was not statistically significant. The overall mean density of coral recruits was 53 ind/m^2, which was almost the same as last year's 53.75 ind/m^2 (Table 5). The highest coral density at this depth was recorded in Station 1A (87.77 ind/m^2) and Station 1B (62.21 ind/m^2), while the lowest was documented in Station 2A with 27.49 ind/m^2 (Table 5).

Table 5. Coral recruit density of all station per year at five (5) meters.

Station	2018	2019	2020	2021
1A	14.47	30.09	65.28	87.77
1B	41.67	38.77	54.86	62.21
2A	41.67	39.35	40.28	27.49
2B	34.72	25.46	63.89	41.96
3A	11.00	15.63	68.75	53.53
3B	10.42	25.46	60.42	56.91
4A	14.47	28.94	37.50	42.44
4B	27.20	26.04	47.22	52.08
JBA	32.41	4.63	47.22	53.05
JBB	18.52	15.05	52.08	52.57
Mean Density	**24.65**	**24.94**	**53.75**	**53.00**

In Stations 1A and 1B, the combination of encrusting corals of genus *Porites*, *Echinopora, Pavona,* and *Psammocora,* as well as branching *Acropora* and *Pocillopora* contributed to this year's increase.

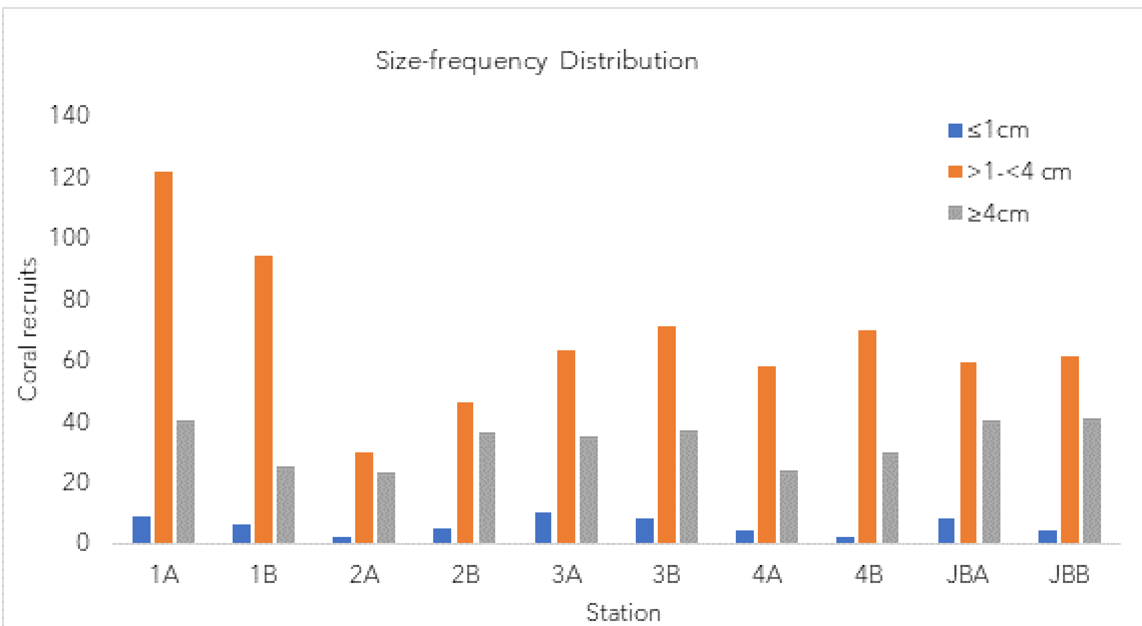

Figure 22. Size frequency distribution of coral recruits at five (5) meters.

The frequency of newly settled corals (<1 cm in size) was lowest across all stations. The most frequently observed were the juvenile coral recruits between >1 to <4 cm. As recruits reached maturity (≥4cm) the population decreased, as was observed since 2018.

Coral recruitment in the deep areas

Family and Percentage Cover. In the deep area, 49 genera belonging to 18 families were recorded. This is the highest recorded number of coral genera since 2018. Throughout the years of monitoring, three coral families – Agariciidae, Poritidae and Poccilloporidae – were the most dominant. Consistently, family Agariciidae had the highest percentage cover at 27.81%, followed by Poritidae and Pocilloporidae at 17.53% and 15.45%, respectively (Figure 23). The highest number of coral genera was observed at Station 3A (22 coral genera), while the lowest was observed in Station JBA (13 genera).

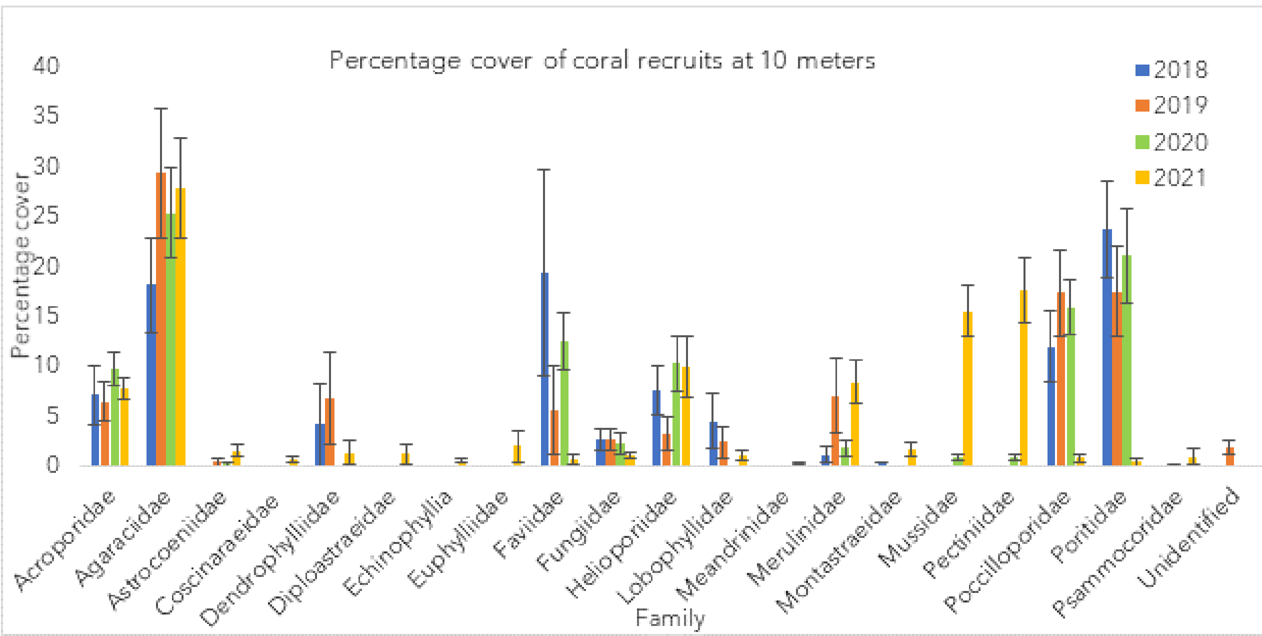

Figure 23. Mean percentage cover per family of all coral recruits at 10 meters. Error bars represent standard error of the mean.

Density. In general, the encrusting type of corals from genus *Pavona*, *Porites* and branching *Pocillopora* dominated all the stations. The highest increase in density was observed in Site 3B, where the values this year (141.67 ind/m^2) almost doubled compared to 2020 (85.42 ind/m^2). The deep portion of both stations in Site 3 were characterized by a gradual slope, open spaces, and a stable substrate with rubbles covered by high crustose coralline algae. High crustose coralline algae in a substrate provides settlement cues and influences coral recruitment in an area (Gleason and Hofmann 2011).

Table 6. Coral recruit density of all stations at 10 meters.

Station	2018	2019	2020	2021
1A	33.33	48.61	64.58	79.17
1B	41.67	27.78	56.25	58.33
2A	22.92	22.22	42.36	47.92
2B	34.03	50.69	31.25	55.56
3A	52.78	42.25	87.50	87.50
3B	68.06	36.81	85.42	141.67
4A	41.67	40.97	78.47	83.33
4B	47.22	58.33	65.28	111.81
JBA	33.33	43.06	38.19	117.36
JBB	27.78	52.08	67.36	97.22
Mean density	**40.28**	**42.28**	**61.67**	**87.99**

The most dominant corals recorded in the deep areas were the brooder type, such as the genus *Pavona*, *Hydnopora*, and *Porites,* which contributed to the increase this year. The lowest mean density was observed in Station 2B at 55.56 ind/m^2 (Table 6).

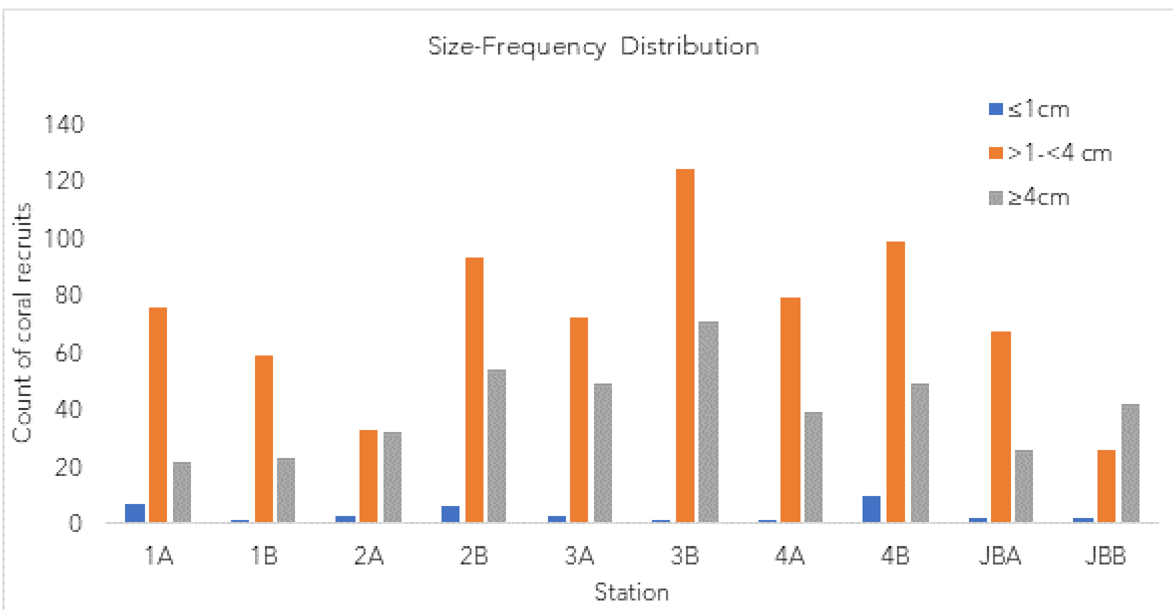

Figure 24. Size frequency distribution of coral recruits at 10 meters.

The newly settled coral recruit measuring ≤1cm comprised 3%, while the juvenile coral between >1 to <4 cm had the highest frequency at 62%. In all the stations, only 35% of the population measured ≥4cm (Figure 24). According to the study of Adjeroud et al.

(2016), juvenile corals are susceptible to mortality since they are still in the development stage. Those that reach ≥4cm are most likely to survive. The Chi-square test for size-frequency distribution did not show a significant difference among size classifications across all stations (p=0.07, α=0.05).

Ship grounding sites

Density in USSG. This year, the mean densities recorded at the USS Guardian grounding site were 15.19 ind/m^2 in the impact zone, 31.35 ind/m^2 in the control zone, and 23.63 ind/m^2 in the buffer zone. All showed an increased from 2020 (Figure 25). The control zone recorded an increase of 45%, followed by the impact zone which increased by 21%, while the buffer zone only marked a 3% increase. However, variation of densities did not show significant difference between years and between plots.

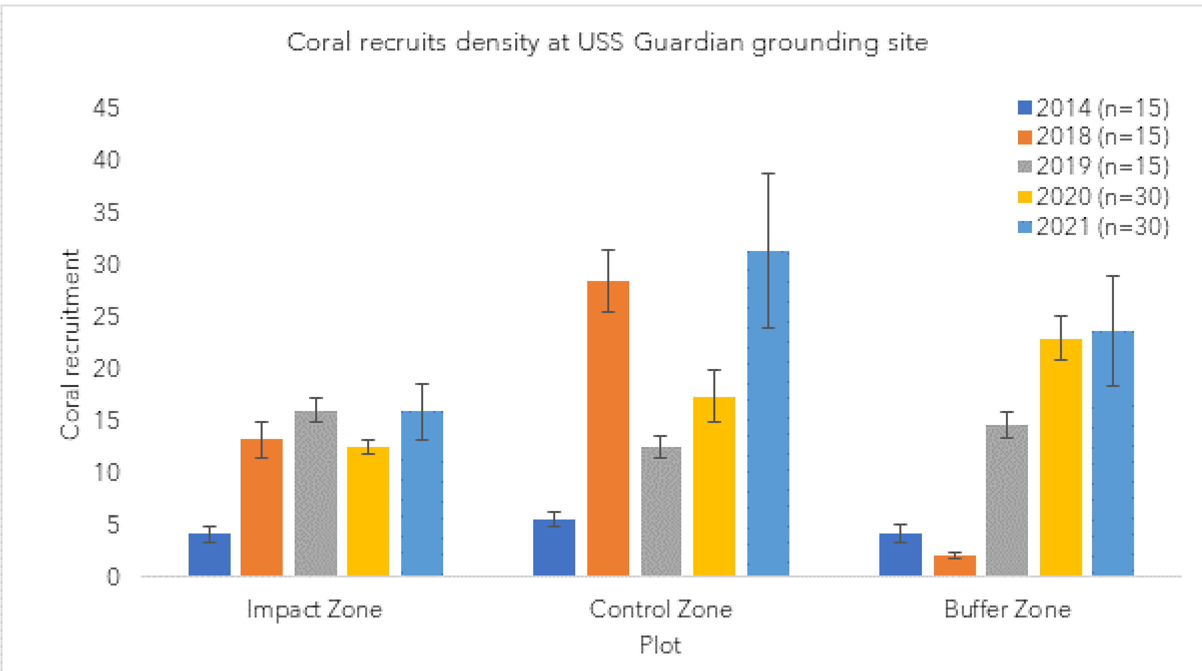

Figure 25. Coral recruit density at the USS Guardian plots. Error bars represent standard error of the mean.

Density in MPY. The average density in the MPY grounding site (18.65 ind/m^2) was lower than in the USSG grounding site (23.63 ind/m^2). Coral recruitment densities were recorded at 19.29 ind/m^2 in the impact zone, 15.91 ind/m^2 in the control zone, and 20.74 ind/m^2 in the buffer zone (Figure 26). In MPY, an increase of 26% in the coral recruit density was recorded in the large fragments plot, while both small fragments and adjacent control plots decreased by 58% and 34%, respectively. There was a significant decrease between years (ANOVA $p<0.01$) and between plots (ANOVA $p<0.05$).

Unfortunately, we were not able to identify the most dominant species and their corresponding percentages in the grounding sites due to limitations in the sampling area and in identifying recruits. Identifying coral recruits is largely dependent on the mature coral colonies within the sampling area, which did not exist in the grounding sites.

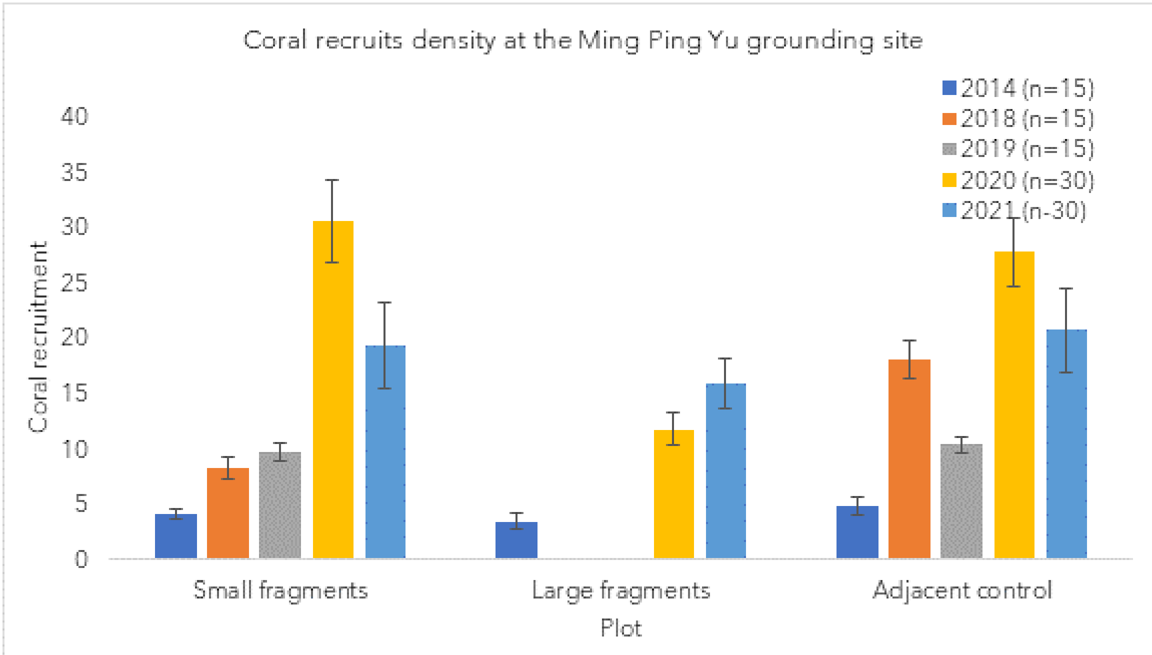

Figure 26. Coral recruit density at the Ming Ping Yu plots. Error bars represent standard error of the mean.

DISCUSSIONS

The density of coral recruits in Tubbataha was higher compared to other tropical sites that use similar sampling methods. The deep area had a mean density of 87.89 ind/m^2, four times higher than in Tioman Island in Malaysia at 25.92 ind/m^2 (Muhhanmad et al., 2017) and two times higher compared to Code Hole Reef in Australia at 36.67/m^2 (Burgess et al., 2010). Meanwhile, the shallow areas recorded an overall mean density of 53 ind/m^2, almost the same as last year at 53.78 ind/m^2.

Shallow Areas. In the shallow areas, the brooder coral families of Agariciidae, Poritidae, and Pocilloporidae were the most dominant. In previous years, the broadcast spawning coral from the family Acroporidae consistently dominated the shallow areas. Only a few coral recruits of Acroporidae were observed in most of the stations in this year. The broadcast spawning coral families release eggs and sperm that fertilize externally, and the larvae usually settle in the substrate after four to seven days (Fiuiredo et al., 2013). In contrast, the brooder coral families undergo internal fertilization and release their offspring as larvae, which is a relatively advanced stage of development. After the larvae are released in the water, they attach to the substrate. This type of corals is capable of high recruitment, but have high turnover and mortality, e.g., Family Pocilloporidae and Agariciidae. They are fast growing but have low resistance to stress (Adjeroud et al., 2016). However, some genera under the Family Poritidae usually show resistance to stress, e.g., massive, and encrusting forms. They produce fewer offspring with high capacity for survival (Kayal et al., 2015).

Deep Areas. In the deep areas, the coral recruits were dominated by brooder corals, *e.g.,* genus *Porites*, *Pocillopora* and *Pavona*. This type of corals tends to reflect the local abundance of fecund colonies. 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 and dominance of parent colonies within the area also affect coral recruitment. Over the years, both depths showed an increasing trend, suggesting continuous coral propagation in the area.

Density: Shallow vs Deep. A similar pattern from last year was observed, where the deep areas had higher coral recruit density compared to the shallow areas. 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). This dominance could likewise be due to more localized factors such site characteristics (Turner et al., 2018).

The deep areas in Tubbataha are usually composed of packets of open spaces covered by crustose coralline algae, which may enhance settlement and serve as refuge for coral recruits. The lower density of recruits in the shallow area, may be related to the site profile. Shallow areas in Tubbataha are generally characterized by reef flats dominated by mature coral colonies, which may provide limited space for recruits to settle. Previous disturbances, such as the bleaching incident of 2020, which affected most of the stations, may have provided open spaces and therefore, an opportunity for coral recruits to flourish. Among all the sites, the shallow areas of Sites 1 and 4 were the most heavily affected by the bleaching event (TMO 2020), hence providing spaces for coral recruits.

Size Distribution Pattern. A similar size frequency distribution pattern was observed at both depths. The newly settled coral recruits comprised 3-5%, the juvenile coral recruits ranged between 62-68%, and 31-35% of the population were mature recruits. These mature coral recruits have the greatest possibility of survival and become adult colonies. This proportion follows the natural curve which shows that the frequency of coral recruit decreases when the size class increases (Moulding 2005). It is likely that only 35% of the entire coral recruit population would survive, as the juvenile corals are very easily affected by stressors from marine environments such as sedimentation, currents, and predation (Andriyani and Nugraha 2020).

Density in the Grounding Sites. The average density in the MPY grounding site (18.65 ind/m^2) was lower than in the USSG grounding site (23.63 ind/m^2). The lower coral recruit density in MPY was attributed to the relatively unstable substrate, which is composed of rubbles and sand, especially in the small fragment plot. An increase of 26% was recorded in the large fragments plot, where coral recruits were mostly found attached to small packets of stable substrates, which provided shelter for the coral recruits to survive.

Despite the high variability of the recruitment densities in the two grounding sites, both areas seem to be gradually improving since the disturbance in 2013. The improvement was made evident by the dominance of larger coral colonies inside most of the plots. The continuous study of the grounding sites will provide evidence of recovery and resiliency of corals to disturbances.

