TUBBATAHA REEFS NATURAL PARK

WORLD HERITAGE SITE

ECOSYSTEM RESEARCH & MONITORING REPORT 2024

Tubbataha Reefs Natural Park and World Heritage Site

Ecosystem Research and Monitoring Report 2024

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Executive Summary

Reef Benthos. The shallow areas of TRNP exhibited an average hard coral cover (HCC) of 24.2%. This is roughly 1% lower than the average HCC reported in 2023 (25.6%). From 2012 to 2024, hard coral cover declined annually at a rate of 1.2% per year. With the decline in HCC, almost all stations in the shallow areas experienced an increase in algal assemblage cover. However, differing trends between monitoring stations suggest that highly localized stressors influence these changes. A slightly higher HCC (26.4%) was recorded in the deep areas in 2024. Although a 3.7% decline was recorded between 2023 and 2024, long-term data showed that the HCC in the deep sites does not show significant changes. Nevertheless, these non-significant values may be attributed to limited sample size or data fluctuations between years.

Reef fish. The average biomass of reef fish in TRNP was 117.5 g/m². The shallow stations have been experiencing a decline in density over the years, while biomass remained relatively stable. This suggests the presence of larger individuals in the population. The deep areas were significantly declining in both density and biomass. Long-term declines may be attributed to habitat degradation, declines in HCC, and heightened sea surface temperature (SST). Despite these declines, the values in TRNP far exceeded the minimum standard set for a healthy reef fish population in the Philippines.

Ship Grounding Sites. The HCC of both grounding sites- Min Ping Yu (MPY) and USS Guardian (USSG)- was generally low, with HCC values ranging from 1.33 to 24.7%. Over the years, monitoring plots in MPY showed improvement in HCC, with annual increases ranging from 0.2% (small fragments plot) to 1.3% (adjacent control plot). The recovery in the monitoring plots at USSG was at a much slower pace, with an increase of 0.6% and 0.7% in ground zero and impact border, respectively. The adjacent control plot, on the other hand, recorded a 1.2% annual decline since 2014. The slow recovery in USSG plots may be due to low recruitment levels or the presence of a chronic stressor.

The density and biomass for MPY stations have been fluctuating from year to year, with no clear increase or decrease. Surgeonfish was the largest contributor to the MPY biomass, especially in deep stations. The shallow stations had a more even distribution of biomass among families but are slow to recover due to the sandy substrate. The distance between the deep and shallow stations in MPY (50m) makes it difficult to contextualize the site. The shallow stations of USSG experienced a fluctuating decrease in fish density over the years, but this is not statistically significant. Fish biomass experienced a significant increase, with triggerfish being the largest contributor. The density in deep stations has been decreasing while biomass has been relatively stable.

Seabirds. A total of 31,295 adult individuals from seven breeding species have been recorded in 2024, a 4% increase compared to the census in 2023. Bird Islet hosted 73% of TRNP's breeding population in 2024. Similar to 2023, the most abundant species in 2024 was the Great Crested Tern (*Thalasseus bergii*), accounting for 54% of the total count. The Sooty Tern exhibited a shift in breeding cycle, as they began breeding in January and left before the census was conducted in May. The adult Masked Booby continued to breed in Bird Islet, while the two immatures were seen pairing. The population of the endangered Black Noddy decreased by 15% from 2023, possibly due to the lack of nesting materials around the islets. Habitat restoration on both islets and the construction of nesting structures is vital in the recovery of the population.

Water Quality. Twenty (20) stations were revisited for water quality monitoring, including three at the buffer zone. Class SA, the highest classification of water quality set by the DENR Administrative Order (DAO) 2016-08 and DAO 2021-19 was met for the following parameters: color, suspended solids, fecal coliform, and oil & grease. However, elevated sea surface temperature was recorded in all sites, ranging from 33.15 to 34.95 °C. The elevated SST coincided with the 4th global massive bleaching event. Corals can experience bleaching when SST exceeds 29°C. In the following month (June), coral bleaching was reported in several areas of Tubbataha.

Fish Inventory. This study aims to identify other fish species in TRNP using the roving diver survey method in depths and sites beyond the monitoring area. This year, 281 species were recorded in the outer reefs and 164 within the lagoon. Twenty-three (23) species previously unrecorded, were identified, with 12 unique to the lagoon. Since 2018, a total of 117 species have been added to the TRNP list. Abundance declined from 2018 which was attributed to the increasing SST in the Sulu region and the loss of coral cover, particularly in Jessie Beazley. The continuation of this study is vital to discover unrecorded species, especially within the lagoons where diving is off-limits to tourists, and to monitor the overall trends in abundance of fish in areas not monitored by TMO.

Coral Bleaching. The 2024 bleaching event prompted a bleaching survey in five sites in Tubbataha. Severity of bleaching differed among sites, ranging from 0.04% in Malayan Wreck to 43% in Elbow Mac. When the bleaching survey was conducted, waters have already cooled down, with temperature levels ranging from 29–31°C. A month prior, SST ranged from 33 to 34 °C. In general, bleaching was severe in the western side compared to the eastern side of both atolls. Branching form of genus *Millepora* and *Heliopora* were impacted the most, followed by *Porites* (branching), *Pocillopora*, and *Seriatopora*. Extensive bleaching of *Aglaophenia* beds were also noted at West Wall in the South Atoll.

Benthos Assessment. The continuous decline of HCC in the monitoring stations prompted an assessment of areas outside these stations. A total of 13 stations were assessed to better understand the shallow reefs of TRNP. The average HCC in the stations was at 33.3%, which was higher compared to the monitoring stations. This value corresponds with the reported HCC of TRNP in Licuanan et al. (2017). This survey provided more optimistic values compared to the annual benthos monitoring and suggests that the decline in regular monitoring stations is localized.

Ranger Report. TRNP marine park rangers collect data during their tour of duty. The data they collect throughout the year compliment the monitoring conducted by experts and researchers once a year. The monthly distance and direct counts of seabirds are incorporated in the seabird report.

For the turtle survey, the rangers counted 131 sea turtles near the islets and over the reef flats in June 2024. The biannual beach profiling of Bird Islet gave a better understanding to Bird Islet's coastal contours from 2020-2024. The rangers also weigh and categorize marine debris collected in the park. Data shows that nylon is the largest contributor to marine debris (in terms of weight), outweighing all other categories combined. Coral bleaching observed by the rangers and divers was also recorded.

Introduction

The National Oceanic and Atmospheric Administration announced the occurrence of the 4th global bleaching event (NOAA, 2024). Coral reefs worldwide experienced widespread bleaching and risk of mortality due to elevated sea surface temperatures (Reimer et al., 2024). This event follows previous events in 1998, 2010, and 2015–2016, all of which caused severe bleaching in coral reef ecosystems across many regions (Hughes et al., 2018; Sully et al., 2019).

Elevated sea surface temperatures (SST) and ocean acidification driven by climate change, are major stressors on corals and key triggers of coral bleaching (Glecker et al., 2012). Recovery would be challenging if these stressors persist, leading to coral mortality and triggering cascading effects on reef fish populations, benthic communities, and ecosystem services (Koester et al., 2023; Pratchett et al., 2011; Eddy et al., 2021).

More than 85% of reefs in the Coral Triangle are threatened, not only by climate change, but also by local stressors such as unsustainable fishing practices, pollution, and coastal development (Burke et al., 2012). The Philippines is particularly vulnerable since it is situated at the apex of the coral triangle and is exposed to many of these local and global stressors (Burke et al., 2012; DA-BFAR, 2021). This reinforces the necessity of marine protected areas (MPA's) and effective management strategies.

As one of the most well-protected marine reserves in the Philippines, TRNP plays a critical role in marine biodiversity conservation (Mualil et al., 2019). TRNP remains a benchmark for MPA's in the Philippines by mitigating local stressors through its strict no-take policy and high management effectiveness. Despite this, data show declines in hard coral cover (HCC) and reef fish populations over time (Cadiz et al., 2023; Gedoria et al., 2023). This can be largely attributed to the aforementioned changes in climate.

Data collection for ecosystem monitoring in TRNP dates back to 1999, with the intent to monitor long-term trends in TRNP. Reef benthos, reef fish, and seabirds are monitored annually to analyze current and temporal data. The Ecosystem Research and Monitoring strategy of TRNP is specifically aimed at achieving the following goals:

1. Determine ecosystem health;
2. Generate sound scientific information;
3. Provide basis for formulating strategies;
4. Measure biophysical indicators of management effectiveness.

Beyond regular monitoring activities, this report also includes specialized surveys designed to gather more comprehensive information about Tubbataha. The beach erosion mitigation survey aimed to determine the characteristics of Bird Islet and formulate strategies to mitigate coastal erosion. Reef benthos was assessed apart from regular monitoring to better understand TRNP's reef health as a whole. In response to the 4th global bleaching event, bleaching survey were also conducted. Marine park rangers also collected data on beach profiling, marine debris, and marine turtle populations, which was subsequently integrated into this report.

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1| REEF BENTHOS

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Overview

Coral reefs cover approximately 0.1% of the seafloor (Spalding and Grenfell, 1997; Allen Coral Atlas, 2022) but support an estimated 25% of the world's marine species and provide critical ecosystem services such as food provision and coastal protection to millions of people. These ecosystems have suffered substantial damage, with an estimated half of coral cover lost between 1957-2007 (Eddy et al., 2021) and a third lost in the Philippines in the last decade alone (Licuanan et al., 2019). While reefs in the Coral Triangle have exhibited an ability to recover from past disturbances such as coral bleaching events (Souter et al., 2021), threats remain. Monitoring and data-based management are essential to maintaining coral cover and diversity.

Regular reef monitoring is conducted in Tubbataha Reefs Natural Park to determine the state of reefs and assess the effectiveness of management strategies. It is reported in the Reef Benthos section of the 2023 Coral Monitoring Report that hard coral cover continued to decline in both shallow and deep areas. This report presents the current status of the monitoring stations in TRNP and the spatio-temporal patterns since 2012.

Methods

Study Sites

Twelve monitoring stations were surveyed following a hierarchical sampling design as described by van Green et al. (2011; see Figure 1). Six monitoring sites were situated on separate reefs, with each site consisting of a pair of monitoring stations situated approximately 200 m from each other on the same reef. Each monitoring station covered a 75 m x 25 m area, with the deepest part of the station on the upper reef slope at an approximate tide-corrected depth of 5-6 m. Ten of the 12 monitoring stations have been surveyed annually since 2012. To study the conditions at different depths, the shallow (5 meters) and deep (10 meters) sections of each station were surveyed since 2017, while two (Stations 5A and 5B) have been surveyed in only the shallow areas annually since 2021.

In addition, two monitoring stations were surveyed on the USS Guardian grounding site in the South Atoll and the Min Ping Yu grounding site in the North Atoll, respectively. These monitoring stations consist of three permanent 4 m x 4 m quadrats each and have been monitored annually since 2014.

Data Collection

Each of the 12 monitoring stations were surveyed using the photo-transect method described in Luzon et al. (2019). A 75 m transect was first deployed at the deepest limit of each station following the contour of the reef slope. Four 50 m transects were then deployed parallel to each other on the shallow side of the base transect, with the position of each transect randomized. A 50 m section of each of the five transects was photographed at one-meter intervals using a digital camera enclosed in an underwater housing and mounted on an aluminum monopod; for the base transect, the 50 m section to be photographed was randomized. A total of 250 transect photographs were then processed for each monitoring station.

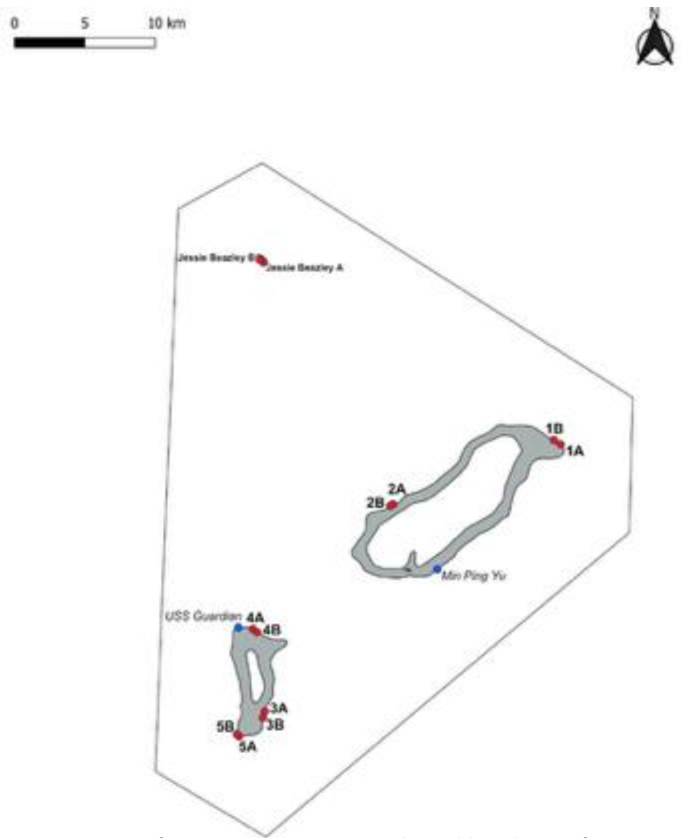

Figure 1. Map of monitoring stations in the Tubbataha Reefs Natural Park

Reef benthos in the deep areas of the monitoring stations were sampled by deploying four 20-meter transects spaced 5 m apart along the same depth and following the reef contour. Photographs were taken at one-meter intervals on the shallower side of each transect using cameras enclosed in underwater housings with wide-angle lenses. The cameras were mounted on 1-meter x 1.2-meter aluminum monopods. A total of eighty images were processed from each deep monitoring station.

Photographs of coral recruits and turf algae were also taken for future analysis. At least ten photographs were taken at random 1 m x 1 x m sections along each transect, with the photos of coral recruits and turf algae being taken within the same sections. The coral recruits were photographed in a random 0.33 m x 0.33 m section of each 1 m 1 m section using a digital camera enclosed in an underwater housing mounted on a PVC tetrapod; at least one metal washer of known diameter was captured in each photo to serve as scale. Turf algae was photographed by placing a level ruler on the highest point of the substrate within each 1 m x 1 m section to capture the height of the turf algae at this point.

Data Processing

The transect images from both the monitoring and assessment stations were processed using Coral Point Count with Excel extensions software version 4.1 (CPCe; Kohler and Gill 2006). Ten random points were overlaid on each of the 250 images per survey station. Each point was identified based on the taxonomic amalgamation units (TAUs) described by Licuanan et al. (2019). The benthos were summarized into six general categories: hard coral (HC), algal assemblage (i.e., bare carbonate rock or carbonate rock with a thin layer of turf algae, recently dead coral, or coralline algae; AA), abiotic material (i.e., sand, silt, or rubble; AB), macroalgae (MA), *Halimeda* (HA), and other biota (i.e. benthic invertebrates other than hard coral; OB). Hard corals were further classified into 59 TAUs representing genus-growth form combinations optimized for the identification of corals in transect images. The average relative cover of each TAU and coral diversity (number of hard coral TAUs; referred to as "coral generic diversity" in Licuanan et al., 2019) between the five transects were reported for each station.

The quadrat images from the USS Guardian and Min Ping Yu grounding sites were processed by randomly selecting 30 images from each quadrat and identifying the benthos in CPCe as described above.

Data Analysis

The average hard coral cover (HCC) and coral diversity were described at the station, site, atoll, and location level and categorized according to the national scales introduced by Licuanan et al. (2019).

Simple linear regression analysis (LR) and one-way repeated measures analysis of variance (ANOVAR) was used to determine significant changes in benthic cover over time. LR was also used to determine the direction and rate of change (i.e., slope) of HC, AA, and sponge (SP) cover from 2012 to 2024 for the shallow monitoring stations and from 2017 to 2024 for the deep monitoring stations. Statistical analyses were performed in RStudio (R Core Team, 2021) and Paleontological Statistics (PAST; Hammer et al., 2001) software.

Results

Present Conditions

Shallow areas

At the location level, the average HCC of the monitoring stations (Sites 1-4) of TRNP was 24.2% ± 2.0 SE, and the average coral diversity was 18.6 ± 0.8. There was no significant difference in HCC between 2023 and 2024 and a small difference in coral diversity for the same period. Both hard coral cover and coral diversity remained in Category C. Table 1 summarizes the hard coral cover and coral diversity (TAU richness) at each level of the hierarchical sampling design.

At the atoll level, both HCC (30.7% ± 2.4) and coral diversity (20.3 ± 0.7) were higher in the North Atoll (Sites 1 and 2) than in the South Atoll (Sites 3-5; HCC: 17.8% ± 2.4; coral diversity: 17.0 ± 1.4). HCC did not change significantly between 2023 and 2024 in either atoll, remaining in Category C. Coral diversity decreased slightly in the South Atoll, moving from Category C to Category D.

Table 1. Summary table for hard coral cover (HCC), TAU density, rates of change in HCC, and differences in HCC among years in the shallow areas. Statistically significant (p<0.05) results from linear regression, ANOVAR, and one-way ANOVA are indicated.

	Average % HCC (± SE) 2024		Average TAU Richness (± SE) 2024		Rate of change in HCC (Linear Regression) 2012-2024	Difference among years in HCC (ANOVAR, p<0.05 is significant) 2012-2024*
	% HCC	Category	TAU Richness	Category		
TUBBATAHA (with JB, without Site 5)	25.6 ± 1.8	C	18.4 ± 0.8	C	⬇ (-1.2%)	p < 0.05
TUBBATAHA (w/o JB, Site 5)	24.2 ± 2.0	C	18.6 ± 0.8	C	⬇ (-0.9%)	ns
ATOLL LEVEL						
North Atoll	30.7 ± 2.4	C	20.3 ± 0.7	C	ns	ns
South Atoll (w/o Site 5)	17.8 ± 2.4	D	17.0 ± 1.4	D	⬇ (-2.1%)	p < 0.05
SITE LEVEL						
Site 1	37.2 ± 2.3	B	22.2 ± 0.8	B	ns	ns
Site 2	24.1 ± 3.2	C	18.4 ± 0.7	C	⬆ (+0.6%)	ns
Site 3	10.6 ± 2.2	D	13.5 ± 1.7	D	⬇ (-3.8%)	p < 0.005
Site 4	24.9 ± 2.8	C	20.4 ± 1.5	C	ns	ns
Site 5	42.0 ± 1.4	B	23.6 ± 0.9	B	⬇ (-2.4%)	ns
Jessie Beazley	31.1 ± 4.3	C	17.4 ± 2.4	D	⬇ (-3.8%)	ns
STATION LEVEL						
Station 1A	31.2 ± 1.4	B	21.8 ± 0.7	C	⬇ (-0.9%)	p < 0.005
Station 1B	43.2 ± 1.9	B	22.6 ± 1.6	B	⬆ (+0.7%)	p < 0.005
Station 2A	15.3 ± 2.2	D	17.2 ± 1.0	D	ns	p < 0.05
Station 2B	33.0 ± 1.4	C	19.6 ± 0.9	C	⬆ (+1.1%)	p < 0.005
Station 3A	10.9 ± 3.5	D	14.2 ± 2.2	D	⬇ (-0.9%)	p < 0.005
Station 3B	10.4 ± 3.2	D	12.8 ±2.8	D	⬇ (-4.5%)	p < 0.005
Station 4A	18.0 ± 2.8	D	18.0 ± 1.8	D	⬇ (-0.7%)	p < 0.05
Station 4B	31.7 ± 2.2	C	22.8 ± 2.0	B	ns	ns
Station 5A	44.4 ± 1.9	A	22.4 ± 1.3	B	ns	p < 0.005
Station 5B	39.6 ± 1.6	B	24.8 ± 1.0	B	ns	ns

Jessie Beazley A	22.2 ± 5.8	C	10.6 ± 1.4	D	⬇(-5.7%)	$p < 0.005$
Jessie Beazley B	40.1 ± 3.3	B	24.2 ± 1.1	B	⬇(-1.4%)	$p < 0.005$

At the monitoring site level, Site 5 had the highest HCC (42.0% ± 1.4) and coral diversity (23.6 ± 0.9), with both falling into Category B. This was lower than the Category A values (HCC: 45.3%; coral diversity: 26.1) reported in 2023. As in 2023, Station 5A had the highest HCC of any monitoring station (44.4% ± 1.9). While this was fairly close to the HCC in Station 5B (39.6% ± 1.6), it was one category higher than the latter, being classified under HCC Category A. Station 5B had the highest coral diversity of any monitoring station (24.8 ± 1.0), although both Stations 5A and 5B were classified under coral diversity Category B (see Figure 2 for a summary of HCC and coral diversity per station).

Meanwhile, Site 3 had both the lowest HCC (10.6% ± 2.2) and coral diversity (13.5 ± 1.7), with both falling into Category D. This was not a significant drop from 2023 (HCC: 13.3% ± 2.9; coral diversity: 14.3 ± 2.7). Stations 3A and 3B had similar HCC (10.9 ± 3.5 and 10.4 ± 3.2, respectively) and coral diversity values (14.2 ± 2.2 and 12.8 ± 2.8, respectively).

Site 1 remained in Category B for both HCC (37.2% ± 2.3) and coral diversity (22.2 ± 0.8), although the latter was slightly lower than it was in 2023 (24.9 ± 0.8). HCC was significantly higher in Station 1B (43.2% ± 1.9) than in Station 1A (31.2% ± 1.4), although both were classified under HCC Category B. Conversely, while Stations 1A and 1B had similar coral diversity values (21.8 ± 0.7 and 22.6 ± 1.6), the former was classified under diversity Category C while the latter fell under Category B.

Site 2, likewise remained in the same category as 2023, with HCC (24.1% ± 3.2) and coral diversity (18.4 ± 0.7) classified under Category C. Stations 2A and 2B differed starkly in terms of HCC. Station 2A was classified under HCC category D, with an HCC of 15.3% ± 2.2%, while Station 2B was classified under HCC Category C with an HCC of 33.0% ± 1.4. Coral diversity was similar between the two stations (17.2 ± 1.0 and 19.6 ± 0.9, respectively), but Station 2A fell under diversity Category D while Station 2B fell under diversity Category C.

Site 4 also remained in Category C for both HCC (24.9% ± 2.8) and coral diversity (20.4 ± 1.5). Station 4A had a much lower HCC (18.0% ± 2.8) and lower coral diversity (18.0 ± 1.8) than Station 4B, with both falling under Category D. Station 4B had an HCC of 31.7% ± 2.2 (Category C) and coral diversity of 22.8 ± 2.0 (Category B).

Lastly, HCC in Jessie Beazley remained in Category C (31.1% ± 4.3) and Category D for coral diversity (17.4 ± 2.4). Both HCC and coral diversity were significantly lower in Jessie Beazley A (22.2% ± 5.8 and 10.6 ± 1.4, respectively) than in Jessie Beazley B (40.1% ± 3.3 and 24.2 ± 1.1, respectively), but these values did not differ significantly from those observed in 2023.

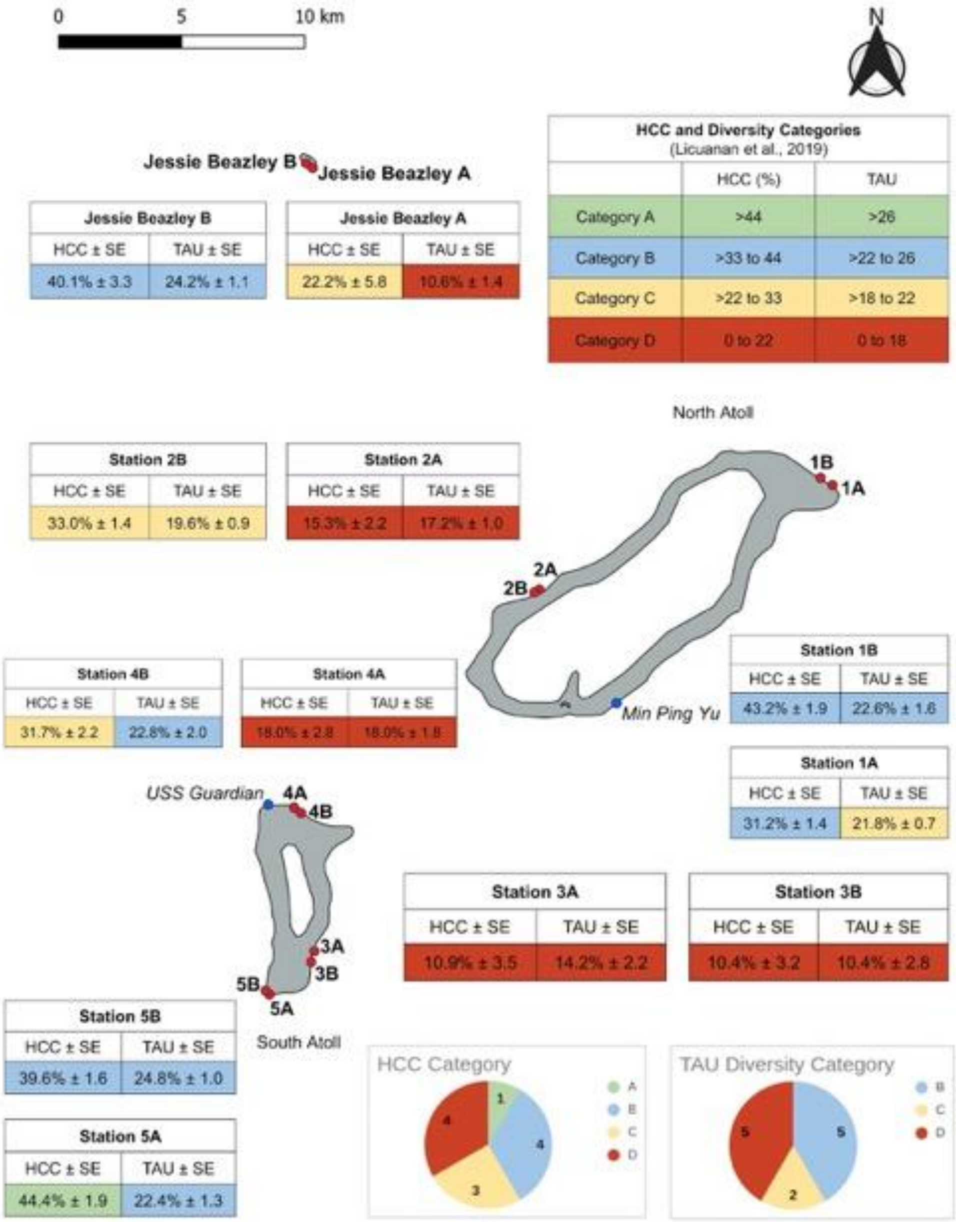

Figure 2. Map of Tubbataha monitoring stations labeled according to hard coral cover (HCC) category and TAU diversity category (Licuanan et al. 2019). 2024 values for average HCC and TAU diversity (± SE) of each station are indicated.

In terms of algal assemblage (AA), the reefs of TRNP had an average percent cover of 59.3% ± 5.1, on par with that observed in 2023 (60.4% ± 2.5). Table 2 summarizes the cover of AA at each level of the hierarchical sampling design. The percentage cover of AA ranged from 32.6% ± 2.6 in Station 1B to as high as 84.0% ± 4.4 in Station 3A. As in 2023, Station 3A had the greatest increase in AA cover, rising from 75.2 ± 2.5 to 84.0% ± 4.4; it was the only station where AA significantly increased between 2023 and 2024. Conversely, Jessie Beazley A had the greatest decrease in AA cover over the same period, dropping from 74.8% ± 1.8 to 65.8% ± 4.0. Percent cover of AA also decreased in Station 1A, Station 2A, and Jessie Beazley A. Sponges were present in all monitoring stations, with an average percent cover of 3.9% ± 1.0. This was not significantly different from 2023 (3.6% ± 0.5). Percent cover of sponges ranged from 0% in Station 3B to 10.8% ± 1.0 in Station 4B. Only three monitoring stations exhibited significant changes in percent cover of sponges between 2023- 2024, with all of them decreasing at a similar magnitude (~1%; see Table 2).