Consistent patterns of coral recruitment were observed throughout the years. The high recruitment densities at both depths and in the grounding sites, coupled with high densities of the local population of brooding corals suggest that there is continuous propagation in the area. This may be viewed as a potential indicator that the reef could replenish itself after certain disturbances. Continuous efforts in monitoring will shed light and more in-depth understanding of the complexity of coral recruitment in Tubbataha.

RECOMMENDATIONS

Streamlining of data collection for future studies may be necessary to increase the accuracy and precision of sampling. Specifically, there is a need to:

- Increase sampling by 30 samples per depth for a more robust data;
- Perform random sampling by using computer-generated points, to lessen researcher bias; and,
- Continue recruitment study in the monitoring sites to determine future trends. Future studies such as the use of settlement plates may yield different results and may provide additional insights in understanding the coral recruitment in Tubbataha.

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CHAPTER 4. SEABIRDS

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OVERVIEW

Objectives

The objectives of the seabird monitoring and inventories at TRNP are:

- Determine developments and trends in seabird populations, the condition of habitats, and emerging threats;
- Identify management actions to respond to and deflect on 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

Period: The field work was delayed by lockdowns caused by the COVID-19 pandemic. The team arrived at the Ranger Station on 26 May. The inventory was conducted from 27 May to 28 May at Bird Islet and on 31 May, from 9:00am to 12 noon (high tide) at South Islet.

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 2020 to August 2021 were evaluated.

Prior to the fieldwork, an online discussion was held between TMO staff and Mr. Arne Jensen on actions taken in response to the 2020 recommendations.

Weather: The weather was dominated by limited wind coming from a southwesterly direction with wind speed ranging from 0 to 3 meters/second. Daily cloud cover averaged to 2/8 or 20%. Daytime temperatures ranged from 30° to 34.5°Celsius.

Seabird inventory team

A total of 19 TMO staff and MPRs headed by the Park Superintendent (PASu) of TRNP, and three local volunteers participated in the seabird inventory (Appendix 1). The team included nine researchers and MPRs from the TMO and WWF Philippines, three MPRs from the Philippine Coast Guard, one from the Philippine Navy, and three from the Municipal Government of Cagayancillo. Due to continued travel restrictions brought about by the COVID-19 pandemic, the avifauna consultant and volunteers from outside of Palawan were unable to join the survey. M/Y Navorca of WWF Philippines transported the team to Tubbataha.

METHODS

The field work followed methods for distance count monitoring and for inventories of breeding seabirds established and used since 2004 (Jensen 2004). For 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 into roost was conducted from 4:30pm to 6:30pm on 28 May at Bird Islet (Appendix 10) and on 31 May at South Islet (Appendix 11). 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 followed the IOC World Bird List Version 11.2 (10 July 2021) and Wild Bird Club of the Philippines Checklist of Birds of the Philippines 2021.

Calculation of land area and vegetative cover

Photos of permanent photo documentation sites in Bird Islet and South Islet were taken (Appendix 13). 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 located and 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 2021 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 *Sula sula* 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 2020; and data gathered by MPRs from June 2020 to August 2021. 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., 2017-2020).

RESULTS

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 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 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: From two separate GPS measurements, it appears the land area has substantially decreased by 27.5% - from 19,297 m^2 in 2020 to 14,009 m^2 in 2021. Compared to the 18,760 m^2 land area in 1981, (Kennedy 1982), the decrease is to about 4,571 m^2 or 25% (See Table 7). The circumference of the islet measured along the high tide line was 513 meters compared to 610 meters in 2020 and 574 meters in 2019, or a decrease by 16%. Erosion was particularly observed at the northeast part of the islet, Figure 27.

The 'Plaza', defined as the central area of the islet dominated by compacted barren soil with very limited vegetation (Figure 29), was measured to be 3,253m^2 representing a very substantial area decline of 44.2% 6.1% (5,826 in 2020). However, the circumference of the 'Plaza' is not demarcated and the substantial regrowth of grasses that had expanded into 'Plaza' by May 2021 may have affected the measurements.

Table 7. Approximate changes in the land area of Bird Islet from 1911 to 2021. Source: Worcester 1911, Kennedy 1982, Heegaard and Jensen 1992, Manamtam 1996, WWF Philippines 2004 and Tubbataha Management Office 2004 to 2021.

Year	Land area (length x width)/ Circumference (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	NW: stable sandbars SE: Stable sandbars	Erosion of NE-part

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 27. Erosion of Bird Islet, May 2021. Photo: Joan Pecson

Figure 28. Land area development of Bird Islet from 1911 to 2021, and projected development until 2091.

Figure 29. Landscape of 'Plaza', Bird Islet, May 2021. Photo: Rowell Alarcon

The land area development over 110 years at Bird Islet since Dean C. Worcester's assessment in June 1911 shows a continued decline from approximately 60,000 square meters to 18,760 square meters in 1981, a time span of 70 years (Kennedy 1981). The average decline in land area per year was 589 square meters. Over the past 40 years, from 1981 to 2021, there has been a further loss to 14,000 square meters or about 199 square 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 28. A visible sign of the decline are the increased areas of eroded cemented calcite guano sandstone that used to be the core area at the center of the islet ('Plaza').

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 30. 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 reclamation of additional marine areas.

Figure 30. Landscape of South Islet, May 2021. Photo: Rowell Alarcon

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 tree vegetation has 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 May 2021 the survival rate of the planted saplings on Bird Islet was very low at 7%. On South Islet, the survival rate was around 50%. The reasons for the low survival rates may be the lack of Phosphorus fertilizer and compost soil application in the planting holes, combined with the absence of shade for the saplings during their first week of growth, Appendix 6.

The local government of Cagayancillo has established a nursery of Abok-abok *Heliotropium foertherianum* and Anuling *Pisonia grandis* (from stem cuttings) in February 2021. The LGU donated about 312 saplings (199 Abok-abok and 113 Anuling), which were brought to TRNP after the May inventory to be planted from June and onwards, during the rainy season. The new saplings were kept under the shade prior to planting, gradually removing the shade to provide more and more sunlight, and constantly watering them.

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. In May 2021, only 23 saplings had survived, Appendix 5 and 13. Among these some have been protected against Red-Footed Booby by building protective bamboo enclosures around the trees, Figure 32.

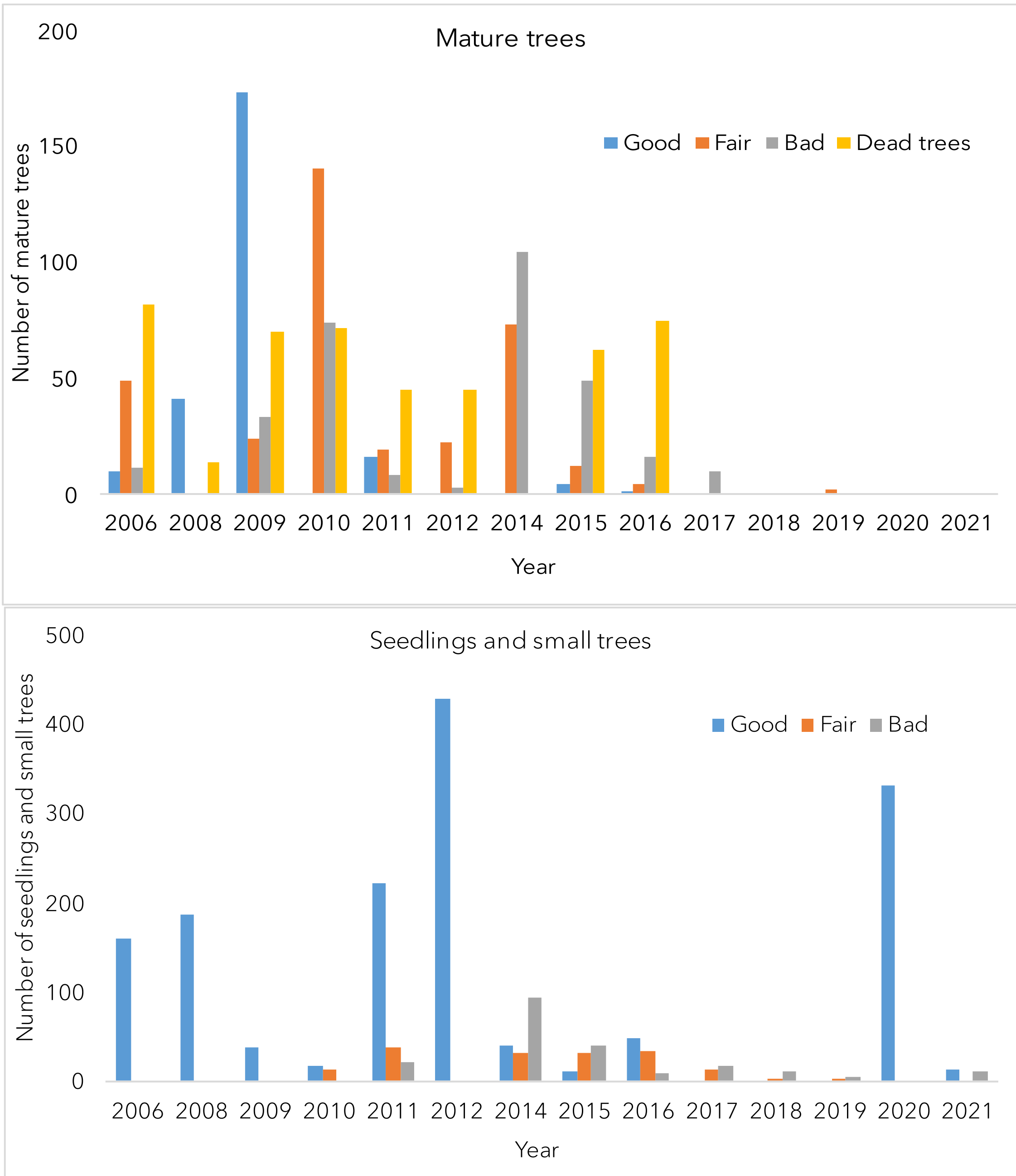

Figure 31. Status of vegetation in Bird Islet from 2006 to 2021.

Figure 32. Planted Anuling protected against Red-footed Booby on Bird Islet by enclosing them in bamboo structures. Photos: Joan Pecson

South Islet: Until 2009, the beach forest comprising of 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 51 saplings were alive in May 2021 (survival rate 50%). In 2021 they represent the vegetation on the islet, together with three stands of Coconut *Cocos nucifera* and patches of grass species (Figure 30, Figure 33, Appendix 5, and Appendix 13).

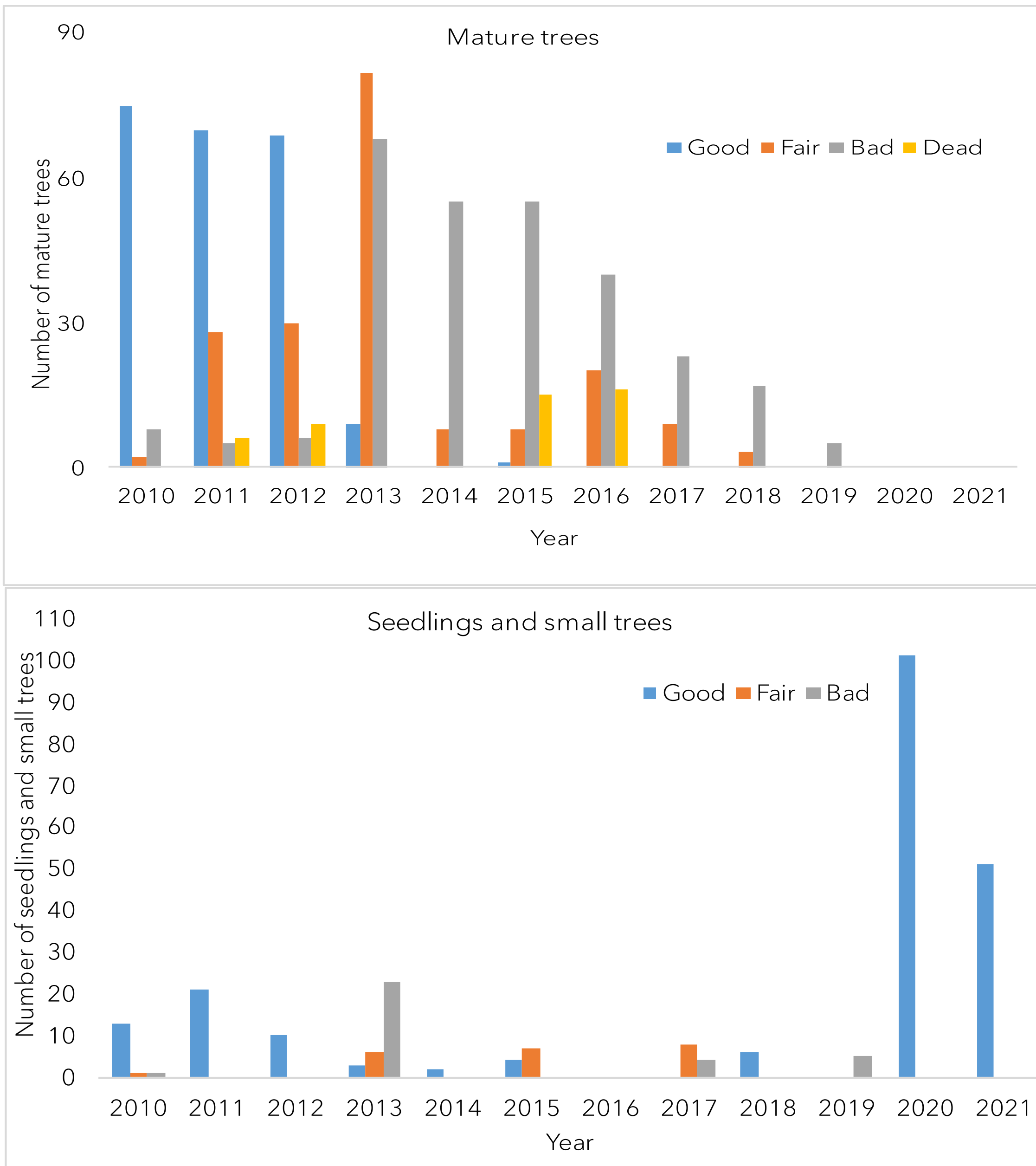

Figure 33. Status of vegetation in South Islet from 2010 to 2021.

Avifauna Inventory Results

A total of 13 species of birds were identified during the inventory (Appendix 9). The total number of all avifauna species, including migratory species, recorded in TRNP over time is 119.

Nine of the observed species can be classified as pelagic seabirds. Of these, seven species breed or attempt to breed 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 Heron *Egretta sacra* breeds annually; the Barred Rail *Gallirallus torquatus* has become an irregular breeder and was not observed during the inventory; and the Eurasian Tree Sparrow *Passer montanus*, which also was not recorded during the inventory, may have become 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 May inventory results therefore represents only the breeding population present during the time of the inventory. The data analysis and conclusions, however, takes into consideration MPR data prior to and after the May 2021 inventory.

In May 2021, a minimum of 28,178 adult individuals of seven breeding seabird species were recorded; 19,889 individuals on Bird Islet and 8,289 individuals on South Islet (Table 8). Bird Islet hosted almost 71% of the breeding population (89 % in 2020) and South Islet 29% of the population (11% in 2020). Compared to the inventory in 2020, the population on Bird Islet decreased by 32%. However, the number of seabirds on South Islet has increased by around 134% compared to the inventory result of May 2020. Since 2020 the population of Black Noddy substantially recovered by around 116%, and Great Crested Tern increased its breeding population by 447%.

Compared to the 2020 inventory, the May 2021 count result is 14% lower (Table 8, Appendix 8). The total of adult seabirds in May 2021 is at the same level as the population in 2013 (28,846 individuals) but about 108% higher than in the baseline year of 1981 (Kennedy 1982). If the sub-population breeding numbers of Sooty Tern is added and the number of Brown Noddy in February 2021 is used, the total would be around 31,344 breeding seabirds.

The difference in result for May 2021 compared to 2020 is mainly due to a decrease in the numbers of Brown Noddy by 48%, and of Great Crested Tern by 25%.

Table 8. Total count numbers of adult resident seabirds present on Bird Islet and South Islet from 27 to 31 May 2021 compared to the inventory result of May 2020.

Species / Number	2020			2021			% change 2019-2020	% change 2020 - 2021
	Bird Islet	South Islet	Total	Bird Islet	South Islet	Total		
Brown Noddy	2,134	1,128	**3,262**	>798	904	**>1,702**	+52	- 48
Black Noddy	1,974	676	**2,650**	1,414	1,462	2) **2,876**	+28	+ 8
Great Crested Tern	16,762	1,048	**17,810**	7,644	5,732	**13,376**	+5	- 25
Sooty Tern	>5,272	0	**> 5,272**	6,000	0	3) **6,000**	+21	+13
Masked Booby	2	0	**2**	2	0	**2**	0	0
Red-footed Booby	430	230	**660**	321	101	**422**	-39	-36
Brown Booby	>2,528	449	**> 2,977**	3,710	90	**3,800**	-5	+28
Total	29,102	3,531	32,633	19,889	8,289	>28,178	+ 18	-14

1) May 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

Review of Marine Park Rangers Data

Since the inventory in May 2020, MPRs made four inventories on Bird Islet and on South Islet in August and November 2020, and in February 2021 and in August 2021. The inventory in November 2020, February 2021 and August 2021 included in-flight counts of booby species.

Until May 2021 the MPRs also conducted 11 monthly distance monitoring counts around Bird Islet and South Islet. No counts were carried out at Jessie Beazley Reef.

The data gathered revealed several important observations (see Table 9 and for details Appendix 7).

Table 9. Selected results of MPR distance and direct counts from June 2020 to April 2021.

Species	Bird Islet	South Islet
Brown Noddy	Overwintering, e.g. 1,050 individuals on 16 January 2021. Part of population has been overwintering since 2017. Early start of breeding season with 1,912 adults with 313 eggs and 67 pulli in February 2021.	Absent from November 2020 to February 2021 which is the normal pattern for this species on this islet. 816 adults with 320 eggs already by 14 February 2021.
Black Noddy	Following distance count data, present throughout the year since 2017, e.g. overwintering with 537 individuals in December 2020 and 750 individuals in January 2021. Started breeding season in February 2021: 1,378 adults with 202 eggs and 21 pulli already on 18 February 2021.	Absent from November 2020 to mid-February 2021. 358 adults with 222 nest and 92 eggs counted on 14 February 2021.
Great Crested Tern	Absent from September 2020 to January 2021 with major breeding influx observed from mid-February. No active breeding before April/May 2021.	Absent from September 2020 to March 2021 No active breeding before April/May 2021.
Sooty Tern	Absent in July to September 2020 where birds again arrived around 20 September. Major breeding (7,500 individuals) from	No breeding population.

	November 2020 to February 2021 where about 2,100 individuals remained together with 987 pulli. Largely absent in March and April 2021 but a new breeding cycle started in May.	
Masked Booby	Two adults present from June 2020 to May 2021. Eggs in August 2020 which produced one pullus observed in November. It grew to juvenile stage but died around 20 January 2021. Since then, two breeding attempts with courtship observed: March resulting in two eggs first reported in April. On 12 August, no eggs and a second courtship observed. On 17 August with one egg, lost around 1 September 2021.	No breeding population.
Red-footed Booby	Continued low number of adults except in February 2021 (almost 800 adults). Numbers of nest, however, remained low and of these empty nests were removed.	Compared to the period 2020 to 2021, an increased number of adult birds and relative high nesting rate, 50%. Empty nests were removed.
Brown Booby	A high number of 3,388 adults actively breeding in August 2020 (1,813 eggs, pulli and juveniles) Similar to November 2017, 2018, and 2019, more than 3,000 adults in November 2021; with 851 nests of which 58% had either eggs, pulli or juveniles. In February 2021 also relatively high number of around 2,00o adults. These were less active in breeding with just about 50 offspring and eggs.	Six pairs breeding from August to and November 2020 and two pairs in February 2021. Previous documented breeding is from 2016, 2019 and 2020.
Eastern Reef Egret	Reported with maximum of six individuals	Maximum eight individuals which is a significantly lower number 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 February
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 5. 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 6. Percentages of in-flight populations of Brown Noddy, Black Noddy, Red-footed Booby and Brown Booby are shown in Appendix 10 (Bird Islet) and Appendix 11 (South Islet). A complete list of avifauna records in May 2021 is found in Appendix 12.

Brown Noddy (Conservation Status - Philippine Red List: Vulnerable): Declining population. Total estimated annual population: 3,300 to 3,500 individuals (over one year, November 2020 to August 2021, the species produced at least 1,550 eggs equivalent to 3,100 adults, Appendix 7).

The breeding population in May, > 1,702 individuals, was 48% lower than in May 2020, and 20% lower than the baseline inventory year in 1981 (Kennedy 1982) (Table 8, Figure 34, and Appendix 8). The population on Bird Islet is declining; on South Islet it is still recovering the man-made habitat changes made in 2019.

Following the data set for Bird Islet where no birds were counted along the shoreline, 798 individuals were recorded in May 2021 compared to 2,134 individuals in 2020 suggesting a substantial decline. It may, however, represent change in phenology with more birds breeding in February (1,912 individuals) than in May (Appendix 7). On South Islet where 904 individuals were counted, the population is lower by 20% compared to 2021 (1,128 individuals).

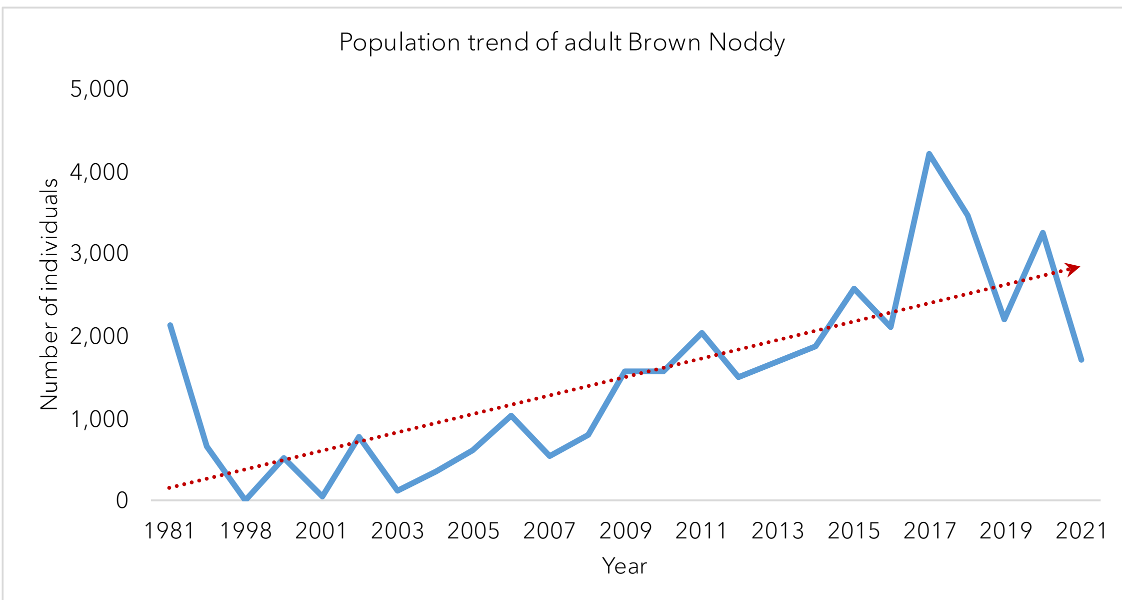

Figure 34. Population trend of adult Brown Noddy from 1981 to 2021.

Similar to February 2018 to 2020, Brown Noddy already bred in February. On 14 February 2021, 2,728 adults had nests containing 633 eggs and 67 pulli. This is an increase by 73% compared to 2020. In May 2021, a low number of 851 nests with 406 pulli and 177 eggs were counted at TRNP (Figure 35, Appendix 7 and Appendix 9). Of the breeding population on Bird Islet, 58% of the adults had nests, on South Islet 77%.

The species is normally absent from TRNP from November to February, but on Bird Islet it has overwintered since 2017, e.g., 1,050 individuals counted on 16 January 2021. No noddies overwintered at South Islet.

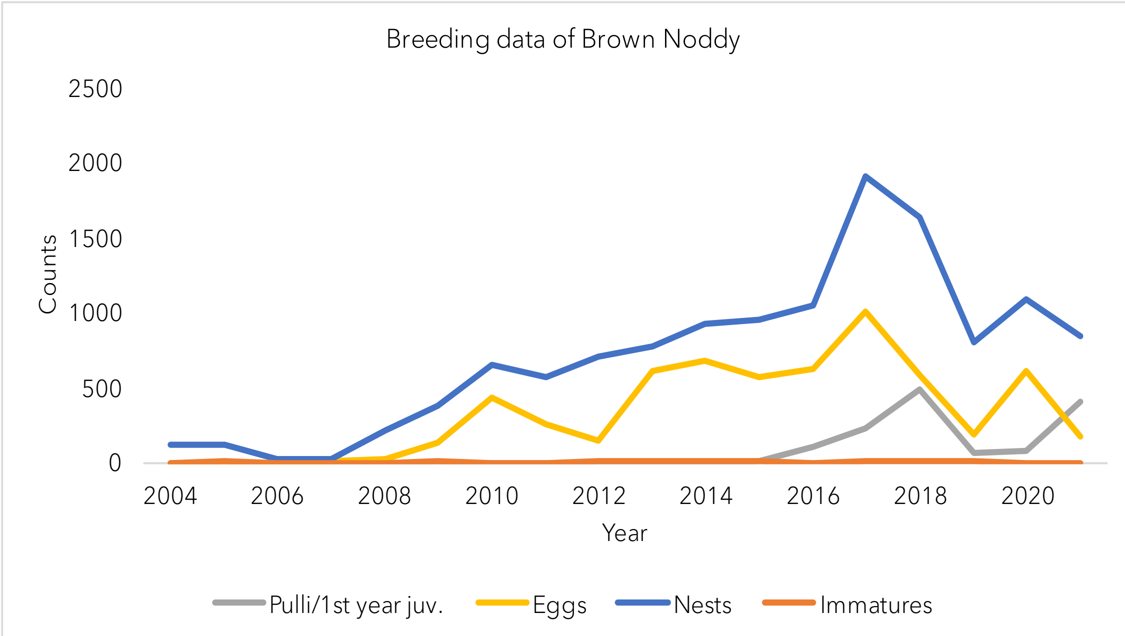

Figure 35. Breeding data of Brown Noddy from 2004 to 2021.

Black Noddy (Conservation Status – Philippine Red List: Endangered): Declining population. Total estimated population: 3,700 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).

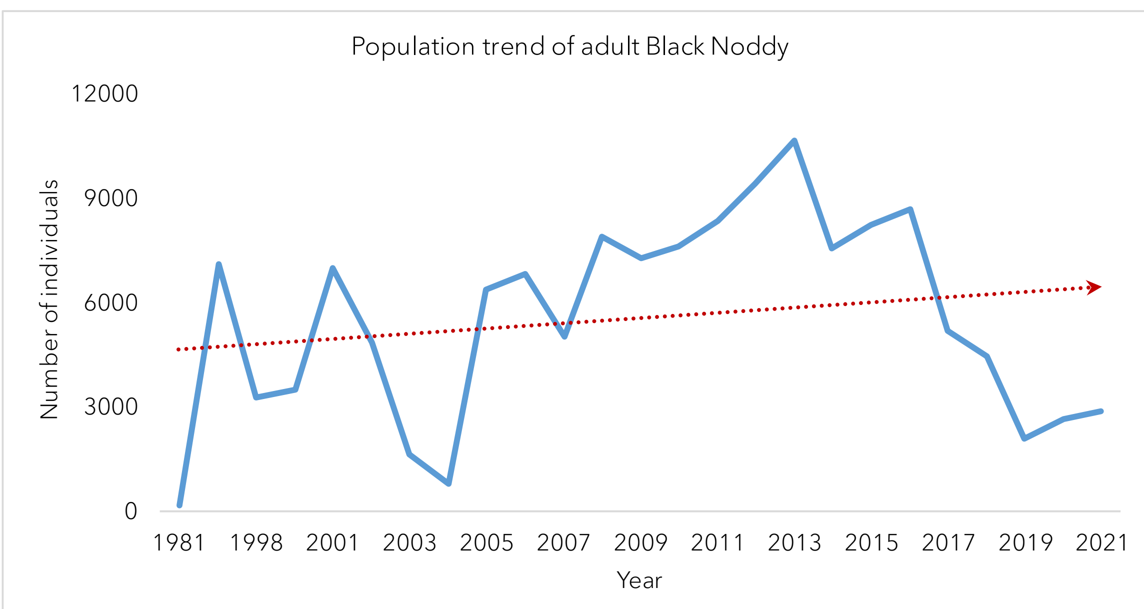

Figure 36. Population trend of adult Black Noddy from 1981 to 2021.

Of the original population of 10,656 adult birds (2013), only about 35% remain, Appendix 7 and Appendix 8. Its population decline is correlated with the loss of its natural breeding habitat over time.

A total of 2,876 adult birds were counted in May 2021 compared to 2,650 individuals in 2020, Table 10. The result suggests an overall population increase by 8% but still representing a decline by 28% on Bird Islet. The population in South Islet increased by 116%. However, it is still lower by 28% compared to 2018, the year before the islet was reconstructed.

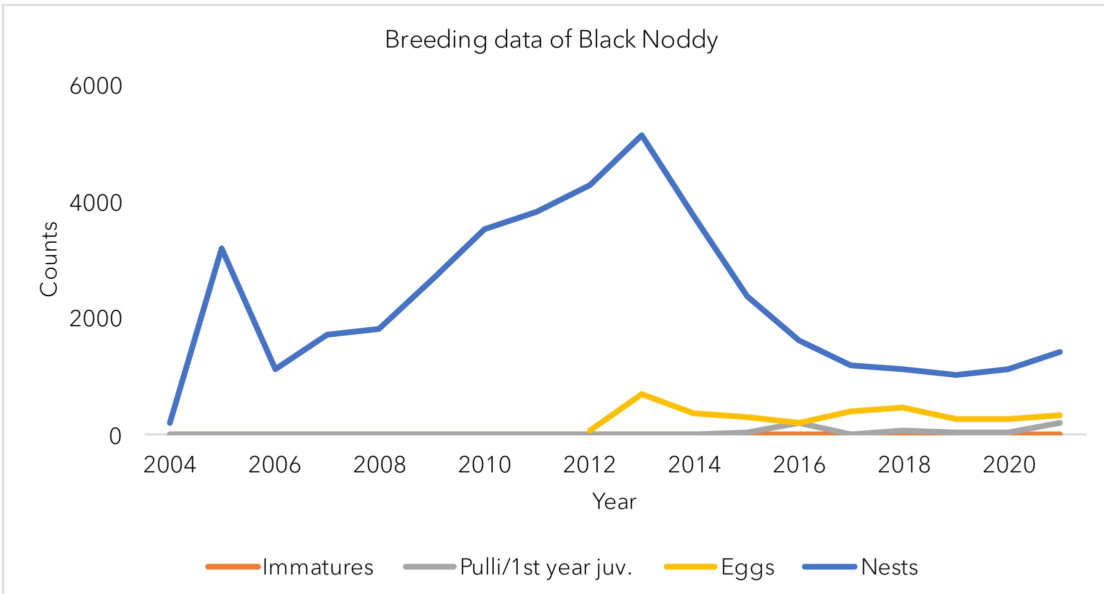

Figure 37. Breeding data of Black Noddy from 2004 to 2021.

The species was present at Bird Islet every month since the May 2020 inventory and overwintering with 537 individuals in December 2020 and 750 individuals in January 2021. At South Islet, it was absent from November 2020 to February 2021. Early breeding, similar to 2017 to 2020, was noted on 14 February 2021 when 1,822 adults had 917 nests (Appendix 7).

Of 1,438 nests found in May 2021, 37% or 530 contained eggs or pulli (27% in 2020). It represents a considerable increase in nest numbers compared to the May 2020 inventory (1,135 nests). The number of breeding birds increased by 8% compared to the inventory in May 2020 (Table 8, Figure 36, Appendix 5). On Bird Islet only about half of the population had nests. Of these only 23% were nests with eggs or offspring.

Together, the February and May 2021 inventory data represents <u>at least about 3,636 adults</u> with 2,355 nests of which 845 nests or 36% had eggs (617 nests), and pulli or juveniles (228 nests).

In comparison, 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 10, Figure 37 and Appendix 9. The average percentage was substantially higher from 2018 to 2021, 22.8 %, in 2021 even as high as 33.6%.

Table 10. Comparison of numbers of adult Black Noddy and numbers of their eggs, pulli and juveniles found from February to November 2013 to 2020, and February to August 2021 at Bird Islet and South Islet.

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

Note: Egg data not collected in 2004 and in 2007, 2009, and 2010. 2011 data are limited to presence or absence of eggs.

Breeding Structures

Except for a maximum of 80 individuals on South Islet attempting to breed on the ground and two successful breeding, and in the absence of its natural breeding habitat, Black Noddy is only breeding on artificial nesting structures; 10 structures on Bird Islet and seven on South Islet. Of these, seven structures are made of PVC plastic nest platforms held together by steel frames, Figure 38. Ten are made of bamboo.

The experimental PVC structures were installed in September 2020 and February 2021. Three designs were used, and two structures were provided with a covering as protection against the northeast monsoon. One protection sheet made of bamboo, however, blew away shortly after its installation.

In Bird Islet, of nine bamboo structures in May 2020, only 5 remained. In September 2020 and in February 2021, five PVC structures were added. In South Islet, five bamboo structures established in May 2020, still stands in May 2021. In September 2020, two PVC structures were added.

Breeding materials (mainly cut grasses, leaves, and seaweeds) were provided in June and August 2020, and in 2021 in May, June, and August.

Given the continued decline in the population of the endemic Black Noddy subspecies, TMO has collected detailed monthly data on the breeding population since June 2020. These data are particularly important in order to understand reproduction rates and the species' preference between the types of artificial breeding structures (bamboo and PVC plastic). The dataset still has to be analyzed in detail but there are some initial trends that are very important to have in mind in improving the conservation management.

On South Islet, from September 2020 to August 2021, there was a very significant difference in the use of the PVC structures and the bamboo structures with a clear preference by the birds for structures made of bamboo, Table 11. As an average per structure, only 5.5% of the birds used the PVC structures. The highest average number was 57 individuals in August 2021 compared to 600 individuals found at bamboo structures. There are only datasets for three months from Bird Islet but they show the same trend, a minority or 28.5% of the birds showed preference for the PVC structures. However, it must be considered that the first PVC structures were introduced only in 2019 while the bamboo structures were installed in 2016.

The noddies had 107 nests at South Islet and 479 nests at Bird Islet placed in the PVC structures. In these nests, they only produced a total of 103 eggs and 31 pulli and juveniles equivalent to 22.8% of reproductive nests. The eggs per structure averaged 15 eggs, highest at Bird Islet. The average of pulli and juveniles was below five birds per structure (22.8%).

Figure 38. PVC breeding structure for Black Noddy in Bird Islet, May 2021. Photo: Rowell Alarcon

In terms of preferences of structures, among the bamboo structures at Bird Islet, Structure number 3 and 4 had the highest attendance by the adult birds followed by Structure number 2. Out of the five PVC structures, the hexagon-designed structure (N-NS5) appeared to be the most preferred. At South Islet, there was no preference among the two PVC structures installed. Among the bamboo structures, however, Structure number 5 appeared to be highly preferred by the birds.

Table 11. Average numbers of adult Black Noddy per nest structures at South Islet and Bird Islet from September 2020 to August 2021.

South Islet												
Adults	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Aug	Average
PVC	0	19	0	0	2	18	42	7	25	51	57	20
Bamboo	246	386	0	0	230	380	393	479	492	549	600	341
Total	246	40	0	0	232	398	435	486	517	600	657	
Bird Islet												

PVC			19			?			43		83	48
Bamboo			116			197			121		124	120
Total			125						164		207	

Despite the initial 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. The 2021 population of 3,636 adults, from February to August 2021, only produced 1,223 eggs, pulli and juveniles. As mortalities of eggs and hatchlings are known to occur, especially during periods with strong winds or when exposed to cold or heat in the nest, not all of these may have survived to fledging stage (Gauger 1999). Furthermore, mortality rates among juvenile terns may also be high. Although it is unknown for Black Noddy, mortality rates, e.g. of juvenile Roseate Tern *Sterna dougallii* is about 44% (Montecelli et al., 2008).

An estimate of the survival rate of the 2021 eggs and pulli at around 70%, will mean only 856 juveniles. If the survival rate of these after two years is only 60%, it would mean that by 2023 there would only be about 514 individuals that have reached breeding maturity. Hence, the population will continue to decline.

Great Crested Tern (Conservation Status - Philippine Red List: Vulnerable): Deceasing population. Total estimated population: 14,000 adult individuals. For the first time since 2014 there is a population decrease. Compared to May 2020 and 2021 by 25% to 13,376 individuals or around the same numbers as in 2016 (Table 8, Figure 39, Appendix 8). The result for May 2021 is, however, about six times higher than the baseline count of 2,264 individuals in 1981 (Kennedy 1982).

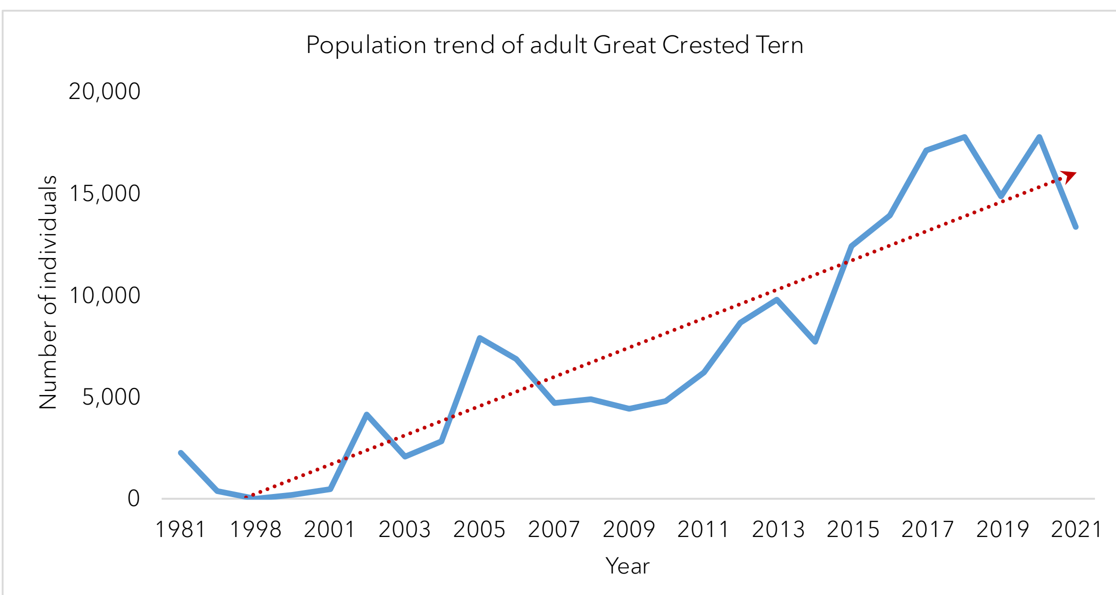

Figure 39. Population trend of adult Great Crested Tern from 1981 to 2021.

Adult birds were present at Bird Islet from mid-February 2021 and at South Islet from mid-March 2021 (Appendix 7). At the end of May 2021, 4,447 eggs and 2,292 eggs were counted (Figure 40, Appendix 9). On South Islet, the species had increased its breeding numbers by 450% to 5,732 individuals since May 2020 (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
Adults	2,264	135	50	560	64	1,026	5,732
Eggs	1,132	+	12	145	7	512	1,790
Pulli	0	0	0	25	19	2	872
Juveniles	0	0	0	0	0	0	256

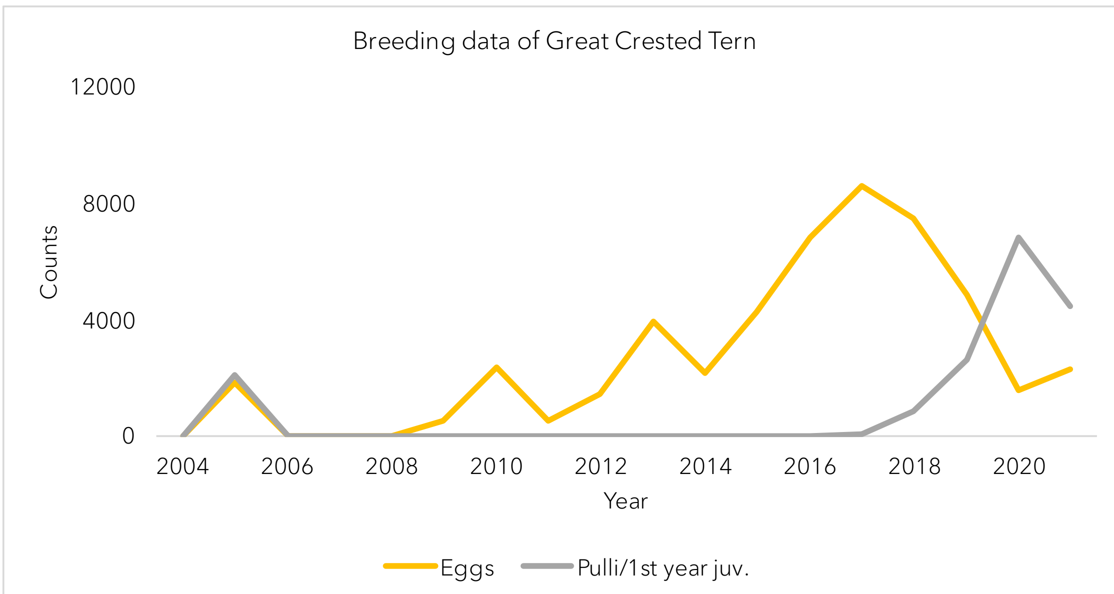

Figure 40. Breeding data of Great Crested Tern from 2004 to 2021.

Sooty Tern (Conservation Status – Philippine Red List: Vulnerable): Stable population. Total estimated population: 12,000 adults.

The breeding population at Bird Islet, estimated at night in May 2021, to be 6,000 individuals, is 18% higher than in the baseline inventory year of 1981, and higher by 14% compared to the May 2020, Table 8, Figure 41 and Appendix 8. The species does not breed on South Islet.

Sooty Terns were present from the end September 2020 to February 2021, absent in March and April 2021 and again present from May to August 2021.

MPR data shows that at least 9,000 adults were breeding in January 2021 (16 Feb: 4,243 eggs and 288 pulli). The May inventory revealed that all February offspring had left and the population was in the early stage of breeding as indicated by predominantly night presence and just 593 eggs laid. It suggests that the population was in the early stage of the egg-laying which can extend to more than one month.

The total adult May population could not be accurately counted as they were in the night courtship phase known as 'night clubbing' (Reynolds et al., 2014). MPR data from 12 August, however, shows that 9,460 birds had around 4,110 pulli and juveniles indicating egg-laying may have started late in May and ended in July 2021.