Table 2. Summary table for algal assemblage cover (AA), sponge cover (SP), rates of change in AA and SP, and differences in AA and SP among years in the shallow areas. Statistically significant (p<0.05) results from linear regression, ANOVAR, and one-way ANOVA

	Average % AA (± SE) 2024	Rate of change in AA (Linear Regression) 2012-2024*	Difference among years in AA (ANOVAR, p<0.05 is significant) 2012-2024	Average % SP (± SE) 2024	Rate of change in SP (Linear Regression) 2012-2024*	Difference among years in SP (ANOVAR, p<0.05 is significant) 2012-2024*
TUBBATAHA	57.1 ± 4.8	⬆ +1.8%	ns	3.6 ± 0.9	⬆ +0.2%	ns
TUBBATAHA (with JB, without Site 5)	59.3 ± 5.1	⬆ +1.5%	ns	3.9 ± 1.0	⬆ +0.2%	ns
TUBBATAHA (without JB, Site 5)	61.1 ± 5.2	⬆ +1.5%	p < 0.005	4.6 ± 1.0	⬆ +0.2%	p < 0.005
ATOLL LEVEL						
North Atoll	49.0 ± 0.6	⬆ +0.8%	p < 0.005	5.3% ± 0.1%	ns	p < 0.05
South Atoll (without Site 5)	30.0 ± 3.3	⬆ +2.1%	ns	3.2% ± 0.7%	⬆ +0.4%	ns
SITE LEVEL						
Site 1	40.6 ± 3.11	⬆ 0.8%	p < 0.05	5.4 ± 0.6	ns	ns
Site 2	57.4 ± 3	⬆ 0.9%	p < 0.005	5.3 ± 1	⬆ 0.3%	p < 0.05
Site 3	81.5 ± 3.26	⬆ 3.4%	p < 0.005	0.8 ± 0.4	⬆ 0.2%	p < 0.05
Site 4	65.0 ± 4.54	⬆ 0.8%	p < 0.005	7.0 ± 1.4	⬆ 0.6%	p < 0.05
Site 5	45.8 ± 2.11	ns	ns	1.8 ± 0.4	⬇ -0.4%	ns
Jessie Beazley	52 ± 5.1	⬆ 3.5%	ns	1.2 ± 0.3	ns	ns
STATION LEVEL						
Station 1A	48.7 ± 2.06	⬆ 1.2%	p < 0.005	6.1 ± 0.8	⬆ 0.3%	p < 0.005
Station 1B	32.6 ± 2.64	ns	p < 0.005	4.8 ± 0.9	⬇ -0.6%	p < 0.005
Station 2A	65.1 ± 2.98	⬆ 1.5%	p < 0.005	2.9 ± 0.5	⬆ 0.3%	p < 0.005
Station 2B	49.6 ± 1.3	ns	p < 0.005	7.7 ± 1.1	ns	p < 0.005
Station 3A	84.0 ± 4.41	⬆ 3.0%	p < 0.005	1.6 ± 0.7	⬆ 0.3%	p < 0.05
Station 3B	79 ± 5.03	⬆ 3.8%	p < 0.005	0 ± 0	ns	p < 0.05
Station 4A	76.5 ± 3.64	⬆ 1.4%	p < 0.005	3.2 ± 0.5	⬆ 0.3%	p < 0.005

Station 4B	53.6 ± 3.7	ns	p < 0.005	10.8 ± 1	⬆ 0.9%	p < 0.005
Station 5A	42.7 ± 3.1	ns	ns	0.9 ± 0.2	ns	ns
Station 5B	49 ± 2.37	ns	ns	2.8 ± 0.6	ns	ns
Jessie Beazley A	65.8 ± 4.03	⬆ 1.4%	p < 0.005	6.1 ± 0.8	ns	p < 0.05
Jessie Beazley B	38.3 ± 2.46	ns	p < 0.005	4.8 ± 0.9	ns	p < 0.005

Deep areas

The average hard coral cover in deep areas of Tubbataha was 26.4% ± 1.5 and the average coral diversity (TAU richness) was 20.7 ± 0.8 (Table 3). The HCC decreased by 3.7% from 30.1% in 2023, while the coral diversity increased by 6.7 TAUs compared to 14.5 TAUs in 2023. The North Atoll had slightly higher HCC (29% ± 2.2) compared to South Atoll (23.8% ± 2.3), consistent with the trend observed from 2022-2023. This year, HCC decline became more apparent to Site 4 and Jessie Beazley.

At the site level, Site 1 had the highest HCC at 33.6% ± 3.8 and coral diversity of 23.7 ± 1.1 in 2024. Despite an overall decline in HCC of-2.7%, Site 1 still has the highest HCC of all monitoring stations for three years in a row (2022- 2024). Jessie Beazley had the lowest recorded HCC this year (20.9% ± 5.5) and has experienced a-5.7% decline in one year. At the station level, Station 1B had the highest HCC (39.5% ± 2.3) showing a 9.5% improvement from 2023, with coral diversity of 23.2 ± 1.8 recorded. Station 1A had a coral diversity of 24.7 and experienced the greatest decline of any station in HCC this year, with HCC falling to 25.9% ± 5.7, a 16.6% decline from 2023. Meanwhile, Jessie Beazley A had the lowest HCC of all the stations (10.9% ± 0.4), which declined by-11.6% from the coral cover of 22.5% in 2023. Overall, no significant change in HCC was detected in all stations between 2023 and 2024.

In this year's survey, the reefs of Tubbataha had an average algal assemblage (AA) cover of 26.4% ± 1.5 in 2024, 16.8% higher than in 2023 (9.6%). In the North Atoll, AA cover increased by 24.6%, a fivefold increase from the 4.4% recorded in 2023. The South Atoll saw a more modest increase of 8.6% from 2023. Both atolls exhibited similar patterns of minor and insignificant increases in algal cover between 2023 and 2024; however, both were not significant (Figure 7 and Figure 8). Station level AA cover ranged from 10.9% ± 0.4 in Jessie Beazley A to as high as 39.4% ± 2.3 in Station 1B (Table 4). Amongst the stations, only Jessie Beazley B showed a significant decline in AA from 2017 to 2024 (-1.5% per year). Meanwhile, AA in Station 3B decreased from 37.8% ± 6.5 in 2023 to 15.9% ± 1.2 this year but did not show a significant trend from 2017 to 2024.

Sponges (SP) were also observed in all sampling stations, with an average percent cover of 5.6% ± 0.5 (Table 4). At the site level, SP percent cover declined by-2% in Site 3,-3.8% at Site 4, and-0.7% in Jessie Beazley (2023 to 2024). In 2024, at the station level, SP cover ranged from 2.5% ± 0.6 (Jessie Beazley A) to 8.3% ± 2.5 (Station 1A) (Table 4). Almost all monitoring stations experienced a decrease in SP cover over the last year, the largest of which was in Station 2B, where SP cover fell from 21.6% ± 2.0 in 2023 down to 2.8% ± 1.0 in 2024, but the change was not significant. Between 2023 and 2024, significant declines in SP cover were observed only at Station 3A, Station 4A, 4B, and Jessie Beazley B (-5%,-4.3%, 3.2%, and-1.6, respectively).

Soft corals accounted for 62.9% ± 3.3 of the total benthic cover at Jessie Beazley A, almost double its value in 2023 (36.6%). Furthermore, both stations at Site 4 demonstrated an increase in soft coral cover. In contrast, Station 1B, which previously recorded a 12.4% increase in 2023, experienced a decline of approximately 6.4% this year. Despite this variability, no notable change was observed in the soft coral cover across sites and stations between 2023 and 2024.

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

	Average % HCC (±SE) 2024	Average TAU Richness (± SE) 2024	Rate of change in HCC (Linear Regression) 2017-2024	Difference Among Years in HCC (ANOVAR; p<0.05 is significant) 2017-2024
TUBBATAHA (with JB)	25.3 (± 1.7)	18.1 (±0.5)	ns	p<0.001
TUBBATAHA (without JB)	26.4%% (± 1.5)	20.7 (± 0.8)	ns	p<0.001
ATOLL Level				
North Atoll	29 (± 2.2)	21.2 (± 1)	ns	p<0.001
South Atoll	23.8 (± 2.3)	20.2 (± 1.3)	ns	ns
SITE Level				
Site 1	33.6 (± 3.8)	23.7 (± 1.1)	ns	ns
Site 2	25.4 (± 1.8)	18.7 (± 1)	ns	p<0.0001
Site 3	22.2 (± 2.8)	18.7 (± 1.6)	ns	ns
Site 4	25.5 (± 3.7)	21.7 (± 2)	ns	p<0.05
Jessie Beazley	20.9 (± 5.5)	18.1 (± 0.5)	ns	ns
STATION Level				
Station 1A	25.9 (± 5.7)	24.2 (± 1.8)	ns	p<0.001
Station 1B	39.4 (± 2.3)	23.2 (±1.8)	ns	ns
Station 2A	23.7 (± 2.3)	19.5 (± 2.2)	ns	p<0.001
Station 2B	27.1 (± 3)	18 (± 0.4)	ns	p<0.01
Station 3A	28.5 (± 2.9)	22.7 (± 0.6)	ns	ns
Station 3B	15.9 (± 1.2)	14.7 (± 1.2)	ns	ns
Station 4A	20.8 (± 5.8)	18.5 (± 2.9)	ns	ns
Station 4B	30.1 (± 4.1)	25 (± 2.1)	ns	p<0.001
Jessie Beazley A	10.9 (± 0.4)	17.5 (± 0.6)	ns	p<0.01
Jessie Beazley B	31 (± 8.6)	18.7 (± 0.8)	ns	p<0.001

Table 4. Summary table for percent cover, rates of change, and differences among years in algal assemblage and sponge cover in the deep areas. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated. ns = not significant.

	Average % AA (±SE) 2024	Rate of change in AA (Linear Regression) 2017-2024	Difference Among Years in AA (ANOVAR; p<0.05 is significant) 2017-2024	Average % SP (±SE) 2024	Rate of change in SP (Linear Regression) 2017-2024	Difference Among Years in SP (ANOVAR; p<0.05 is significant) 2017-2024
TUBBATAHA (with JB)	41.5 (± 3)	ns	p<0.0001	5.4 (± 0.5)	ns	p<0.0001
TUBBATAHA (without JB)	26.4 (± 1.6)	ns	p<0.0001	5.6 (± 0.5)	⬇ -0.4%	p<0.0001
ATOLL Level						
North Atoll	29 (± 2.2)	ns	p<0.0001	5.9 (± 0.9)	ns	p<0.0001
South Atoll	23.5 (±2.3)	ns	p<0.0001	5.3 (± 0.6)	⬇ -0.9%	p<0.0001
SITE Level						
Site 1	32.6 (±3.8)	ns	p<0.0001	7.3 (± 1.3)	ns	p<0.001
Site 2	25.4 (±1.8)	ns	p<0.0001	4.6 (±1.2)	ns	p<0.0001
Site 3	22.2 (±2.7)	ns	p<0.0001	4.1 (± 0.6)	⬇ -0.7%	p<0.0001
Site 4	25.5 (±3.7)	ns	p<0.0001	6.4 (± 0.9)	⬇ -1%	p<0.0001
Jessie Beazley	20.9 (±5.5)	⬇ -1.2%	p<0.0001	4.5 (± 1.3)	⬇ -0.8%	ns
STATION Level						
Station 1A	25.9 (± 5.7)	ns	p<0.0001	8.3 (± 2.5)	ns	p<0.1
Station 1B	39.4 (± 2.3)	ns	p<0.0001	6.3 (± 0.8)	ns	p<0.001
Station 2A	23.7 (± 2.3)	ns	p<0.0001	6.5 (± 2)	ns	p<0.01
Station 2B	27.1 (± 3)	ns	p<0.0001	2.8 (±1)	ns	p<0.0001
Station 3A	28.5 (± 2.9)	ns	p<0.0001	3.6 (± 0.7)	⬇ -0.8%	p<0.05
Station 3B	15.9 (± 1.2)	ns	p<0.0001	4.6 (± 0.9)	ns	p<0.0001
Station 4A	20.8 (± 5)	ns	p<0.0001	6.2 (± 1.8)	ns	p<0.0001
Station 4B	30.1 (± 4)	ns	p<0.0001	6.7 (± 1)	ns	p<0.0001
Jessie Beazley A	10.9 (±0.4)	ns	p<0.0001	2.5 (± 0.6)	ns	ns
Jessie Beazley B	31.0 (± 8.6)	⬇ -1.5%	p<0.0001	6.6 (± 2.3)	⬇ -1.6%	p<0.05

Ship Grounding Sites

Min Ping Yu Grounding Site

Hard coral cover was generally low in all permanent plots of the Min Ping Yu grounding site (see Figure 3). In particular, HCC in the "small fragments" plot declined from 3.4% ± 1.0 in 2023 to just 1.33% ± 0.63 in 2024, roughly on par with the 0.3% ± 0.3 observed immediately after the ship grounding in 2014.

HCC in the "large fragments" plot (11.0% ± 3.0%) remained comparable with that observed in 2023 (12.8% ± 2.7). The "adjacent control" plot, on the other hand, experienced an increase in HCC from 15.3% ± 2.9 in 2023 to 24.7% ± 3.7 in 2024, moving from HCC Category D to Category C.

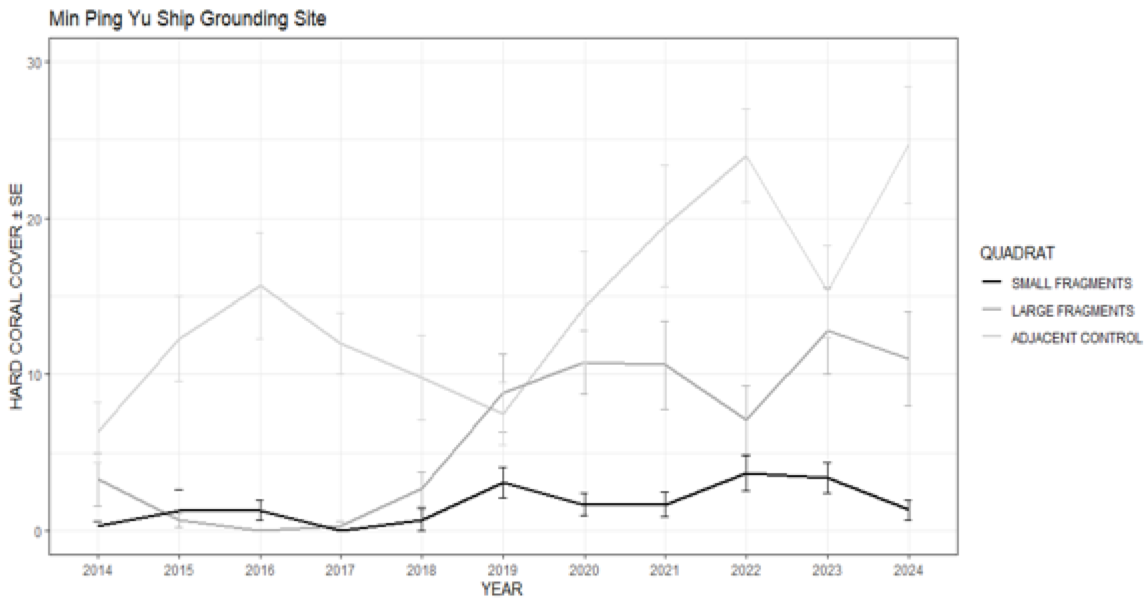

Figure 3. Percent hard coral cover (% HCC) in the Ming Pin Yu ship grounding site from 2014 to 2024. % HCC (± SE) is reported for three fixed plots: small fragments, large fragments, and adjacent control.

USS Guardian Grounding Site

Hard coral cover was low in all permanent plots of the USS Guardian ship grounding site (see Figure 4). The "ground zero" plot, which was directly impacted by the ship grounding, had the lowest HCC at 9.33% ± 2.0, which was not significantly different from the 7.7% ± 1.6 reported in 2023. In the "impact border" plot, HCC also remained steady between 2023- 2024 (11.5% ± 2.2 and 13.7% ± 2.7, respectively). HCC increased from 11.7% ± 1.9 to 18.4% ± 3.5 in the "adjacent control" plot located ~50 m from the impact area.

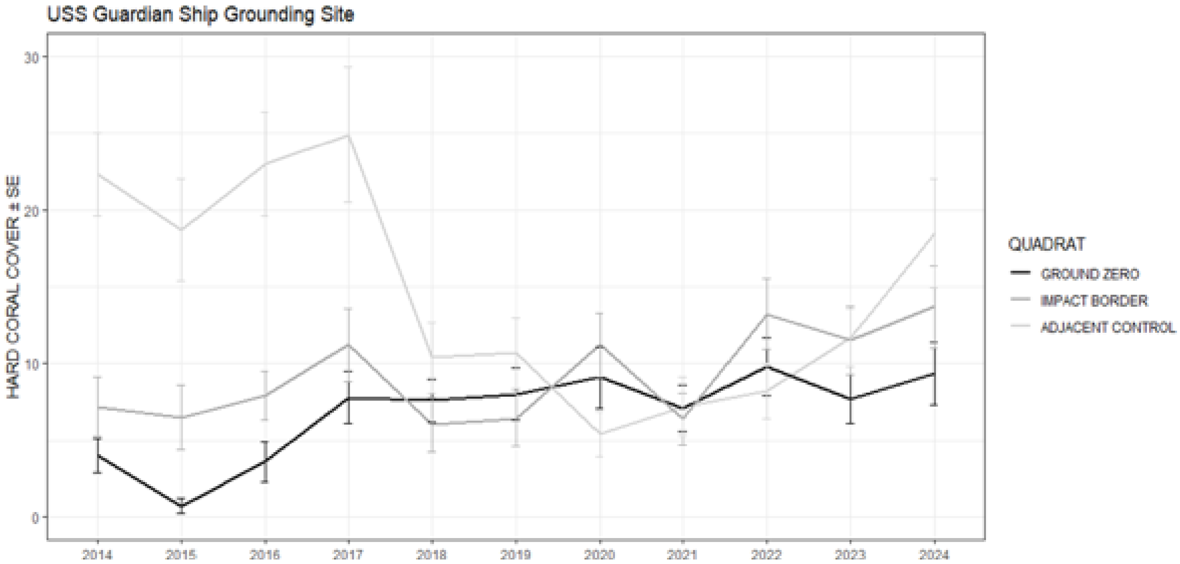

Figure 4. Percent hard coral cover (% HCC) in the USS Guardian ship grounding site from 2014 to 2024. % HCC (± SE) is reported for three fixed plots: small fragments, large fragments, and adjacent control.

Temporal patterns

Shallow areas

Across the monitoring stations in TRNP, there was a declining trend in HCC between 2012 and 2024. Based on linear regression, HCC declined at a rate of 1.2% per year. (Note that this calculation excluded Site 5, which was established in 2021; See Table 1). As there was no significant difference in HCC over this period in the North Atoll, the 2.1% per year decline of HCC in the monitoring stations in the South Atoll (excluding Site 5) drove this declining trend. Further, at the site level, only Site 3 exhibited a significant decrease in HCC, declining at a rate of 3.8% a year.

At the station level, however, nearly all monitoring stations exhibited significant differences in HCC from 2012 to 2024 (see Figure 5, which shows trends in HCC, AA, and sponge cover over time per station). Half of the monitoring stations exhibited declining trends in HCC (see Table 1), with Jessie Beazley A having the highest annual rate of decrease (5.7% per year), followed by Station 3B (4.5% per year) and Jessie Beazley B (1.4% per year). Station 3A, Station 1A, and Station 4A exhibited lower rates of decline (between 0.7% and 0.9% per year; see Table 1). Only two stations, Station 2B and Station 1B, had increasing trends in HCC from 2012 to 2024 (1.1% and 0.7% per year, respectively). Notably, trends in HCC were not consistent within sites, with the stations of Sites 1 and 2 having opposite trajectories. This indicates the factors behind the changes were likely highly localized (e.g., typhoon impacts) and not widespread (e.g., nutrient enrichment).

In terms of algal assemblage (AA), significant differences among the years from 2012 to 2024 were found in the North Atoll, where AA increased at a rate of 0.8% per year. Significant differences were also found in all sites except for Site 5 and Jessie Beazley (see Table 2). Site 3 had the highest rate of increase in AA at 3.4% per year, with Station 3A increasing at a rate of 3.0% per year and Station 3B increasing at a rate of 3.8% per year. Within other sites, however, trends in AA were not consistent between stations. AA in Station 2A increased at a rate of 1.2% per year, but no significant trend was found in Station 1B. Similarly, AA in stations 2A, 4A, and Jessie Beazley A increased at a rate of ~1.5% per year; see Table 2) while their paired stations showed no significant trend. However, nearly all stations exhibited differences among years from 2012 to 2024 based on the results of a one-way ANOVA (see Table 2).

Sponge cover exhibited small but significant increasing trends in Sites 2-4 from 2012 to 2024 (see Table 2). Only Site 5 exhibited a negative, but similarly small, significant trend from 2021 to 2024, although this was not significant at the station level. Paired stations, again, sometimes had differing trends in sponge cover. While sponge cover in Station 1A increased at a rate of 0.3% from 2012 to 2024, sponge cover in Station 1B decreased by 0.6% over the same period. Sponge cover in Stations 2A and 3A both increased by 0.3% per year, while their paired stations showed no significant trends. A one-way ANOVA, however, showed that there were differences between the years from 2012 to 2024. Sponge cover in Stations 4A and 4B increased by 0.3% and 0.9% per year, respectively.

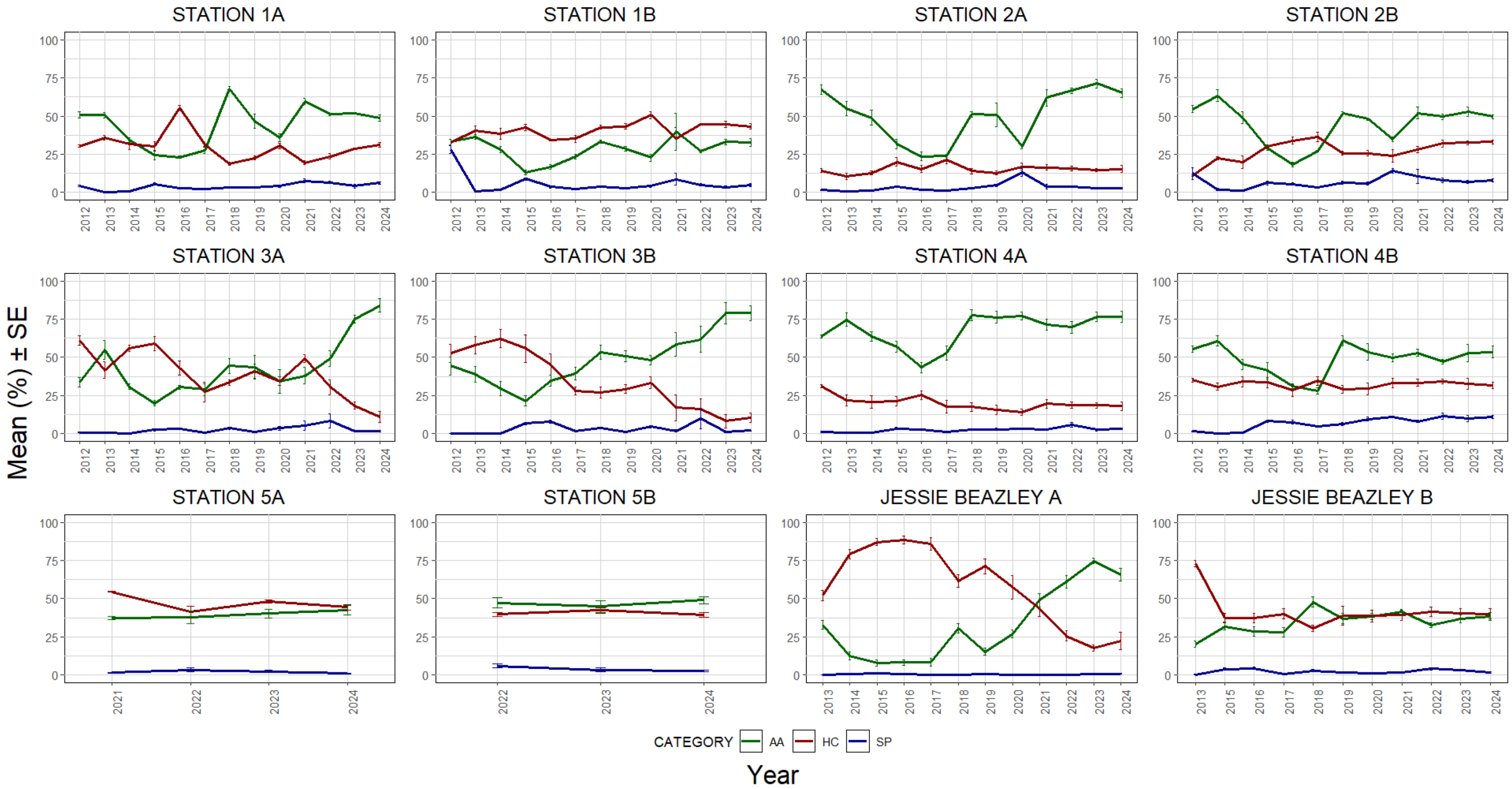

Figure 5. Percent cover of algal assemblage (AA), hard coral (HC), and sponge over time in the monitoring stations.

Deep areas (2017 to 2024)

The average hard coral cover (HCC) at all sites declined from 2017 to 2024, but these changes were not statistically significant (Figure 6). Among the five monitoring sites, Site 4 experienced the largest decline, as the 25.4% ± 3.7 cover in 2024, represented a decrease compared to the baseline measurement of 38.7% ± 2.6 in 2017. This represents an overall annual decline of approximately 1%. Both Sites 2 and 3 showed a gradual increase over time, with a rate of increase of 0.2% per year; however, these variations were statistically insignificant at the site level (Table 3). At the station level, a positive trend in HCC was observed only at Stations 3A, 3B, and Jessie Beazley B from 2017 to 2024, with annual rates of increase of 0.9%, 0.8%, and 0.1%, respectively. In contrast, a total of six monitoring stations exhibited a gradual decline in HCC annually, including Stations 1A, 2A, 3B, 4A, 4B, and Jessie Beazley A.

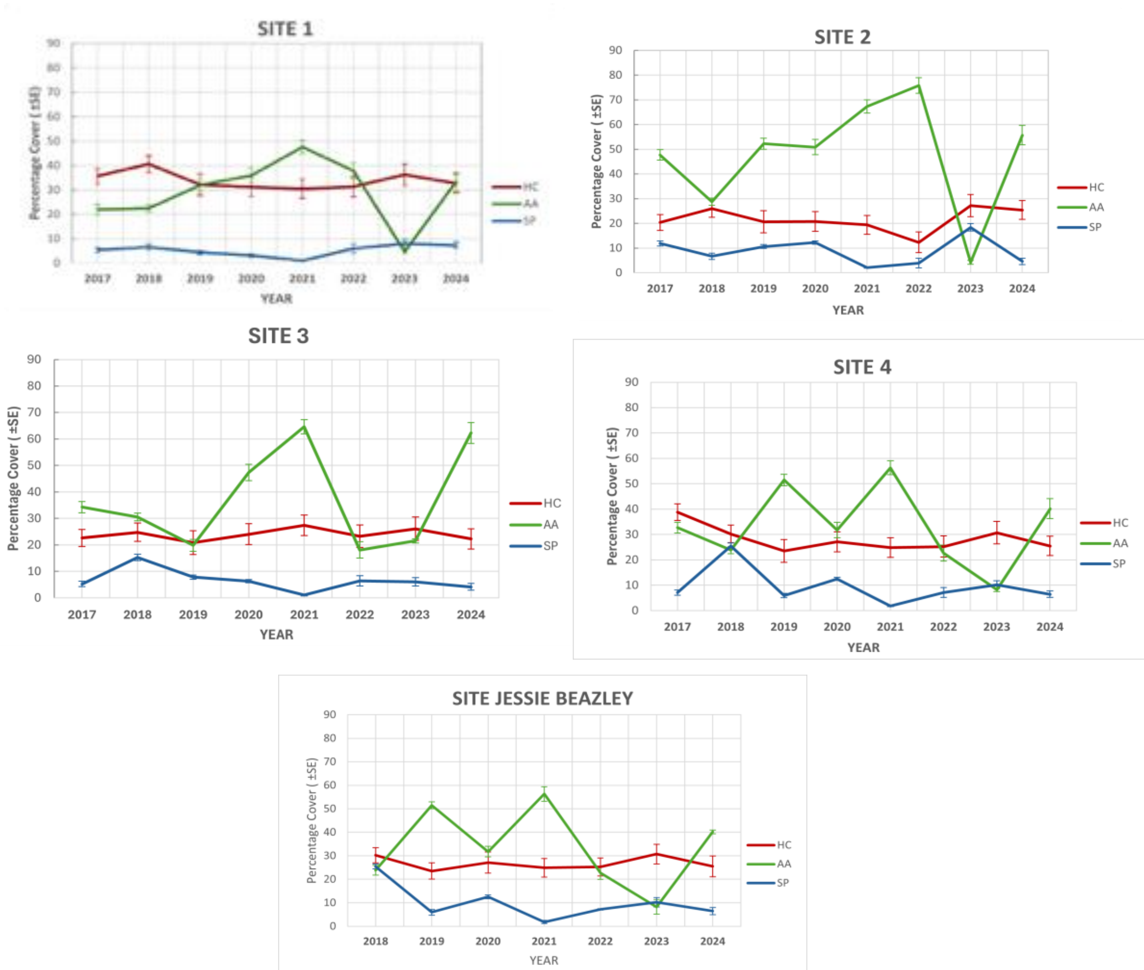

Figure 6. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring sites from 2017 to 2024. Error bars represent +/- one standard error.

Figure 7. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring stations from 2017 to 2024. Error bars represent +/- one standard error.

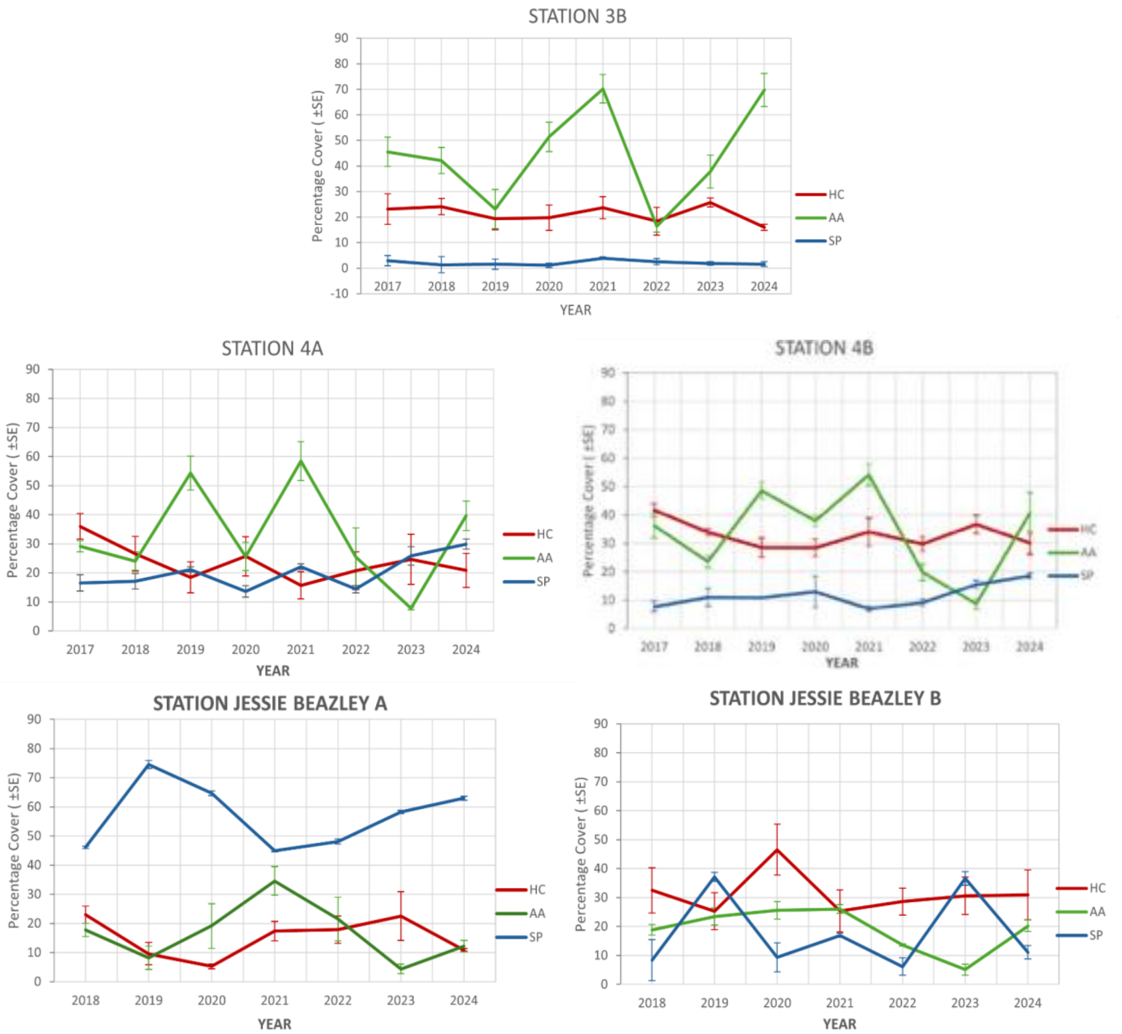

Figure 8. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring stations from 2017 to 2024. Error bars represent +/- one standard error.

In Tubbataha, in terms of algal assemblage, no significant differences were found from 2017 to 2024, despite an annual increase of 0.3%. At the site level, AA cover increased by 0.2% annually since 2017 at Sites 1 and 2 and by 1.9% annually at Site 3, but the values were not significant. In contrast, Site 4 experienced a decline of -1% annually, which was also not statistically significant. Among the five sites, only Jessie Beazley showed a significant decrease in AA cover at a rate of-1.2% annually, with Jessie Beazley B experiencing an annual decline of-1.5% from 2017 to 2024 (Table 4).

Sponge cover declined overall from 2017 to 2024, but the rate of decline varied across the locations, sites, and stations. The Tubbataha atolls and Jessie Beazley both experienced significant decreases, with annual declines of -0.4% (Tubbataha atolls) and -0.8% (Jessie Beazley), respectively. Sites 3, 4, and Jessie Beazley showed consistent negative trends, with annual declines of-0.7%,-1%, and-0.8%, respectively (Table 4). While Site 2 had a rapid decline of-13.8% between 2023 and 2024, an overall annual decline at approximately-0.2% (2017 to

2024) is not significant. At the station level, only Station 3A and Jessie Beazley B exhibited significant decreases. Station 3A had the highest year-on-year decline in SP cover between 2023 and 2024 and an overall decline of -0.8% annually from 2017 to 2024. Jessie Beazley B experienced a decline of-1.6% annually during the same period. Overall, the data indicates a general decline in sponge cover in TRNP from 2017 to 2024, with the rate of decline varying across monitoring stations (Table 4).

Ship Grounding Sites

In the Min Ping Yu ship grounding site, all permanent plots exhibited a positive trend in HCC from 2014 to 2024 despite some fluctuations over time (see, Table 5). HCC increased at similar rates in the "large fragments" and "adjacent control" plots (1.2%- 1.3% per year, respectively). Recovery in the "small fragments" plot, however, was much slower at a rate of 0.2% per year. HCC was generally lower in this plot, and the value observed in 2024 was a small improvement from that observed after the ship grounding in 2013 (3.4% ± 1.0 in 2023 to just 1.33% ± 0.63 in 2024).

Recovery rates in the USS Guardian ship grounding site plots were generally lower than in the Min Ping Yu grounding site despite having comparable or greater HCC (see Figure 4, Table 3). The overall trends in the "ground zero" and "impact border" plots were positive (0.7% and 0.6% per year; see Table 5). HCC in both these plots improved significantly since the ship grounding in 2013, increasing from 4.0% ± 1.1 to 9.33% ± 2.0 in the "ground zero" plot and from 7.2% ± 1.9 to 13.7% ± 2.7 in the "impact border" plot.

The "adjacent control" plot had a declining trend in HCC based on linear regression (-1.2% per year) due to sudden sharp declines in HCC in 2018 and 2020, but HCC has increased gradually since then and is now at par with the 2014 value of 22.3% ± 2.7 (Figure 4).

Table 5. Summary of ordinary least squares linear regression results for % HCC changes in Min Ping Yu and USS Guardian grounding sites from 2014 to 2024. Statistically significant ($p < 0.05$) results are highlighted. ns = not significant ($p > 0.05$).

Plot	Annual rate of change in HCC (%)	Permutation p-value	R^2
Min Ping Yu Grounding Site			
Small Fragments	↑0.2	$p < 0.05$	0.38
Large Fragments	↑1.2	$p < 0.01$	0.71
Adjacent Control	↑1.3	$p < 0.01$	0.54
USS Guardian Grounding Site			
Ground Zero	↑0.7	$p < 0.01$	0.61
Impact Border	↑0.6	$p < 0.05$	0.42
Adjacent Control	↓1.2	ns	0.32

Discussion

Shallow

Hard coral cover across the North and South Atolls (i.e., the whole of TRNP excluding Jessie Beazley) was 27.8% ± 4.1, while coral diversity was 19.6 ± 1.3 TAUs, both classified under Category C according to the national scales proposed by Licuanan et al. (2019). These were slightly lower than the average reported for fringing reefs in the Sulu Sea bioregion of the Philippines (HCC – 28.4%; TAUs- 20.8; Licuanan et al., 2019). While the average HCC was 0.9% higher than that reported in 2023, this difference was not statistically significant and fell below the estimated minimum detectable change for the location (3%; Licuanan et al., 2017b), suggesting that it was likely the result of sampling artifacts rather than an actual increase in HCC. HCC remained similarly unchanged in Jessie Beazley Reef.

At the site level, all changes in HCC between 2023 and 2024 fell below the minimum detectable annual changes (7%; Licuanan et al., 2017b). Significant changes in HCC between 2023 and 2024 could only be detected at the station level, with Station 3A and Station 5A exhibiting decreases in HCC and Station 1A exhibiting an increase. It should be noted, however, that the changes in these stations still fell below the estimated threshold for detection for this location (9% at the station level; Licuanan et al., 2017b).

In Station 3A, HCC fell by 7.5%, with *Isopora* and branching *Acropora* suffering the greatest decreases. This continued the steady trend of decline which began in 2022. There was a concurrent increase in AA during this period. The declining trend in HCC in this station was likely precipitated by successive typhoons in 2021 and 2022 (Typhoons Odette and Paeng, respectively), as the *Isopora brueggemanni* which dominated the coral community in this station is highly susceptible to mechanical damage (Darling et al., 2012). The continued decline between 2023 and 2024 may have been influenced by the passage of Typhoons Egay and Kabayan in July and December 2023, respectively.

The 3.9% decrease in Station 5A between 2023 and 2024 was driven by declines in submassive *Isopora* and encrusting *Montipora*. Again, the passage of Typhoons Egay and Kabayan may have contributed to this decline. However, as the most common corals in this station are much less susceptible to mechanical stress, the mechanism for the decline in HCC may differ from that affecting Station 3A.

Station 1A was the only monitoring station to display a significant increase in HCC, rising by 2.7%. *Pocillopora*, a “weedy” coral genus (Darling et al., 2012), contributed the bulk of this increase.

While only minimal changes in HCC could be detected between 2023 and 2024, the overall trend in TRNP was one of decline. Since 2012, HCC throughout TRNP (excluding Jessie Beazley and Site 5) has declined at a rate of 0.9% per year and by 9.3% in total. After steadily increasing from 2012 and 2015, steep drops in overall HCC were observed in 2017 and 2018. HCC recovered somewhat from 2019 to 2020 before dropping again in 2021 and declining slowly from thereon.

These sudden drops often coincided with acute stressors affecting multiple monitoring stations. Eneria and Licuanan (2017) attributed the steep decline in Site 3 from 2015 to 2017 to damage from drifting logs and metals buoys, although this may not explain the concurrent decline in Stations 1A and 4A. There was no apparent acute stressor which caused the drop in HCC in 2018, which affected half of the monitorin stations (Stations 1A, 2A, 2B, 4B, and Jessie Beazley A).

The passage of several storms through TRNP coincided with drops in HCC. After Tropical Storm Vicky in December 2020, HCC declined in nearly half of the monitoring stations (Stations 1A, 1B, 3B, and Jessie Beazley A) by 2021. Similarly, HCC declined in three monitoring stations (Stations 3A, 5A, and Jessie Beazley A) after the passage of Typhoon Odette in December 2021, and in two monitoring stations (Station 3B and Jessie Beazley A) after the passage of Typhoon Paeng in October 2022. The stations most affected by storms tended to have a high proportion of mechanically fragile corals, such as *Isopora brueggemanni* in Stations 3A and 3B and encrusting and foliose *Montipora* in Station 5A and Jessie Beazley A.

Not all declines in coral cover, however, could be attributed to acute stressors. As previously mentioned, there was no apparent reason for the declines in Stations 3A and 5A between 2023 to 2024. Based on linear regression, Station 4A and Jessie Beazley B exhibited declining trends in HCC since 2012 despite no apparent acute stressors. This decline may be indicative of an unknown chronic stressor (Flower et al., 2017). While Licuanan & Bahinting (2021) suggested that one possible chronic stressor could be increased eutrophication in the South Atoll due to bird guano from an increasing seabird population around that area, this stressor is not widespread throughout TRNP (Cadiz et al., 2023).

Only Station 1B and 2B were found to have increasing trends in HCC. Station 1B was dominated by *Echinopora* and *Millepora* in 2024, while Station 2B was dominated by the fairly sturdy massive *Porites* and submassive *Isopora*, faviids, and encrusting *Montipora*.

Trends based on linear regression, however, should be interpreted with caution, as they fail to account for fluctuations in HCC. It should be noted that HCC in half of the monitoring stations (Stations 1A, 1B, 2A, 2B, 4B, and Jessie Beazley B) has remained relatively stable or increased since 2018.

The changes in AA appear inversely proportional to the changes in HCC, as the rate of decline in HCC of 0.9% per year is coupled with an increase in AA by 1.5% per year. Compared to 2023, decreases in AA are observed in sites where the HCC increased, such as in Sites 1 and 2, and Jessie Beazley; likewise, in Sites 3 and 4, where the HCC decreased, the AA increased.

Turf algae and hard corals have been shown to share a competitive dynamic with each other (Barott et al., 2012; Vermeij et al., 2010). The observed inverse relationship between HCC and AA is indicative of the coral-algal phase shift that is ongoing worldwide, wherein the abundance of turf algae and macroalgae increases as HCC declines (McManus & Polsenberg, 2004; Tebbett & Bellwood, 2019). Possible factors contributing to the phase shift are natural or anthropogenic disturbances, reduced fish herbivory, and/or eutrophication (McManus et al., 2004; Vermeij et al., 2010; Barott et al., 2012; Harris, 2015). As mentioned earlier, some recorded acute and chronic stressors — such as typhoons, floating debris, and eutrophication — may be contributing to the ongoing phase shift among certain stations within the TRNP, but they cannot completely account for the widespread phase shift observed throughout the entire TRNP.

Deep Areas

Hard coral cover declined in the deep monitoring areas across nearly all sites and stations, in contrast with the previous year's gradually increasing trend. At the atoll level, HCC decreased by -3.7%, with a more pronounced decline in the South Atoll (-4.6%) compared to the North Atoll (-2.7%) between 2023 and 2024. South Atoll's HCC decline was primarily driven by a -3.9% decrease at Site 3 and a -5.2% loss at Site 4. Between 2023 and 2024, the deep areas of Site 3, dominated by branching corals like *Acropora* and *Pocillopora*, and massive corals like *Diploastrea* and *Porites*, experienced algal (AA) overgrowth.

Similarly, Site 4, primarily composed of encrusting corals such as *Montipora*, *Echinopora*, and *Porites*, was also impacted by increased algal cover (AA). In North Atoll, Site 1 experienced the most substantial decline in HCC, with stations 1A and 1B decreasing by -16.6% and -9.5%, respectively. In Site 1, both stations dominated by *Echinopora*, *Montipora* and massive coral, e.g., the genus *Porites and Goniopora*. However, between 2023 and 2024, these coral genera appeared to be overgrown by the increasing dominance of AA cover and soft corals. Jessie Beazley A was dominated by soft coral, which rapidly increased to 62.9% in the 2024 survey, and lost approximately -11.6% of HCC over this period (2023 and 2024). However, changes in HCC for the two atolls in Tubbataha and Jessie Beazley were not statistically significant.

Concurrent with some of the notable HCC declines, algal cover (AA) increased by 32.8% (Tubbataha including Jessie Beazley) from 2023 to 2024. While all sites exhibited an increase in AA, this increase was more significant at Jessie Beazley (site level) but was primarily reflected only at Jessie Beazley B (station level), where AA cover increased by 16.1% and 25.9%, respectively in 2023 and 2024. The increase in AA cover corresponds to a significant decrease in sponge cover (SP) observed at Site 3, Site 4, and Jessie Beazley, each declining by approximately -1% from 2017 to 2024, SC continuously proliferated in some monitoring stations.

Over time, SC levels have shown a minimal increase, particularly in Jessie Beazley A, where the observed changes have not reached statistical significance. These changes may be attributed to the impact of two typhoons that struck the reef. Typhoon Egay in July 2023, passing northwest of the Philippines, brought strong winds that exacerbated monsoon conditions in Tubbataha. In December 2023, Typhoon Kabayan directly hit the Sulu Sea, which potentially hindered recovery in the deep monitoring sites. Climate-related incidents may have generated waves that battered the reef, creating spaces for algae to proliferate and potentially contributing to the rapid increase in the area (Hughes et al., 2017; Mumby et al., 2007).

Both stations in Jessie Beazley were observed to have higher SC cover compared to the other stations. In Jessie Beazley A, a continued increase of SC cover at 0.05% was recorded annually. Although this value may seem negligible, visual observations of researchers suggest that SC cover has increased within the area, especially in the area outside the transects. The proliferation of SC in this station should be closely monitored. The proliferation of soft corals in hard coral dominated reefs may be caused by disturbances such as typhoons and high turbidity (McClanahan et al., 2002). Meanwhile, in Jessie Beazley B, the abrupt change observed resulted in a loss of 25.6% in SC cover in 2024 (11%) compared to the 2023 SC cover of 36.6%. This may be due to the sampling bias, which may lead to inconsistent data.

The 2023 data indicate an increase in sand and rubble cover across all study sites. Specifically, at Site 3, the sand and rubble coverage plummeted from 30.8% in 2023 to a mere 0.1% in 2024. Similar reductions were observed at Site 4 (10.8% to 0.6%) and Jessie Beazley (3.8% to 0.5%). These dramatic changes may be attributed to the inconsistent identification of the benthic categories and to the impact of stressors such as past typhoons, which could have created vacant spaces on the reef, potentially facilitating the growth of algal cover. While not directly addressed in this analysis, it is essential to consider the possibility of eliminating or lessening the sampling bias prior to the survey, which is speculated to artificially increase the AA cover in Jessie Beazley, between 2023 and 2024. To mitigate future data variability, refining data collection and processing protocols is recommended.

Ship Grounding Sites

The hard coral cover HCC in both the “large fragments” plot in MPY grounding site exhibited consistent levels between 2023 to 2024, whereas HCC in the “adjacent control” showed an increasing trend during the same period. Both plots had a positive trend in HCC, increasing at a similar annual rate (1.2% and 1.3%, respectively) and exceeding the HCC at the beginning of monitoring in 2014. In the “small fragments” plot, HCC decreased from 2023 to 2024 to a level only slightly higher than that recorded immediately after the ship grounding (1.33% ± 0.63 in 2024 compared to 0.3% ± 0.3 in 2014). This was despite an overall positive trend since 2014 of 0.2% per year.

The majority of HCC in the “large fragments” comprise a few large colonies of massive *Porites*, which, based on their size, likely predated the ship grounding. Small quantities of submassive *Isopora* and *Stylophora* were also present. Meanwhile, HCC in the “small fragments” plot was composed of small colonies of *Pocillopora*, corymbose *Acropora*, and submassive *Isopora*, the former two of which are “weedy” genera. The “adjacent control” plot was also dominated by branching genera, particularly *Pocillopora*, various forms of *Acropora*, and *Millepora*. Massive *Porites* colonies were also present. The “adjacent control” plot was much more diverse than the plots impacted by the ship grounding, with a total of 13 coral TAUs compared to the three present in the other plots. The comparatively erratic and lackluster recovery in the “small fragments” plot might be due to the absence of a stable substrate and large “stress-tolerant” corals.

In the USS Guardian ship grounding site, HCC remained steady between 2023 and 2024 in the “ground zero” and “impact border” plots. HCC in both these plots had a positive trend since the beginning of monitoring (0.7% and 0.6% per year, respectively). While HCC was highest in the “adjacent control” plot and increased between 2023 and 2024, it experienced large drops in 2018 and 2020, and its value in 2024 remains roughly comparable to its 2014 value.

All three plots in the USSG grounding site had a solid carbonate substrate and similar coral diversity, with 9-10 coral TAUs. *Pocillopora* was the most abundant genus, and faviids, massive *Porites*, *Acropora*, and other encrusting corals were also present in all plots. The overall low rate of recovery in this site might be attributed to limited coral recruitment or a chronic stressor such as elevated nutrient levels. However, given the similarities and the proximity between the plots, there is no apparent reason why the “adjacent control” plot managed to recover more quickly from recent disturbances, especially given that many of the commonly observed corals in all plots were fast-growing and belong to the “weedy” and “competitive” genera.

Conclusion

Overall, HCC in the shallow monitoring stations of TRNP continued to decline. This decline was primarily driven by half of the monitoring stations. Nearly all stations with declining trends in HCC also had increasing trends in algal assemblage cover, but trends in sponge cover were mixed. In particular, Site 3 and Jessie Beazley A exhibited severe ongoing negative trends in HCC. While these could be attributed to storm damage, there was no obvious cause for the decline in other monitoring stations, which is possibly indicative of a chronic stressor. Differing trends between monitoring stations in the same site suggest that highly localized factors may be influencing the susceptibility of each monitoring station to stressors.

In the deep monitoring stations, the non-significant values may be attributed to data fluctuations or limited sample sizes, which can reduce the statistical power to detect ecological changes. The persistent increase in soft corals observed in both stations of Jessie Beazley suggests that the site may be experiencing ongoing disturbances.

The permanent plots in the USS Guardian ship grounding site displayed relatively steady or slowly increasing trends in HCC in recent years. Although the impacted plots have not yet reached the level of HCC in the control, the coral communities in these plots are extremely similar. HCC in the “large fragments” and “adjacent control” plots of the Min Ping Yu grounding site have generally increasing trends despite some fluctuations. Recovery in the “small fragments” plot, however, is poor, likely hampered by the absence of a stable substrate for coral recruitment and large “stress-tolerant” corals.

Recommendations

1. If possible, temporarily suspend/limit tourism activities near Station 3A and Jessie Beazley A to allow recovery and reduce anthropogenic impacts on hard corals.

2. Conduct periodic (every 3-5 years) assessments of coral assemblages outside of the monitoring stations, as described in [Box on assessment]

3. Monitor additional parameters, such as coral recruitment, turf algae height, temperature, and nutrient levels, to identify the factors influencing trends in hard coral cover (HCC) at the ship grounding and monitoring sites where paired stations display divergent trends.

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

5. Explore substrate stabilization for stations with large rubble patches (e.g., Station 3B, Min Ping Yu grounding site) to enhance successful recruitment and survival of juvenile corals. However, this should be done with caution as a controlled experiment. For example, in Apo Island, sponges and algae proliferated because the stabilization mats protected the grazers from feeding on them.

6. Review the TMO monitoring protocol in the deep stations to minimize errors and biases during sampling.

7. Establish blocks at the beginning of every 20-meter transect in the deep areas, particularly at Jessie Beazley. These blocks should be permanent and serve as guides for correct transect placement, ensuring efficient data collection in the future.

Footnote

Significance values reported as the results of repeated-measures ANOVA (ANOVAR) in previous reports were actually the results of one-way ANOVA.

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2| REEF FISH

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Overview

Fish are a vital component of coral reef ecosystems, serving as both players in the trophic structure and as indicators of ecosystem health. Reef fish help maintain ecological balance by controlling algal populations and supporting coral resilience through various functional roles, such as herbivory and predation (Bellwood et al., 2004). As climate change and human activities threaten marine biodiversity globally, it becomes imperative to monitor the status of fish populations, particularly in a no-take marine protected area like Tubbataha. Monitoring the changes in fish density, biomass, and species richness provides critical insights into the overall health of the reef and informs adaptive management strategies.

Long-term monitoring in marine protected areas (MPAs) like TRNP is crucial for assessing the effectiveness of protection measures in mitigating biodiversity loss. Globally, MPAs have shown varied success; however, only fully protected areas are effectively meeting the objectives of conserving biodiversity (Sala et al., 2018). This report builds upon previous monitoring efforts that aim to:

- Assess the current fish populations and species diversity across shallow (5 meters) and deep (10 meters) areas;
- Track temporal trends in fish biomass and density over the years to identify shifts in ecosystem health;
- Explore factors that may be driving declines in deep fish populations;
- Explore the interactions between herbivorous fish and coral and algal cover, which are crucial for maintaining reef resilience (Mumby & Steneck, 2008); and
- Document IUCN-threatened species and other significant ecological observations.

By addressing these objectives, the report aims to provide actionable results to guide future conservation and management efforts of TRNP, ensuring it remains resilient in the face of mounting environmental challenges.

Methods

Data Collection

In the same sites where benthos was monitored, three replicate transects, each 50 meters long and separated by a 10-meter interval, were established at designated shallow and deep areas within each station. The length of each transect was further divided into 5-meter segments. Fish community data, including biomass, density, and species richness, were collected through a modified daytime Fish Visual Census (FVC) method outlined by English et al. (1997).

Data Analysis

Species richness reflects the average number of species identified within a 500-square-meter area, while fish density refers to the number of individual fish per 500-meter area. Fish biomass (measured in grams per square meter) was calculated using a length-weight model developed by Kulbicki et al. (1993):

$$W = a \times Lb$$

where *W* represents weight (grams), L represents total length in centimeters, and *a* and *b* are values obtained from FishBase (Froese & Pauly, 2023; www.fishbase.org) to establish the length-weight relationship for specific fish species.

RStudio (RStudio Team 2021) software was utilized for data processing and analysis. A paired t-test was used to determine if there were significant differences in biomass and density between 2023 and 2024. For temporal analysis, a simple linear regression (LR) and one-factor analysis of variance (ANOVA) were employed to assess significant changes in biomass throughout the study period. Linear regression helped pinpoint the direction and rate of biomass change from 2013 to 2024. Meanwhile, ANOVA determined whether statistically significant variations existed in density and biomass across the years, with a significance threshold of $p < 0.05$. The data was visualized using Microsoft Excel.

To reduce fluctuations in the graph, Scombridae (tunas and mackerels) and Sphyraenidae (barracudas) were excluded from the calculations. While these species are often observed in Tubbataha, they were not consistently recorded in the transects yearly. However, when present, they significantly impact biomass estimates due to their large size and schooling behavior.

We further analyzed the fish populations by ecological groups. Fish species are classified into three ecological groups: indicator, major, and target species, each essential for assessing marine ecosystems. Indicator species, like corallivores, are sensitive to environmental changes and important to tracking reef health (Sutcliffe et al., 2012). Major species, making up most of the fish density and biomass, support ecosystem stability by maintaining the food chain and recycling nutrients (Friedlander & DeMartini, 2002). Target species, valued for their commercial or recreational importance, are often overexploited, risking population collapse and food web disruption (Jennings & Kaiser, 1998). Conservation efforts focus heavily on these species due to their economic and ecological significance.

We also classified them based on their nature. Reef-associated pelagic species, which inhabit the water column above and around reefs, link reef systems to the broader marine environment. In Tubbataha, predators like trevallies, tuna, barracuda, and small pelagics like fusiliers, help regulate prey populations and maintain the reef's trophic structure (Broaden & Kingsford, 2015). Their abundance is influenced by prey availability, water quality, and oceanographic conditions (Forrester, 1990; Angel & Ojeda, 2001). Demersal fish, closely tied to the reef substrate, support reef health through bioerosion, nutrient cycling, and algal control (Bellwood et al., 2004; Graham et al., 2011).

In order to assess the relationships between herbivore density/biomass and algal assemblages (AA) at regular monitoring stations, Pearson's correlation coefficients were computed. Pearson's was applied to detect linear relationships to better understand the interactions between the variables across different stations. In this analysis, we only considered the herbivorous fish species collated by Green & Bellwood (2009) that play a key role in preventing coral-algal phase shifts.

Additionally, we compared species richness, biomass, and density values against the established Philippine reef fish standards outlined by Hilomen et al. (2000) and Nañola et al. (2006) (Table 6).

Table 6. Health categories of reef fish population in the Philippines.

Metric	Measure	Category
*Species richness (species per 500m^2) Hilomen et al. (2000)	0-23.5 24 -37 37.5 -50 >50	Very poor - Poor Moderate High Very high
*Density (individuals per 500m^2) Hilomen et al. (2000)	<100.5 101 – 338 338.5 – 1,133.5 1,134 – 3,796 >3,796	Very poor Low Moderate High Very high
Biomass (mt/km^2) Nañola et al. (2006)	0-10 11-20 21-40 >40	Very low to low Moderate High Very High

Results

Regular Monitoring Stations

Present Conditions: Shallow areas

Three hundred ten (310) species spanning 37 families and sub-families were recorded in this year's survey. Two hundred sixty-one (261) species were identified in the shallow stations with species richness of 56.6 species/500m^2, falling under the very high category in the Philippine reef fish standard (Hilomen et al., 2000). Station 1A was the most diverse station, with a species richness of 67 sp/500m^2. The least diverse station was Station 3B (39.7 sp/500m^2) but still falling under the high category in the Philippine reef fish standard (Table 6).

The shallow stations had a mean density of 1388.9 ind/500m^2, considered high per the Philippine standard for reef fish health (Hilomen et al., 2004). Damselfish (Pomacentridae) was by far the most abundant family with a mean density of 640.89 ind/500m^2, followed by wrasses (Labridae), fairy basslets (Anthiadidae), and surgeonfish (Acanthuridae). Figure 9 presents the mean density of all shallow stations, with station 1A having the highest density followed by JBA. Station 3B had the lowest mean density among all shallow stations.

The mean biomass of the shallow stations was 96.65g/m^2, exceeding the minimum value (40 g/m^2) for a healthy reef fish population (Nañola et al., 2006). Station 5B had the highest mean biomass, followed by Stations 1A and 4B (Figure 9, right). The lowest mean biomass among all the shallow stations was 3B with 58.9g/m^2. Triggerfish (Balistidae) had the highest mean biomass among all families and sub-families in the shallow stations, with 26.63g/m^2, followed by parrotfish (Scarinae). Demersal species accounted for 82% of the mean biomass. Most (65%) of the fish contributing to the biomass were target fish.

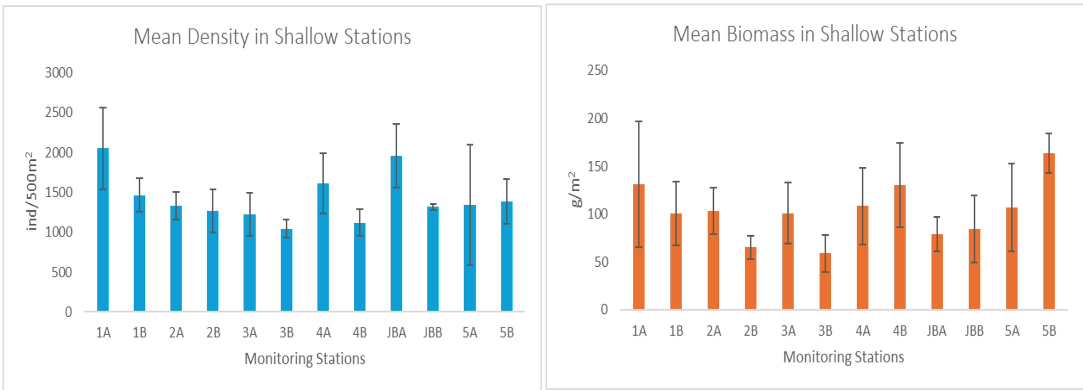


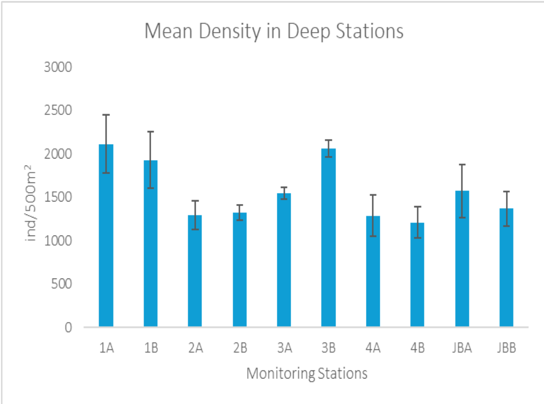
Figure 9. Mean density (left) and biomass (right) in each monitoring stations in shallow (~5m). Vertical bar denotes the standard error of the mean.