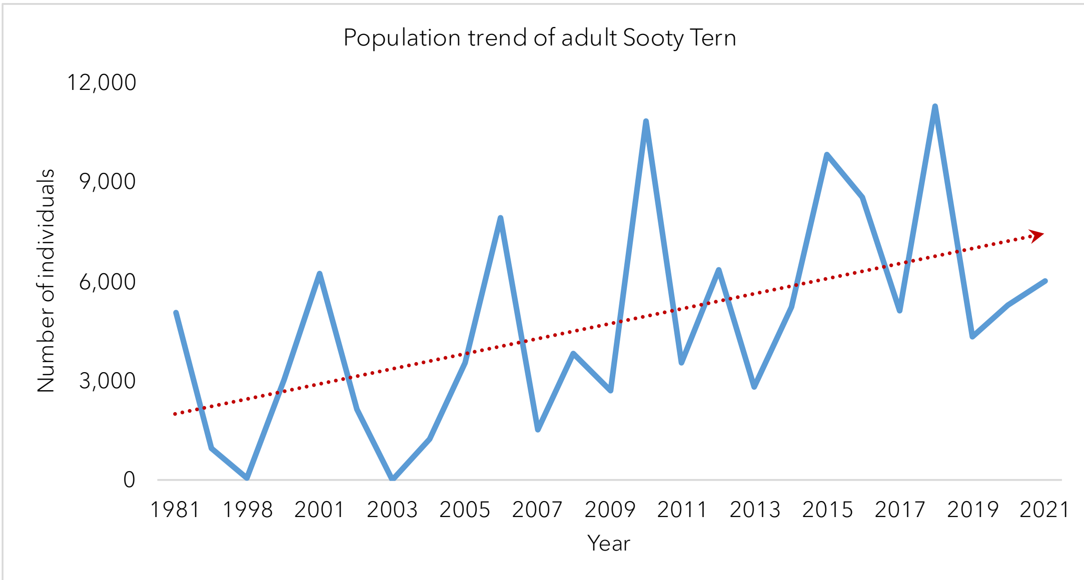

Figure 41. Population trend of adult Sooty Tern from 1981 to 2021.

Breeding of the species in successive periods is not documented from the Philippines. TMO data from 2017 to 2021 indicate that the Sooty Tern either has a sub-annual breeding cycle or has two separate sub-populations with breeding cycles that tend to shift over time, e.g., one population bred from November 2020 to February 2021 and another population from May to August 2021, Table 13. The shift in the breeding cycles may perhaps be impacted by irregular periodic variation in winds and sea surface temperatures caused by El Niño–Southern Oscillation (Pagliawan 2013).

If the terns breed twice a year, then sub-annual breeding intervals may translate to breeding peaks at different months of the year as suggested in Table 13. Sub-population breeding cycles could also translate into shortened courtship periods of around two months, e.g., in 2017, 2020 and 2021, when it matched the different breeding intervals of the birds. MPR distance counts and inventory datasets since 2004, though, needs to be analyzed to reach conclusions on intervals of breeding and the numbers of birds per breeding cycle over time.

Table 13. Breeding months of Sooty Tern 2017 to 2021. Egg laying periods indicate a sub-annual breeding cycle or breeding cycles composed of two sub-populations (yellow and red font).

	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				

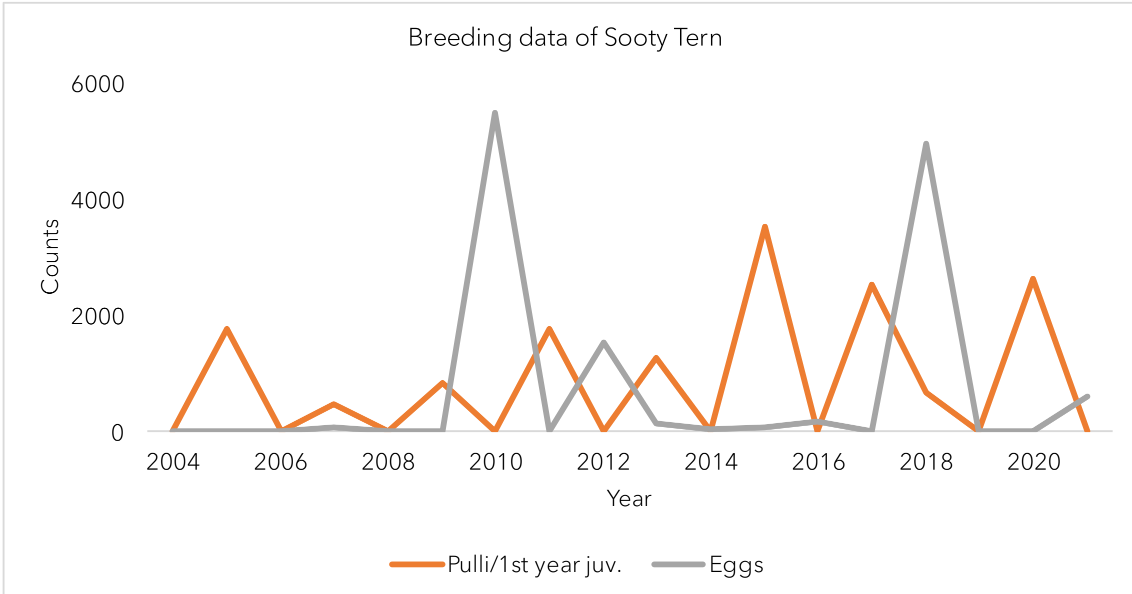

Figure 42. Breeding data of Sooty Tern from 2004 to 2021.

Masked Booby (Conservation Status - Philippine Red List: Critically Endangered): MPR records show the species was present with two adults at Bird Islet within the colony of Brown Booby at the 'Plaza" from June 2020 to August 2021. Noted with eggs in August 2020 which produced one pullus observed in November. It grew to juvenile stage (6 months) but was found dead on 20 January 2021. Since then, two breeding attempts with courtship were observed: The first in March resulting in two eggs reported in April and in June 2021. On 12 August, however, the pair had no eggs and a second courtship

Figure 43. Masked Booby with dead offspring, January 2021. Photo: Segundo Conales

was observed. On 17 August they had one egg. This is the fifth time that the pair laid eggs.

Red-footed Booby (Conservation Status - Philippine Red List: Least Concern): Declining population. Total estimated population: 980 adult individuals. The adult population in May 2021 was 422 individuals, lower by 36% compared to the inventory in May 2020 (660 adult individuals), or by 58% compared to 2019 (Table 8, Figure 44 and Appendix 8). Compared to the baseline inventory year in 2004 (2,435 adult individuals), the population is lower by 83%. Except for February 2021 when about 980 birds were present, MPR data shows that since June 2020 the number of adults has consistently been falling from around 750 individuals to around 500 in August 2021. Correspondingly, the number of nests is also relatively low although nest numbers in May 2021 was higher than in 2020 (Figure 45 and Appendix 9). The declining population is a result of the reduced breeding habitat.

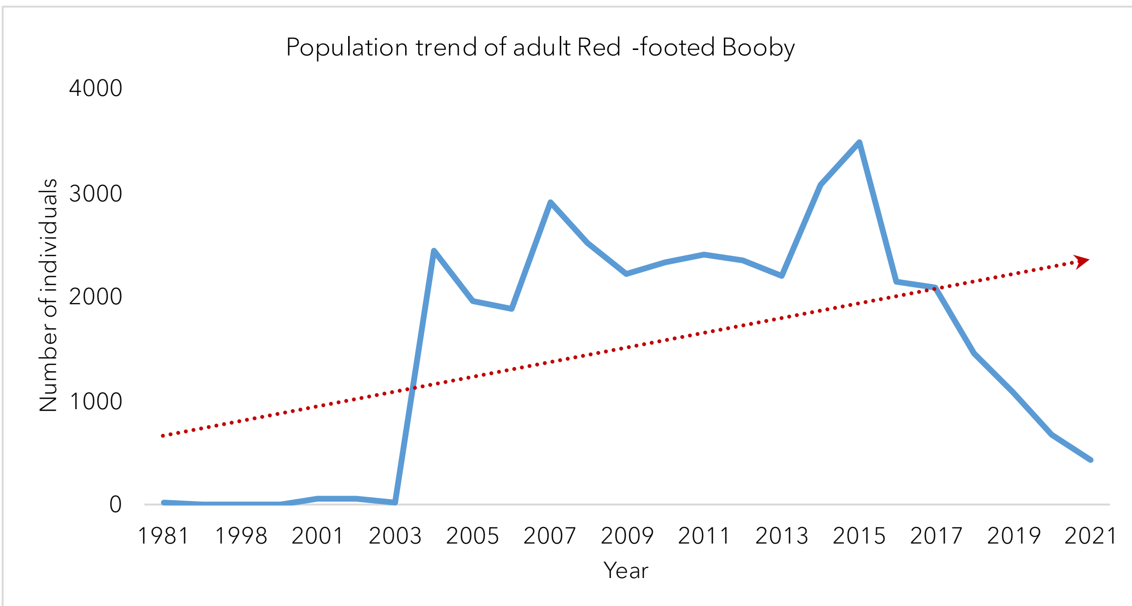

Figure 44. Population trend of adult Red-footed Booby from 1981 to 2021.

Only 26% of the population at Bird Islet had nests while 61% of the birds at South Islet were breeding. In reproductive terms, within one year from August 2020 to 2021 the species produced just 36 pulli and juveniles, and laid around 190 eggs. A total of 65 pairs, however, were prevented from egg laying by nest removal in May 2021.

Of the adult population recorded in May 2021, 76% were found on Bird Islet, an increase by 11% compared to May 2020 (Table 8). On South Islet, the population was 56% lower than in May 2020.

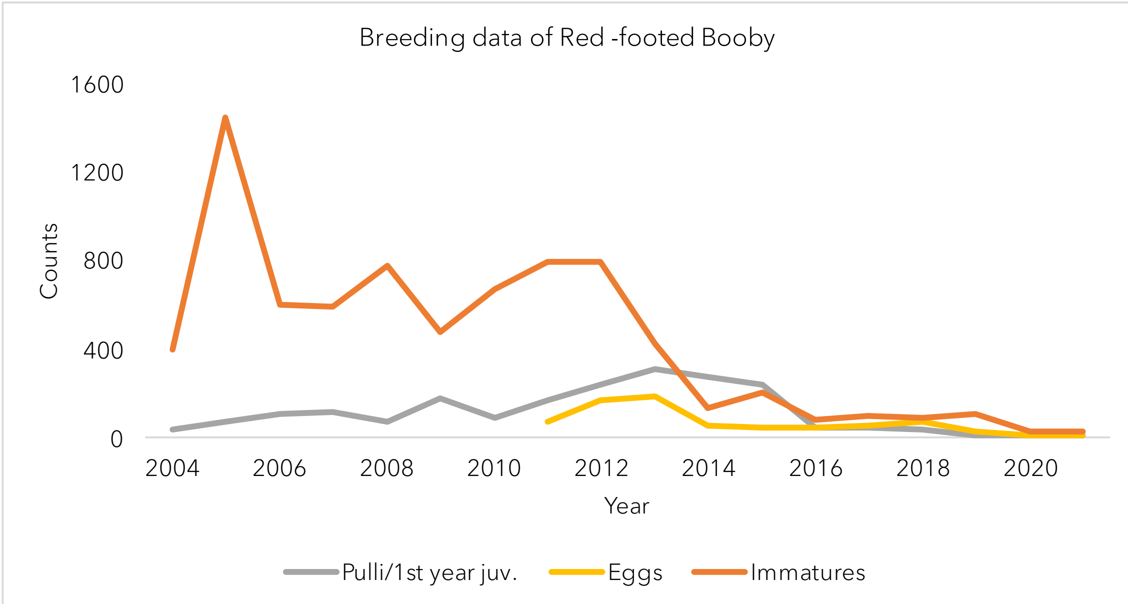

Figure 45. Breeding data of Red-footed Booby from 2004 to 2021.

Brown Booby (Conservation Status - Philippine Red List: Endangered): Increasing population. Total estimated population: <u>4,500 adult individuals</u>. Based on direct counts, the population is now at same level as in the baseline inventory year of 1981 (3,768 adults), Appendix 8. However, MPR data from 12 August 2021, shows 4,484 adults which is 19% higher than in 1981.

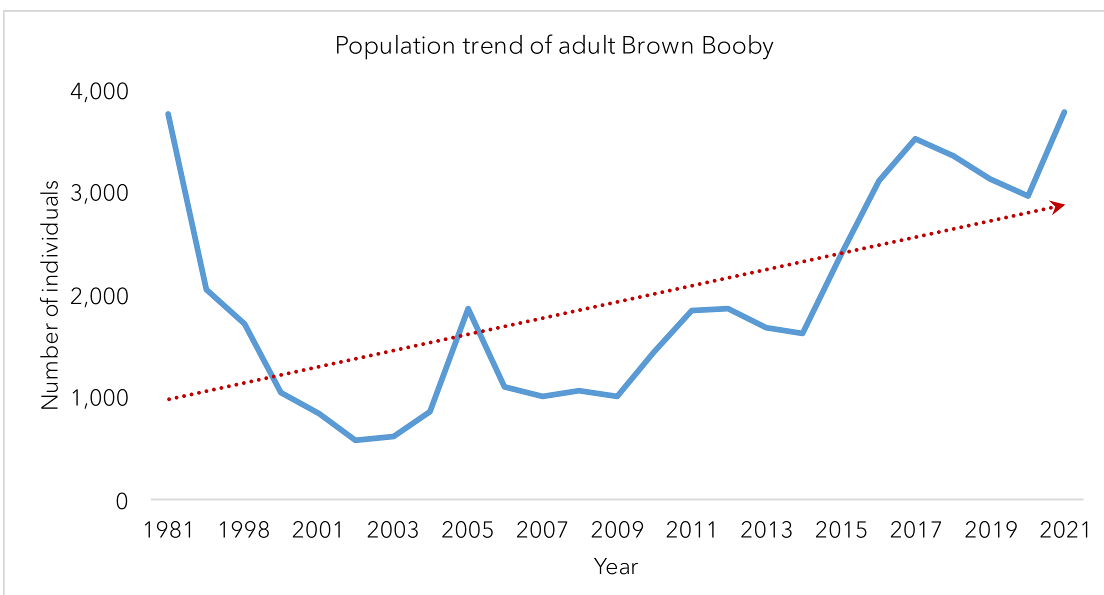

Figure 46. Population trend of adult Brown Booby from 1981 to 2021.

In 1911 Dean C. Worcester, the first avian explorer to visit the Tubbataha Atolls, found the Brown Booby breeding in "enormous numbers", Figure 47. He also passed by South Islet and landed on the now submerged Black Rock Islet and found both islets "covered" by breeding boobies (Worcester 1911).

Figure 47. Segment of the breeding population of Brown Booby on Bird islet, 24 June 1911. Photo: D.C.Worcester.

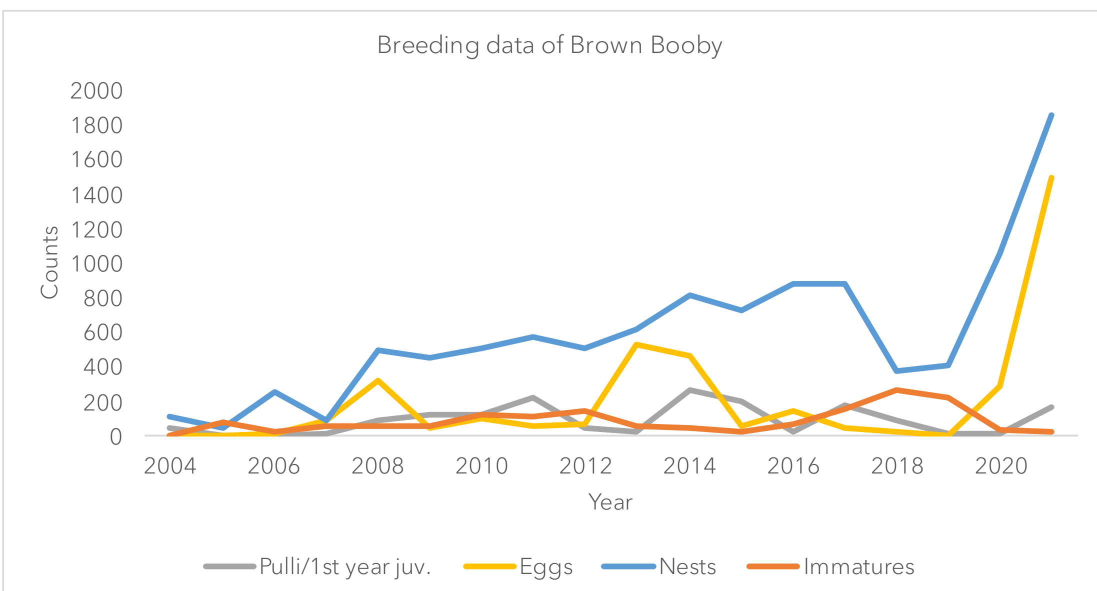

Figure 48. Breeding data of Brown Booby from 2004 to 2021.

High number of adults, > 3,000, were observed by the MPRs during their inventories in August and November 2020, and as high as 4,484 adults on 12 August 2021. The total counted in May 2021, 3,800 individuals represent an increase by 28% compared to the May inventory in 2020 (Table 8, Figure 46 and Appendix 8).

The 1,855 nests found in May 2021 represents an extraordinary increase by 75% compared to the result in May 2020 (Figure 48, Appendix 9). Of these nests, 1,492 contained eggs and 172 pulli and juveniles representing an active breeding rate of about 60%. In comparison, in August 2021, MPRs noted 2,192 nests of which 75% had either eggs or offspring.

On South Islet, of 90 adult birds, six pairs had nests. Nesting was also observed by the MPRs in 2020 (August and November) and in 2021 in February and August.

<u>Banded birds:</u> In November 2020 and in May and August 2021, a total of 107 Brown Boobies, color banded and steel ringed between 2006 to 2009 on Bird Islet, had their bands and rings read. Of these birds, 57 were banded as adults and 50 individuals as pulli, Table 14. The birds banded as pulli are now from 12 to 15 years old, or on average about half the lifespan of the species, which can reach the age of 25 years. Adults banded in 2006 are at least 19 years old and have lived about 75% of their lifespan (Hennicke et al., 2012).

Table 14. Results of ring readings of Brown Booby on Bird Islet in November 2020 and May and August 2021.

Year of Banding	Pulli	Adult	Total
2006	1	5	6
2007	21	27	48
2008	24	12	36
2009	4	13	17
Total	50	57	107

Pacific Reef Heron: The total adult population in May 2020 may have been overlooked since the TMO team only noted three individuals at Bird Islet and four birds at South Islet. This is below the average numbers 15 individuals counted from 2016 to 2019. In March 2021, though, MPRs observed 14 individuals. No nests were reported until September 2021.

Mortalities

The total number of carcasses were not recorded but was estimated to be around 10 pulli of either Red-footed Booby or Brown Booby. The condition of the specimens was in advanced decomposition. Other than these, a wounded Black Noddy, banded at Bird Islet in 2008, landed on the research vessel on 3 June. It had an infected abdominal wound which exposed its liver, as well as a fractured foot. The part of the liver at the wound was whitish to yellowish in color. The other organs were intact, and no other discoloration was observed. The stomach showed no traces of food items.

RECOMMENDATIONS

Habitats

1. Restoration of Beach Forest: Despite considerable effort, the reforestation is facing substantial problems in the form of very low survival rate of planted saplings, on Bird Islet as low as 7%. As success is vital for the long-term survival of the declining and threatened population of Black Noddy, it is recommended not to continue reforestation unless advice from experienced forest experts is taken into consideration. Appendix 6 outlines a set of recommendations to be piloted. It is further recommended to monitor the survival rate of saplings per species planted and that planting continue to be limited to areas where the former beach forest was located on both islets.

2. Habitat restoration of South Islet: Ensure a wide enough sandy beach habitat free of vegetation enabling Great Crested Tern and Brown Booby to breed on the islet.

Land area at Bird Islet

3. As erosion continues to be a serious long-term problem, it is advised that areas in Bird Islet that are eroding be mapped out. If erosion continues in the next two years, by 2024 start securing and even expanding the land area using best practice nature-based solutions including beach sand nourishment. Sand deposits may have to be pumped in from sandbars elsewhere along the coral crest.

Species

4. Black Noddy: To play safe, and as the pilot using PVC plastic breeding option so far have had very limited success, continue to install bamboo structures until it is documented that the species is breeding successfully and in sufficient numbers at the PVC plastic structurers. Overall, there is a need to maintain about 10 structures per islet with sufficient breeding materials to provide at least 4,000 noddies with breeding opportunities.

5. Contrary to beach forest, 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.

6. Satellite tracking devices have become very light weight. Use of these devices cause the least disturbance on the population and can provide important information for the management of the species. It is recommended to include in fund-raising activities a budget for the purchase of satellite tracking devices, including the cost of capacity-building of TMO, installation, data analysis, and results dissemination.

7. It is further recommended that previously banded Black Noddy be recaptured and ring numbers read for analysis.

8. Red-footed Booby: Where the species places nests in the artificial breeding structures or on plant protection devices, it is advised that MPRs remove these nest regularly. Data on the number of nests removed should be made part of the MPRs reporting to TMO.

9. Brown Booby. There are substantial data on the readings of the color and steel bands applied on the Brown Booby from 2006 to 2009. It is recommended that these data be analyzed.

Methodology

10. Recommended improvements on data collection and reporting includes:

a) Data on empty nests to be separated from data on nests with eggs, pulli and juveniles;

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

c) Immatures (birds on 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, there is no need to try to report them.

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CHAPTER 5. WATER QUALITY

OVERVIEW

Water quality monitoring 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 in general water quality, and identify the possible sources and impacts of these changes.

Twenty (20) monitoring stations were established in TRNP based on location, anthropogenic activities, and monitoring sites for other components. 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. Some water quality parameters are determine on-site using multiparameter digital water quality meter. Water samples were also collected and brought to the environmental laboratory for analysis.