Present Conditions: Deep Areas

Two hundred fifty (250) species were identified in the deep stations, with a species richness of 69/500m^2. This also falls under the very high category of the Philippine reef fish standard (Hilomen et al., 2000) (Table 6). The highest species richness identified (78 sp/500m^2) was in Station 3B.

The deep stations had a mean density of 1818.47 ind/500m^2, also falling under high category (Hilomen et al., 2000). Like the shallow stations, Station 1A had the highest mean density, followed by Stations 3B and 1B (Figure 10). Damselfish and fairy basslets dominated the deep stations with mean densities of 660.5 ind/500m2 and 493.2 ind/500m^2, respectively. Surgeonfish, the third highest family, only had a mean density of 83 ind/500m^2.

The mean biomass of the deep stations was 139.34 g/m^2, considered very high per Nañola et al. (2006). Site 2 recorded the highest mean biomass across all sites, with 197.1 g/m^2 value. Station JBA, the lowest-ranked deep station, had a mean biomass of 100.9 g/m^2 which is still well considered very high (Nañola et al., 2006). Surgeonfish was the main contributor to the mean biomass this year, followed by parrotfish and snappers.



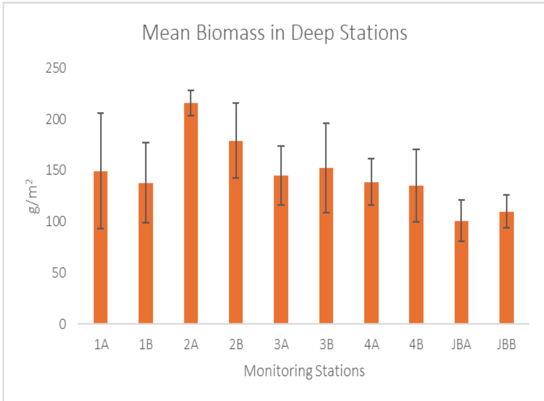


Figure 10. Mean density (left) and biomass (right) in each monitoring stations in the deep (~10m). Vertical bar denotes the standard error of the mean.

Temporal Patterns: Shallow Areas

General Trend

Figure 11 shows the mean fish density and biomass in the shallow stations of Tubbataha Reefs over the years, revealing distinct patterns. Fish density in shallow areas has been decreasing by about 74 individuals per 500 sqm each year. Interestingly, while density declined, biomass remained relatively stable, with periodic spikes observed during specific years. For instance, in 2015, despite a moderate density, the biomass reached one of its highest values. This was due to large individuals, such as giant sweetlips observed in the South Atoll, schools of trevallies exceeding 30 cm, and groups of bumphead parrotfish *Bolbometopon muricatum*. These larger individuals contributed disproportionately to the biomass without significantly impacting density, implying that a smaller number of larger fish were present during these years.

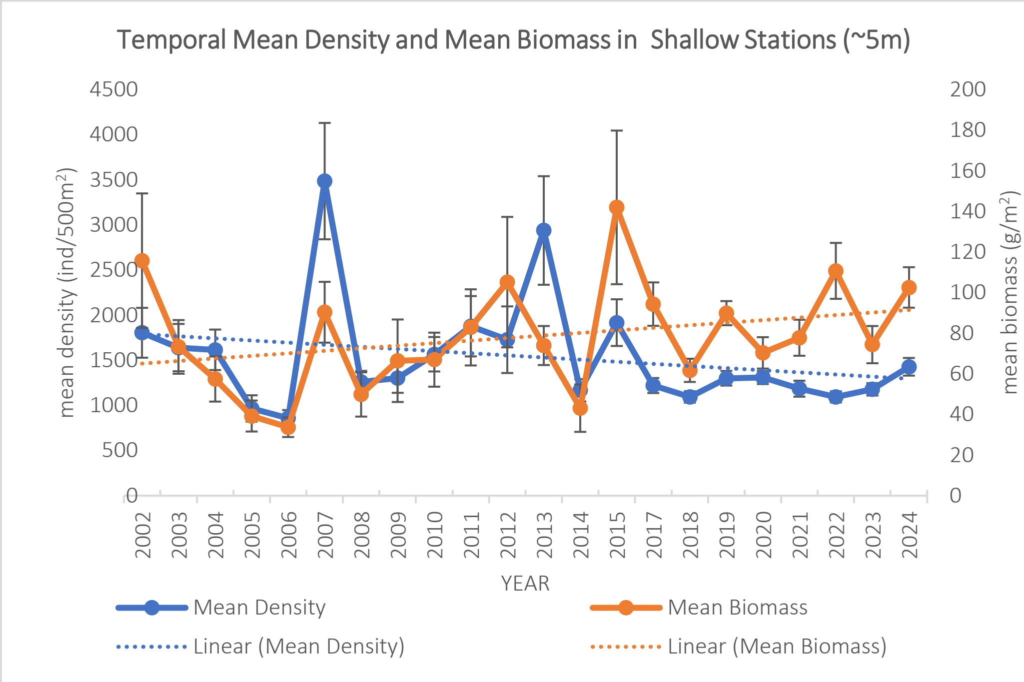


Figure 11. Mean biomass and density in the shallow (~5m) monitoring stations. Error bars denote the standard error of the mean. No shallow data in 2016.

Table 7 provides a summary of density and biomass across shallow sites. ANOVA and regression analysis indicate that Site 2 experienced a significant decline in density (-135 ind/500m² per year), contributing to the overall decline in mean density in shallow. The mean biomass remained essentially unchanged across all sites.

Table 7. Shallow Sites: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated as *. Significant codes: 0 '***' 0.001 '**' 0.01 '*' ns = not significant

	Overall	Site 1	Site 2	Site 3	Site 4	JBR
DENSITY - Rate of Change (ind/500m^2) (2013-2024)	↓-74.33***	ns	ns	↓- 135.21**	ns	ns
Difference Among Years in Density (ANOVAR; 2013-2024) (g/m^2)	***	ns	**	**	ns	ns
BIOMASS - Rate of change	ns	ns	ns	ns	ns	ns
Difference Among Years in Biomass (ANOVAR; 2013-2024)	**	ns	ns	ns	ns	ns

Trends in the Pelagic and Demersal Fish Groups

The comparison between pelagic and demersal species reveals distinct patterns in their population dynamics. Pelagic fish maintained relatively stable densities, with only minor fluctuations and no significant peaks (Figure 12). In contrast, demersal fish showed more pronounced variations in density and biomass. A noticeable peak occurred in the mid-2000s, suggesting favorable conditions for demersal populations during that time. However, since that peak, the mean density has experienced an annual decline (Table 8). Meanwhile, the biomass of the demersal fish showed an increasing trend, albeit nonsignificant.

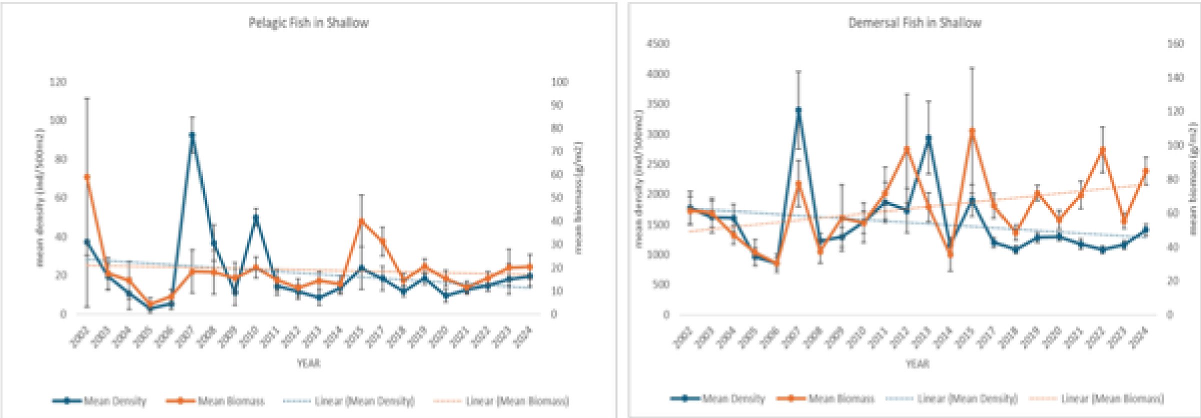


Figure 12. Temporal mean density (ind/500m^2) and mean biomass (g/m^2) of pelagic and demersal fish groups in shallow stations. Vertical bar denotes the standard error of the mean.

Table 8. Pelagic and Demersal in Shallow: Summary for 12-year mean density biomass, rates of change, and differences among years in TRNP. Statistically significant (p<0.05) linear regression and ANOVA results are indicated as *. Significant codes: 0 '***' 0.001 '**' 0.01 '*' ns = not significant

	Demersal	Pelagic
2024 Mean Density (ind/500m^2)	1370.83	17.47
Average Mean Density (ind/500m^2) (2013-2024)	↓- 74.69 ***	ns
DENSITY - Rate of Change (ind/500m^2) (2013-2024)	***	ns
2024 Mean Biomass (g/m^2)	82.22	18.14
BIOMASS - Rate of change (g/m^2) 2013-2024) -	ns	ns
Difference Among Years in Biomass (ANOVAR; 2013-2024)	*	*

Trends in the Population of Ecological Groups

The density of indicator species declined over time, starting relatively high in 2002, peaking the following year, and then gradually decreasing, with occasional fluctuations (Figure 13, left). The lowest density was recorded in 2020, followed by a modest recovery in 2024. Despite these changes, statistical analysis indicated no significant overall trend in density, suggesting a stable population. Meanwhile, the biomass remained low and stable from 2002 to 2014, with a notable spike in 2015, likely due to a record of larger individuals, i.e., Bumphead parrotfish.

After this peak, biomass dropped again but gradually increased in recent years. Despite these fluctuations, there were no significant changes in biomass over the years (Table 9) pointing to overall consistency with a slight recent improvement.

Major species also exhibited significant fluctuations in density, peaking in 2007, caused by abundance of damselfish and fairy basslets, followed by sharp declines before stabilizing over the years. Biomass also fluctuated, with moderate peaks in 2007 and 2015, aligning with periods of higher density. While the rate of change in biomass was not statistically significant, a negative value over the past decade was noted (Table 9), signaling a marked decline in the population. Despite this, the relatively stable biomass suggests that while population numbers have decreased, individual sizes may have increased or remained steady.

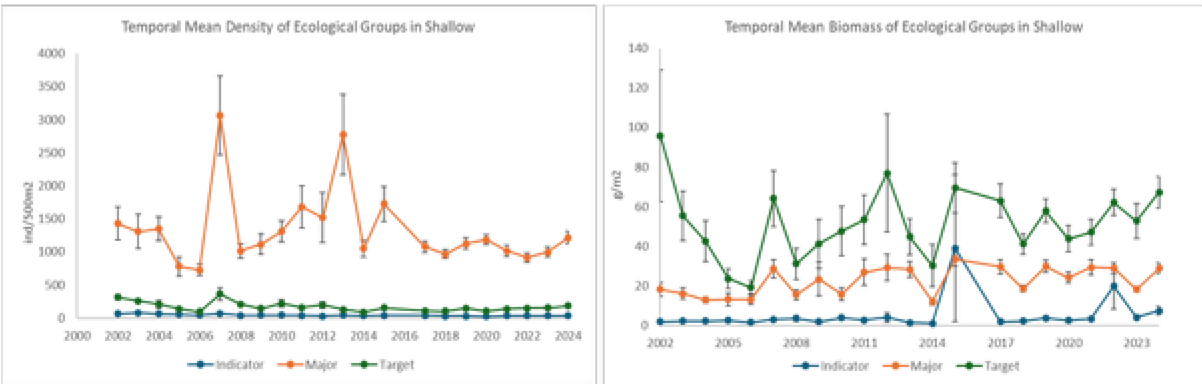


Figure 13. Annual trends in mean density (left) and biomass (right) of each ecological group in shallow sites in Tubbataha. The vertical bar denotes the standard error of the mean.

On the other hand, the density of target species remained low throughout the monitoring years with periodic fluctuations. Target species are usually larger individuals and very few species aggregate. Noticeable dips or declines were noted in 2005 and 2014, followed by moderate recovery. Biomass also showed similar fluctuations, peaking in some years. After a post-drop in 2015, biomass began recovering around 2020 (Figure 13). Despite moderate densities, high biomass values suggest that larger individuals were present in years like 2015, i.e., high biomass of parrotfish and trevallies. This supports the idea that target species biomass is influenced by individual size rather than population number. The mean biomass in shallow showed no statistically significant differences across years, indicating relative stability. However, a positive trend in density (Table 9) has emerged, with an increase of 4.6 individuals per 500 m^2 annually since 2013, reflecting a statistically significant improvement in population size.

Table 9. Ecological Groups in Shallow: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant (p<0.05) linear regression and ANOVA results are indicated as *. Significant codes: 0 '***' 0.001 '**' 0.01 '*' ns = not significant

	Target	Indicator	Major
2024 Mean Density (ind/500m^2)	174.89	33.58	1179.75
DENSITY - Rate of Change (ind/500m^2) (2013-2024)	↑ 4.614***	ns	↓-78.41 ***
Difference Among Years in Density (ANOVAR; 2013-2024)	***	ns	*
2024 Mean biomass (g/m^2)	65.22	7.14	28
BIOMASS Rate of change (g/m^2) 2013-2024)	ns	ns	ns
Difference Among Years in Biomass (ANOVAR; 2013-2024)	*	ns	***

Trends in the Population of Functional Groups

Figure 14 illustrates the proportional comparison of the density and biomass of each functional group in shallow stations. The presence and fluctuations in density and biomass reflect the underlying balance within Tubbataha, particularly in terms of predator-prey dynamics, herbivory, and energy transfer.

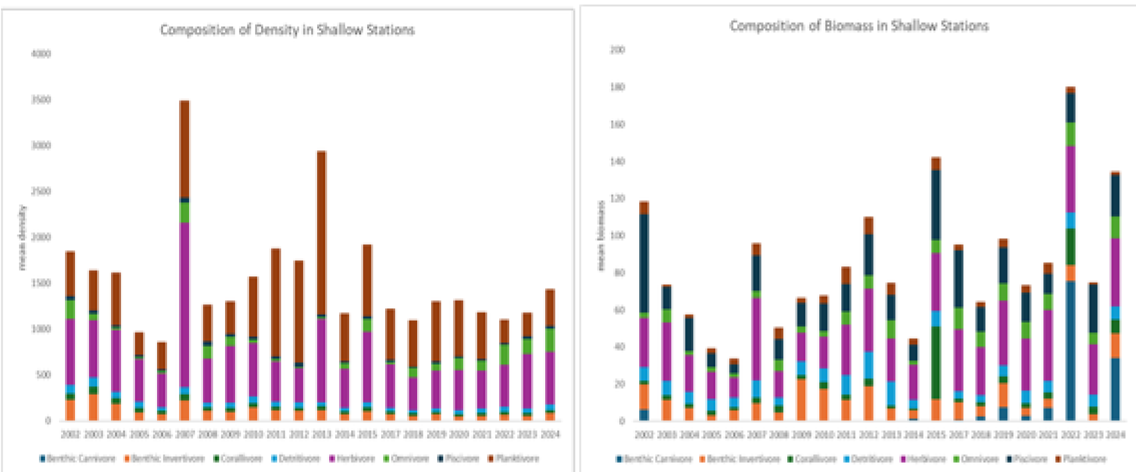


Figure 14. The composition of functional groups in the shallow stations.

Piscivores, top-level predators, and corallivores showed low but steady densities and biomass throughout the monitoring period. Omnivores generally represent a smaller portion of the fish community, with significant increases in both density and biomass detected (Table 10), potentially driven by shifts in prey availability or habitat conditions. Herbivores consistently dominate the functional group composition in both density and biomass. A notable increase in biomass was detected (Table 10), indicating growth in individual size or biomass contribution over time.

Benthic invertivores showed a significant decline in both density and biomass around 2007 (Table 10), suggesting a potential shift in the benthic community, which might be attributed to environmental changes, reduced prey availability, or increased competition for food resources. However, biomass stabilized between 2020 and 2024, indicating that while fewer in number, individual sizes have remained consistent. Benthic carnivores, which feed on invertebrates living on the reef substrate, exhibit consistently low densities across the years, with occasional peaks in 2007, 2019, and 2022. Biomass values, though generally low, were relatively stable over time, with a significant increase in biomass detected (Table 10).

Significant increases in the density of detritivores were detected (Table 10), pointing to a growing population over time. However, biomass remained stable, indicating that while there are more individuals, their size or biomass contribution has not changed significantly. Detritivores play a significant role in nutrient cycling and energy flow, contributing to the overall productivity of the reef ecosystem.

Planktivores sustained moderate to high densities across the years, with notable peaks linked to the aggregating behavior of species such as fusiliers and fairy basslets. These species can significantly influence overall fish density in shallow stations. Despite high numbers in some years, the biomass of planktivores driven by damselfish and fairy basslets remained relatively unchanged, suggesting that the individual sizes of larger planktivores (e.g., fusiliers, have not varied significantly over time. Significant declines were detected in both density and biomass (Table 10), reflecting a concerning downward trend in this group. Planktivores are crucial for transferring energy from the pelagic food web to the benthic environment, and their declining numbers may have broader ecological implications. These declines may reflect natural population fluctuations, observer bias, or the inherent difficulty in accurately estimating schooling, fast-moving planktivorous species like fusiliers, damselfish, and fairy basslets. Localized disturbances or a combination of factors (see Discussion) affecting the overall fish population in Tubbataha may be the reason for the decline.

Table 10. Functional Groups in Shallow: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant (p<0.05) linear regression and ANOVA results are indicated as *. Significant codes: 0 '***' 0.001 '**' 0.01 '*' ns = not significant

Functional Groups	DENSITY - Rate of Change (ind/500m^2) (2013-2024)	Difference Among Years in Density (ANOVAR; 2013-2024)
Piscivore	0.4	ns
Omnivore	↑17.01***	***
Herbivore	-8.58	ns
Corallivore	-0.09	ns
Benthic Invertivore	↓-2.21**	**
Benthic Carnivore	0.02	ns
Detritivore	↑1.65**	**
Planktivore	↓-65.78***	***

Temporal Patterns in Deep Areas

General Trend

Figure 15 shows the annual trend of mean density and mean biomass in the deep stations of Tubbataha, exhibiting distinct patterns over the years. The density displays notable fluctuations, with marked peaks and troughs. In the mid-2000s, a prominent peak indicates a period of high fish density. However, following this peak, there was a general downward trend in density, with the more recent years showing a stabilization at lower levels compared to earlier periods. This decline in density might suggest changes in the fish community structure or environmental conditions in the deep reef habitats.

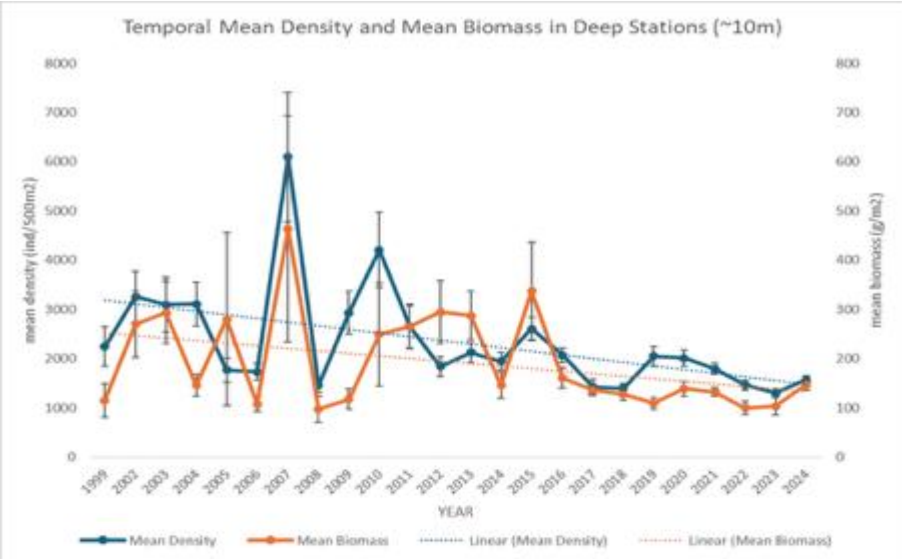


Figure 15. Annual trends in mean density and mean biomass in the deep areas of Tubbataha. The vertical bar denotes the standard error of the mean.

Similarly, the mean biomass displayed a downward trend over the years, mirroring the overall pattern of fish density. The biomass peaked around the same period as the density, suggesting that the increased number of fish also included more prominent individuals or species with higher biomass. However, after the peak period, the biomass declined and has since remained lower than in the early years of monitoring. Linear regression analysis indicates a statistically significant negative mean density and biomass trend over time (Table 11). These significant declines are observed in most sites, except in the Jessie Beazley, and reflected in the general outputs of Tubbataha. The regression model shows a significant decrease in mean density, with an estimated annual decline of approximately 69 ind/500m^2, and in biomass, a decrease of about 13 g/m^2 (Table 11).

ANOVAR results further support the finding of significant interannual variation in both density and biomass. These variations point to changes in the deep reef environment, which various ecological and environmental factors may influence.

Table 11. Deep Sites: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant ($p<0.05$) linear regression and ANOVA results are indicated as *. Significant codes: 0 '***' 0.001 '**' 0.01 '*' ns = not significant

	OVERALL	Site 1	Site 2	Site 3	Site 4	JBR
2024 Mean Density (ind/500m^2)	1605.02	2019.83	1305	1803	1238.33	1468.5
DENSITY - Rate of Change (ind/500m2) (2013-2024)	-69.19***	-84 *	ns	ns	-86.43 *	ns
Difference Among Years in Density (ANOVAR; 2013-2024)	***	**	**	ns	**	
2024 Mean biomass (g/m^2)	139.34	118.17	150.76	116.53	103.62	79.84
BIOMASS Rate of change (g/m2) 2013-2024) -	-13.11***	-10.73*	-7.18*	-10.33*	-33.41*	ns
Difference Among Years in Biomass (ANOVAR; 2013-2024)	***	ns	**	ns	ns	ns

Trends in the Population of Pelagic and Demersal Groups

The pelagic fish population in deep stations exhibited significant variability over time (Figure 17), with sharp peaks followed by declines. The marked peak in the mid-2000s was due to encounters with schools of large-sized trevallies (>50cm) and unicornfish. Following this peak, density and biomass declined sharply, indicating either a change in environmental conditions, a stressed population, or a result of natural fish behavior (e.g., migration). In recent years, pelagic fish density and biomass appeared to have stabilized, albeit at levels lower than the earlier peaks, suggesting a more stable but smaller pelagic population in the deep sites.

Demersal fish populations at deeper stations exhibited a trend similar to pelagic species, with fluctuations in density and biomass observed over time. Initially, both metrics showed an upward trend, suggesting favorable conditions for demersal fish populations in the early years of monitoring. Post-2015, density and biomass also appeared to stabilize, but at lower levels than in the earlier years of monitoring.

The population of both demersal and pelagic fish in the deep sites has shown statistically significant downward trends in density and biomass over the last 12 years (Table 12). While the density of pelagic fish is declining, they make up a small proportion of the overall density of Tubbataha (Figure 16, left) and are seldom observed in more than a couple of hundred individuals in a single observation. In contrast, demersal fish, which includes damsels and fairy basslets, congregate in hundreds to thousands in a small area. These two fish families comprise more than 60% of the total density in Tubbataha. Hence, their presence or absence strongly influence the mean density.

In the context of biomass, demersal fish have shown a statistically significant downward trend over the past 12 years (Figure 16, right). The decline was influenced by a sharp peak in mean biomass in 2015, followed by a sharp drop from 2016 onwards. The peak in 2015 was largely due to the presence of 60 individuals of 110cm Bumphead parrotfish *Bolbometopon muricatum*, which were not recorded in the same numbers/sizes in the succeeding years.

However, the general long-term trend in demersal biomass (see Figure 16, right) exhibits stability with less fluctuation compared to pelagic fish.

Similarly, for pelagic fish, the regression model suggests a downward trend (Figure 16, left). In Tubbataha, reef-associated pelagic fish include trevallies, unicornfish, and fusiliers. Due to their relatively large sizes and nature to form schools, they greatly influenced the overall mean biomass in the deep transect, especially when encountered in schools.

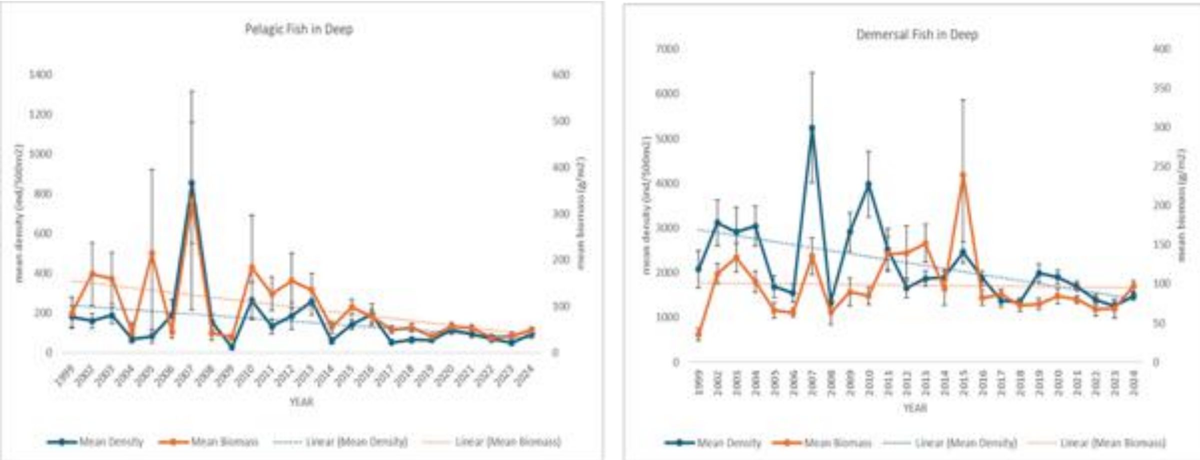


Figure 16. Temporal mean density (ind/500m^2) and mean biomass (g/m^2) of demersal and pelagic fish groups in deep stations. The vertical bar denotes the standard error of the mean.

Table 12. Pelagic and Demersal in Deep: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated as *.

	Pelagic	Demersal
2024 Mean Density (ind/500m^2)	95.1	1471.83
DENSITY - Rate of Change (ind/500m^2) (2013-2024)	↓-8.972***	↓-60.30***
Difference Among Years in Density (ANOVAR; 2013-2024)	***	***
2024 Mean biomass (g/m^2)	49.38	96.94
BIOMASS - Rate of change (g/m^2) (2013-2024) -	↓-5.730 ***	↓-7.43 **
Difference Among Years in Biomass (ANOVAR; 2013-2024)	***	**

Trends in the Population of Ecological Groups

The declines observed in the deep stations are evident across various ecological groups. Indicator species density remained consistently low throughout the monitoring period, with minor peaks in some years followed by a steady decline from 2015 through 2024 (Figure 17). Biomass also remained low, with a notable spike in 2015, likely due to more prominent individuals. However, after 2015, biomass fluctuated without a clear trend. Although no statistically significant decline in biomass was detected, the variability across years, combined with the significant drop in density over the last decade (Table 12), suggests that indicator species are becoming increasingly scarce in deep stations.

Major species exhibited volatile trends in density, with multiple peaks observed over time. Density was initially high in the mid-2000s but experienced significant declines after 2010, followed by partial recovery by 2024. However, the overall trend points to a gradual decrease in population size. Biomass also showed fluctuations, peaking in 2007, but remained relatively low compared to density, indicating a predominance of smaller individuals within this group. From 2017 to 2024, biomass has stabilized without showing significant upward trends. The combination of high density and low biomass suggests that the population is primarily composed of smaller fish species, such as damsels, fairy basslets, and wrasses. This declining trend in density and biomass (Table 13) indicates a reduction in population and individual fish size, potentially due to resource depletion or increasing environmental pressures within the deep reef ecosystem. Target species also exhibited fluctuating density, peaking in 2007 and steadily declining after that, reaching its lowest point in 2017 (Figure 17). A partial recovery followed, but by 2024, density remained well below the 2007 peak. Biomass trends closely followed those of the fish density, with a sharp rise in 2007, followed by a steady decline. Despite some fluctuation and a slight recovery in 2015, biomass continued to decrease. The parallel trends in density and biomass suggest that while the population size decreased, individuals during peaks like 2007 and 2015 were likely larger, contributing disproportionately to biomass. The ongoing decline in density and biomass post-2015 suggests a potential long-term decline in target species populations in deep reefs, possibly due to a combination of natural factors, environmental stressors, or anthropogenic impacts.

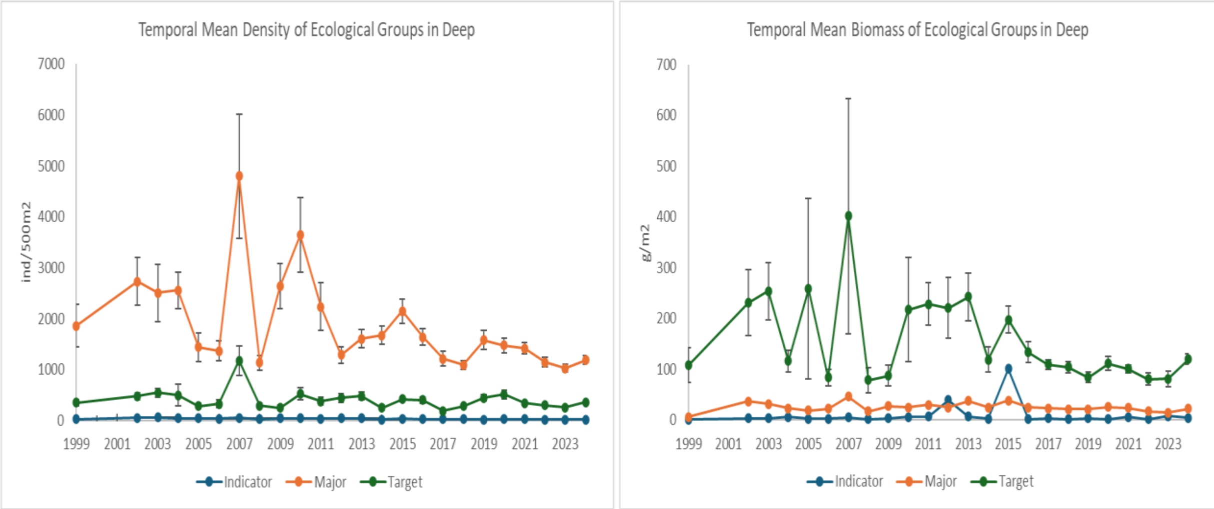


Figure 17. Annual trends in mean density (upper) and biomass (lower) of each ecological group in deep sites in Tubbataha. The vertical bar denotes the standard error of the mean.

Table 13. Ecological Groups in Deep: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant (p<0.05) from linear regression and ANOVA results are indicated as *.

	Indicator	Major	Target
2024 Mean Density (ind/500m^2)	23.57	1185.3	358.07
DENSITY - Rate of Change (ind/500m^2) (2013-2024)	↓-1.41 ***	↓-63.69**	ns
Difference Among Years in Density (ANOVAR; 2013-2024)	***	***	ns
2024 Mean biomass (g/m^2)	4.71	22.22	119.4
BIOMASS Rate of change (g/m^2) 2013-2024) -	ns	↓-1.38 ***	↓-8.871***
Difference Among Years in Biomass (ANOVAR; 2013-2024)	***	***	***

Functional Groups

The composition of functional groups (Figure 18) in the deep stations of Tubbataha reveal distinct trends compared to shallow stations, with notable increases and declines in density and biomass across different groups over the years.

Piscivore population has shown significant long-term declines in the deep area (Table 14). Although piscivores are a smaller part of the deep community in terms of density, biomass peaks in the same years indicate the presence of larger individuals, which were more prominent in earlier years.

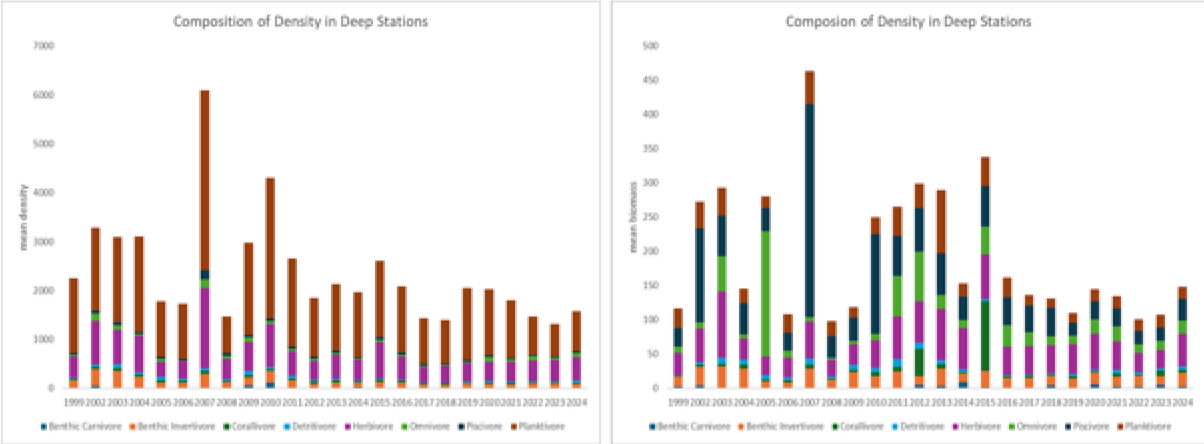


Figure 18. The composition of functional groups in the deep stations.

Omnivores have maintained low densities overall, but a significant increase in density was observed in 2022. Their biomass also peaked in 2012 and 2024, likely driven by the presence of larger individuals in those years. Corallivores demonstrate consistently low densities and biomass, with a significant long-term decline in density (Table 14).

Detritivores present a relatively stable trend, with significant increases in density and biomass in some years suggesting periodic population expansions, likely driven by favorable environmental conditions. Planktivores' density and biomass have significantly declined in recent years (Table 14). Factors cited affecting the shallow population of planktivores might also affect the deep population, i.e., natural population fluctuations, observer bias, the inherent difficulty in accurately estimating size and counts, or local disturbances.

The population of benthic invertivores, benthic carnivores, and herbivores remained stable over the years in the deep station.

Table 14. Functional Groups in Deep: Summary for 12-year mean density and biomass, rates of change, and differences among years in TRNP. Statistically significant ($p<0.05$) from linear regression and ANOVA results are indicated as *

Functional Group	Rate of Change Density	ANOVAR P-value Density	Rate of Change Biomass	ANOVAR P-value Biomass
Piscivore	↓ -1.55**	**	↓-2.68***	***
Omnivore	↑5.00**	**	-0.92	ns
Herbivore	-3.97	ns	-1.91	ns
Corallivore	↓ -1.1 **	**	-2.82	ns
Benthic Invertivore	-0.78	ns	-0.16	ns
Benthic Carnivore	0.29	ns	0.09	ns
Detritivore	↑1.11**	**	↑0.09*	*
Planktivore	↓ -42.9***	***	↓-2.94***	***

Families contributing to the decline

In the shallow, no fish families were detected to statistically decline. In the deep stations, the top fish families contributing to overall biomass are listed in Table 15. These families exhibit varying baseline biomass estimates, with most showing no statistically significant trends over the years, indicating stable biomass levels. Among the families contributing to the observed decline in deep reef biomass, Carangidae (jacks and trevallies) and Haemulidae (sweetlips) stand out with statistically significant decreases.

Table 15. The top 15 families, arranged in descending order of contribution, significantly contributed to the overall biomass in the deep stations in Tubbataha. The rate of change for the last 25 years has been presented.

Family	Sum of biomass (g/m^2)	Slope (Rate of Change: Generalized Linear Model) 1999-2024 (g/m^2)	p-Value
Carangidae (jacks and trevallies)	1139	↓-3.56	*
Acanthuridae/Nasinae (unicornfish)	1060	-1.48	ns
Scaridae (parrotfish)	599	0.07	ns
Caesionidae (fusiliers)	531	-0.80	ns
Haemulidae (sweetlips)	305	↓-0.82	**
Lutjanidae (snappers)	222	0.22	ns
Pomacentridae (damselfish)	201	-0.15	ns
Acanthuridae (surgeonfish)	199	0.12	ns
Balistidae (triggerfish)	195	0.18	ns
Holocentridae (bigeye)	190	-0.14	ns
Serranidae (groupers)	179	-0.16	ns
Lethrinidae (emperorfish)	162	0.00	ns
Kyphosidae (rudderfish)	106	0.213	ns
Labridae (wrasses)	106	-0.16	ns
Chaetodontidae (butterflyfish)	93.9	-0.02	ns

To further investigate the changes in the declining families (jacks and trevallies and sweetlips), a multinomial logistic regression was applied to assess the size class distribution over time (Figure 20).

The analysis of jacks and trevallies revealed notable shifts in size class distribution ($p<0.05$), with larger individuals (50-70 cm) showing a decline over time. For instance, in 2007 and 2010, there was a higher proportion of individuals in the 60-70 cm range, but by 2019, the distribution shifted toward smaller size groups, predominantly in the 30-60 cm range. Notably, individuals above 90 cm have diminished since 2015, signaling potential changes in population dynamics or a trend toward smaller fish. The smallest class (20-30 cm) displayed a positive coefficient, indicating an increasing likelihood of observing fish in this range over time. In contrast, larger size classes, such as 50-60 cm and 60-70 cm, showed negative coefficients, underscoring the decline in larger individuals.

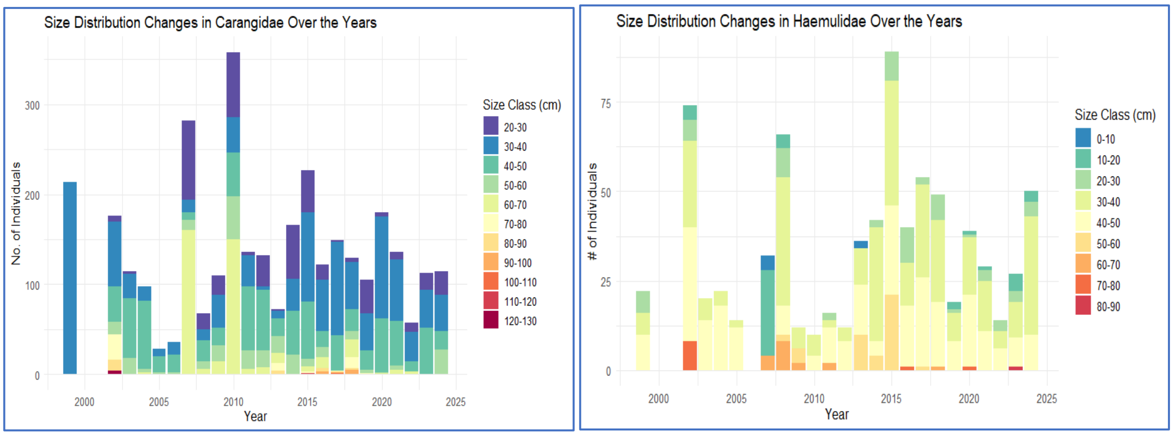


Figure 20. Size frequency distribution of Carangidae (jacks and trevallies) and Haemulidae (sweetlips) in the deep area over the years.

The decrease in the jacks and trevallies family, especially the larger fish, is particularly concerning because these individuals typically play a crucial role in maintaining healthy populations, as they contribute more to reproduction. The decline in their numbers suggests shrinking reproductive capacity, potentially affecting future population stability. Meanwhile, the growing prominence of smaller size classes (e.g., 20-30 cm) could indicate that although younger fish are being born, they may not be surviving long enough or growing to reach larger sizes.

Meanwhile, the same shifting was also observed with the size distribution of Haemulidae (grunts or sweetlips), with smaller fish becoming more abundant and larger individuals (over 50 cm) declining. In deep stations, the smallest size class (10-20 cm) showed a decreasing trend while medium-sized classes (20-30 cm, 30-40 cm, and 40-50 cm) exhibited positive trends, with increasing likelihoods of occurrence. In contrast, larger size classes (50-60 cm and 60-70 cm) were declining over time, suggesting that larger individuals are decreasing. In the early years of the monitoring, smaller fish (10-20 cm) were dominant, but over time, medium-sized fish (20-30 cm) have increased. The decline in larger fish suggests that they are being caught or dying off, reducing the overall presence of big Haemulidae in the population.

Grounding site: USS Guardian

Present Condition

A total of 100 fish species were recorded in the shallow transects at the USS Guardian grounding site, with an average species richness of 58 species per 500 m², representing 21 families and subfamilies. Most species belonged to damselfish and wrasses. The fish density of 791 ind/500m^2 was largely driven by damselfish, wrasses, and surgeonfish. This diverse community highlights the importance of schooling species like damselfish and individual species like surgeonfish and wrasses that thrive in shallow reefs.

Regarding biomass, the shallow area was dominated by triggerfish, contributing the most with 69.3 g/m². Surgeonfish, parrotfish, triggerfish were the top contributors to the total biomass. Overall, the biomass was distributed across a range of families, highlighting the presence of larger fish species, even if their density was lower compared to smaller schooling species.

In the deep area, 109 species were observed, with an average species richness of 64 species per 500 m², also representing 21 families and subfamilies. The fish density of 1,512 ind/500m^2 was also marked by a dominance of smaller schooling species. Damselfish, fairy basslets, and wrasses were the contributors. The biomass of 103 g/m^2 in the deep saw the highest contributions from parrotfish, triggerfish, and unicornfish. While smaller species dominated in density, the biomass was supported by a mix of larger individuals, including parrotfish and unicornfish.

Overall, the density in the shallow area of the USS Guardian grounding site featured a more diverse range of species, with surgeonfish, damselfish, and wrasses playing significant roles. The deep, in contrast, was dominated by smaller schooling species like damselfish and fairy basslets. In terms of biomass, both depths had larger species contributing to the biomass despite the high density of smaller species.

Temporal trends

Shallow: The overall trend in the fish density in the shallow showed a fluctuating, gradual decline over time (Figure 21). While there were years of higher densities, especially in the early years (2014 and 2018), recent years (2022-2024) displayed lower density values. However, this decline is not statistically significant, suggesting that while the density has fluctuated, the changes are insufficient to point to a consistent decline. Meanwhile, biomass showed a slightly upward trend in recent years, with the estimate showing a statistically significant increase of 3.9 g/m^2 annually, suggesting a gradual recovery of biomass in the shallow waters of USS Guardian. Triggerfish consistently contributed the highest biomass in the shallow, with notable increases in certain years. Their large size significantly increased biomass, compensating for the fluctuations in density. Overall, the interplay between increasing populations of wrasses and surgeonfish and fluctuating numbers of damselfish and triggerfish shaped the non-significant decline in fish density. Meanwhile, the stable biomass contributions of parrotfish and substantial biomass of triggerfish helped maintain reef ecosystem health despite density fluctuations.

Demersal species dominated density and biomass trends in the shallow area of the USS Guardian. Families like triggerfish, parrotfish, and surgeonfish played a crucial role in maintaining demersal biomass and density, even when numbers fluctuated. After a relatively high density in 2014, the numbers decreased between 2017 and 2020 before stabilizing later in 2022-2024. Biomass trends for demersal species largely mirrored their density patterns. Biomass was relatively high in the early years (2014) but saw declines that persisted through to 2020, followed by gradual recovery in the later years. Meanwhile, pelagic species remained relatively stable in density and biomass, contributing less to the overall community structure.

Although Carangidae occasionally provided biomass peaks, pelagic species did not significantly impact the long-term trends observed in the shallow areas.

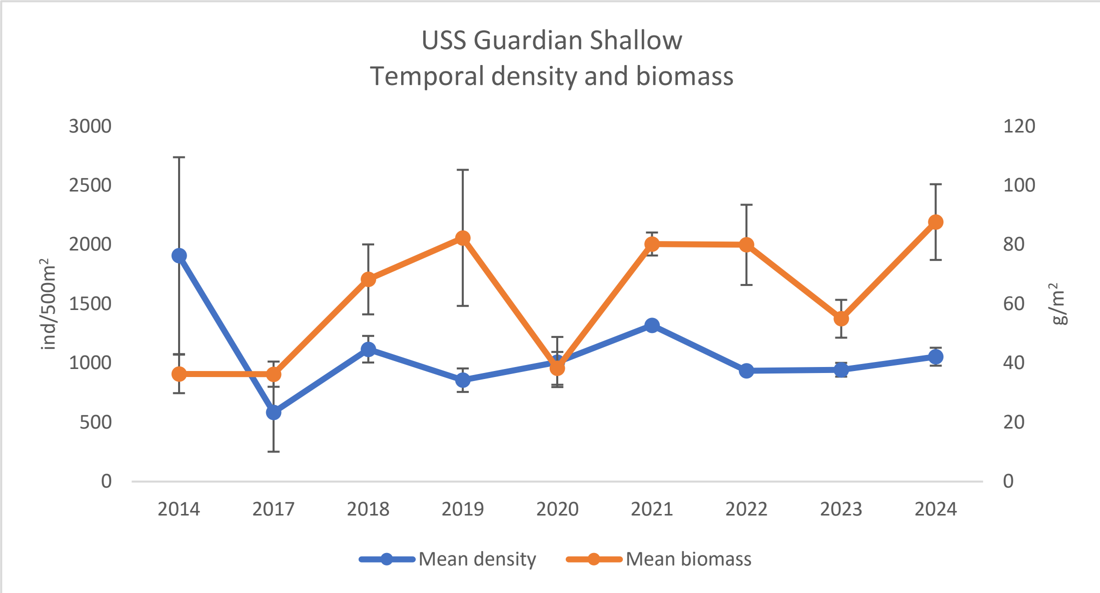


Figure 21. Annual trend in mean density (ind/500m²) and biomass (g/m²) in the shallow transects of USS Guardian. Vertical bar denotes the standard error of the mean.

Regarding the various ecological groups, target species showed a slight decline in density but stabilized in biomass in recent years. The indicator species were consistently low in density and biomass, reflecting their smaller sizes. Meanwhile, the major species dominated in density but contributed moderately to biomass. These species remained resilient across the years, with damselfish and wrasses consistently representing most of the community.

Deep: The density in the deep displayed a significant decline of 134 ind/500m^2, suggesting a long-term reduction in the number of fish. Meanwhile, the biomass has been fluctuating over the years (Figure 22) was driven by larger individuals from families like parrotfish. However, there has not been a significant change over the years. These suggest that while density declines significantly over time, the biomass is stable.

The fish community in the USS Guardian is largely dominated by demersal fish, both in density and biomass. The density of demersal fish has declined over the years while the biomass remained stable. The pelagics showed much lower densities than demersal fish throughout the years, indicating that the pelagic community has remained sparse, contributing less to the overall density of the fish community. While fewer in number, pelagic fish continue to influence the biomass significantly due to their larger body sizes.

Meanwhile, the density and biomass of major fish groups have declined since the early years of monitoring. They showed signs of recovery in recent years, but the overall numbers remain low compared to earlier years of monitoring. The indicator species experienced the most dramatic fluctuations, with a significant peak in biomass in 2020, followed by a decline. This pattern may signal changes in reef health, as these species are typically sensitive to environmental conditions. Target fish have shown more volatility, with high densities and biomass recorded in 2020, followed by a notable decline in recent years. Although statistically insignificant, the decrease in biomass suggests that the overall size of the target species has diminished, even if some density recovery is observed.

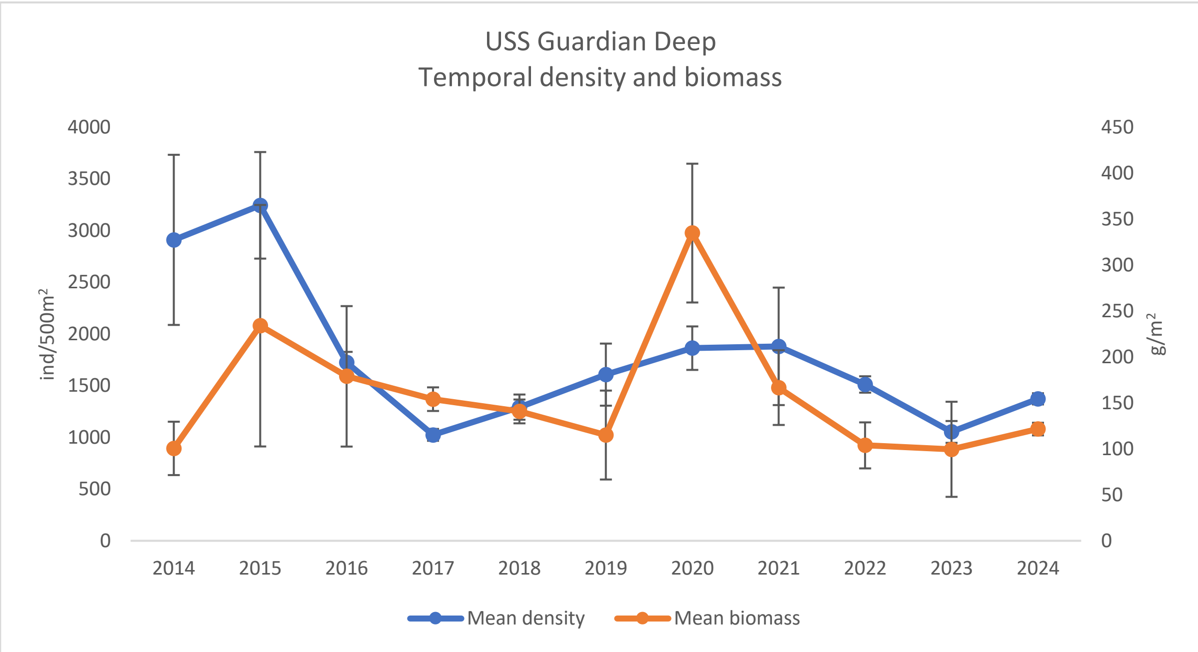


Figure 22. Temporal trends in density and biomass in USS Guardian

The herbivorous species showed a recovery in density and biomass in recent years. Planktivores also experienced a steep decline in density and biomass, with smaller individuals dominating the population. Piscivores have notable decreases in biomass, suggesting a reduction in larger predatory fish. The benthic invertivores decreased in both density and biomass in the deep. Corallivores also showed declining densities and biomass, potentially reflecting reduced coral health in the deeper area of the reef. Meanwhile, the omnivores showed fluctuations in density and biomass, with a notable decline in large omnivores, suggesting potential changes in food availability.

Grounding site: Min Ping Yu

Present condition

Fish density in the shallow area of Min Ping Yu was dominated by damselfish, surgeonfish, and wrasses. The fish community in the shallow area of Min Ping Yu consists mainly of small, schooling species that are typically dominant in sandy or less complex habitats. In terms of biomass, the surgeonfish family also significantly shaped the community structure, contributing 35.04 g/m² to the total biomass. The triggerfish family comprised 8.89 g/m², reflecting the presence of larger individuals in the population. In addition, parrotfish were also one of the main contributors (6.93 g/m²), indicating the presence of herbivory that helps maintain reef health.

In the deep areas, the damselfish also dominated fish density, with 5,134 individuals recorded, far surpassing other families. Fusiliers (117 individuals/500m^2) and unicornfish (33 individuals/500m^2) were also top contributors. The prevalence of these species indicates that the deep area of Min Ping Yu hosts a mixed community, including those that thrive in open water and others that depend on structurally complex habitats.

Regarding biomass, the unicornfish family contributed 70.25 g/m², indicating the presence of larger individuals in the deep. Fusiliers followed with 40.03 g/m², showing that even with lower numbers, their biomass was substantial due to the size of the individuals. Despite their overwhelming numbers, damselfish contributed only 25.68 g/m² to the total biomass, reflecting their smaller individual sizes. Other families like parrotfish and Holocentridae (squirrelfish) also contributed significantly to biomass in the deep area, suggesting a varied but biomass-rich community in this area.

Generally, the deep area of MPY has a relatively higher fish density, dominated by small schooling species, i.e., damselfish. In contrast, the shallow area features more diverse contributors to density, with surgeonfish and wrasses playing prominent roles. While the deep's biomass is driven by large fish species, particularly from unicornfish and fusilier families, the shallow exhibits a more balanced biomass distribution, with larger species such as triggerfish and parrotfish contributing significantly despite lower numbers.

Temporal trends

Shallow: The overall trends in density and biomass at both depths in the Min Ping Yu grounding site showed substantial variability from year to year, with no clear increasing or decreasing pattern (Figure 23).

Although there is a slight indication of declining density and biomass over time, the changes were not statistically significant, suggesting that other factors (e.g., observer bias) may influence fish populations at shallow depths. The fluctuations in contributor families, such as surgeonfish and parrotfish, where dips follow periods of growth, mirror the inconsistent overall trends. For example, the sharp decline in 2020 for both families align with the overall drop in biomass and density, indicating that family-specific fluctuations drive the shallow water trends. The demersal and pelagic groups in the shallow area of Min Ping Yu exhibited year-to-year fluctuations, with no clear long-term trend in density or biomass. The demersal group, primarily supported by families like surgeonfish, damselfish, and parrotfish, consistently contributed to the overall fish population. In contrast, the pelagic group, represented by families like jacks and trevallies, and fusiliers, showed a more variable presence.

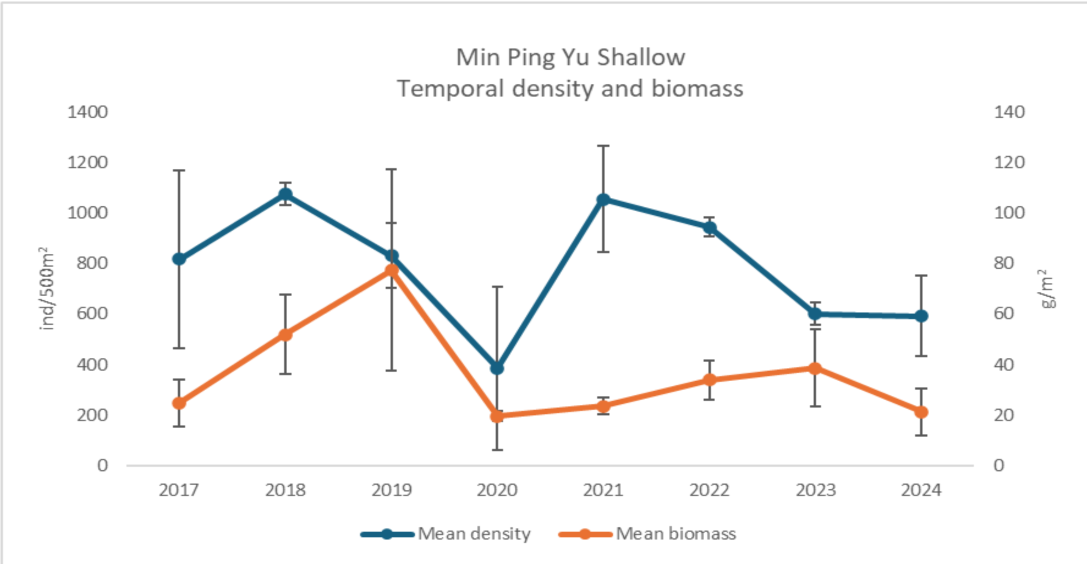


Figure 23. Annual trends in mean density (ind/500m²) and biomass (g/m²) in the shallow station of the Min Ping Yu. Vertical bar denotes the standard error of the mean.

Deep: The deep trends showed significant year-to-year variability in density and biomass (Figure 24), with surgeonfish, parrotfish, damselfish, and fusiliers contributing heavily. Surgeonfish and parrotfish influenced both metrics, while damselfish dominated density, and fusiliers led in biomass in recent years. Fluctuations were seen among major and target species, but no clear long-term trend emerged. Among the functional groups, herbivores and planktivores were the main contributors to density and biomass. While piscivores, such as large jacks and trevally species, are fewer in number, they significantly influence the biomass because of their size when they are present.

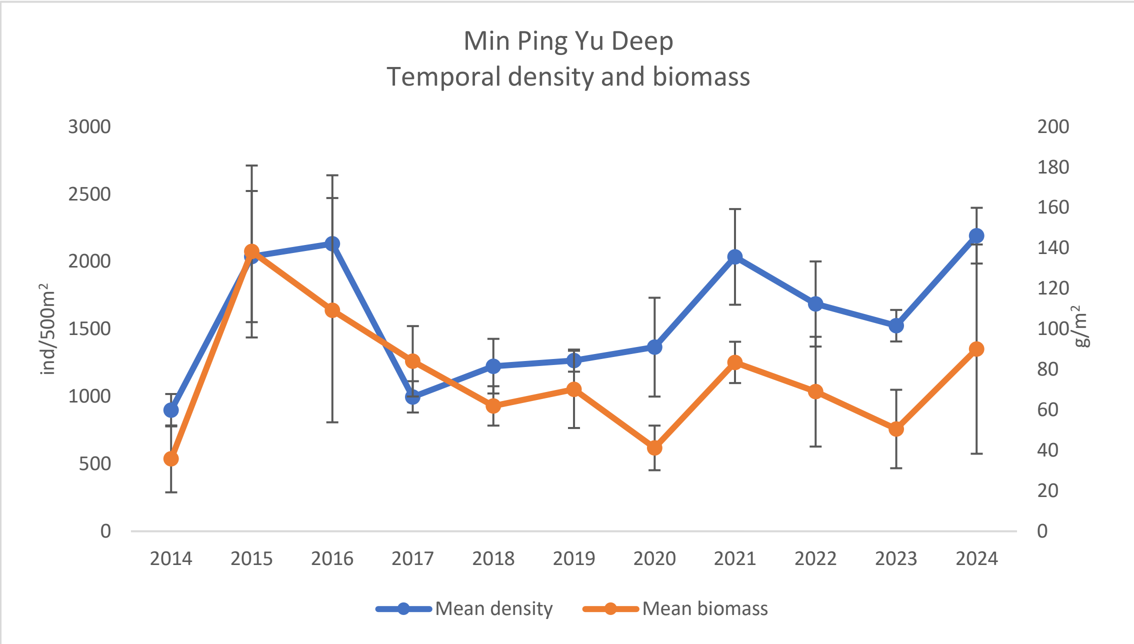


Figure 24. Annual trend in mean density (ind/500m^2) and biomass (g/m^2) in the deep transects of Min Ping Yu. Vertical bar denotes the standard error of the mean.