This is the second water quality monitoring conducted in TRNP since the COVID-19 pandemic. This report presents the trends in water quality during pre-pandemic period, from 2014 to 2017, and pandemic times in 2020 and 2021.

METHODS

Water Quality Monitoring Stations

Water quality monitoring was conducted on 30 June to 1 July 2021 by the staff of Tubbataha Management Office. Seawater samples were collected from twenty (20) monitoring stations located in North Atoll, South Atoll and Jessie Beazley Reef (Figure 49).

These stations were identified and established in 2014. As monitoring 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 by moving some stations closer to the dive sites and to the monitoring stations for fish and benthos components. In 2021, adjustments were made to three stations, WQ07 was moved closer to South Islet, WQ13 was moved closer to Bird Islet, and WQ17 was moved to the Ranger Station. Table 15 presents the location and description of the water quality monitoring sites in TRNP.

Figure 49. Water quality monitoring stations in TRNP, June 2021.

Table 15. Coordinates and site description of water quality monitoring stations in TRNP, June 2021.

Site	Latitude	Longitude	Site description
South Atoll			
WQ01	N8.80850	E119.81907	Fish and benthos monitoring station 4A; top of reef; dive site
WQ02	N8.76090	E119.81323	top of the reef; not frequently visited by divers
WQ03	N8.74000	E119.81985	top of the reef; near mooring buoy
WQ04	N8.75591	E119.82881	Fish and benthos monitoring station 3A; top of reef; dive site
WQ05	N8.79677	E119.82043	original water quality site; inside lagoon; off limits to tourists
WQ06	N8.78020	E119.82298	original water quality site; inside lagoon; off limits to tourists
WQ07	N8.74861	E119.81894	South Islet; off limits to tourists
WQ09	N8.85174	E119.93661	Min Ping Yu grounding site; shallow reef, not visited by divers
North Atoll			
WQ10	N8.89222	E119.90623	Fish and benthos monitoring station 2A; top of reef; dive site
WQ11	N8.94423	E119.96908	top of the reef; dive site
WQ12	N8.93532	E120.01302	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	N8.90721	E119.95018	original water quality site; inside lagoon; off limits to tourists
WQ15	N8.89108	E119.94903	original water quality site; inside lagoon; off limits to tourists
WQ16	N8.88924	E119.97104	original water quality site; inside lagoon; off limits to tourists
WQ17	N8.85177	E119.91705	Ranger Station; lagoon, off limits to tourists
Jessie Beazley Reef			
WQ19	N9.04393	E119.81599	Fish and benthos monitoring station JB Reef; top of reef; dive site
Buffer Zone			
WQ08	N8.71731	E119.88983	original water quality site; buffer zone
WQ18	N8.84606	E120.02347	original water quality site; buffer zone; deep waters
WQ20	N9.09828	E119.78667	original water quality site; buffer zone; deep waters

Collection of Water Samples

The weather was calm and sunny during the collection of samples. Grab water samples were taken from each station in three separate containers: wide mouth glass with 1 liter capacity for oil and grease, 2.5-liter capacity-HDPE for physico-chemical 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.

Samples were collected by holding the 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 environmental laboratories for analysis. Parameters such as total suspended solids and oil and grease were analyzed in the DOST Laboratory while color, phosphates, nitrates, and total and fecal coliform were analyzed at PCSD Environmental Laboratory.

Water Quality Parameters and Guidelines

The water quality monitoring focused on seven (7) parameters as enumerated in Table 16. Appendix 14 shows the complete list and general description of parameters analyzed in TRNP since 2014.

Table 16. Water quality parameters monitored in Tubbataha Reef Natural Park.

Parameter	Method of Analysis
Total Suspended Solids (TSS)	Gravimetric dried at 103 - 105^{0}C
Color	Visual Comparison Method (Platinum Cobalt Scale)
Nitrogen as Nitrates	Colorimetric using Hach Nitrate Powder Pillows
Phosphorus as Phosphates	Colorimetric using Hach Phosphate Powder Pillows
Oil and Grease (O&G)	Gravimetric Method (Petroleum Ether Extraction)
Total Coliform (TC)	Multiple Tube Fermentation Technique
Fecal Coliform (FC)	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 17). 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 216-08).

Table 17. Water quality guidelines for primary parameters for Class SA.

Parameters	Unit	DAO 2016-08	DAO 2021-19
Color	PCU	5	-
Total Suspended Solids	mg/L	25	-
Oil and Grease	mg/L	1	-
Fecal Coliform	MPN/100mL	<1.1	20
Phosphates	mg/L	0.1	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).

RESULTS

2021 General Water Quality

This activity marked the second water quality monitoring in TRNP during the COVID-19 pandemic, when the park was closed to tourism since April 2020.

Table 18 shows the concentration of physico-chemical and microbiological parameters in all WQ monitoring stations in TRNP vis-à-vis the water quality guideline for Class SA based on DAO 2016-08 and DAO 2021-19.

Most of the parameters measured are within the WQ guidelines. The phosphates levels, however, exceeded 0.1 mg/L (DAO 2016-08) in six (6) water quality monitoring stations. The concentration of total coliform, fecal coliform, and oil and grease showed the lowest values measured for the first time in all stations in TRNP.

Table 18 shows the results of the analysis of water samples taken from TRNP in 2021. The measured color of seawater surrounding TRNP ranged from <5 to 5 PCU while the total suspended solids ranged from <3.7 mg/L (WQ12) to 18 mg/L (WQ08). While exceeding in previous years, the oil and grease in all WQ stations was below the minimum detection limit of <1 mg/L. Similarly, fecal coliform concentration was <1.8 MPN/100 mL except WQ13 (Bird Islet) at 2 MPN/100 mL but still within the WQ guidelines of 20 MPN/100 mL. The improved water quality in TRNP, especially in fecal coliform and oil and grease can be expected as tourism plummeted since April 2020.

Table 18. Results of water quality monitoring conducted in TRNP on 30 June 2021.

WQ Monitoring Stations	Color, PCU	Phosphates mg/L	Nitrates mg/L	Total Coliform MPN/ 100mL	Fecal Coliform MPN/100 mL	Total Suspended Solids mg/L	Oil and Grease mg/L
South Atoll							
WQ01	5	1.2901	0.7908	79	<1.8	10	<1
WQ02	<5	0.1534	0.8218	<1.8	<1.8	10	<1
WQ03	5	0.0379	1.2502	<1.8	<1.8	10	<1
WQ04	5	0.0558	0.4504	<1.8	<1.8	5	<1
WQ05	5	0.0614	0.3933	<1.8	<1.8	15	<1
WQ06	5	0	0.4186	2	<1.8	11	<1
WQ07	5	0.0469	0.5631	7.8	<1.8	9	<1
North Atoll							
WQ09	5	0.0237	0.3084	<1.8	<1.8	7	<1
WQ10	5	0.1315	0.3607	<1.8	<1.8	10	<1
WQ11	5	0.0267	0.3998	<1.8	<1.8	15	<1
WQ12	5	0.4688	1.3694	<1.8	<1.8	<3.7	<1
WQ13	5	0.082	0.2791	13	2	13	<1
WQ14	5	0.0509	0.3337	2	<1.8	9	<1

WQ15	5	0.0369	0.6161	<1.8	<1.8	8	<1
WQ16	5	1.0515	0.5312	<1.8	<1.8	12	<1
WQ17	5	0.0963	0.5182	<1.8	<1.8	6	<1
Jessie Beazley Reef							
WQ19	5	0.0267	0.6675	<1.8	<1.8	9	<1
Buffer Zone							
WQ08	5	0.1649	0.51	<1.8	<1.8	18	<1
WQ18	5	0.0371	1.0503	<1.8	<1.8	13	<1
WQ20	5	0.024	0.6488	<1.8	<1.8	11	<1
WQG*	5	0.1	10	none	20	25	1

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

The results in WQ17 can be used as the baseline data of water quality in the only inhabited sandbar in Tubbataha. All the parameters in WQ17 were within the WQG for Class SA.

All parameters measured during the 2021 water quality monitoring were within the water quality guidelines for Class SA, except for the phosphates which exceeded the 0.1 mg/L WQG in six monitoring stations. Figure 50 shows the concentration of phosphates and nitrates in all WQ monitoring stations in TRNP.

Trends of Water Quality of TRNP

Tourism in TRNP has been interrupted for more than a year since the onset of the COVID-19 pandemic in March 2020. Only researchers and park rangers were able to visit and stay in the park.

The trends in water quality conducted during the pre-pandemic period from 2014 to 2017, and during the pandemic in 2020 and 2021 are shown in the succeeding discussion. The monitoring sites are divided into four (4) groups based on the location, South Atoll, North Atoll, Jessie Beazley Reef, and the buffer zone.

There were fourteen (14) parameters monitored in TRNP, both measured *in situ* and analyzed in the laboratory since 2014. However, due to the limitations on multiparameter water quality meter for *in situ* measurement and scope of the laboratory, the parameters were reduced to eight (8) in 2021. These still account for important parameters that represent the aesthetic water quality (color and total suspended solids), nutrients (phosphates and nitrates), presence of oil (oil and grease), and microbiological aspects (total and fecal coliform) of waters in TRNP.

The subsequent discussion is focused on nine (9) parameters from 2014 to 2021 in comparison to the water quality guidelines for Class SA (DAO 2016-08 and DAO 2021-19).

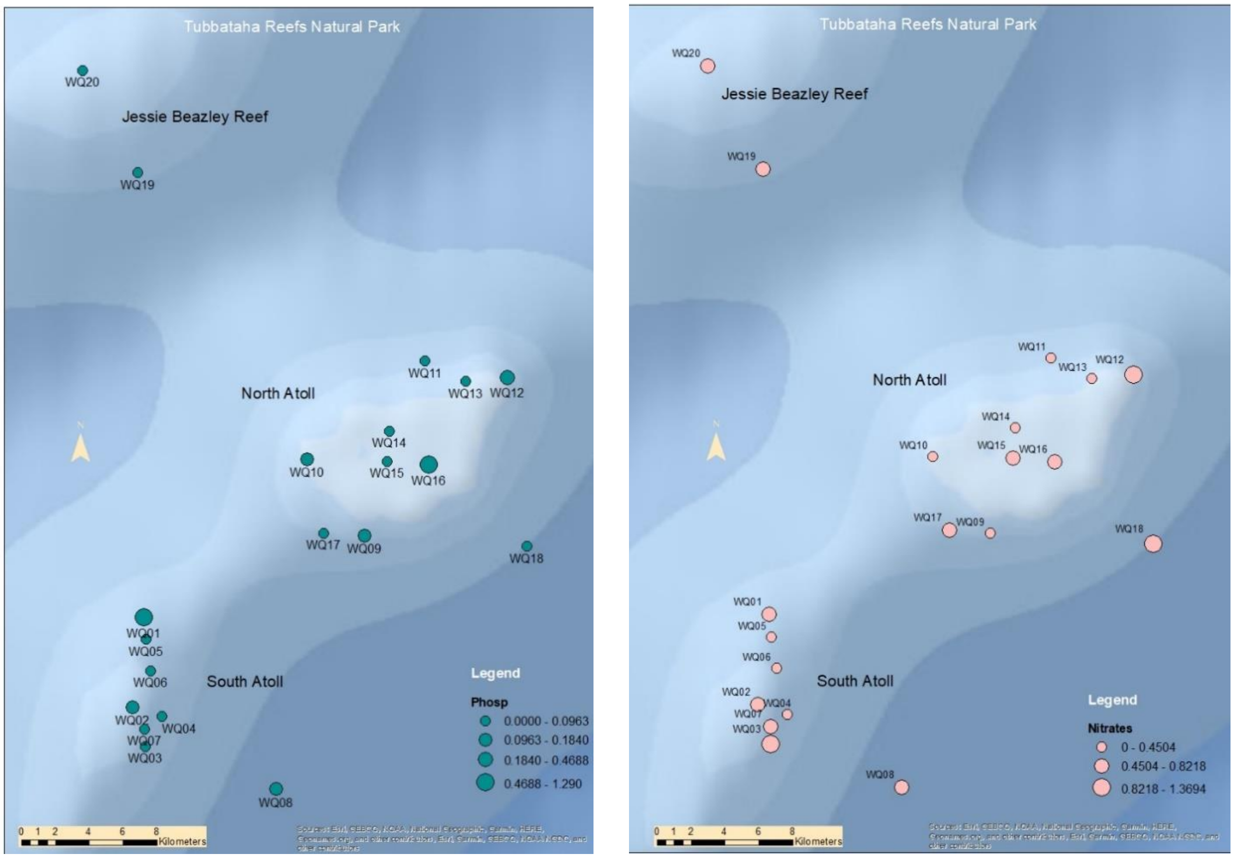

Figure 50. Concentration of phosphates (left) and nitrates (right) in water quality monitoring station in TRNP in 2021.

South Atoll

The South Atoll consists of shallow platforms that surround a sandy lagoon, with a small islet that serves as roosting and nesting site for seabirds. There are seven (7) water quality stations in the South Atoll, WQ01 to WQ07, four of which are located on the reef (WQ01 to WQ04). Two are situated inside the lagoon (WQ05 and WQ06), and one close to the roosting site of seabirds in the South Islet (WQ07).

Figure 51 shows the trends of water quality parameters monitored in South Atoll from 2014 to 2021. The aesthetic or physical appearance of seawater is measured by the degree of clarity (color) and the presence of dissolved organic matter, metallic salts, or suspended solids (total suspended solids, TSS). The concentrations of color in South Atoll ranged from <5 to 10 PCU. The TSS ranged from <1 mg/L to 19 mg/L, all below the water quality guidelines (25 mg/L, Class SA). The recorded pH levels were within the range of 7.0 to 8.5 (Class SA), except in 2017 when the average pH in South Atoll was at

8.73, or slightly higher than the standard. The records of 2020 showed that pH was within the WQ guidelines.

The recorded exceedance on concentration of oil and grease in almost all stations in South Atoll from 2014 to 2017 when compared to the WQ guideline (1 mg/L, Class SA) has been attributed to the active tourism activities before the pandemic, since the WQ monitoring activities coincided with the peak tourism season.

Similarly, the concentration of fecal coliform in South Atoll was observed to be in decline from 2016 to 2017 and has improved to below 20 MPN/100mL (Class SA, DAO 2021-19) during the closed season of 2020 and 2021.

The concentration of phosphate recorded from 2014 to 2020 exceeded the WQ guidelines for protected areas (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. On the other hand, nitrates concentration from all water quality monitoring stations were below the water quality guidelines (10 mg/L).

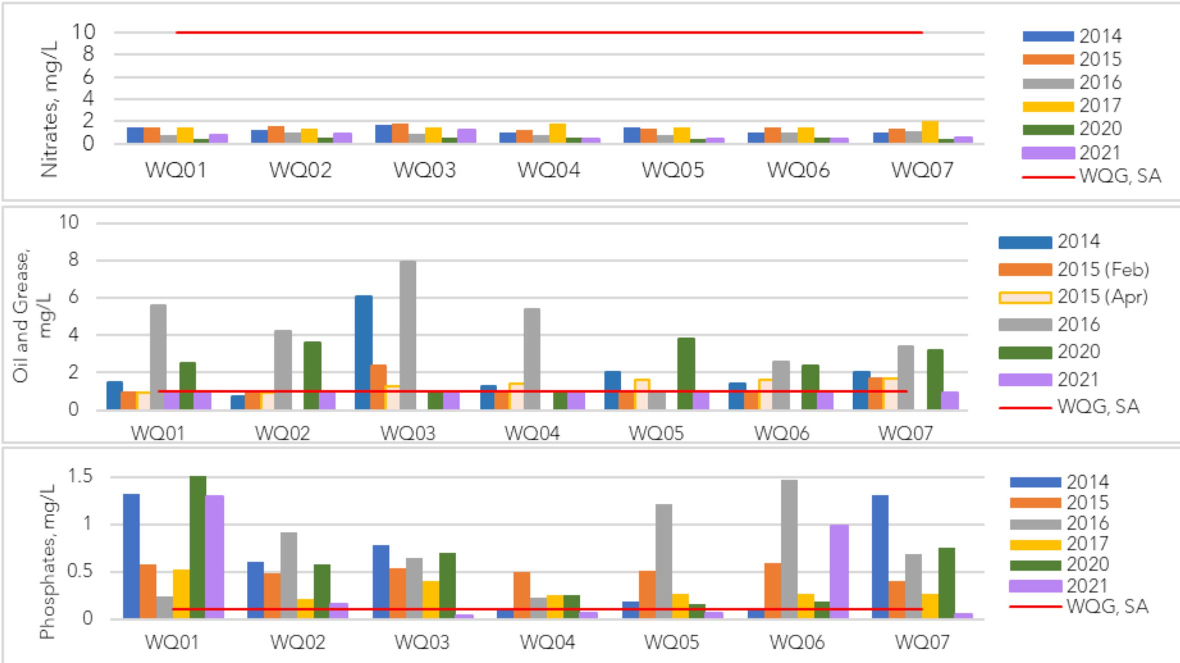

Figure 51. Trends of water quality parameters monitored in South Atoll from 2014 to 2021.

North Atoll

The North Atoll is the bigger reef complex in TRNP with a large oblong-shaped platform. It also hosts seabirds and marine turtles in Bird Islet. Nine (9) water quality monitoring stations are located in North Atoll (WQ09 to WQ17); WQ09 where the Min Ping Yu run aground in 2013, three stations are located on top of the reef (WQ10 to WQ 12), three stations are located inside the lagoon, (WQ14 to WQ16), one station is located at the Bird Islet (WQ13) and Ranger Station (WQ17). Figure 52 shows the trends in water quality in the North Atoll from 2014 to 2021.

The concentrations of TSS (<1 mg/L to 20 mg/L) were all below the water quality guideline (25 mg/L, Class SA) while the color ranged from <5 to 15 PCU, with recorded exceedance to 5 mg/L WQG in 2015 and 2016. Recent results showed consistently clear waters in North Atoll. Color and TSS refer to the suspended solids and dissolved organic matter that could affect the visual and aesthetic quality of seawater. The pH around North Atoll was 7.28 (WQ07, 2020) from 8.81 (WQ03, 2017). While pH greater than 8.5 was recorded in North Atoll in the past, recent monitoring showed levels within the range of 7.0 to 8.5 (Class SA), all within the WQ guidelines.

The highest concentration of oil and grease measured in North Atoll was 5.83 mg/L (WQ17, 2014) while the lowest was <1 mg/L observed in various stations in 2020 and 2021. The exceedance of oil and grease when compared to the WQ guideline (1 mg/L, Class SA) can be attributed to the activities in and around the North Atoll before the pandemic. There are three (3) diving sites that correspond to the WQ sampling sites (WQ10- WQ12) in North Atoll. This could have contributed to the presence of oil and grease since the WQ monitoring activities coincided with the dive season in 2014 to 2017.

The level of fecal coliform in North Atoll has improved since 2016 to 2017. As in South Atoll, the fecal coliform level in North Atoll was within the prescribed concentration for protected waters (Class SA, DAO 2021-19), it improved to below 20 MPN/100mL during the shutdown of tourism activities in 2020 and 2021.

A high concentration of phosphate has been observed in North Atoll since 2014 to 2021, exceeding WQ guidelines for protected area (Class SA, 0.1 mg/L). The average concentration of phosphate in North Atoll throughout the monitoring period was 0.42 mg/L. The highest concentration 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. Nitrates were present in all water quality monitoring stations but were below the WQ guideline of 10 mg/L.

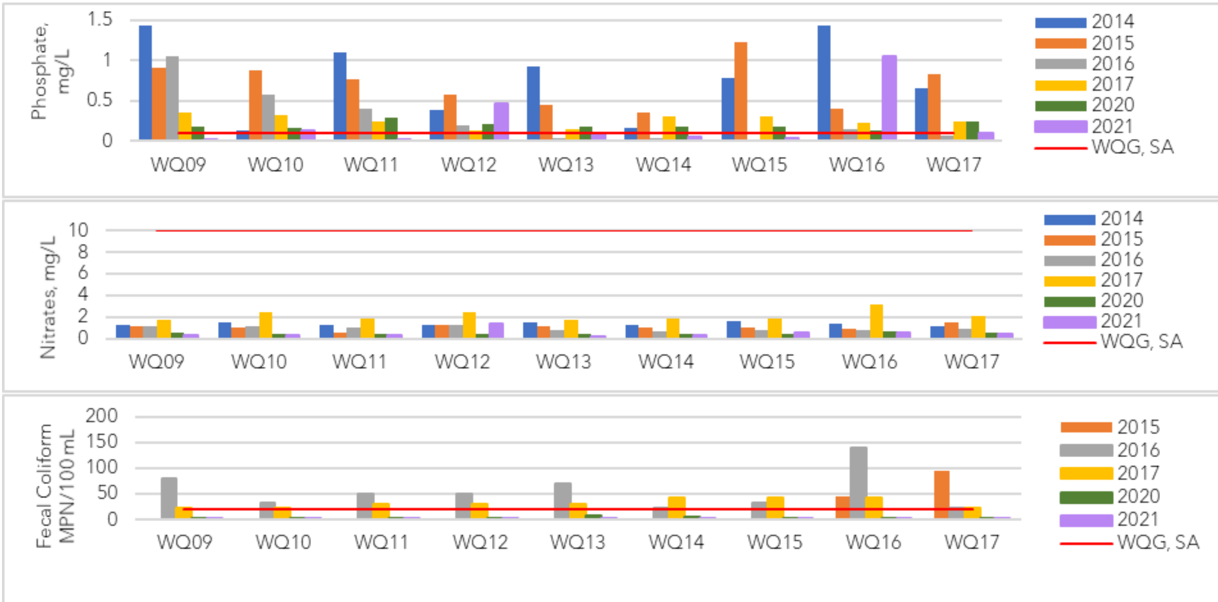

Figure 52. Trends of water quality parameters monitored in North Atoll from 2014 to 2021.