Discussion

Regular Monitoring Sites

The mean biomass estimates for shallow and deep stations in Tubbataha were 96 and 139 g/m^2, respectively, with an average of 117.5 g/m^2. These values are consistent with the 106.5 mt/km^2 (or 106.5 g/m^2) reported in a study that recognized Tubbataha as a benchmark for high fish biomass in reef systems (Muallil et al., 2019). The consistently high biomass levels highlight the effectiveness of protection measures and confirm Tubbataha's importance as a reference site for coral reef conservation and management in the Coral Triangle and beyond (Muallil et al., 2019).

Long-term monitoring of fish populations in Tubbataha has revealed distinct temporal patterns between shallow and deep reef habitats. Fish density has declined over the years in shallow areas, while biomass has remained relatively stable. This stability in biomass, despite the reduction in fish density, is likely due to the presence of larger individuals compensating for the overall decrease in population size. In contrast, deep reef stations exhibit declines in density and biomass, indicating a more substantial reduction in fish populations at this depth. These declines may be linked to natural fluctuations in fish behavior, environmental factors, habitat degradation, and anthropogenic influences, among others.

Despite its lower density, the stable biomass in the shallow stations can be explained by reduced encounters with schooling species such as fairy basslets and damselfish, whose large aggregations can significantly influence density metrics. The fewer numbers of these families during certain monitoring years can disproportionately affect density, highlighting that species-specific behaviors shape population assessments.

In deep stations, the more consistent declines in density and biomass were further complicated by pelagic species like fusiliers, jacks and trevallies, and unicorn fish, which add variability to the overall trends. Notably, significant declines have been observed in families such as Carangidae and Haemulidae.

Migrations and Home Range of Fishes

One of the factors that can cause variations in density and biomass is the movement of fish species. Both pelagic and demersal fish show horizontal and vertical migrations driven by various ecological and environmental factors. Vertical migration is one of the most well-documented phenomena where fish move up and down the water column. One example is the diel vertical migrations, common among species like barracudas and jacks, where fish move between deeper waters during the day and shallower areas at night. This behavior is often driven by the need to avoid predators and optimize feeding efficiency (Meyer and Holland, 2005; Gauther & Rose, 2002). Some demersal species also exhibit vertical movement, although typically over shorter distances. For example, parrotfish may rest in deeper crevices or sandy bottoms at night and move to feed on algae on the reef during the day (Ogden & Buckman, 1976; Howard et al., 2013).

On the other hand, horizontal migrations involve movement across different reef areas or between reefs and open water. This behavior is common among highly mobile pelagic species like unicornfish, jacks, and fusiliers, which traverse large areas of the reef in search of food, breeding sites, or to avoid predators (Meyer & Holland, 2005). These movements are influenced by prey availability, tidal cycles, and spawning behavior (Johannes, 1978). Demersal species also engage in horizontal migrations, although usually over shorter distances. Larger demersal species, e.g., parrotfish, sweetlips, or snappers, often migrate horizontally across the reef to access different feeding areas (Mumby et al., 2004).

Another factor in understanding the decline in fish populations is the home range behavior of pelagic species. Unlike demersal fish, which have relatively smaller ranges and are closely tied to reef habitats, pelagic species such as those in the jacks and trevallies family are highly mobile, traversing vast areas of the open ocean. Their transient nature and wide-ranging movements can cause biomass estimates to spike during monitoring when large schools are encountered (Williams et al., 2015; Russ, 2002).

Fishing Pressure in Adjacent Areas

The intensity of fishing pressure outside MPA boundaries can affect fish populations within the MPA, particularly for species with large home ranges that regularly move between protected and unprotected areas (García-Charton et al., 2008). Reef-associated pelagic species such as jacks, trevallies, and barracudas often venture beyond MPA boundaries, making them vulnerable to fishing pressure in adjacent areas, which can reduce their abundance inside the MPA.

One of the declining fish families was Carangidae. Carangidae's home range can span from a few kilometers to over 100 kilometers depending on the species and life stage. Smaller Carangidae species tend to have a smaller home range, often staying within a short range from their primary habitat (Holland et al., 1996; Novac et al., 2020), typically associated with reefs or coastal areas where prey is abundant. Larger species, like the giant trevally (*Caranx ignobilis*), are more mobile and have been documented traveling distances exceeding 100 kilometers, particularly in open ocean environments, where they move between different habitats in search of food and optimal environmental conditions (Meyer et al., 2007). This wide-ranging behavior makes pelagic species vulnerable to pressures both inside and outside MPAs. While Tubbataha is a no-take zone, the spillover effect—where fish move beyond the protected boundaries—can expose them to fishing pressure in adjacent, unprotected waters.

Areas surrounding Tubbataha are frequented by commercial fishers (Figure 25). Over the years of trips to Tubbataha, we have observed fishing vessels operating just outside the core zone. While these vessels technically remain outside the park's boundaries, their proximity suggests that fish populations, particularly larger, mobile species, may be targeted as they move in and out of the protected area. Although these observations are anecdotal, they raise concerns about the potential impact of fishing activities near the park on fish populations, especially for migratory or highly mobile species that may move in and out of the protected area. This potential interaction could be partially contributing to the observed decline in fish biomass and diversity within Tubbataha.

Figure 25. Records of commercial fishing boats around Tubbataha (green hexagon) detected using Visible Infrared Imaging Radiometer Suite (VIIRS) in 2017 (left) and 2024 (up to September) (right). Source: OCEANA's https://karagatanpatrol.org/.

Hence, the wide-ranging behavior of Carangidae and other pelagic species can be a challenge for conservation as they become vulnerable to fishing pressure outside, reducing their populations within the protected area. Fishing practices often target larger, more commercially valuable individuals, leaving behind smaller fish. Over time, this size-selective removal of larger individuals can result in population shifts toward smaller fish within the MPA (Heupel et al., 2015).

The opportunistic illegal fishing inside the park remains a potential issue, particularly in sites that are difficult to regularly patrol (i.e., Jessie Beazley Reef) due to distance from the ranger station. In several instances, the rangers apprehended boats made of wood, which are indetectable via radar. This poses an additional challenge, especially during nighttime, when visibility is low. Although illegal fishing activities have decreased since the 2010s, they continue to present a threat to the park. Removing fish due to these activities may also contribute to the decline in the fish population.

Loss of Coral Cover

The declining trend in the hard coral cover (Chapter 1) could also indirectly contribute to the decline in the overall density and, in turn, in biomass in both depths. Declines in coral cover and complexity can reduce the availability of shelter and foraging grounds for reef fish. Reduced coral cover often leads to a shift toward algal dominance, which can significantly alter trophic dynamics (Pratchett et al., 2008). The loss of structurally complex corals decreases the availability of habitats and foraging grounds for reef-associated fish species, particularly bottom-dwelling invertebrate feeders. This reduction in coral-associated invertebrates further limits the prey base for higher trophic levels, exacerbating the decline in smaller fish populations (e.g., sweetlips, a benthic invertivore). This would, in turn, affect the food availability for other bigger fishes that rely on smaller fishes to feed on. This could indirectly lead to a decline in the overall population of the fish in a reef ecosystem. While the biomass in shallow stations is increasing, the density is declining even in deep stations. It is plausible that the decline in coral cover at monitoring sites has already triggered a cascading effect on the overall population of reef fish in Tubbataha.

Elevated Sea Surface Temperature (SST)

From 2000 to 2021, the Sulu Sea experienced a clear upward trend in sea surface temperature (SST), SST anomalies, and the number of days exceeding 30°C (Figure 26). This intensifying thermal stress poses a significant threat to tropical marine ecosystems like Tubbataha, where such changes disrupt ecological stability and resilience. Recent data from NOAA (2024) revealed that SSTs in 2024 reached record highs, marking 15 consecutive months (September 2023 – November 2024) of unprecedented temperatures. These conditions have triggered mass bleaching events worldwide, including severe bleaching on the Great Barrier Reef in March 2024 (ICRI, 2024). Such global trends underscore the vulnerability of coral reef ecosystems to thermal stress, a challenge mirrored in Tubbataha's marine environment.

Rising SSTs are a significant stressor for coral reef ecosystems, influencing the behavior and distribution of marine species (Poloczanska et al., 2016). Marine species, including fish, are redistributing to deeper waters and higher latitudes in response to climate change. For instance, a study by Chaikin et al. (2021) in the Mediterranean Sea found that marine species migrated deeper to escape warmer surface waters. Similarly, fish in the Bering and North Seas are moving beyond their traditional habitats, with demersal species exhibiting a "deepening" response due to rising temperatures (DeFilippo et al., 2023; Perry et al., 2005; Kulvy et al., 2008). Recruitment success also plays a critical role in these shifts, as changes in temperature and food availability directly affect fish distribution and migration patterns (Rijnsdorp et al., 2009).

This global trend may already be influencing schooling fish behavior in Tubbataha. Pelagic species such as jacks, though less frequently recorded in transects than in previous years, are still observed in the vicinity. Reports from tourists and park management indicate these species persist but are found at depths beyond the 10 meters typically monitored by TMO (see General Observations). This aligns with published studies that fish often migrate to deeper, cooler waters in response to thermal stress (Munday et al., 2008; Pörtner & Knust, 2007). These behavioral shifts underscore the importance of monitoring both shallow and deeper zones to fully understand climate change's impacts on fish populations in Tubbataha.

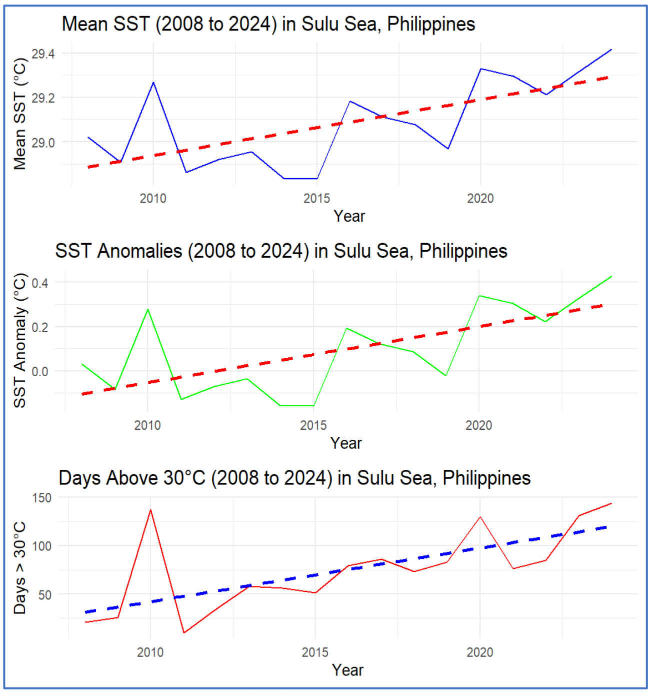


Figure 26. Mean Sea Surface Temperature (SST), SST anomalies, and days exceeding 30°C in the Sulu Sea, Philippines, from 2000 to 2024. Rising trends in mean SST and an increasing number of thermal stress days indicate growing environmental challenges for the region. Data sourced from Copernicus Climate Change Service (C3S), 2025.

Elevated SSTs also have severe implications for coral reef habitats, particularly for demersal fish species that rely on corals for shelter and food. During the summer of 2024, Tubbataha recorded water temperatures of 34°C (Chapter 4), correlating with a mass bleaching event that affected up to 43% of coral colonies at depths of 5–7 meters (Chapter 10), with bleaching observed as deep as 22 meters (Figure 27). Similar events have been reported globally, such as in Mexican Pacific reefs, where mortality rates exceeded 50–93% due to extreme thermal anomalies (López-Pérez et al., 2024). These events illustrate the devastating consequences of prolonged thermal stress on coral ecosystems.

Such bleaching events degrade coral habitats, reducing food availability and shelter for demersal species, which can lead to declines in density and biomass even among less mobile fish populations (Graham et al., 2007). These changes impact ecosystem resilience, as seen in other reefs affected by bleaching. As coral reefs degrade due to increasing temperatures, the ecological balance these fish help maintain is threatened, making the continued protection and monitoring of ecosystems like Tubbataha critical for their future sustainability.

Figure 27. A bleached coral colony found at more than 20 meters. Photo by Dindo Paquibot

Observer bias

The potential for observer bias is an important consideration when assessing the reliability of long-term monitoring data. Variability in how observers identify species, estimate fish sizes, and count individuals can introduce inconsistencies in the data (Edgar et al., 2016). While efforts have been made to standardize monitoring protocols over the years, inherent challenges in underwater surveys can still introduce variability in the data.

The trends in Tubbataha's fish populations might be a result of a complex interplay of factors—ranging from habitat degradation, elevated sea surface temperatures (SST), species-specific behaviors, and fishing pressure—that collectively shape the reef ecosystem. No single cause can be isolated as the primary driver of the observed declines in fish density and biomass; instead, multiple stressors may be acting simultaneously, and their precise contributions are difficult to quantify. Additionally, other factors may influence these trends that have yet to be fully accounted. Despite these challenges, the stability of fish biomass in shallow areas and the role of Tubbataha as a no-take Marine Protected Area (MPA) remain critical in preserving biodiversity and providing refuge for vulnerable species (Russ & Alcala, 2011). MPAs continue to be the best conservation strategy to mitigate broader environmental pressures and sustain fish populations in the face of climate change and external fishing pressure (Edgar et al., 2014). While uncertainties remain in the face of changing climate, and continued monitoring is essential, Tubbataha's protected status offers significant hope for the long-term resilience of fish populations.

Grounding sites

USSG Guardian

In both the shallow and deep stations at USS Guardian, fish density and biomass followed distinct recovery trajectories over the 12 years since the grounding event. There has been a modest increase in fish density in the shallow stations, particularly among herbivorous species such as parrotfish and surgeonfish. These herbivores play a critical role in reef recovery by grazing on macroalgae, which would otherwise overgrow and outcompete corals for space. Their gradual increase helps stabilize the ecosystem, maintaining the balance between algae and coral cover. However, despite this positive trend, fish density remains below the levels recorded in the years immediately following the grounding in 2013.

Coral reef systems, particularly those impacted by physical disturbances like ship groundings, often take decades to fully recover. Research indicates that the structural complexity of coral habitats, essential for supporting diverse fish populations, can take anywhere from 10 to 50 years to return to pre-disturbance levels, depending on the extent of the damage and the conditions for recovery (Precht et al., 2001). The slow recovery in the impact site of the USS Guardian grounding may be attributed to compounded stressors and other factors beyond the boundaries of the grounding site, including the lack of a nearby coral larvae source (Cadiz et al., 2023), which corresponds with the declining trend in coral recruit density in Tubbataha (Alarcon et al., 2023).

Elevated SST exacerbates coral bleaching, weakens coral structures, and reduces reproductive success, which hinders recovery efforts (Hughes et al., 2010). Additionally, warming waters interfere with larval settlement, further slowing the natural regeneration process at these damaged sites. Without favorable environmental conditions, including cooler temperatures and higher larval recruitment, the recovery of these coral reefs remains uncertain.

In the deep stations, the trends in density and biomass show greater variability. These stations are located along a steep reef wall, which supports different fish assemblages compared to the shallower, flatter areas. Piscivorous species such as groupers and jacks occasionally dominate the biomass in these deeper waters, but their density fluctuates.

The steep reef wall at the USS Guardian site offers a vertical habitat that supports species adapted to strong currents and deeper waters. Vertical habitats, such as steep walls, tend to host distinct communities compared to flat or gently sloping areas. These walls provide structural complexity that offers protection and refuge for reef-associated species, particularly planktivores and piscivores (Friedlander & Parrish, 1998). The reef wall allows for quicker recolonization by species that use the wall as shelter, facilitating persistence after disturbances. Vertical habitats can support the recovery of fish populations due to their ability to offer refuge from predation and provide access to abundant resources like plankton (Graham et al., 2015).

The proximity of the shallow impact zone to the deep reef wall may also explain why certain groups, such as herbivores and planktivores, have maintained relatively stable densities across depths. The connectivity between the shallow and deep areas facilitates fish movement, allowing species to exploit resources across both habitats. This movement is particularly beneficial for planktivores, which thrive near vertical structures where plankton is more abundant. The high current flow near the steep wall supports higher plankton densities, which in turn sustains the planktivore population (Friedlander & Parrish, 1998).

The steep reef wall at the USS Guardian site has been crucial in recovery by offering refuge and resources for fish species. Its vertical structure supports recolonization and sustains fish populations, emphasizing the vital role of habitat complexity in the long-term recovery of coral reef ecosystems after grounding events.

Min Ping Yu

In the shallow waters of Min Ping Yu, fish density and biomass have exhibited considerable variability since the grounding in April 2013, shaped in part by the unique habitat characteristics of the area. The predominantly sandy and rubble shallow environment provides a less favorable habitat for coral-dependent species. Sandy habitats, by nature, tend to lack the structural complexity that rocky or reef-dominated areas offer, often supporting lower species richness and abundance, particularly among species like parrotfish and damselfish that rely on coral cover for shelter and food (Bellwood et al., 2019; Wilson et al., 2010).

In the deeper stations, located approximately 50 meters from the shallow impact zone, fish populations show greater variability, with occasional increases in density and biomass. Piscivorous species, such as jacks, have shown declining trends in recent years, potentially attributed to the transient nature of this pelagic species. This trend in jacks and trevallies also mirrors what is happening in the monitoring sites. Factors that may contribute to the reduced presence of jacks and trevallies in the deeper areas observed at the monitoring sites could also be influencing these patterns.

The distance between shallow and deep also shapes the fish communities at Min Ping Yu. With limited habitat continuity between the two areas, recolonization of shallow fish populations from deeper waters may be less efficient. The sandy substrate in shallow areas contribute to slower rates of fish population and coral cover recovery.

Overall, the trends at Min Ping Yu reflect the complex interplay between habitat characteristics and fish population dynamics. In the shallow areas, herbivores have adapted to the available resources. However, overall recovery is impeded by the lack of coral and structural complexity. The sandy nature of the site presents significant obstacles to coral recolonization, slowing the restoration of habitat complexity critical for supporting diverse fish communities. As a result, fish density and biomass at Min Ping Yu continue to experience year-to-year variability, shaped by the unique environmental conditions of this grounding site.

Trends in Herbivorous Fishes with the Increase in Algal Assemblages in Monitoring Stations

This analysis examines the relationship between herbivorous fish populations—measured as biomass and density—and algal assemblages (AA) across monitoring stations in Tubbataha. As noted in Chapter 1, several stations have experienced an increase in algal cover alongside a decline in hard coral cover (HCC) over recent years. Although overall herbivore biomass and density remain relatively stable, it is critical to understand how these fish populations interact with the shifting benthic community.

Contrary to the expectation that higher herbivore presence would suppress algal growth through grazing, the Pearson correlation results reveal several stations with positive associations between herbivore metrics and algal cover. This suggests that the relationship between herbivores and algae is more complex than a simple top-down control mechanism.

At Station JBA, herbivore density exhibited a strong positive correlation with algal assemblages (r = 0.70, p = 0.0163), indicating that higher herbivore density is significantly associated with increased algal cover, while the positive correlation for herbivore biomass (r = 0.40) was not statistically significant (p = 0.22). Similarly, at Station S3A, there was a significant positive correlation between herbivore density and algal cover (r = 0.73, p = 0.0114), although the correlation for herbivore biomass was negative (r =-0.29) and not significant (p = 0.38). At Station S3B, both herbivore biomass (r = 0.66, p = 0.0270) and density (r = 0.67, p = 0.0232) displayed significant positive correlations with algal assemblages, highlighting a robust association at that station. In contrast, at the remaining stations (JBB, S1A, S1B, S2A, S2B, S4A, and S4B), the correlations between herbivore metrics and algal assemblages were weak to moderate and not statistically significant, suggesting that, in these areas, herbivory may not be the primary driver of algal cover variability.

Table 16. Pearson Correlation Results for Algal Assemblages versus Herbivore Biomass and Density in Shallow Stations. Significant results are indicated where p<0.05.

STATION	Pearson_Corr_ Biomass_AA	P_Value_ Biomass_AA (p<0.05)	Pearson_Corr_ Density_AA	P_Value_ Density_AA
JBA	0.40	0.22	0.70	0.01
JBB	0.01	0.96	0.47	0.17
S1A	-0.02	0.94	-0.41	0.21
S1B	0.58	0.06	0.24	0.47
S2A	-0.40	0.22	0.33	0.31
S2B	0.44	0.17	0.37	0.26
S3A	-0.29	0.38	0.73	0.01
S3B	0.66	0.027	0.67	0.02
S4A	-0.54	0.08	-0.40	0.22
S4B	0.09	0.77	0.37	0.25

Several speculations and possible factors might explain these patterns. One possibility is that shared favorable conditions could be influencing both herbivore populations and algal cover. Areas with higher algal abundance may also offer environmental conditions—such as elevated nutrient levels, optimal light, and reduced physical disturbances—that simultaneously support denser herbivore populations.

Another factor could be habitat structural changes. For instance, Station JBA experienced a significant loss of hard coral cover, likely increasing the available substrate for algal colonization. This newly available space may attract herbivores that are either capitalizing on the altered habitat or responding to the increased algal biomass.

Behavioral and species-specific factors might also be at play. The positive correlations observed—especially at Stations S3A and S3B—could reflect selective feeding behaviors or the presence of particular herbivore species that are less effective at controlling algal growth despite their abundance. Larger-bodied or selectively feeding herbivores may not graze evenly across algal assemblages, thereby allowing algae to persist or even flourish.

Overall, the complex ecological interactions suggest that herbivory is just one of many factors influencing algal cover. Other elements such as water quality, substrate availability, and competitive interactions with corals also play significant roles. Studies by William and Polunin (2001), Bellwood et al. (2006), and Burkepile & Hay (2008) support the idea that the effectiveness of herbivores in controlling algae depends on a combination of species-specific traits and environmental conditions.

The results underscore that in certain stations—particularly JBA, S3A, and S3B—higher herbivore density (and in some cases biomass) is associated with increased algal cover. This counterintuitive pattern may arise because the same favorable conditions that promote algal proliferation (such as nutrient enrichment or substrate availability following coral loss) also support higher herbivore populations. Thus, herbivorous fish alone may not be sufficient to mitigate algal overgrowth, especially when other environmental stressors are at play. Future studies should incorporate additional ecological factors and examine species-specific behaviors to better understand these complex interactions.

Other General Observations

Throughout the monitoring efforts, notable species and events were recorded to document the current conditions and occurrences around the survey areas. These observations provide a broader context of what is happening around the survey areas, offering deeper insights into the ecosystem's dynamics and ongoing challenges.

At station 3B, three hawksbill sea turtles (*Eretmochelys imbricata*), an IUCN listed Critically Endangered species, were observed. Additionally, 45 Napoleon wrasses (*Cheilinus undulatus*), an Endangered reef fish, were recorded within the transects, with 15 individuals recorded in station 2A. An additional 16 Napoleon wrasse were observed outside the transects, bringing the total to 61. These sightings highlight the significance of Tubbataha as a refuge for critically endangered species.

Shark sightings within the transects were limited, with only three sharks recorded. Two juvenile grey reef sharks (*Carcharhinus amblyrhynchos*, 45 cm) were observed in the deep waters of station 3B, and one white-tip reef shark (*Triaenodon obesus,* 120 cm) was recorded at Station JBB. Outside transects, two grey reef sharks were noted at JBA and one white-tip reef shark at station 1A.

Schools of fish were documented during the survey. At site 5, two schools of big-eye trevallies (*Caranx sexfasciatus*) were observed, with an estimated 900 and 800 individuals. A school of 300 humpback snappers (*Lutjanus gibbus*) was also noted at the same site, while a school of 150 blackfin barracuda (*Sphyraena qenie*) was seen at JBA. A small group of bumphead parrotfish (*Bolbometopon muricatum*) (14 individuals) was also recorded in Site 4.

During the survey, loud acoustic disturbances were reported by researchers, raising concerns about potential external threats. On April 27, 2024, at station 1A, four consecutive blasts were heard, startling both the researchers and the surrounding fish. Three days later, on April 30, similar blasts were heard at station 3B on the South Atoll. While the exact cause remains unknown, it was speculated that these blasts could have been caused by blast fishing outside the park, as soundwaves from such explosions can travel over long distances underwater.

Conclusions

The long-term monitoring of fish populations in TRNP has revealed both promising signs of resilience and concerning trends that warrant attention. While the deep reef stations continue to show declines in both fish density and biomass, the shallow stations present a more stable scenario, with biomass remaining consistent despite fluctuations in density. This stability in the shallow waters, driven by larger species compensating for fewer individuals, reflects the resilience of some fish populations within the protected area.

However, the overall trends underscore the multitude of factors shaping these populations, including habitat degradation, climate change, and species-specific behaviors like migration. It is important to acknowledge that there may be other unaccounted-for factors influencing these trends, adding complexity to our understanding of the ecosystem.

Demersal species, though experiencing more stable trends than their pelagic counterparts, also show signs of long-term decline, particularly in deep areas. Their closer association with the reef substrate may provide some refuge from external pressures, but environmental changes such as habitat degradation, coral loss, and increasing SST still impact their populations. Notably, the stabilization of demersal fish density at lower levels in recent years may indicate a potential threshold beyond which further declines could occur without intervention.

Despite these challenges, Tubbataha remains an exceptional marine ecosystem, with biomass and density levels that continue to rank within the "high" and "very high" categories of Philippine reef fish standards. Tubbataha's role as a no-take MPA continues to be vital in maintaining the biodiversity of its fish populations, especially in the face of broader environmental pressures. The stable biomass in the shallow areas is a testament to the effectiveness of the MPA in providing a refuge for fish populations, allowing them to persist amid changing conditions. Continued monitoring and targeted research are essential to further understand the drivers behind these trends and to ensure the long-term resilience of Tubbataha's marine life. The declines in fish groups highlight the need for adaptive management strategies that account for both local and global environmental changes.

Recommendations

1. Further research is required to investigate the most probable cause of the decline in density and biomass in TRNP fish populations, as current monitoring does not provide sufficient data to draw conclusions. Below is a list of specific research that can isolate the possible factors of the decline which will be beneficial to understanding our fish populations:

- o Pelagic Species Movement Studies: Use tracking technologies (e.g., acoustic telemetry or satellite tags) to monitor the movements of pelagic fish species, allowing for a better understanding of their range and how they interact with the MPA boundaries
- o Assess whether coral degradation indirectly drives the decline in fish populations through habitat loss and altered food availability, for example, understanding the interactions between coral cover loss and the increase of algal assemblages to herbivorous species, loss of habitat complexity for invertebrates that can affect benthic invertivores
- o Conduct genetic connectivity studies of species (both demersal and pelagic) to assess the extent of population exchange between TRNP and nearby areas. This can help identify source-sink dynamics, where populations inside TRNP might be replenished from external areas or vice versa. This will help us understand whether the populations within TRNP are isolated or connected to larger regional fish stocks, and how that affects their resilience to environmental pressures or fishing activities outside the park.

2. Introduce/continue long-term, consistent monitoring of critical environmental parameters such as sea surface temperature (SST), salinity, pH levels, dissolved oxygen, and nutrient concentrations. These parameters can be continuously monitored using oceanographic sensors and integrated into the existing research and monitoring program of Tubbataha. This will help us correlate fish population (and benthos) changes/declines with environmental variables that are indicative of climate change or local stressors.

3. Continue implementing regular calibration exercises and training programs to standardize fish monitoring methods and minimize observer bias. This will improve the accuracy of fish visual census data and reduce variability caused by different observer techniques.

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3| SEABIRDS

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Overview

The fieldwork was conducted from 8 to 13 May 2024. The team arrived at the Ranger Station on 8 May, and inventories were conducted from 9 to 11 May 2024 at Bird Islet and 12 to 13 May 2024 at South Islet.

An orientation was conducted at the Ranger Station, where the Protected Area Superintendent (PASu) of the Tubbataha Management Office (TMO) explained the monitoring protocols and the highlights of previous years' results. Each participant was assigned tasks to carry out over the succeeding days.

The 2024 survey constituted 24 participants headed by the PASu of Tubbataha Reefs Natural Park , including 18 TMO staff and Marine Park Rangers (MPRs), one crew from M/Y Navorca, and five volunteers (Appendix 1). The team of MPRs consisted of three from the Philippine Coast Guard, two from the Philippine Navy, three from the Municipal Government of Cagayancillo, and four from TMO. Headed by Captain Darius Cayanan, M/Y Navorca of WWF-Philippines transported the team to Tubbataha Reefs and back to mainland Palawan.

Methods

The fieldwork followed methods for distance count monitoring and for inventories of breeding seabirds established and used since 2004 (Jensen 2004). The counts of the breeding bird populations represent a combination of these different count methods:

- direct daytime inventories of adults, immatures, juveniles, pulli, eggs, and nests;
- in-flight count of booby species from 4:30 pm to 6:30 pm; and,
- standardized measurements of the Bird Islet and vegetation development.

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

Taxonomic treatment and sequencing follow the IOC World Bird List Version 12.2 (10 July 2023) and Wild Bird Club of the Philippines Checklist of Birds of the Philippines 2023.

Calculation of land area and vegetative cover

Photos of permanent photo documentation sites in Bird Islet and South Islet were taken (Appendix 11). 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 on the islets was assessed through a census of tree and vegetation conditions. Most trees planted on the islets in the past years were mainly saplings of *Pisonia grandis* (commonly known as Anuling, Bird-catcher, or Lettuce Tree). The condition of the trees was categorized as optimal (good), moderately deteriorating (fair), severely deteriorating (bad), or dead. Figure 27 presents a photographic documentation of the most common beach forest species in TRNP. The 2024 vegetation inventory was conducted using the same methodology as in previous years, allowing for a reliable comparison of trends over time.

Figure 28. From left to right: *Scaevola taccada* (beach cabbage/sea lettuce/beach naupaka), *Heliotropium foertherianum* (tree heliotrope), and *Pisonia grandis* (Anuling, bird-catcher tree/lettuce tree). Photos by Teri Aquino

Calculation of breeding populations

This report includes data from June 2023 to May 2024. The methods used to calculate the seabird populations followed the previous years' approach:

- Daytime direct counts of birds, nests, and eggs;
- Dawn count estimations (5 am) of the Brown Booby *Sula leucogaster* and Red-footed Booby *Sula sula* populations at the 'Plaza' and the adjacent area;
- In-flight data of Red-footed Booby and Brown Booby;
- 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 2024; and data gathered by MPRs from June 2023 to May 2024. 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 data published from 2004 to 2006, and in the 2009 to 2023 seabird monitoring reports (see Jensen 2004 to 2006 and 2009 to 2016, and Jensen et al., 2017-2023).

Results and Discussion

Monitoring of Changes in Land Area and Habitats

Independent sets of measurements were taken using two GPS units. The measurements were taken at high tide (1 meter) along the shoreline as the vegetation line previously used as a reference has disappeared. Due to this shift in methodology, data sets from 2016 onwards are not comparable to the previous years.

Bird Islet. The land area increased by 21%, expanding from 13,993m^2 in 2023 to 16,905m^2 in 2024. The islet's circumference, measured along the high-tide line, grew by 9%, from 540 meters in 2023 to 591 meters in 2024. As in the previous year, erosion was notably observed on the northeast side of the islet. The central area, known as the "Plaza," is characterized by compacted barren soil with minimal vegetation (Figure 29). It now covers 6,842 m^2, representing a 26% increase compared to its size in 2023 (5,435 m^2). However, the boundaries of the "Plaza" are not clearly defined, leading to some uncertainty in the measurement data.

Figure 29. Landscape of 'Plaza', Bird Islet, May 2024. Photo by Gerlie Gedoria/TMO

When vegetation on Bird Islet was first assessed in 2006, 229 beach forest trees were recorded. However, the vegetation began to deteriorate due to the effects of bird droppings combined with several years of drought. By 2016, all the trees had died. In response, reforestation efforts were undertaken between 2017 and 2019, with small numbers of beach forest saplings being planted. In June 2020, 329 *Pisonia grandis* (Anuling) saplings were planted, but by 2023, only eight remained. These eight saplings, protected by bamboo guards, have since matured into trees ranging from 4 to 7 feet in height. All of the trees are in good condition, except for one 4-feet high tree that lacks a bamboo guard.

South Islet. South Islet was originally part of a large sandbar until a circumferential concrete seawall was built in the 1980s to accommodate a lighthouse (Kennedy 1982). In 2019, further modifications, including the construction of a new seawall and lighthouse, altered the size of the islet. Since the completion of the new seawall in 2020, the islet's circumference changed to 307 meters, up from 230 meters in 2018. The land area also increased from 2,884 m^2 in 2018 to 5,222 m^2.

Up until 2009, the beach forest, consisting of approximately 125 trees, was in optimal condition, with some trees reaching heights of around 30 feet. However, by 2014, most of the trees were in poor condition. In 2019, the last five dying trees were buried under sand during the islet's reconstruction. In June 2020, 101 Anuling saplings were planted, but by April 2022, all had died due to sea spray from rough sea conditions. After the vegetation inventory in April 2022, 19 additional saplings were sent to the park and planted on South Islet, but by May 2023, none had survived. In June 2023, five more saplings were planted, but by May 2024, only one Anuling sapling, standing 3 feet tall, had survived.

Avifauna Inventory Results

Eighteen (18) bird species including breeding seabird *species* were identified (Appendix 10). The total number of all avifauna species, mostly migratory, recorded in TRNP over time is 124. Among these are seven seabird species that 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*. In addition to these, three other species also breed in the park. The Pacific Reef-Egret *Egretta sacra* breeds annually, while the Barred Rail *Gallirallus torquatus* breeds irregularly. The Eurasian Tree Sparrow *Passer montanus* is now only occasionally observed.

Among the breeding seabirds, the Masked Booby is classified as Critically Endangered, and both the Brown Booby and Black Noddy are listed as Endangered. The Brown Noddy, Great Crested Tern, and Sooty Tern are considered Vulnerable (DENR, 2019). Additionally, the Philippine subspecies *worcesteri* of the Black Noddy is included in Appendix II of the Convention on Migratory Species, recognizing the need for international protection and management agreements.

In TRNP, booby species breed year-round, whereas tern species have a breeding season lasting about nine months each year (Heegaard and Jensen 1992; Manamtam 1996; Kennedy et al., 2000; Jensen 2009; Jensen and Songco, 2016). Therefore, the April/May inventory only reflects the breeding population present during that period.

Table 17. Total count numbers of adult resident seabirds present on Bird Islet and South Islet in May 2024 compared to the inventory result of end of May 2023.

Species / Numbers	2023			2024			% Change
	Bird Islet	South Islet	Total	Bird Islet	South Islet	Total	
Brown Noddy	541	621	1,162	1,332	189	1,521	+31
Black Noddy	1,590	1,252	2,842	1,580	832	2,412	-15
Great Crested Tern	3,438	12,718	16,156	11,065	5,972	17,037	+ 5
Sooty Tern	3,900	715	4,615	>320	760	1,080	-77
Masked Booby	2	0	2	4	0	4	+100
Red-footed Booby	258	231	489	346	156	502	+3
Brown Booby	4,728	126	4,854	8,117	622	8,739	+80
Total	14,457	15,663	30,120	22,764	8,531	31,295	+ 4

In May 2024, a total of 31,295 adult individuals from seven breeding seabird species were recorded, with 22,764 on Bird Islet and 8,531 on South Islet (Table 17). Bird Islet hosted 73% of the breeding population (compared to 48% in 2023), while South Islet accounted for 27% (down from 52% in 2023). Compared to the 2023 inventory, the seabird population on Bird Islet increased by 57%, whereas South Islet saw a 46% decrease. As in the previous year, the Great Crested Tern was the most abundant species, representing 54% of the total May 2024 count.

Overall, the May 2024 count was 1,175 birds higher than the 2023 inventory, marking a 4% increase (Table 17). The 2024 seabird count was also 131% higher than the baseline counts recorded in 1981 (Kennedy, 1982). Although the total seabird numbers in May 2024 were similar to 2023, there were significant changes in the populations of certain species. The Brown Booby population increased by 80%, while the Brown Noddy population grew by 31%. The substantial increase in the Brown Booby population is likely due to the high number of in-flight individuals, possibly influenced by the increase in breeding numbers from 2017 and 2019, as the Brown Booby matures after four years.

In contrast, the Sooty Tern population decrease of 77% does not represent a real decline, but a shift in breeding phenology. According to ranger data, Sooty Terns began breeding in January 2024, which may explain the lower numbers recorded during the May inventory.

Review of Marine Park Rangers Data

Since the inventory in May 2023, MPRs made three (3) inventories in Bird Islet and four (4) in South Islet until February 2024. In-flight counts for Brown and Red-footed Boobies were also carried out on Bird Islet in November 2023.

By April 2024, the MPRs had conducted 11 distance counts on Bird Islet and 10 on South Islet, while also recording the number of seabirds roosting at the Ranger Station. The data collected from these observations revealed several significant findings (see Table 18 below).

Table 18. Highlights of MPR distance and direct counts from June 2023 to April 2024

Species	Bird Islet	South Islet
Brown Noddy	Since 2017, a change in phenology has been evident with overwintering Brown Noddies. Distance counts revealed that the Brown Noddies were present from June 2023 to May 2024. In November 2023, Brown Noddy was recorded breeding in Bird Islet with 1,014 adults, 20 immatures, 7 juveniles, 40 pullus, and 267 eggs.	Brown Noddy was also present in South Islet from June 2023 to May 2024. Breeding extended until December, with 1,116 adults, 235 juveniles, 50 pullus, and 519 eggs recorded.
Black Noddy	Distance counts revealed Black Noddy's presence throughout the year, with breeding recorded in August and November 2023, and February 2024.	Used to be absent from November to February, now present throughout the year. Breeding recorded in June, August, and December 2023, and February 2024.
Greater Crested Tern	Absent from October to December 2023. 1,030 non-breeding adults recorded in February 2024. Egg-laying began in April, but peaked in May with 195 pullus and 4,623 eggs recorded.	Not present on the islet in October, but 450 individuals noted in December 2023. No breeding recorded after May 2023 inventory. Next breeding cycle likely began in April 2024 (slightly earlier than in Bird

		Islet) with 1,430 pullus and 1,549 eggs recorded in May 2024.
Sooty Tern	Absent from October to November 2023. Breeding began in January, with 646 adults, 253 juveniles, and 56 eggs recorded in February 2024.	Absent in October, but overwintered with 9,045 adults and 6,105 juveniles recorded in December 2023. 11,050 adults recorded during distance count in January, while 10,710 adults, 2,648 juveniles, 646 pullus, and 1,885 eggs recorded during the February inventory.
Masked Booby	Two (2) adults, one (1) pullus, and one (1) egg recorded in August 2023. From October 2023 to February 2024, three (3) adults were noted by the rangers during distance counts. In February 2024, rangers reported one (1) juvenile and one (1) egg. The juvenile reported is the second successful fledgling of this pair. Two (2) eggs were reported on March 13 and May 22, but both failed to produce pulli. In August 2024, two immatures were observed pairing 20 meters from their parents within the plaza. They were tagged with metal and plastic rings in May 2024.	No breeding population
Red-footed Booby	Low number of adults, less than 200 individuals since June 2023. Numbers of nests also remained low, less than 50, and in general with very few off-springs.	Less than 200 individuals, except in August 2023 when there were 237 adults recorded. Nesting rate low as empty active nests are removed. A total of 141 active nests, with just one (1) juvenile, eight (8) pulli, and 32 eggs reported during the quarterly inventories from June 2023 to February 2024.
Brown Booby	Low number of active nests in August (535) and November 2023 (49). In February 2024, 1,731 active nests were recorded, with high number of pulli/juvenile at 1,232 individuals.	Lower number of active nests compared to Bird Islet, with 38 in June 2023 and less than 15 from August 2023 to February 2024.
Pacific Reef Egret	Not reported	One observed in June 2023
Barred Rail	Not observed	Not observed
Eurasian Tree Sparrow	Not observed	Not observed

Species Account of Breeding Birds

Brown Noddy (Conservation Status - Philippine Red List: Vulnerable): Fluctuating population. The total estimated annual population was 2,163 individuals (including inventory counts in February 2024). This figure is relatively close to the 2023 population estimate of 2,646 individuals. The population is gradually declining after it peaked in 2017 (see Figure 30).

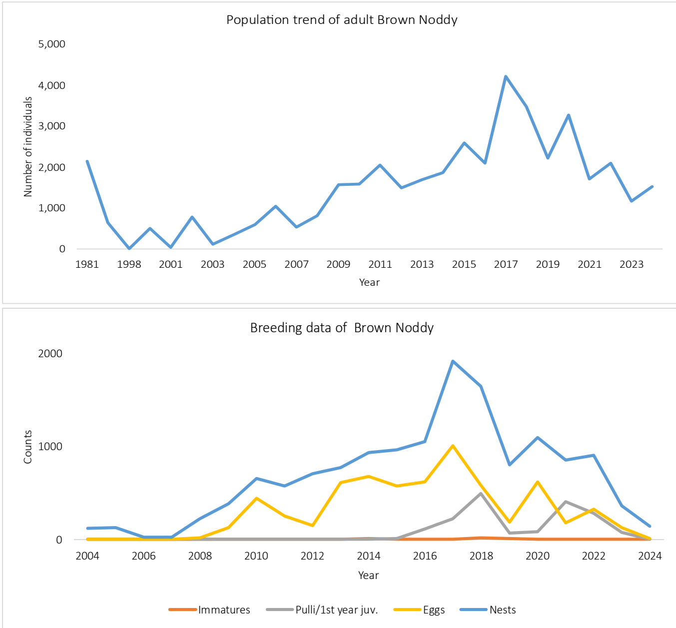

Figure 30. Population trend (top) and breeding data (bottom) of Brown Noddy.

The breeding population in May 2024 was 1,521 individuals, 31% higher than in May 2023 (1,162 individuals). In Bird Islet, the breeding population increased threefold, while a 70% decline was observed in South Islet.

The species is normally absent in TRNP from November to February. However, similar to 2023, a portion of the population overwintered and bred on Bird and South Islets.

Despite the overall increase in population, the breeding numbers in May 2024 were notably low, with only one egg and one juvenile observed on Bird Islet, and seven eggs on South Islet.

Black Noddy (Conservation Status – Philippine Red List: Endangered): Declining population. The total estimated annual population is 3,730 adult individuals (including February 2024 counts), which did not deviate much from the 2023 estimate of 3,802 individuals.

The Black Noddy is classified as Endangered by the Department of Environment and Natural Resources (DENR DAO 2019-09) and is listed as a conservation-dependent species under Appendix II of the Convention on Migratory Species. Currently, only 35% of the original population of 10,656 adult birds recorded in 2013 remains. This population decline is linked to the gradual loss of the species' natural breeding habitat. To mitigate this, artificial nesting structures have been constructed by the MPRs since 2017 in Bird Islet and since 2019 in South Islet, providing an alternative breeding habitat for the Black Noddy.

In May 2024, the adult population was recorded at 2,412 individuals, showing little variation from the 2,842 individuals counted in May 2023. The species may now be breeding year-round, as eggs, juveniles, and pulli were observed during each quarterly inventory. Historically absent from November to February, the Black Noddy overwintered and bred on Bird Islet in November

2023, with 166 eggs and 39 pulli recorded, and on South Islet in December 2023, with 226 eggs and 32 pulli.

Figure 31. Population trend (top) and breeding data (bottom) Black Noddy

The Black Noddy has utilized the artificial nesting structures on both islets, with cut grasses provided to supplement the lack of natural nesting materials. As some structures have deteriorated, additional ones are being built. Despite the success of these nesting structures in boosting reproduction rates, the current rate remains insufficient to sustain the breeding population, as more offspring are needed to replenish the population over time. Observations of nests revealed that they were primarily composed of grass from the islet, with about 20% plastic and a few seaweeds mixed in.

Mortalities were recorded on both islets. On Bird Islet, 29 individuals were found dead, either trapped in gaps between the nesting structures or tree guards, or entangled in plastic debris, while seven deaths were recorded on South Islet.

Additionally, rangers reported between 250 and 400 Black Noddies roosting at the Ranger Station and on patrol boats from June to November 2023.

Great Crested Tern (Conservation Status- Philippine Red List: Vulnerable): Stable population. The total estimated annual population was 17,037 adult individuals, which was relatively more than last year's estimate of 16,156 individuals.

Compared to May 2023, the population in May 2024 increased by 5%. Bird Islet saw a significant population increase of 222%, while South Islet experienced a 54% decline. In 2024, 64% of the breeding population was recorded on Bird Islet.

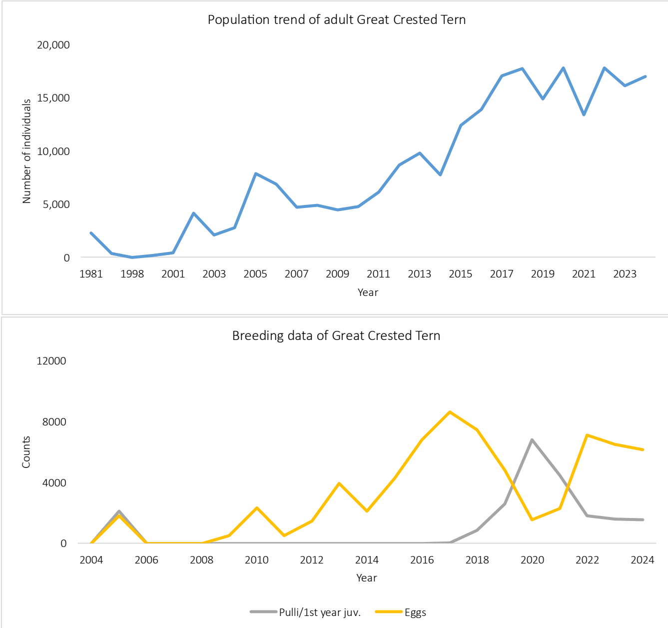

Figure 32. Population trend (top) and breeding data (bottom) of Great Crested Tern

The breeding cycle for the Great Crested Tern began in April and peaked in May. Among all seabirds breeding in TRNP, the Great Crested Tern has one of the most stable breeding populations.

Sooty Tern (Conservation Status – Philippine Red List: Vulnerable): Stable population. The total estimated annual population is 12,056 adults, which is nearly the same as last year's estimate of 12,210 individuals.

The Sooty Tern exhibits the most variable breeding cycle among all the seabirds in the Park. During the May 2024 inventory, the Sooty Tern had just completed a breeding cycle, which likely began in December 2023. The team only saw one juvenile Sooty Tern in Bird Islet during the daytime counts. However, during low tide, they recorded at least 320 adults on the sand bar near the islet. Following the inventory protocol, the team conducted a nighttime survey around Bird Islet to check for roosting Sooty Terns, but none were found. Despite this, distant Sooty Tern calls were heard, suggesting the population might be in the early stages of a new breeding cycle.

Figure 33. Population trend (top) and breeding data (bottom) of Sooty Tern

On South Islet, the team recorded at least 30 adults, 300 juveniles, and three eggs. By May, most adults and fledglings had already left the islets, underscoring the value of the quarterly inventories conducted by MPRs in August, November, and February.

Since the Sooty Tern's breeding cycle includes populations not actively breeding in May 2024, data from the February 2024 count when 10,358 adults were recorded, along with 3,294 juveniles and pulli, and 1,885 eggs was used to estimate the annual breeding population.

Masked Booby (Conservation Status- Philippine Red List: Critically Endangered)

To date, TRNP hosts the only confirmed breeding pair of Masked Booby in the Philippines, making close monitoring of this population a priority for TMO.

Masked Booby had been declared as locally extirpated since 1995. After 21 years, one individual was recorded in Bird Islet in May 2016. A second individual appeared in October 2019. The pair began to lay eggs in June 2020. In June 2022, a nest monitoring camera was installed near their nest on Bird Islet. Since then, the same Masked Booby pair has laid eggs eight times, five of which occurred between February and September 2024. In total, this breeding pair has laid eggs 14 times from June 2020 to September 2024.

Figure 34. Four individuals of Masked Booby taken on 8 August 2024. Photo by Seconds Conales

The rangers have closely monitored the population development of the Masked Boobies. The original breeding pair successfully raised two fledglings, one in 2022 and another in 2024. On May 9, 2024, the team captured and tagged two Masked Boobies: one with an existing plastic ring and another without a tag. The individual with the existing tag (plastic ring number 912 on its left leg) was the second fledgling, originally tagged as a juvenile in December 2023. The rangers added a metal band to its right leg with the number A0437. The other bird was tagged with both a plastic ring (number 017 on its left leg) and a metal band (A0550 on its right leg). In August 2024, the MPRs reported a total of four Masked Boobies on Bird Islet (Figure 33).

Red-footed Booby (Conservation Status - Philippine Red List: Least Concern): Declining population. <u>The total estimated annual population is 604 adult individuals,</u> which was 24% more than last year (489 individuals).

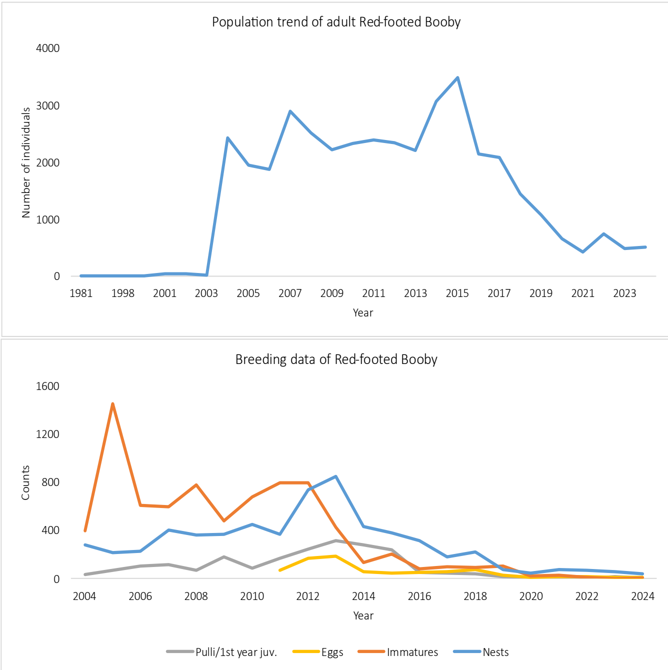

Figure 35. Population trend (top) and breeding data (bottom) of Red-footed Booby

The adult population in May 2024 was recorded at 502 individuals, a 3% increase compared to May 2023. However, this represents a 79% decline from the baseline population recorded in 2004. The number of active nests in May 2024 was notably low, with only 38 nests observed. The declining population can be attributed to breeding habitats (trees) and population management efforts by the MPRs, which included the removal of empty nests. Red-footed Booby was observed nesting on the ground in South Islet, as also observed in 2022.

Brown Booby (Conservation Status- Philippine Red List: Endangered): Increasing population. <u>The total estimated annual population is</u> <u>10,830 to 12,215 adult individuals</u>, approximately double the 2023 estimate of 5,998 individuals.

In May 2024, a total of 8,739 adults were recorded, reflecting an 80% increase compared to May 2023. This figure was also 132% higher than the baseline population recorded in 1981 when 3,768 individuals were counted. This significant increase in the adult population may be attributed to the high breeding numbers observed in 2017 (1,437 eggs) and 2019 (1,318 eggs) and beyond.

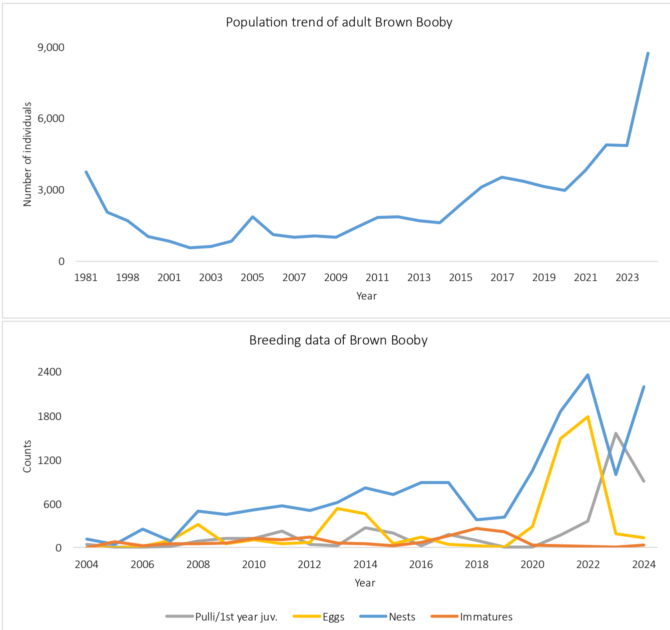

Figure 36. Population trend (top) and breeding data (bottom) of Brown Booby

The team observed a number of dead pulli on Bird Islet. In a 15x15 meter plot near the campsite, they recorded 13 dead pulli. These pulli may be representing the 2nd offspring not normally being fed by the parents.

RECOMMENDATIONS

Habitats

1. Restoration of Beach Forest: Continue to produce saplings from Cagayancillo and plant them in the islets during rainy season to ensure survival.

2. Habitat restoration of South Islet: Continue to remove grass to enable Great Crested Tern, Sooty Tern, and Brown Booby to breed on the islet.

Land area at Bird Islet and South Islet

3. Produce an erosion map with coordinates highlighting erosion-prone areas and areas under direct erosion at Bird Islet. Based on the erosion study results in 2024 and the advice of experts, start securing eroding areas using best-practice nature-based solutions.

4. At South Islet, fill the cavities along the perimeter wall with sand to prevent birds from falling in and pulli from being separated from their parents during inventory work. TMO has requested the Philippine Coast Guard to do the repair, and it is scheduled for 2025.

5. During inventories, limit the number of people to reduce human-induced stress among birds and separation of pulli from their parents.

Species

6. Black Noddy:

a) Ensure that the design of bamboo structures has few openings to reduce risks of birds becoming entangled in their heads, feet, or wings.

b) Maintain a sufficient number of breeding structures for at least 4,000 noddies.

c) Place nesting materials directly in the least attractive breeding structures, e.g., pyramid PVC breeding structures.

d). Marine plastic debris is increasingly used as nesting materials, particularly by the Black Noddy and Brown Booby populations (Jensen and Songco, 2016). Each year, Black Noddies are found strangled at their nests due to entanglement in discarded or lost fishing lines that the birds have used as nesting material. However, the impact of plastic debris used in the nests is often overlooked, posing a significant threat to the survival of the species. It is recommended to:

- Remove as much plastic debris from the nests that cause direct threats to the birds without destroying the nests' integrity, and

- Include plastic debris monitoring in the monitoring of the Black Noddy breeding population.

e). When observed, previously banded Black Noddy should be recaptured, and ring numbers read for analysis.

7. Red-footed Booby: Nests in the artificial breeding structures or on tree guards, or directly on the ground should be regularly removed.

Methodology

8. Recommended improvements on data collection and reporting includes:

a) Continue separating data on pulli from that of juveniles, which are birds living in their first calendar year;

b) Do not report immatures (birds in their second calendar year or more) of Sooty Tern, Great Crested Tern, and the two noddy species. They cannot be easily distinguished from adult birds, or at all.

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4| WATER QUALITY

Overview

Water quality monitoring in Tubbataha is a key component of the annual ecosystem research and monitoring conducted by the Tubbataha Management Office . The objectives of this monitoring are to: 1) assess the current water quality by evaluating the prevailing water conditions in TRNP; 2) track changes and trends to identify and analyze variations in water quality over time to understand long-term ecological shifts; and 3) determine potential sources of water quality changes and their impacts on the park's environment.

To achieve these objectives, twenty (20) monitoring stations were strategically established throughout TRNP, considering factors such as location, anthropogenic activities, and existing biophysical monitoring stations. These stations are distributed across the core zone (17 stations) and the park's buffer zone (3 stations).

On-site measurements of temperature, dissolved oxygen, pH, total dissolved solids, salinity, and turbidity were taken using a multiparameter water quality meter. Water samples were also collected from each station for laboratory analysis of parameters for solids, nutrients, oil and grease, and coliform.

Water quality monitoring commenced in April 2014 and continued annually until 2017. Monitoring was temporarily paused from 2018 to 2019 but resumed in 2020 up to the present. This report provides an overview of the latest water quality data for TRNP and examines trends in physico-chemical and microbiological parameters across these monitoring periods.

Methods

Monitoring Stations

Figure 36 shows the location of the 20 monitoring stations in TRNP, with detailed geographic coordinates and descriptions provided in Table 19. In the South Atoll, seven (7) monitoring stations are situated on top of the reef and one near South Islet, which serves as a roosting and nesting site for seabirds. North Atoll contains nine (9) monitoring stations (WQ09 to WQ17). The Jessie Beazley Reef has one station (WQ19) located on the reef's surface and serves as both a dive site and a monitoring site for fish and benthos. Additionally, three (3) monitoring stations are located in the TRNP buffer zone, adjacent to the reef formations: WQ08 in South Atoll, WQ18 in North Atoll, and WQ20 in Jessie Beazley Reef.