Jessie Beazley Reef

Jessie Beazley Reef is located 20 kilometers northwest of North Atoll. It has a small cay of broken corals that serves as roosting area of seabirds during low tide. WQ19 is located on top of the reef, where the fish and benthos monitoring station and a dive site are located. Figure 53 shows the trends in the parameters monitored in this station from 2014 to 2021.

The physical appearance of seawater in Jessie Beazley Reef was consistently clear with color ranging from <5 to 10 PCU and TSS concentration (<1 mg/L to 9 mg/L) below the water quality guideline (25 mg/L, Class SA). The prevailing pH level was recorded to be within the range of 7 to 8.5, except in 2017 (8.81). The dissolved oxygen was all above 6 mg/L, enough to sustain the aquatic organisms.

The concentration of oil and grease ranged from <1 mg/L (2020 and 2021) to 4.8 mg/L (2016). It is important to note that the recent levels of oil and grease have reduced to concentrations below the water quality guideline (Class SA, 1 mg/L). A similar trend was observed for fecal coliform, where the highest concentration measured in 2016 (94 MPN/100 mL) was reduced to <1.8 MPN/100 mL in 2021, thus, way below the 20 MPN/100 mL standard for protected waters (Class SA, DAO 2021-19).

The average concentration of phosphate from 2014 to 2021 was 0.256 mg/L, exceeding the water quality guideline of phosphates for protected waters (Class SA, 0.1 mg/L), except in 2016 and 2021. On the other hand, nitrate levels were all within the WQ guidelines (Class SA, 10 mg/L).

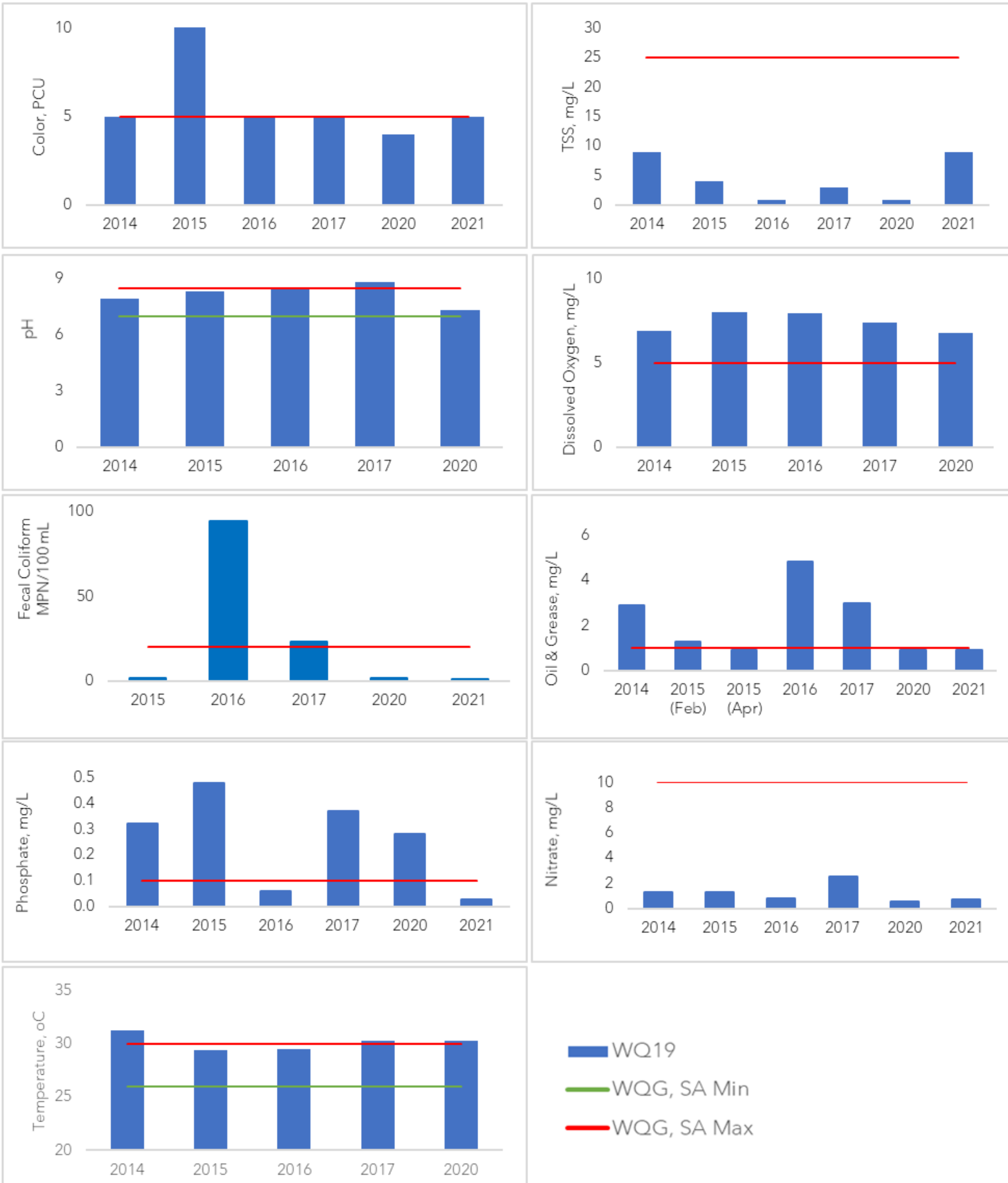

Figure 53. Trends of water quality parameters monitored in Jessie Beazley Reef from 2014 to 2021.

Buffer Zone

Water quality monitoring stations in the buffer zone adjacent to the core zone were established. WQ08 is located close to South Atoll, WQ18 at the buffer adjacent North Atoll, and WQ20 at Jessie Beazley Reef. Figure 54 shows the trends of parameters monitored in these stations from 2014 to 2021.

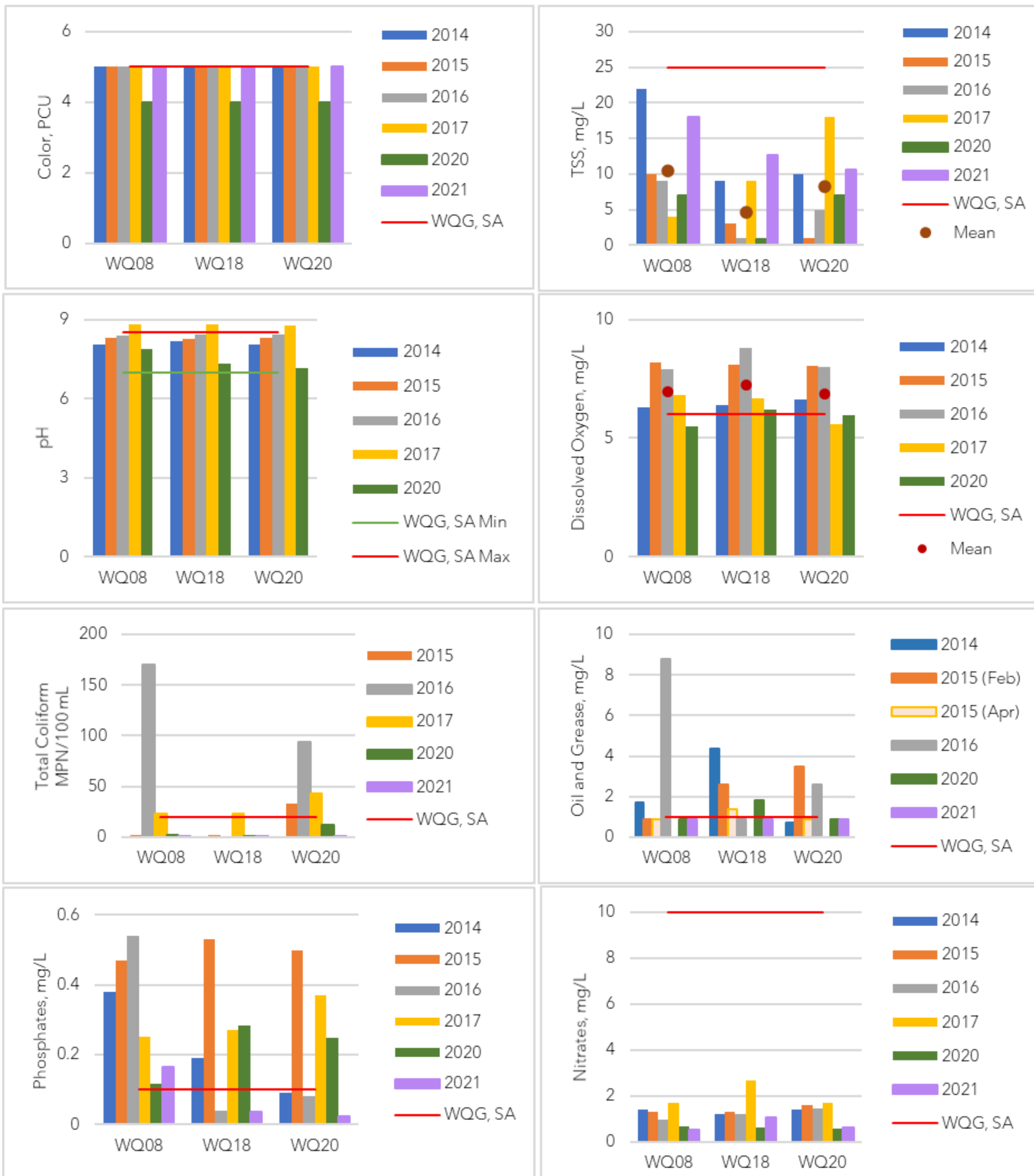

Figure 54. Trends of water quality parameters monitored in the buffer zone of TRNP from 2014 to 2021.

The concentrations of color and TSS were within the Class SA WQ guidelines. The color ranged from <5 PCU to 5 PCU, while the TSS concentrations were recorded from <1 mg/L to 22 mg/L. The pH level was recorded from 7.16 (WQ20, 2020) to 8.82 (WQ18, 2017), with recent record within the Class SA WQ guidelines for pH at 7 to 8.5. The dissolved oxygen was all within the WQ guideline, thus above 6 mg/L, except for WQ08 in 2020 with 5.5 mg/L.

The highest concentration of oil and grease in all stations in TRNP was in WQ08 (8.8 mg/L) measured in 2016. This station is located on the eastern part of TRNP, which was a passageway of local and international ships until 2017, when Tubbataha was designated as a Particularly Sensitive Sea Area. The concentration of oil and grease started to decrease in 2020 and was within 1 mg/L WQ guidelines for protected areas in 2021. Fecal coliform was also highest in WQ08 in 2016 at 170 MPN/100 mL. A decreasing concentration was observed in the other two stations and are now all within the 20 MPN/100 mL guideline for protected areas.

The phosphate levels ranged from 0.024 mg/L (WQ20, 2021) to 0.54 mg/L (WQ08, 2016) in the buffer zone. Phosphate concentration in WQ18 and WQ20 were within the water quality guidelines for protected waters (Class SA, 0.1 mg/L) in 2021. On the other hand, nitrate levels were all within the WQ guidelines (Class SA, 10 mg/L).

DISCUSSIONS

The COVID-19 pandemic has affected socio-economic activities all over the world, and its impact was felt even in remote protected areas. A series of national and granular lockdowns have been implemented since March 2020 to prevent the further health and economic effects of COVID-19. In Palawan, the restrictions on inbound and outbound travelers resulted in the shutdown of various tourism activities in all destinations. It included the shutdown of TRNP to all tourism activities. Even after one year, when the travel restriction was eased out allowing local tourists to visit and enjoy the tourist destinations in Palawan, the TRNP has not attracted scuba diving tourists.

While the socio-economic sector has suffered due to the pandemic, various studies show that the quality of surface lake water (Yunus et al., 2020), beach and coastal water (Ormaza-Gonzaìlez et al., 2021), and global air (Venter et al., 2020; Shrestha et al., 2020) improved during the lockdown. Likewise, this was observed in the trends of the water quality parameters being monitored in TRNP. Most of the water quality parameters monitored from 2014 to 2021 showed improvements and fell within the water quality guidelines for protected waters. These parameters refer to the physical and aesthetic quality of water such as color and total suspended solids; pH that pertains to level of acidity or basicity of seawater; dissolved oxygen that denotes the amount of oxygen in water that is essential for survival of aquatic animals.

The concentration of oil and grease, a parameter that relates to the presence of oil from anthropogenic sources in TRNP was recorded to be high and in exceedance to water quality guidelines since 2014. The latest monitoring in June 2021 showed concentrations below <1 mg/L in all WQ monitoring stations. This could be attributed to the reduced number of boats carrying tourists to the park. Further, the designation of TRNP as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Office in 2017, establishing it as an Area to be Avoided (ATBA) by all ships beyond 150 gross tons, may be a factor in this marked improvement. This provided protection against the possibility of indiscriminate disposal of wastes from vessels and the risk of oil and chemical spills.

High concentrations of fecal coliform were recorded since 2015 in TRNP. While the fecal coliform concentrations in 2015 to 2020 exceeded the WQ guideline for protected area (Class SA, 20 MPN/100 mL), these were within the guideline for areas identified as tourist zones for ecotourism activities and recreational waters intended for primary contact recreation such as bathing, swimming and skin diving (Class SB, 100 MPN/100 mL). Recent monitoring showed that fecal coliform levels were all within the stricter Class SA guideline (protected waters).

The temporary closure of TRNP to tourism activities for two diving seasons (2020 and 2021) due to the COVID-19 pandemic has led to considerable improvement in water quality. Water bodies have assimilative capacity allowing it to receive and disintegrate a certain amount of contaminants. Fecal coliform naturally die with long exposure to sunlight (Karbadeshi et al., 2017) and without constant addition from non-point or point sources, the fecal coliform eventually diminished in TRNP.

Phosphates and nitrates have exceeded water quality guidelines since 2014. The observed decline in concentrations of other parameters due to the absence of tourism activities did not apply to the phosphates and nitrates, which are high especially in some stations in the North Atoll (WQ01 and WQ06) and South Atoll (WQ12 and WQ16). It can be noted that WQ06 is located inside the lagoon, close to South Islet (WQ07) and WQ12 is close to Bird Islet. These islets serve as rookery for seabirds and are point and constant sources of nutrients from the seabird guano.

There is evidence of assimilation of guano by corals through percolation of accumulated guano via precipitation and direct excretion into the water during flight. Impacts on higher trophic level consumers feeding on corals and even higher trophic level organisms is highly probable (Lorrain et al., 2017).

While these nutrients are essential to support the marine ecosystem (Strynar et al., 1999), excessive levels lead to overfertilization or eutrophication which can cause mortality and sublethal effects on coral reef (Lapointe et al., 2004; Rothenberger et al., 2008). Kleypas et al. (1999) reported that the average phosphorus concentrations on natural reefs are generally low at 0.01 mg/L. This has increased to 0.266 mg/L in recent years as documented on some reefs in the Southern Gulf of Mexico (Cruz-Pinon et al., 2003). While high phosphate levels has no visible effects of stress in corals, and may increase coral growth (Bucher and Harisson, 2002; Koop et al., 2001; Dunn et al., 2012), it results to a brittle skeleton due to increased porosity and decreased coral density caused by the replacement of dense calcium carbonate skeleton by porous calcium phosphate skeleton that is susceptible to breakage and damage due to human activities and storms.

The exposed skeletons may result to algal colonization and a possible shift in the community structure (Dunn et al., 2012).

The average phosphate levels in TRNP since 2014 is 0.420 mg/L. High nutrient uptake was observed in filamentous microalga *Cladophora spp*., turf algae and the benthic cyanobacteria *Lynbya majuscule* compared to other benthic reef organisms (Haan et al., 2016). Licuanan and Bahinting (2021) reported that the increasing presence of filamentous cyanobacteria, probably *Lyngbya*, in South Atoll could be attributed to the increased levels of nutrients in the vicinity of the Islet.

Overall, the reduced pressure on water quality due to the absence of tourism has provided a unique opportunity for ecological restoration in terms of water quality in TRNP. The two-year water quality data may be utilized to develop baseline data sets in physical, chemical, and microbiological factors in TRNP.

Improvements have been observed in the water quality of TRNP from the pre-pandemic (2014-2017) to the pandemic (2020-2021) period. Recent monitoring data showed 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), the highest and most stringent classification for seawater bodies.

The concentration of phosphates has declined in some monitoring stations but were still above the Class SA WQ guideline, especially in the stations close to the islets.

RECOMMENDATIONS

To sustain the improvements in the water quality of TRNP, the following measures are recommended:

- Post-pandemic tourism guidelines should be developed to include requirements for adequate waste containment or treatment facility, and prohibition of the disposal of wastewater in the core and buffer zones of the park.

- The purchase of multiparameter water quality meter capable of measuring temperature, pH, dissolved oxygen, nitrate and phosphates on-site is highly recommended. This period of absence of tourism activities provides a good opportunity to conduct in-depth studies to establish the relationship between the nutrients from seabird guano and the reported changes in benthic cover in some locations in TRNP.

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CHAPTER 6. SHARKS

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OVERVIEW

Prior to 2015, only a very few shark-related studies were conducted in TRNP. These included an assessment of reef shark abundance in 2005 by Walker and Abesamis and in 2010 by Alava. In 2015, the Large Marine Vertebrates Research Institute Philippines (LAMAVE) began to study sharks more regularly in Tubbataha. Their efforts and studies revealed that TRNP has the highest density of grey and whitetip reef sharks in the world (Murray et al., 2019). It also confirmed that TRNP is one of the few places in Southeast Asia where tiger sharks could still be seen. These studies also stressed the importance of large, well-managed marine protected areas in conserving sharks.

This year, the shark survey was led by the Tubbataha Management Office. The team was joined by researchers and volunteers from LAMAVE, World Wildlife Fund for Nature – Philippines, and local diver volunteers.

This study provides information on shark abundance after two years of the absence of tourism in the park.

METHODS

The team replicated the study conducted by LAMAVE in 2015-2017. The Underwater Visual Survey (UVS) method was utilized, where divers swam down current for approximately 40 minutes while identifying and counting the passing sharks within a 30-meter wide transect strip. The team was composed of two groups with three divers each - two acting as observers and one as scriber. The scriber/recorder stayed at a target depth of 15 meters. The two observers on each side of the scriber were positioned 5 meters above and below the scribe and identified and counted the passing sharks. The observers were responsible for finding the sharks and informing the scriber, while the latter confirmed the correct number and species and recorded the sightings.

We visited the eight (8) sites previously surveyed by LAMAVE. We also established a new site in the North Atoll. A check-out dive was conducted on the first day to standardize the width of the transect, distance from the substrate, and sign language for each species. Each site was surveyed twice with a minimum of a two-hour intervals between dives to minimize any interferences between dives.

Table 19. Dive sites, coordinates at the start and end, and distance covered by each transect. The site with * was the newly established site.

Dive number	Dive Sites	Transect Start Coordinates	Transect End Coordinates	Distance covered (m)
1	Malayan Wreck	N08°53.285' E119°53.775'	N08°53.193' E119°53.421'	901
2	Malayan Wreck	N08°53.301' E119°53.850'	N08°53.117' E119°53.395'	901
3	Wall Street	N08°51.769' E119°52.831'	N08°51.500' E119°52.817'	499

4	Wall Street	N08°51.314' E119°53.050'	N08°51.686' E119°52.783'	867
5	Triggerfish City*	N08°44.390' E119°49.156'	N08°44.476' E119°49.542'	724
6	Triggerfish City*	N08°45.404' E119°49.324'	N08°44.338' E119°48.688'	2,593
7	Delsan Wreck	N08°44.736' E119°49.681'	N08°45.319' E119°49.715'	595
8	Delsan Wreck	N08°45.022' E119°49.667'	N08°44.459' E119°49.523'	1078
9	Black Rock	N08°47.804' E119°50.267'	N08°48.058' E119°50.561'	724
10	Black Rock	N08°47.614' E119°50.026'	N08°47.885' E119°50.471'	966
11	Ko-ok	N08°48.558' E119°48.762'	N08°48.492' E119°48.376'	724
12	Kook	N08°48.504' E119°48.388'	N08°48.559' E119°48.750'	676
13	South Park	N08°50.822' E119°55.881'	N08°51.244' E119°56.370'	1190
14	South Park	N08°50.864' E119°55.985'	N08°51.239' E119°56.393'	1030
15	Shark Airport	N08°55.942' E120°00.964'	N08°55.640' E120°00.842'	612
16	Shark Airport	N08°55.529' E120°00.571'	N08°55.747' E120°00.960'	821
17	Seafan Alley	N08°56.777' E119°59.691'	N08°56.539' E120°00.091'	852
18	Seafan Alley	N08°51.244' E119°56.370'	N08°51.244' E119°56.370'	1030

We determined the area covered during each dive by using the mapping software Garmin Basecamp v.4.7.4, by measuring the distance following the contour of the reef between the starting and ending coordinates multiplied by the 30-meter transect strip. In calculating the mean density, we omitted the area covered in dives 5 and 6 due to the discrepancy in the distance covered. We used the estimated total survey area to calculate the mean density values for each species encountered.

RESULTS

A total of 16 UVS were completed covering a distance of 13.9 kilometers with a sampling area of about 39.72 hectares. During the survey, 414 sharks were encountered with the overall mean density of 10.4 ind/ha. Grey reef shark *Carcharinos amblyrhinchos* had the highest density (6.6 ind/ha) followed by whitetip reef shark *Trianodon obesus* with a mean density of 3.8 ind/ha. These two species were encountered in all the dives. One (1) tiger shark *Galeocerdo cuvier* was recorded in Shark Airport.

Table 20. Species, number of encounters and density of sharks and rays recorded during the survey. Note: ns = not significant

Species	Number of encounters	Density (ind/ha)
Sharks		
Carcharhinus amblyrhynchos	263	6.6
Trianodon obesus	150	3.8
Galeocerdo cuvier	1	ns
Rays		
Aetobatus ocellatus	17	0.42
Mobula alfredi	1	ns

We also encountered 18 rays with a mean density of 0.42 ind/ha. Of these, 17 were spotted eagle rays *Aetobatus ocellatus* with a mean density of 0.40 ind/ha. One (1) reef manta ray *Mobula alfredi* was recorded in Malayan Wreck.

The most number of sharks were encountered in Shark Airport although it was not the site with the most area covered (4.2 ha). The least encounters were in Triggerfish City and in Ko-ok. Grey reef sharks were most abundant in Shark Airport and Malayan Wreck, while whitetip reef sharks were most abundant in Shark Airport and in Seafan Alley.

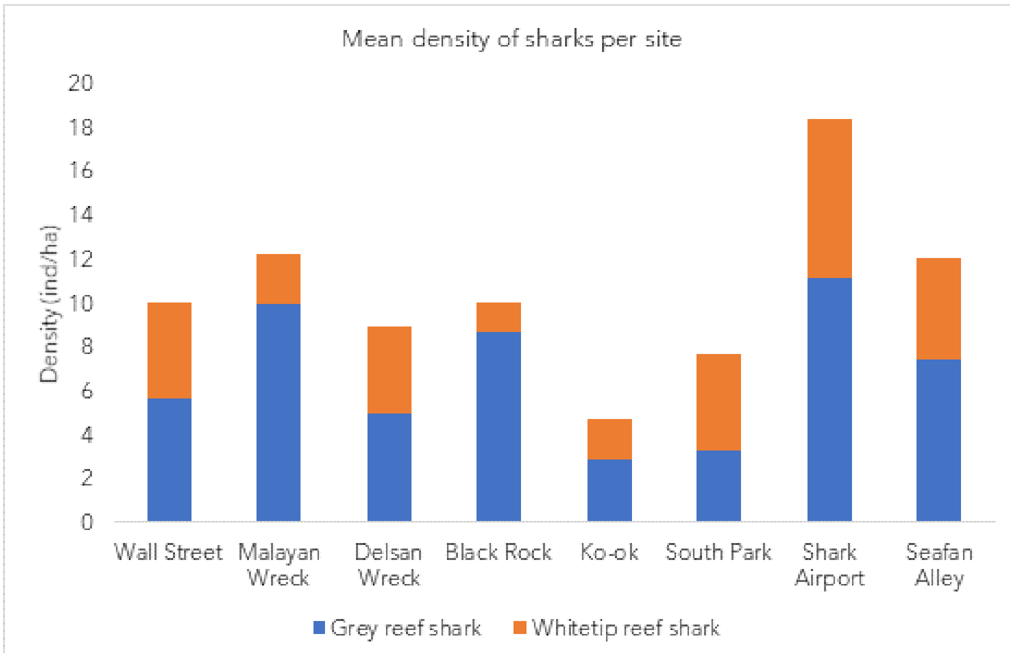

Figure 55. Density (individuals per hectare) of grey and whitetip reef sharks in each dive site.

DISCUSSIONS

This year's mean density of reef sharks was relatively higher than the previous surveys conducted by LAMAVE in various dive sites in 2015 (n=10) and in 2016 (n=10) with average density of 7.18 ind/ha for both years (Murray et al., 2019), and in 2017 (n=8) with 9.2 ind/ha. It should be noted that the 2015-2017 surveys were conducted during the diving season when tourists were present in the area, which may have affected the presence or absence of reef sharks in the specific sites we revisited. Meanwhile, this year's survey was conducted on the second year of absence of tourism activities in the park due to the COVID-19 pandemic. It is possible that one of the attributing factors in the difference was the absence of tourists.

Globally, a major decline in the population of sharks was attributed to human-induced threats such as overfishing and lack of policies (Dulvy et al., 2014; McNeil et al., 2020).

Isolated reefs or marine sites that are far from anthropogenic stress are considered as the last refugia of sharks (Latessier et al., 2019). TRNP is one of the last few remaining places in the Philippines where reef sharks thrive. This is attributed to strict protection and enforcement, and the sufficient size of the Park to support their movement (Murray et al., 2019). Despite this, local and global stressors (e.g., fishery-related activities, climate change) are ever-present threats. The continuous monitoring of shark abundance and species distribution, complemented by other shark studies, will help the park management determine the trend in population density and changes in species composition throughout the years.

Studies on sharks in their natural habitat are extremely limited in the Philippines. The result of this study and further research on sharks in TRNP can be used as benchmark for shark populations in areas with limited direct human activities. Broadening the knowledge on shark ecology could significantly contribute to enhancing the shark conservation strategies implemented in the Philippines.

RECOMMENDATIONS

- Continue monitoring of the reef shark population to determine trends in their population and distribution, behavior, ecology, and movement.

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CHAPTER 7. TECTUS NILOTICUS

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OVERVIEW

The topshell *Tectus niloticus*, locally known as "samong", was abundant in the shallow rocky waters of TRNP (Dolorosa & Schoppe 2005). *T. niloticus* is a large species reaching up to 150 mm across the shell base. It has an off -white shell with oblique reddish stripes and an interior layer of thick pearly shell. It becomes sexually mature as the size of its shell base reaches 50 to 80 millimeters (Jolivet et al., 2015). This species tends to aggregate along shallow areas of boulder and coral rubble and graze for small algae and plants (Lorrain et al., 2015).

T. niloticus is one of the most valuable and sought-after reef gastropods because its shell is used in manufacturing mother-of-pearl buttons, jewelry, decor, and other ornaments (Nash 1993). Over-harvesting lead to population decline, prompting the application of management measures such as more restrictive fisheries regulations and population reseeding. However, these have not prevented the collapse of the stock in most Pacific countries (Purcell 2004).

In the Philippines, *T. niloticus* is a threatened species and collection in the wild is prohibited under the Bureau of Fisheries and Aquatic Resources Fisheries Administrative Order No. 208. Due to the depleting wild population of this species, some conservation measures, such as translocation and stock enhancement, were taken by research institutions and the academe (Dolorosa et al., 2013; Gonzales et al., 2006).

In TRNP, the density of *T. niloticus* declined in most of the monitoring sites due to illegal collection between 2006 to 2008. Its population is being monitored to determine trends with the results of the study used to measure management effectiveness.

METHODS

Nine sites were selected for the assessment of *T. niloticus* in 2017 (TMO 2017). Seven of these coincided with those surveyed in 2006 and 2008 (Dolorosa et al., 2010; Jontila et al., 2014). Two 100-meter transects were laid in each site, parallel to the reef, at depths between 1 to 2 meters. Two divers simultaneously surveyed the 100-meter transect. All *T. niloticus* within the 2.5-meter imaginary corridor on both sides of the transect were counted and its basal diameter measured. The total area covered in this study was 9,000 m^2.

Table 21. Location and coordinates of *T. niloticus* monitoring sites.

Site	Location	Coordinates
1	Shark Airport	N8.92786° E120.01252°
2	Elbow Mac	N8.92318° E119.99562°
3	Ranger Station	N8.84815° E119.91726°
4	Jessie Beazley	N9.04393° E119.81599°

5	Amos Rock	N8.87317° E119.88678°
6	West of South Islet	N8.74951° E119.81232°
7	Black Rock	N8.78537° E119.82962°
8	Delsan Wreck	N8.74432° E119.82717°
9	Kook	N8.80827° E119.80652°

RESULTS AND DISCUSSIONS

A total of 829 individuals were recorded resulting to an average density of 18 individuals/200 m^2, much lower compared to the 31 individuals/200 m^2 recorded in 2017. This decrease was observed in most of the sites, except for Sites 1, 6 and 9. The highest density was recorded in Site 2 with 45 individuals/200 m^2, however, this value was lower than in 2017 (142 individuals/200 m^2). The lowest density was recorded in Site 4 (Jessie Beazley) with the actual count of 2 individuals.

The average basal diameter of *T. niloticus* this year was 92mm ± 4.75mm. This value is larger compared to the average basal diameter recorded in 2006 (67mm ± 14.6mm), 2008 (82mm ± 16mm) and 2017 (79 mm ± 19.4 mm) (Dolorosa et al., 2010; Jontila et al., 2014; TMO 2017). Majority of the *T. niloticus* measured 71 to 100mm in basal diameter, which are considered to be sexually mature individuals (Figure 56).

Table 22. Density and basal diameter of *T. niloticus* in the nine sites.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Density (# of ind/200 m^2)	29	45	13	<1	2	21	7	17	32
Average basal diameter (mm)	88	88	91	86	93	94	101	95	89
Minimum basal diameter (mm)	62	61	30	78	30	57	87	52	23
Maximum basal diameter (mm)	112	103	120	93	110	125	116	115	113

The largest *T. niloticus* recorded this year was 125mm in basal diameter while the smallest measurement was 23mm. Only five (5) individuals were classified as juveniles (<50mm in basal diameter). These were often found under rocks as in the previous years. Majority of the population were greater than 50mm in basal diameter, which are classified as sexually mature.

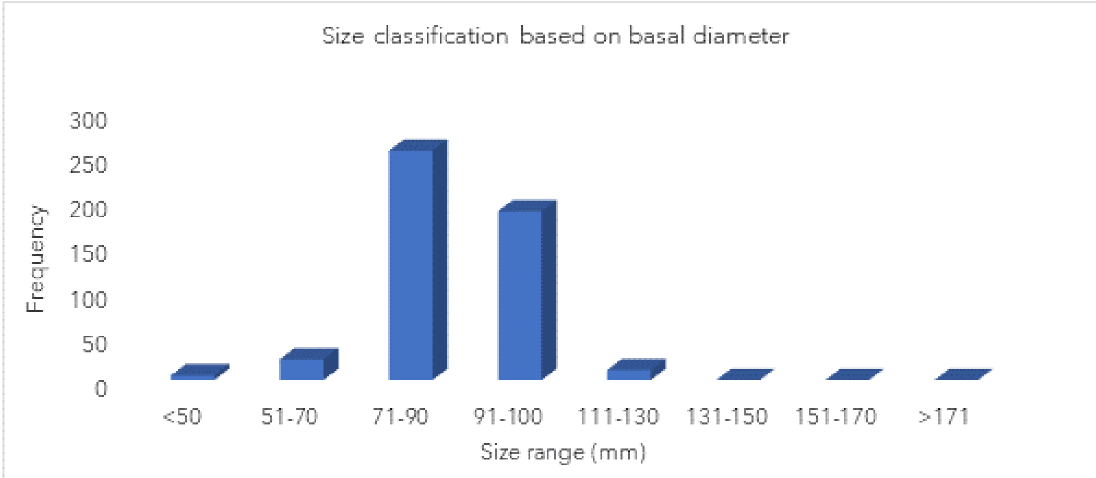

Figure 56. Size frequency distribution of *T. niloticus*.

The individuals recorded this year were larger in terms of basal diameter than those previously recorded in the park. The proliferation of sexually matured individuals (50mm to 100 mm in basal diameter) may be due to the favorable environment allowing them to thrive and mature. However, we observed fewer juveniles this year, which might be influenced by sampling bias. The locations of the monitoring sites were marked using GPS, which accurately led researchers to the general study area but not to the precise site of the previous studies. It is possible that juveniles were located outside the sampling areas this year resulting to lower sightings.

The decrease in the density of *T. niloticus* between 2017 and 2021 was not statistically significant. However, the decline in density needs further investigation so that illegal harvesting may be ruled out as a cause.

RECOMMENDATIONS

1. Review protocols at the beginning of each survey to familiarize the team with the sampling methods and identification of *T. niloticus* since the team includes different researchers, volunteers, and marine park rangers during each study;
2. Establish permanent markers at the start of each transect;
3. Conduct annual assessments to determine trends in the population of *T. niloticus* in the park;
4. Heighten enforcement efforts especially at night to arrest any resurgence in illegal collection of *T. niloticus* in Tubbataha.

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CHAPTER 8. SEAGRASS

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OVERVIEW

Seagrasses are considered one of the most important marine habitats because they support a wide range of keystone and ecologically important marine species from different trophic levels (Orth et al., 2006). They provide shelter and food for several marine species including turtles, invertebrates, and fish. Their high rates of primary production result in well-oxygenated waters that support complex food webs. During photosynthesis, they release oxygen into the water and pump oxygen into the sediments through their roots that promotes nutrient uptake (Ramesh et al., 2018). They are also capable of capturing and storing carbon from the atmosphere and support both commercial and recreational activities (Nordlund et al., 2017).

The result of this assessment will be used as input to the management effectiveness evaluation of TRNP, where seagrasses are considered as one of key indicator species.

METHODS

The assessment was conducted in the three areas in Tubbataha where seagrass beds are relatively dense – around the Ranger Station, Bird Islet, and South Islet. The monitoring sites established in 2017 were revisited this year (see Table 23). Two sites were established at the Ranger Station and Bird Islet, and one in South Islet.

Table 23. Coordinates of the location of seagrass monitoring sites.

Site	Location	Coordinates
1	Bird Islet	N8.93069° E119.99560°
2	Bird Islet	N8.92879° E119.99671°
3	Ranger Station	N8.85163° E119.91849°
4	Ranger Station	N8.85066° E119.91666°
5	South Islet	N8.74861° E119.81894°

We followed the methods described in the DENR-BMB Technical Bulletin No. 2017-05 (Guidelines on the Assessment of Coastal and Management Ecosystem). In each site, three (3) 50-m transect lines were laid perpendicular to the shore. At each transect, a 0.5 m x 0.5 m quadrat was placed starting from the zero (0) mark. The quadrat was placed on the right side of each transect at 5m intervals. Photographs were taken using a camera with underwater housing at five (5), 25, and 45-meter marks for permanent visual record of the transect. In each quadrat, the species composition, percentage cover, and canopy height of seagrasses were determined. The substrate composition, presence of macroalgae, epiphytes, and other fauna were also noted. The seagrass condition used to describe the seagrass cover per site followed Amran (2010) (Table 24).

Table 24. Seagrass composition criterion based on percentage cover (Amran 2010).

Coverage	Condition
>74.4%	Very Good
50.5 – 74.4%	Good
25.5 – 50.4%	Fair
5.5 – 24.5%	Poor
<5.55%	Very Poor

RESULTS AND DISCUSSIONS

There were nine seagrass species previously recorded in TRNP namely *Cymodocea rotundata, C. serrulata, Enhalus acoriodes, Halodule pinifolia, H. uninervis, Halophila ovalis, H. spinulosa, Syringodium isoetifolium, and Thalassia hemprichii.* Five (5) of these were recorded this year: *H. ovalis, H. pinifolia, H. uninervis, C. rotundata,* and *S. isoetifolium*. As in 2017, *H. ovalis* and *H. pinifolia* were the most dominant seagrass species in all of the sites. *S. isoetifolium* was only recorded in Site 4 (Table 25).

Table 25. Seagrass percentage cover and relative cover per species in the five monitoring sites.

Site	% Seagrass Cover	Relative cover per species				
		H. ovalis	*H. pinifolia*	*H. uninervis*	*C. rotundata*	*S. isoetifolium*
1	49.9	52.5	26.4	21.2	0	0
2	41.5	65.3	18.3	16.3	0	0
3	16.7	97.9	0	0	2.1	0
4	22.9	61.2	20.9	0	15.8	2.1
5	18.4	22.1	77.9	0	0	0
Average	29.9	59.8	28.7	7.5	3.6	0.4

The average seagrass cover recorded in Tubbataha this year was 29.9%, categorized under fair condition (Amran 2010). The highest seagrass percentage cover was recorded in Sites 1 and 2, both located in Bird Islet. The seagrass cover in both sites were categorized as fair. Meanwhile, the lowest seagrass cover was recorded in Site 3 (16.7%), which was categorized as poor condition.

The highest seagrass cover was recorded in Site 1. This area seems to be less exposed than other sites, providing opportunity for seagrass to thrive. The poor condition of seagrasses in Site 3 may be attributed to the characteristics of the site. It is located near the unstable sand bar at the Ranger Station, which is exposed to wave action during the southwest monsoon. This sand movement possibly covered or uprooted small patches of seagrass in the area yielding a low seagrass cover this year. The consistent movement of sand may hinder the proliferation of seagrass beds in the area compared to the other areas in Tubbataha that are more sheltered from wave action.

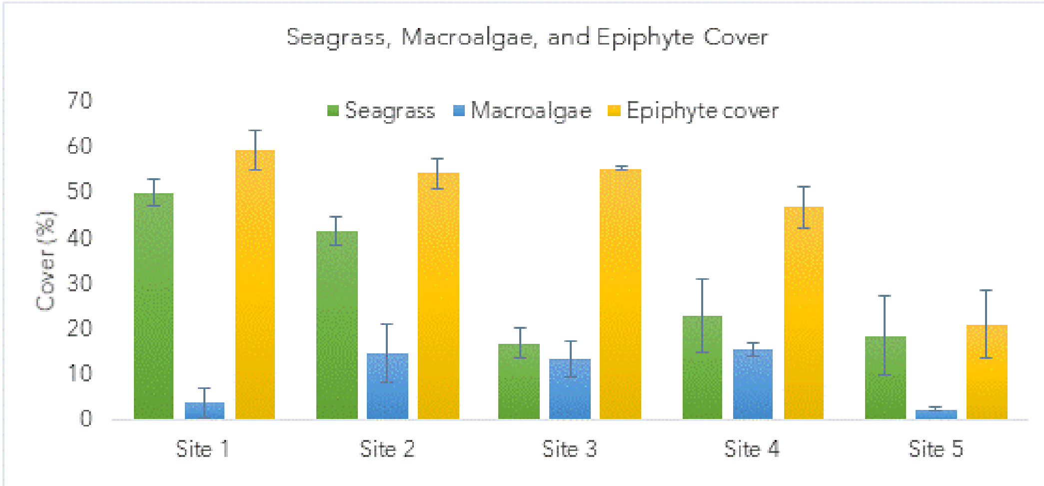

Figure 57. Seagrass, macroalgae, and epiphyte cover in Tubbataha. Error bars represent ±1 standard error.

The overall macroalgae and epiphyte cover in the seagrass beds were 9.8% and 47.3%, respectively (Figure 57). Almost all the seagrass blades were covered by epiphytes. These organisms protect the seagrass against ultra-violet radiation. The dense epiphyte cover found in the seagrass blades may reduce desiccation when the leaves are exposed to the air and sunlight during lowest tide (Aho and Beck 2011).

Macroalgae cover was highest in Site 4 at 15.3%, followed by Site 2 (14.6%), while Site 5 in South Islet recorded the lowest cover at 2.2% (Figure 57). The macroalgae species recorded in most of the sites were *Halimeda sp.*, *Padina sp.*, and filamentous algae such as *Ulva sp*.

Epiphytes were dense in almost all the sites (Figure 57), which could be related to the location. The sites were close to human settlement (ranger station) and seabird community (Bird and South Islets), which are sources of organic matter. The proliferation of organic matter contributes to the considerable epiphytic algae on the seagrass blades.

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APPENDICES

Appendix 1. List of Participants

Fish, benthos, coral recruitment, and seabirds

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Ace Nińo Andew Acebuque, Volunteer
Jomil Rodriguez, Volunteer
Anton Rey Cornel, Volunteer

Water quality and sharks

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Tectus niloticus and seagrass

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CG SN1 Jonald Ersando
CG ASN Jay Ermino
SN1 Peter John Rose PN
SN2 Warren Peralta PN
Rex P. Cayabo, LGU Cagayancillo

Appendix 2. 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
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 3. Categories for evaluating ecological health of coral reef fish communities

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., 2006)	g/m^2	
	0-10	Very Low to Low
	11-20	Moderate
	21-40	High
	>40	Very High

Appendix 4. Hard coral TAU

TAU Code	Hard coral TAU	TAU Code	Hard coral TAU
ACAN	*Acanthastrea*	MILL	*Millepora*
ACB	*Acropora* (branching)	MON	*Montastrea*
ACC	*Acropora* (corymbose)	MONTB	*Montipora* (branching)
ACD	*Acropora* (digitate)	MONTE	*Montipora* (encrusting)
ACH	*Acropora* (hispidose)	MONTF	*Montipora* (foliose)
ACT	*Acropora* (plate)	MYC	*Mycedium*
ACR	*Acropora* (Robusta group)	CB	Other branching corals
AST	*Astreopora*	BUB	Other bubble corals
AF	Attached fungiids	CE	Other encrusting corals
CAU	*Caulastrea*	CF	Other foliose corals
COE	*Coeloseris*	FOT	Other free-living fungiids
COS	*Coscinarea*	CM	Other massive corals
CYP	*Cyphastrea*	OULA	*Oulastrea*
DIP	*Diploastrea heliopora*	OULO	*Oulophyllia*
ECHY	*Echinophyllia*	OXY	*Oxypora*
ECHI	*Echinopora*	PACE	*Pachyseris* (encrusting)
EUP	*Euphyllia*	PACF	*Pachyseris* (foliose)
FAV	*Favia*	PAV	*Pavona*
FVI	*Favites*	PEC	*Pectinia*
CMR	Circular mushroom corals	PLAT	*Platygyra*
GAL	*Galaxea*	POC	*Pocillopora*
GONIA	*Goniastrea*	PORB	*Porites* (branching)
GONIO	*Goniopora*	PORE	*Porites* (encrusting)
HEL	*Heliopora*	PORM	*Porites* (massive)
HYD	*Hydnophora*	SER	*Seriatopora*
ISO	*Isopora*	STY	*Stylophora*
LEPA	*Leptoria*	SYM	*Symphyllia*
LEPS	*Leptoseris*	TUBI	*Tubipora musica*
LOB	*Lobophyllia*	TURB	*Turbinaria*
MER	*Merulina*		

Appendix 5. Condition of vegetation on Bird Islet and South Islet

Condition of vegetation on Bird Islet, May 2006 (baseline year), and 2019 to 2021

Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2006	2019	2020	2021	2006	2019	2020	2021	2006	2019	2020	2021	2006	2019	2020	2021	2006	2016	2018	2019
Dead trees																	82	75	ND	ND
Mature, live trees (> 3 feet)	10	0	0	0	49	2	0	0	11	0	0	0	70	2	0	0				
Small, live trees (2- 3 feet)	109	0	3	13	0	3	0	0	0	0	0	10	109	0	332	23				
Seedlings (< 1 feet)	50	12 *)	0	0	0	0	0	0	0	0	0	0	50	12	0	0				
Total	169	12	3	13	49	5	0	0	11	0	0	10	229	14	332	23	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 Coco Palms: 2018: 3, 2019: 2, 2020: 0, 2021: o																			

Condition of vegetation on South Islet May 2011 (baseline year), and 2019 to 2021

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

Coco Palms 2011: 13, 2016: 6, 2017:6, 2018:10, 2019:6, 2020:7, 2021: 3

Appendix 6. Advice on enhancing survival rate of Beach forest seedlings and saplings

(Dr. Agustin R. Mercado, Jr. PhD in Agricultural Sciences (specialized in agroforestry and, nutrient cycling, World Agroforestry Centre, Research Manager for ICRAF Mindanao)

Beach cabbage *Scaevola taccada* and Anuling *Pisonia grandis* can be planted/propagated using cuttings as they are softwood. Plant them during the start of the rainy season. Use 30-40 inches cuttings.

Heliotrope tree *Heliotropium arboreum* is a hardwood and grows very slowly. It is difficult to propagate it through cuttings, but it produces lots of seeds. You can improve seed germination by soaking the seeds with Giberrellic acid. This can be propagated using plastic bags in a nursery.

A. Cuttings

1. To dramatically increase the percentage of survival, dip cuttings with root hormone using ANAA or IBA or both, e.g., Dip N Grow.

B. In nursery, prior to planting

1. Allow the seedling/sapling to recover for two weeks under shade up to 80%.

2. While under shade, irrigate with water diluted with root hormone auxins, e.g. Hormex (it contains ANAA, IBA and Vitamin B1) at the rate of 40 ml for a drum of water (200 liters). Dose precisely as recommended by the manufacturer.

3. After two weeks, reduce shade up 40% for a week and 20% for the following week.

4. 3 days before planting, do not irrigate the seedlings to keep the soil and root intact. When transporting the seedlings do not hold the stem, but at brim of the plastic bags or the root container.

C. Planting

1. Planting holes should be large: 30-40cm3. At planting, apply Dofus (0-20-0) or any fertilizer containing high Phosphorus (P), about 50 grams for root development. Avoid Nitrogen (N) fertilizer at basal because it burns the roots.

2. Cover the fertilizer with soil. Apply 1 kg compost and cover with soil. At planting, cut 1 cm at the bag bottom of the bag to cut curling roots. Slit the side of the bag up to 3/4. Bring the seedling with the plastic bag to the hole without breaking the seedling ball. Fill the side of the seedling bag up to the slit (3/4).

3. Hold the stem upright while pulling gently the plastic bag. Fill the planting hole completely and compact the soil lightly around the seedling making sure no air circulation happening. Water the plants after planting.

4. Put shade or coconut fronds at the east side of the seedlings. Remove shade after 2-3 weeks.

Appendix 7. Results of Park Rangers' inventory counts, August and November 2020 and January, February and Aug 2021 at Bird Islet and South Islet

Bird Islet	2020				2021								
Species/Date	13 Aug	12 Nov			18 Feb			27-28 May			12 Aug		
Brown Noddy	Day Count	Day Count	In-flight	Total	Day Count	In-flight	Total	Day Count	In-flight	Total	Day Count	In-flight	Total
Adult	616	1325	no count	1,325	1912	no count	1,912	798	No count	>798	405		405
Juveniles	85	31		31	0		0	137		137	3		3
Pullus	4	3		3	67		67	28		28	12		12
Eggs	9	61		61	313		313	68		68	2		2
Nests, empty	98	305		305	0		0	166		166	235		235
Nests, Total	139	475		475	380		380	399		399	249		249
Black Noddy													
Adult	631	774	no count	774	1,378	No count	1,378	1,414	No count	1,414	1) 1,118		1,118
Juveniles	10	12		12	15		15	31		31	20		20
Pullus	20	23		23	6		6	35		35	9		9
Eggs	46	113		113	202		202	95		95	100		100
Nests, empty	102	196		196	472		472	546		546	710		710
Nests, Total	178	344		344	695		695	707		707	839		839
Great Crested Tern													
Adult	43	8		8	2,356		2,356	7,644		7,644	1,228		1,228
Juveniles	8	0		0	0		0	0		0	24		24
Pullus/ Juvenile	0	0		0	0		0	3,319		3,319	3		3
Eggs	0	0		0	0		0	503		503	0		0
Sooty Tern													
Adult	0	8,902		8,902	2,063		2,063	6,000		2)6,000	3) 5,583		5,583
Juveniles	0	0		0	0		0	0		0	3,844		3,844
Pullus/juvenile	0	288		288	987		987	1		1	250		250
Eggs	0	4243		4,243	1		1	593		593	636		636

Masked Booby													
Adult	2	2		2	0		0	2		2	2		2
Pullus	0	1		1	0		0	0		0	0		0
Eggs	1	0		0	0		0	1		1	1		1
Red-footed Booby													
Adult	139	155	173	328	761	32	793	97	224	321	210	69	279
Sub-adult	10	2	8	10	3	3	6	5	20	25	8	13	21
Juvenile	0	2		2	0		0	5		5	0		0
Pullus	0	0		0	2		2	6		6	10		10
Eggs	3	3		3	26		26	6		6	47		47
Nests, empty	21	4		4	32		32	25		25	42		42
Nests, Total	24	8		8	58		58	42		42	89		89
Brown Booby													
Adult	3,388	1,210	1,908	3,118	1,373	576	1,949	2,358	1,352	3,710	1,125	1,137	2,262
Sub-adult	25	352	30	382	6	82	88	3	18	21	61	18	79
Juvenile	3	63		63	13		13	4		4	82		82
Pullus	610	388		381	10		10	168		168	1,054		1,054
Eggs	1,210	71		71	25		25	1,492		1,492	1,039		1,039
Nests, empty	414	357		357	623		623	750		750	550		550
Nests, Total	1,694	851		851	664		664	1,855		1,855	2,192		2192

Bird Islet: Note 1) 1,678 adults based on nests. Note 2) Night estimate Note 3) 9,460 adults based on numbers of offsprings and eggs

South Islet	2020				2021								
Species/Date	14 Aug	14 Nov			14 Feb			31 May			11 Aug		
	Day Count	Day Count	In-flight	Total	Day Count	In-flight	Total	Day Count	In-flight	Total	Day Count	In-flight	Total
Brown Noddy													
Adult	1488	2	No count	2	816	No count	816	904	No count	904	734		734
Juvenile	1080	0		0	0		0	152		152	18		18
Pullus	57	0		0	0		0	89		89	18		18
Eggs	61	0		0	320		320	109		109	114		114
Nests, empty	598	0		0	88		88	102		102	341		341
Nests, Total	744	0		0	408		408	452		452	491		491
Black Noddy													
Adult	631	12	No count	1	444	No count	444	1462	No count	1462	1331		1331
Juvenile	10	0		0	0		0	79		79	78		78
Pullus	20	0		0	0		0	62		62	70		70
Eggs	46	1		1	92		92	228		228	324		324
Nests, empty	102	102		102	130		130			362	763		763
Nests, Total	178	103		103	222		222	731		731	1235		1235
Great Crested Tern													
Adult	232	0		0	0		0	5,732		5,732	949		949
Juvenile	115	0		0	0		0	256		256	60		60
Pullus	1	0		0	0		0	872		872	7		7
Eggs	0	0		0	0		0	1,790		1,790	0		0
Sooty Tern													
Adult	0	0		0	0		0	0		0	1		1
Juvenil	0	0		0	0		0	0		0	0		0
Pullus	0	0		0	0		0	0		0	0		0
Eggs	0	0		0	0		0	0		0	0		0
Red-footed Booby													
Adult	117	84	189	273	128	no count)	128	81	20	101	126	110	236

Sub-adult	1	3	62	65	3	no count)	3	3	2	5	1	28	29
Juvenile/Pullus	0	4		4	1		1	3		3	3		3
Eggs	10	0		0	32		32	8		8	52		52
Nests, empty	39	5		5	31		31	20		20	16		16
Nests, Total	49	9		9	64		64	31		31	71		71
Brown Booby													
Adult	166	120	67	187	289	no count)	289	6	84	90	69	31	100
Sub-adult	3	3	2	5	11	no count)	11	3	3	6	3	3	4
Juvenile	0	0		0	0		0	0		0	0		0
Pullus	0	2		2	0		0	0		0	3		3
Eggs	3	0		0	0		0	4		4	5		5
Nests, empty	4	2		2	2		2	2		2	1		1
Nests, Total	6	4		4	2		2	6		6	8		8

Appendix 8. Population results and population trend of breeding seabirds in TRNP April to June 1981 – 2021

Inventory baseline years are underlined. Source: Kennedy 1982, Manamtam 1996, WWF Philippines 1998-2004 and TMO 2004-2021

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	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	- 15
Masked Booby	0	0	0	0	0	0	1	1	1	1	2	2	
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	+ 28
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	- 48
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	- 25
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	+ 13
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	- 1
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	- 36
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	+ 8
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	- 14

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 2020 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.

Appendix 9. Seabird breeding data from Bird Islet and from South Islet, 2nd Quarter (mainly May) 2004-2021

Source: WWF Philippines 2004 and TMO 2004 to 2021

Species/Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Red-footed Booby																		
Immatures	398	1,455	606	597	780	477	677	795	799	426	134	206	80	97	89	104	24	30
Pulli/1st year juv.	> 35	71	105	116	69	180	88	171	243	312	277	240	49	43	39	14	8	8
Eggs	+	+	+	+	+	+	+	68	>166	>185	>57	>46	> 49	55	74	26	>7	14
Nests	279	217	225	404	361	367	451	369	739	848	431	379	315	177	223	72	43	73
Brown Booby																	Note 1	
Immatures	0	81	26	55	55	61	126	110	140	62	51	28	66	157	264	218	35	27
Pulli/1st year juv.	43	2	7	12	91	126	125	225	46	28	266	200	22	175	95	8	8	172
Eggs	1	0	18	95	317	48	106	52	69	532	466	55	144	43	25	6	286	1,496
Nests	117	43	250	89	497	453	513	575	507	618	816	726	887	886	376	412	1,054	1,861
Brown Noddy																	Note 2	Note 6
Immatures	0	2	0	0	0	4	1	1	2	3	5	2	0	2	14	9	0	0
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	0	0	6	109	223	493	68	79	406
Eggs	0	0	0	3	17	126	438	253	>147	>607	679	571	620	1,005	581	183	615	177
Nests	115	124	20+	25+	218	384	653	571	709	771	931	960	1,048	1,917	1,644	805	1092	851
Black Noddy																	Note 3	Note 7
Immatures	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	o	0
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	0	0	30	193	8	74	d39	40	207
Eggs	ND	+	0	+	+	430	+	+	>80	>700	>351	>299	>191	406	468	254	269	323
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
Great Crested Tern																	Note 4	
Immatures	0	1	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
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
Sooty Tern																	Note 5	
Immatures	0	0	0	0	0	0	0	0	0	0	0	0	1	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
Eggs	9	0	0	63	2	3	5,515	2	1,534	146	37	52	166	0	4,964	3	14	593

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 1,1,700 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 14 Feb 2021 92 eggs

Appendix 10. In-flight to roost statistics of boobies and noddies on Bird Islet May 2005 to May 2021

Species/ Numbers	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	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
	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
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
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
%-in-flight population	55%	65%	78%	51%	69%	56%	55%	81%	48%	46%	29%	25%	25%	43%	44%	72%	70%
Average In-flight (%)	53.6%																
Immature: Daytime	514	>205	275	239	179	194	106	174	125	61	111	8	29	24	27	5	5
In-flight	588	401	295	541	298	483	483	249	149	5	37	17	40	20	34	16	20
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
%-in-flight population	65%	69%	54%	69%	63%	71%	82%	59%	54%	8%	25%	25%	25%	45%	56%	76%	80%
Average In-flight (%)	54.5%																
	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
In-flight	360	225	326	368	368	508	508	819	722	798	848	1,202	1,278	2,072	727	1,640	1,352
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

%-in-flight population	48%	37%	35%	35%	36%	35%	28%	44%	43%	49%	36%	25%	25%	62%	25%	65%	47%
Average In-flight (%)	39.7%																
Immature: Daytime	22	20	21	20+?	22	30+	96	81	30	13	1	25	74	127	187	16	3
In-flight	37	6	31	34	39	96	14	59	32	39	25	41	78	105	30	19	18
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
%-in-flight population	73%	23%	62%	63%	64%	76%	13%	42%	50%	76%	96%	62%	51%	45%	14%	26%	86%
Average In-flight (%)	54.2%																
	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 11.In-flight to roost statistics of boobies and noddies on South Islet May 2014 to 2021

Species/ Numbers	2014	2015	2016	2017	2018	2019	2020	2014	2015	2016	2017	2018	2019	2020	2021
	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	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
<u>Adult:</u> Daytime	401	366	508	584	262	154	32	7	22	40	31	160	41	73	81
In-flight	910	1,020	1,018	633	355	282	198	2	28	24	11	144	158	376	20
Adjusted to 2-hour period	1,820	-	-	-	-	-	-	4	-	-	-	-	-	-	-
Total	2,221	1,386	1,526	1,217	617	436	230	11	50	64	42	304	199	449	101
% in-flight population	82.0	73.6	66.7	52.0	57.5	64.7	86.1	18.2	56.0	37.5	26.2	47.4	79.4	83.7	19.8
<u>Average</u>	46.0							46.1							
<u>Immature:</u> Daytime	68	58	32	27	22	43	5	0	2	0	4	32	1	16	3
In-flight	1	No count	21	1	23	27	4	0	No count	No count	1	0	4	16	2
Adjusted to 2-hour period	2	-	-	-	-	-	-	0	-	-	-	-	-	-	-
Total	70	> 58	63	28	45	70	9	0	>2	0	5	32	5	32	5
% in-flight population	2.9%	-	33.3%	3.6%	51.1%	38.6	44.4	0	-	-	20.0	0	80.o	50.0	40.0
<u>Average</u>	29.0							38.0							

Species	Black and Brown Noddy					
	Year	2015	2016	2017	2018	2019
	(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
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
In-flight			1,461	681	0	249
Adjusted to 2-hour period			-	-	-	-
Total			4,382	2,028	0	676
% in-flight population			33.3	33.6	0	36.8
Average	25.9					
	Black Noddy					
Adult: Daytime			1,205	832	60	948
In-flight			605	654	19	171
Adjusted 2-hour period			-	-	-	-
Total			1,810	1,486	79	1,119
% in-flight population			33.4	44.0	24.0	15.3
Average	29.2					

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 12. Systematic list of avifaunal records from South Islet, Bird Islet, and Ranger Station, Tubbataha Reefs Natural Park from 26 to 31 May 2021

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 (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	Barred Rail *Gallirallus torquatus*	0 0	Bird Islet South Islet	One bird counted during inventory on Bird Islet 18 February 2021
Migrant U common LC	Sanderling *Calidris alba*	2	Bird Islet	
Migrant Fairly common LC	Ruddy Turnstone *Arenaria interpres*	0 0	Bird Islet South Islet	Outside of the May 2021 inventory period, in 2020 3 individuals were counted on 13 August, 8 birds on 18 September, 5 individuals on 14 October and 20 birds on 12 November 2020. In 2021, 10 birds observed on 18 February,10 individuals on 15 March and 11 individuals on 11 -12 Aug 2021
Resident Locally Rare VU	**Brown Noddy** *Anous stolidus*	Adults: 798 Juveniles: 137 Pullus: 68 Nests: 399 Eggs: 68	Bird Islet	1,912 adults with 380 nest on 18 Feb 2021. Empty nests likely undercounted as they are difficult to identify
		Adults: 904 Juveniles: 152 Pullus: 89 Nests: 452 Eggs: 109	South Islet	On 14 February 2021, 816 adults with 408 nests containing 320 eggs
Resident Locally Rare EN	**Black Noddy** *Anous minutus*	Adults: 1,414 Juveniles: 31 Pullus: 35	Bird Islet	Adults per nest count. All breeding birds were

		Nests: 707 Eggs: 95		found on the artificial breeding structures On 18 Feb 2021, 1,378 adults with 695 nests
		Adults: 1,462 Juveniles: 79 Pullus: 62 Nests: 731 Eggs: 228	South Islet	All breeding birds were found on the artificial breeding structures On 14 Feb 2021, 444 adults with 222 nests. In addition 80 adults on the ground without nests
Resident Fairly Common VU	**Great Crested Tern** *Thalasseus bergii*	Adults: 7,644 Pullus: 3,319 Eggs: 503	Bird Islet	A substantial decline compared to May count in 2020
		Adults: 5,732 Juveniles: 256 Pullus: 872 Eggs: 1,790	South Islet	Adult numbers based on nest count. Actually counted = 868 adults. First breeding since 2003. New larger sand habitat makes breeding more possible
Resident Locally Rare VU	**Sooty Tern** *Onychoprion fuscata*	Adults: 6,000 Pullus: 1 Juv: 0 Eggs: 593	Bird Islet	Nigh estimate. On 12 Aug 2021 9,460 adults based on numbers of offsprings and eggs.
		Adults: 0	South Islet	
Migrant Locally uncommon LC	Great Frigatebird *Fregata minor*	Adults: 0 Juvenile: 1	Bird Islet	
		Adults: 0 Juvenile: 1-2	South Islet	
Migrant Locally uncommon LC	Lesser Frigatebird *Fregata ariel*	Adults: 0 Juvenile: 3	South Islet	
	Unidentified Frigatebirds *Fregata sp*	3	Bird Islet	In 2021, 2 birds on 14 March 2021 and 3 on 11 August 2021
		29	South Islet	Highest counts since the May 2020 inventory includes 29 individuals on 14 August 2020 and 21 on 13 August 2021
Rare CE	**Masked Booby** *Sula dactylatra*	Adult: 2	Bird Islet	Noted with eggs in August 2020 which produced one pullus observed in November. It

				grew to juvenile stage but was found dead on 20 January 2021. Since then, two breeding attempts with courtship observed: The first in March resulting in two eggs in April and in June 2021. On 12 August, no eggs and a second courtship was observed, and on 17 August they had one egg which was lost around 1 September 2021.
Resident Locally uncommon LC	Red-footed Booby *Sula sula*	Adults: 321 Immatures: 25 Pulli/juv.: 11 Nests: 42 Eggs: 6	Bird Islet	Nests of 33 pairs breeding on the structures for Black Noddy were removed On 18 Feb 2021, 793 adults with 58 nests
		Adults: 101 Immatures: 5 Pulli/juv.: 3 Nests: 31 Eggs: 8	South Islet	Nests of 32 pairs breeding on the structures for Black Noddy were removed On 14 Feb 2021 128 adults with 64 nests
Resident Rare EN	Brown Booby *Sula leucogaster*	Adults: 3,710 Immatures: 21 Pulli/juv.: 4 Nests: 1,855 Eggs: 1,492	Bird Islet	Only average of 2,190 adults estimated at dawn. MPR data shows > 3,000 adults in the months of August and November 2020, and 4,384 adults in August 2021
		Adults: 90 Immatures: 6 Nests: 6 Eggs: 4	South Islet	
Resident Uncommon LC	Pacific Reef Heron *Egretta sacra*	Adults: 3 Nests: 0	Bird Islet	Up to 6 birds on 14 March 2021
		Adults: 4 Nests: 0	South Islet	Outside of the May 2021 inventory period, up to 8 dark phased birds on 16 October 2020 and 8 on 15 March 2021
Resident Common LC	Eurasian Tree Sparrow *Passer montanus*	0	Bird Islet	
		0	South Islet	

Appendix 13. Comparison of the landscape and habitats seen from the Permanent Photo Documentation Sites on Bird Islet and South Islet, May 2004 and May 2021

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: 7 shots (Stitched by Microsoft ICE) Date: 28 May, 2021 Photo Doc Site NI No. 01 - 2021

Viewing angle for photo: facing NE 038°

Film no: 27, 28

Photo no (camera):

Photo name code: BI 02

Photo no (negative):

Photo name code: BI 02

Comments: 6 shots

Photo Doc Site NI No. 02 – 20201

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

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

Photo Doc Site NI No. 04 - 2004

Viewing angle for photo: facing E 067°

Film no: 14

Photo no (negative):

Photo name code: BI 04

Photo no (camera):

Comments: 1 shot Plaza

Date: May 7, 2004

Photo name code: BI 04

Comments: 8 shots Plaza

Date: 28 May, 2021

Photo nos.: DSC_0654-0661

South Islet:

Viewing angle for photo: facing S 060°

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

Photo taken behind the old nipa hut

Photo name code: SI 01

Date: 31 May 2021

Comments: single shot including new lighthouse at the background

Coordinates for new photocdoc site was taken in 2019

Appendix 14. TRNP Water Quality Parameters and Methods of Analysis

Parameter	Description	Method of Analysis
A. 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
B. 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 15. Water Quality Parameters Per WQ Monitoring Stations 2014-2021

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

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

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

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	<1.1	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

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

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

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

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

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	30.5	5	8.79	6.6	1.8	0.36	no data	23	23	22746	<0.003	5	28.8
2020	7	30.3	<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

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

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

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

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

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

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

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

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

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

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

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