Table 19. Description and coordinates of water quality monitoring stations in TRNP

Site	Latitude	Longitude	Site description
South Atoll			
WQ01	N8.80891	E119.81846	Fish and benthos monitoring station 4A; top of the reef; dive site
WQ02	N8.76091	E119.81324	Top of the reef; not frequently visited by divers
WQ03	N8.74000	E119.81987	Top of the reef; near mooring buoy
WQ04	N8.75575	E119.82881	Fish and benthos monitoring station 3A; top of the reef; dive site
WQ05	N8.79674	E119.82051	Original water quality site; inside lagoon; off limits to tourists
WQ06	N8.78019	E119.82307	Original water quality site; inside lagoon; off limits to tourists
WQ07	N8.74841	E119.81892	South Islet; off limits to tourists
WQ09	N8.85182	E119.93669	Min Ping Yu grounding site; shallow reef, not visited by divers
North Atoll			
WQ10	N8.89209	E119.90627	Fish and benthos monitoring station 2A; top of reef; dive site
WQ11	N8.94419	E119.96900	Top of the reef; dive site
WQ12	N8.93534	E120.01301	Fish and benthos monitoring station 1A; top of reef dive site; near bird islet
WQ13	N8.93001	E119.99559	Bird Islet; lagoon, off limits to tourists
WQ14	N8.90688	E119.95022	Original water quality site; inside lagoon; off limits to tourists
WQ15	N8.89112	E119.94900	Original water quality site; inside lagoon; off limits to tourists
WQ16	N8.88922	E119.97076	Original water quality site; inside lagoon; off limits to tourists
WQ17	N8.85177	E119.91713	Ranger Station; lagoon, off limits to tourists
Jessie Beazley Reef			
WQ19	N9.04388	E119.81595	Fish and benthos monitoring station JB Reef; top of reef; dive site
Buffer Zone			
WQ08	N8.71722	E119.88998	Original water quality site; buffer zone
WQ18	N8.84606	E120.02328	Original water quality site; buffer zone; deep waters
WQ2	N9.09834	E119.78648	Original water quality site; buffer zone; deep waters

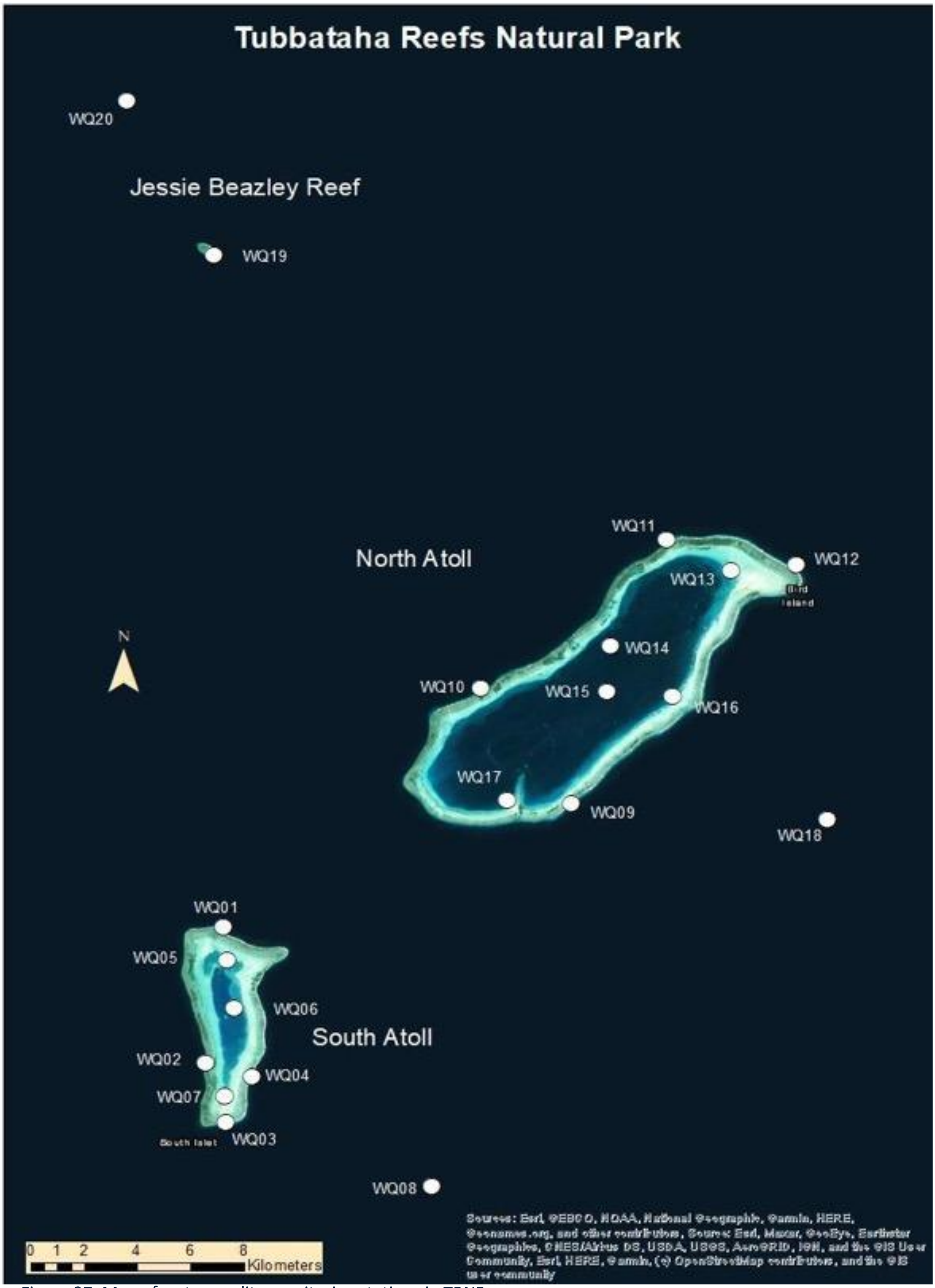


Figure 37. Map of water quality monitoring stations in TRNP

Collection of Water Samples

The TMO and TRNP Marine Park Rangers monitored water quality from May 12 to 13, 2024. Water samples were collected in three containers: a 1-liter wide-mouth glass jar for oil and grease, a 2.5-liter HDPE container for physicochemical parameters such as color and total suspended solids, and a 150-ml sterilized glass bottle for total and fecal coliform analysis.

Table 20 details the collection, preservation, and handling of the water samples. All samples were subsequently transported to the PCSD Environmental Laboratory for further analysis.

Table 20.. Sample container, preservation techniques and handling of water samples per parameter.

Parameters	Sample volume/container	Preservation technique	Holding time
Color	500 mL-Plastic container*	Refrigerate	48h
Solids	300 mL-Plastic container*	Refrigerate	7d
Oil and Grease	1-Liter wide-mouthed glass with screw cap containers	Add 1:1 HCl to pH <2; refrigerate	28d
Total and Fecal Coliform	150 mL-sterilized glass bottles	Analyze as soon as possible or refrigerate	24h

Reference: Standard Methods for Examination of Water and Wastewater, 21st Ed., 2005; *plastic (Polyethylene or equivalent)-Samples for analyses of color, solids, nitrates, and phosphates are contained in one 3-L plastic container.

Water Quality Parameters

Water quality parameters are various measures used to assess the health and safety of surrounding water in TRNP. During the field monitoring and collection of samples, on-site parameters were measured, such as sea surface temperature, dissolved oxygen, pH, turbidity, salinity, conductivity, and total dissolved solids using a HORIBA multiprobe meter. Field data sheets are shown in Appendix 12. Collected water samples were analyzed in terms of suspended solids, color, total and fecal coliform. Table 21 presents the key water quality parameters, method of analysis, and their significance.

The water quality data, obtained from *in situ* measurements and laboratory analyses, were compared to the Water Quality Guidelines (WQG) stipulated in DENR Administrative Orders (DAO) 2016-08 and DAO 2021-19. In the absence of a specific water classification, which falls under the jurisdiction of DENR, the Class SA standards from DAO 2016-08 were applied. Class SA refers to protected waters designated as national or local marine parks, reserves, sanctuaries, or similar areas established by law (such as Presidential Proclamation 1801) or declared as such by relevant government agencies, local government units (LGUs), and other authorities.

Table 21. Significance and water quality guidelines for parameters monitored in TRNP

Parameter	Significance/Methods	WQ Guideline * (Class SA)
pH *	Measures the acidity or alkalinity of water. Most aquatic organisms thrive within a specific pH range. Deviations can indicate pollution or affect the availability of nutrients and metals.	7 – 8.5
Temperature*	Affects the solubility of oxygen and other gases, the rate of chemical reactions, and the health of aquatic organisms. Extreme temperatures can stress aquatic life and alter species composition.	26°C – 30°C
Dissolved Oxygen (DO)*	Essential for the respiration of aquatic organisms. Low DO levels can stress or kill fish and other aquatic life, while high levels can indicate excessive algal growth.	6 mg/L
Turbidity*	Refers to the cloudiness or haziness of a fluid caused by large numbers of individual particles. High turbidity can reduce light penetration, affecting aquatic plant growth, and may indicate pollution.	none
Salinity*	The concentration of salts in water. It affects the density of water and the distribution of aquatic organisms. Changes in salinity can impact marine ecosystems.	none
Conductivity*	Measures the water's ability to conduct electricity, which is related to the concentration of dissolved ions. High conductivity can indicate pollution or changes in water chemistry.	none
Total Dissolved Solids*	High or low TDS can stress or harm aquatic species as it affect fish migration, reproduction, and overall health. TDS affects the availability of nutrients and trace elements essential for marine life..	none
Total Suspended Solids (TSS)	Particles that remain suspended in water, thereby causing turbidity or increase the color of the water. High TSS indicates high turbidity. *Method: Gravimetric dried at 103 - 105^{0}C.*	25 mg/L
Color	Caused by the presence of dissolved organic matter, metallic salts, or suspended. *Method: Visual Comparison Method (Platinum Cobalt Scale).*	5 PCU
Nitrogen as Nitrates	Indicates the presence of nutrients in the water bodies. High concentration can cause severe illness to animals. *Method: Colorimetric using Hach Nitrate Powder Pillows*	10 mg/L
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. *Method:* Colorimetric using Hach Phosphate Powder Pillows	0.1 mg/L

Oil and Grease (O&G)	Fats, oils, waxes, and other related constituents found in water that are recovered in the solvent. *Method: Gravimetric Method (Petroleum Ether Extraction)*	1 mg/L
Total Coliform (TC) and Fecal Coliform (FC)	TC comprises all members of the coliform bacteria group, or the microorganisms from vegetation, soil, and water. FC are members of the TC group that originate in the intestinal gut of warm-blooded animals. *Method: Multiple Tube Fermentation Technique*	TC: none FC: 20 MPN/100mL

Method: HORIBA on-site multiprobe meter Reference: Standard Methods for the Examination of Water & Wastewater, APHA-A4WWA 21st Ed, 2005. *Based on DAO 2016-08 and DAO 2021-19 (for Fecal Coliform and Phosphates)

To identify the correlation among the parameters, the correlation matrix of the parameters monitored from 2015 to 2023 was calculated using Excel 2022 Software. This preliminary descriptive technique to estimate the association between any two monitored water quality parameters was measured by the degree of correlation as coefficient (R). It is used to identify the highly correlated and interrelated water quality parameters that may influence the water quality of the area. The value of correlation coefficient ranges from -1 to +1. The correlation between parameters is characterized as strong positive/negative when it was between +0.7 to +1.0, moderate positive/negative when it was between +0.3 to +0.7, while weak positive/negative when it was between of +0.1 to +0.3 (Seo et al., 2019).

RESULTS

Present Conditions

Elevated sea surface temperature during the 2024 water quality monitoring was observed in all stations. The temperature ranged from 33.15 °C (WQ13, North Atoll) to 34.93 °C (WQ07, North Atoll), all above 30 °C, the maximum temperature for Class SA (DAO 2016-08). The aesthetic and visual quality of the water appeared to be very clear, with a color of less than 5 PCU at all stations. Similarly, the total suspended solids ranged from less than 1 mg/L to 25 mg/L, all within the 25 mg/L WQ guideline for Class SA (DAO 2016-08).

The oil and grease in all WQ stations were below the minimum detection limit of less than 1 mg/L, thus within the WQ guideline of 1 mg/L (DAO 2016-08). Similarly, fecal coliform concentrations were all less than 1.8 MPN/100 mL, all within the WQ guidelines of 20 MPN/100 mL (DAO 2021-19).

Trends in Water Quality (2014 – 2024)

In situ Parameters

Figure 38 shows the trends of water quality parameters, highlighting the temperature, dissolved oxygen, and pH recorded on-site from 2014-2024.

The highest temperature in TRNP monitored from 2014- 2024 was recorded at 38.40°C in 2014 (WQ17, North Atoll), while the lowest was also recorded in the same year at 25.4°C (WQ02, South Atoll). The average temperature from 2014 to 2024 taken in the whole of TRNP was 31.09 °C. In South Atoll it was 30.81 °C, in the North 31.34 °C , 31.14 °C in Jessie Beazley Reef (WQ19), and 30.94 °C in the Buffer Zone.

Dissolved oxygen showed a varying concentration across all WQ stations, from 5.3 mg/L to 9.92 mg/L, with an average of 6.70 mg/L. DAO 2018-06 stipulates that the water quality standard for dissolved oxygen for water classification SA (Protected Areas) should be above 6 mg/L. While previous years showed DO levels above 6 mg/L, 2024 data showed that DO levels in 17 out of 20 were below 6 mg/L.

Table 22. Water quality in TRNP in May 2024

Parameters	pH	DO (mg/L)	Temperature (°C)	Salinity (ppt)	Conductivity (mS/cm)	TDS (mg/L)	TSS (mg/L)	Color (PCU)	Oil & Grease (mg/L)	Fecal Coliform (MPN/100 mL)
South Atoll										
WQ01	7.77	5.47	34.41	32.32	49.4	30.2	10	<5	<1	<1.8
WQ02	8.02	6.32	33.9	31.88	48.9	29.8	15	<5	<1	<1.8
WQ03	7.84	4.84	34.44	32.33	49.2	30	15	<5	<1	<1.8
WQ04	8.06	4.83	34.08	31.94	49	29.9	<1	<5	<1	<1.8
WQ05	7.91	4.75	34.42	32.33	49.4	30.01	5	<5	<1	<1.8
WQ06	7.91	4.75	34.50	32.1	49.1	30	10	<5	<1	<1.8
WQ07	8.23	5.44	34.93	31.78	48.4	29.5	<1	<5	<1	<1.8
North Atoll										
WQ09	7.73	4.56	34.11	31.7	48.7	29.7	<1	<5	<1	<1.8
WQ10	8.11	4.72	33.75	32.66	49.9	30.5	<1	<5	<1	<1.8
WQ11	7.34	4.73	33.78	32.24	49.4	30.1	25	<5	<1	<1.8
WQ12	7.78	4.36	33.95	32.29	49.4	30.2	15	<5	<1	<1.8
WQ13	7.71	4.2	33.15	31.75	48.7	29.7	10	<5	<1	<1.8
WQ14	8.16	4.03	34.41	31.26	48	29.3	10	<5	<1	<1.8
WQ15	8.00	4.13	34.36	32.53	49.8	30.4	15	<5	<1	<1.8
WQ16	8.19	4.32	34.03	31.18	47.9	29.5	10	<5	<1	<1.8
WQ17	7.77	4.8	33.96	31.75	48.7	29.7	20	<5	<1	<1.8
Jessie Beazley Reef										
WQ19	8.15	4.96	33.74	31.75	48.7	29.7	<1	<5	<1	<1.8
Buffer Zone										
WQ08	7.88	4.67	34.46	31	48.9	29.8	<1	<5	<1	<1.8
WQ18	7.95	4.62	34.12	32.45	49.7	30.3	15	<5	<1	<1.8
WQ20	8.14	4.56	33.94	32.52	49.7	30.3	10	<5	<1	<1.8
WQG	Class SA	Class SB	7.0-8.5	6	26-30				25	50

*Based on DAO 2016-08 and DAO 2021-19 (for Fecal Coliform and Phosphates). Abbreviations: DO – Dissolved Oxygen; TSS – Total Suspended Solids; MPN - Most Probable Number; WQG – Water Quality Guidelines; JB Reef - Jessie Beazley Reef

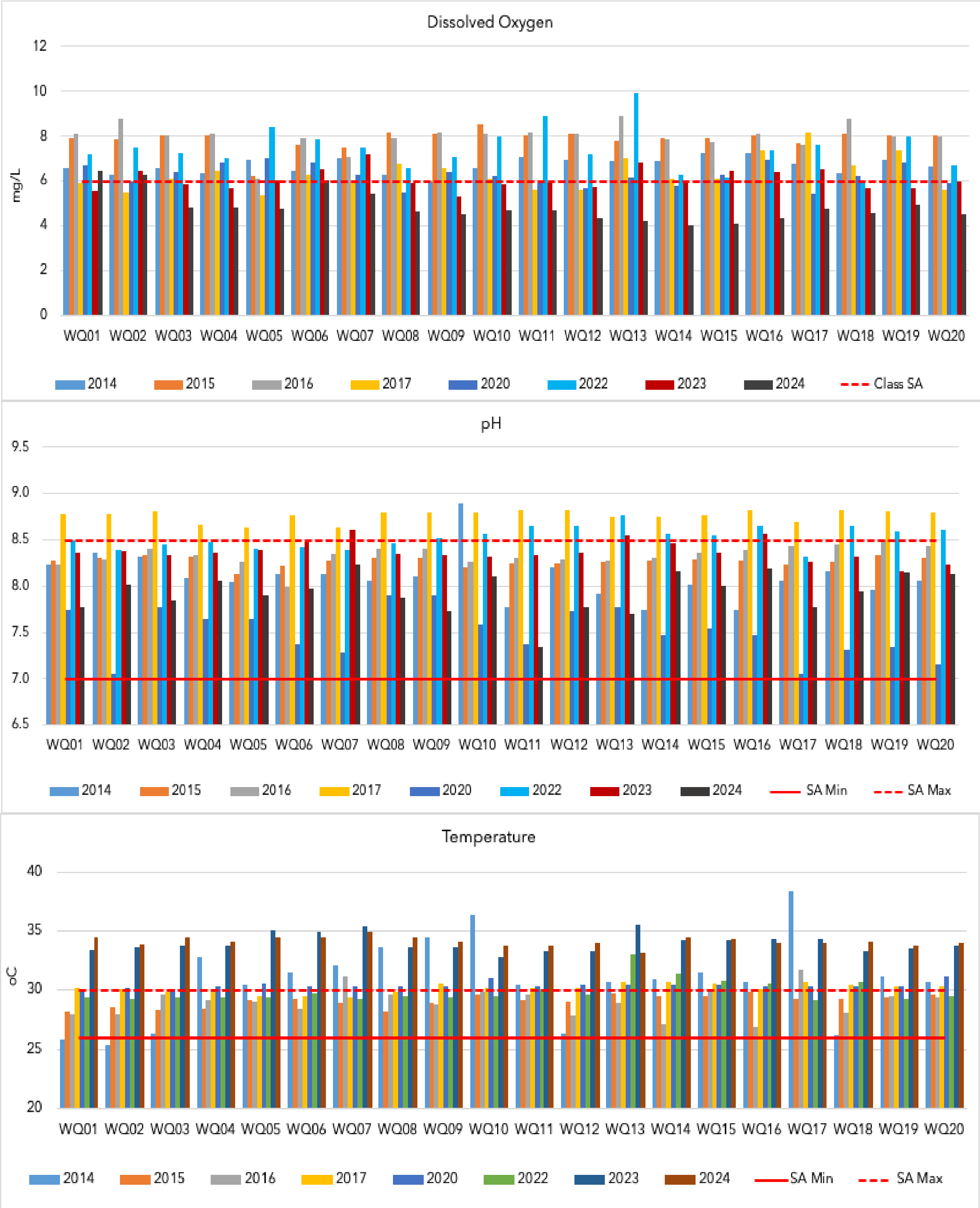
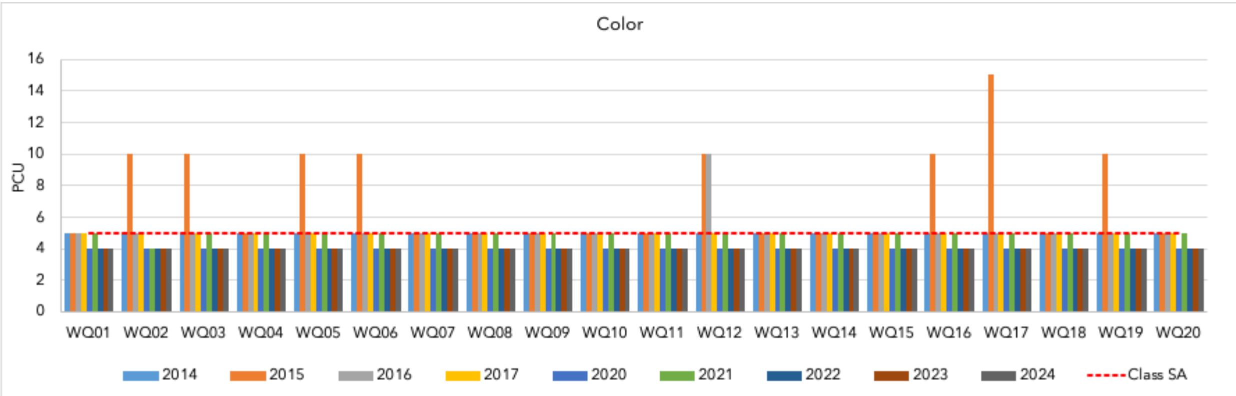


Figure 38. Trends of water quality parameters measured on-site from 2014 to 2024. Water Quality Guideline (Class SA) for Temperature – 26 to 30oC, pH – 7 to 8.5, Dissolved Oxygen – 6 mg/L (DAO 2018-06).

The pH range in North Atoll was from 7.05 (WQ17, 2021) to 8.89 (WQ14, 2014). While recorded to exceed the WQ guidelines in the previous years, the recent pH values in Jessie Beazley Reef and the buffer zone were within the range of 7 to 8.5.

Aesthetic/Visual Water Quality

The latest results of color and total suspended solids, parameters that refer to the physical appearance or aesthetic quality of seawater in TRNP showed levels below the WQ guidelines as shown in Figure 39.



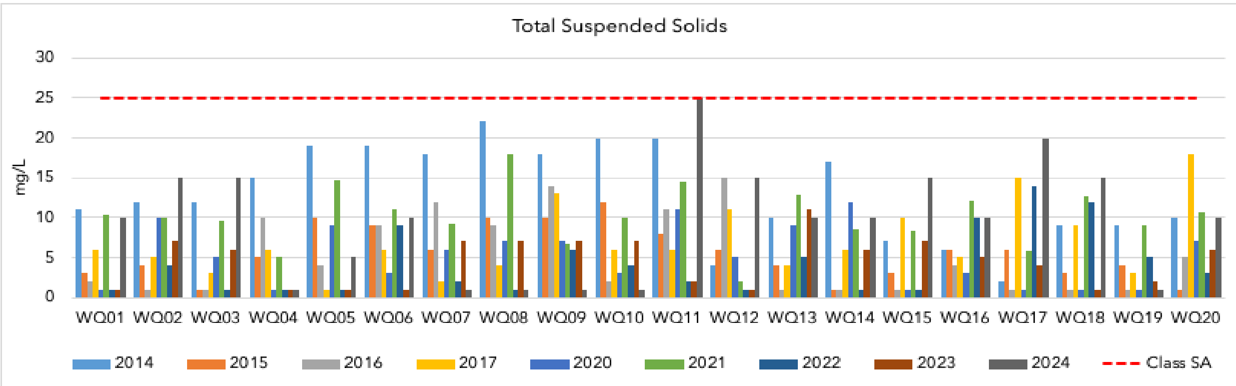


Figure 39. Values of color and total suspended solids (TSS) in TRNP from 2014 to 2024. Water Quality Guideline (Class SA) for TSS – 25mg/L, Color – 5 PCU (DAO 2016-08).

In South Atoll, the color ranged from less than 5 PCU to 15 PCU, with recent results (2020-2024) showing levels within the WQ guideline of 5 PCU (Class SA). Similarly, the total suspended solids (TSS) ranged from less than 1 mg/L to 22 mg/L, all below the water quality guidelines (25 mg/L, Class SA).

While exceedance in color was recorded in 2015 (WQ12, WQ16, and WQ17) in North Atoll, recent results showed clear waters with color below 5 PCU. The concentration of TSS monitored in the North Atoll from 2014 to 2024 ranged from less than 1 mg/L to 25 mg/L (WQ10, WQ11), which were all within the water quality guidelines (25 mg/L, Class SA).

The waters surrounding Jessie Beazley Reef and the monitoring stations in the buffer zone remained clear, as shown by the trends of TSS and color. The concentration of TSS ranged from 1 mg/L to 9 mg/L, way below the guideline (25 mg/L, Class SA), while the color remained at the lowest concentration of less than 5 to 5 PCU from 2016 to 2024.

Oil & Grease & Nutrients

Oil and grease trends showed a concentration of less than 1 mg/L in all WQ stations from 2021 to 2024 (Figure 40). This indicated improvements from high concentrations recorded in some stations from 2014 until 2020. It can be noted from previous monitoring that the highest concentration of oil and grease in TRNP was measured in WQ08 (8.8 mg/L) in 2016.

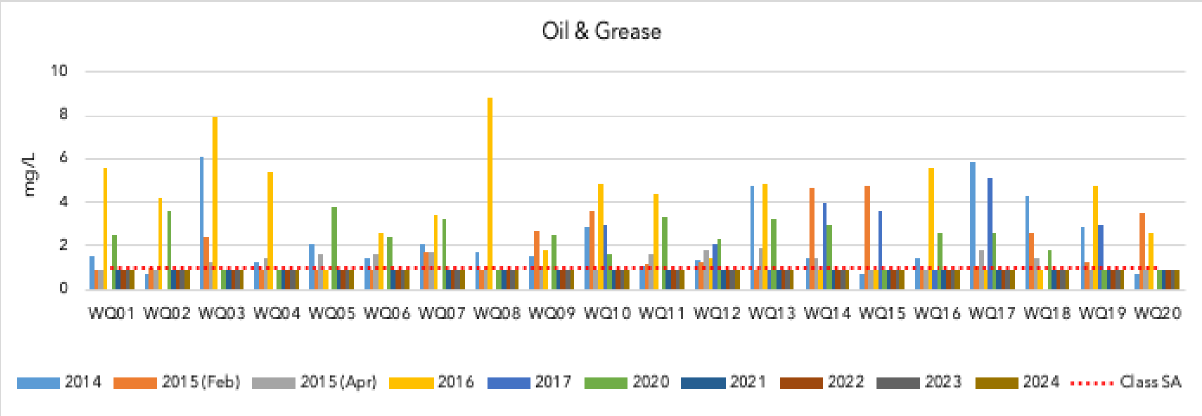


Figure 40. Concentration of Oil and Grease in Tubbataha Reefs Natural Park from 2014 to 2024. Water Quality Guideline (Class SA) for Oil and Grease – 1 mg/L (DAO 2016-08).

In the South Atoll, the highest concentration recorded was 7.9 mg/L at WQ03 in 2016, while in the North Atoll, it was 5.83 mg/L at WQ17 in 2014. Elevated levels of oil and grease were detected at nearly all stations between 2014 and 2017, primarily attributed to tourism activities. However, a gradual decline was observed, with concentrations dropping significantly by 2020. From 2021 to 2024, the concentration of oil and grease at all WQ stations in TRNP consistently remained below 1 mg/L.

Although the 2024 water quality monitoring did not include the analysis of nitrates and phosphates due to the unavailability of laboratory reagents, such parameters must be monitored in the succeeding years. It is worth noting that the previous years' monitoring (2014 to 2023) showed nitrate concentrations ranging from <0.001 mg/L to 3.20 mg/L, all consistently below the water quality guideline of 10 mg/L (Class SA). In contrast, phosphate levels consistently exceeded the guideline of 0.1 mg/L throughout the same period. In the South Atoll, phosphate concentrations were consistently above the protected area standards (Class SA, 0.1 mg/L). In the North Atoll, the highest phosphate concentration was recorded in 2014 and 2016 at 1.43 mg/L, while the lowest level was 0.02 mg/L in 2021. In the buffer zone, phosphate levels varied from 0.024 mg/L (WQ20, 2021) to 0.54 mg/L (WQ08, 2016), In 2023, phosphates concentration exceeded the 0.1 mg/L guideline for Class SA at WQ20 (0.11 mg/L) and WQ08 (0.92 mg/L) with the exception of WQ18, which recorded a level of (0.05 mg/L) .

Fecal Coliform

Figure 41 shows the different levels of fecal coliform measured in TRNP from 2014 to 2024. High levels of fecal coliform were observed in all stations from 2014 to 2017. However, significant improvements were observed during the closed season and lockdown from 2020 to 2021. This low level was maintained even after the resumption of tourism activities in 2022. In 2023, fecal coliform levels remained low and within the acceptable limit of 20 MPN/100 mL, as defined by Class SA (DAO 2021-19). The 2024 water quality monitoring results showed that fecal coliform levels at all WQ stations were less than 1.8 MPN/100 mL, well below the water quality guideline for Class SA.

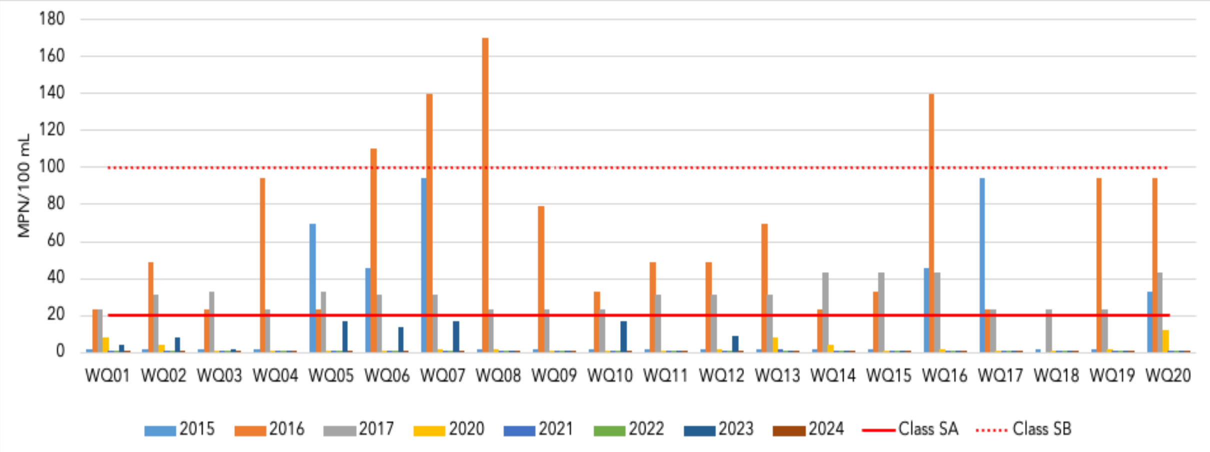


Figure 41. Concentrations of fecal coliform in TRNP from 2015 to 2024. Water quality guideline for fecal coliform: Class SA (Marine Protected Areas): 20 MPN/100 mL, Class SB (Bathing/Recreational Waters): 100 MPN/100 mL (DAO 2021-19).

Fecal coliform trends showed that the concentration in South Atoll exceeded 20 MPN/100 mL from 2016 to 2017, with the highest concentration of 140 MPN/100 mL recorded in 2016. A similar pattern was observed in North Atoll, with the highest concentration at WQ16 in 2016. From 2020 to 2024, fecal coliform levels in North Atoll remained low, consistently within the WQ guideline of 20 MPN/100 mL (Class SA, DAO 2021-19). In the buffer zone, the highest fecal coliform concentration was 170 MPN/100 mL at WQ08 in 2016, while Jessie Beazley Reef recorded 94 MPN/100 mL in the same year. In recent years, fecal coliform levels in the buffer zone and Jessie Beazley Reef has dropped to less than 1.8 MPN/100 mL, remaining well within the Class SA guideline of 20 MPN/100 mL.

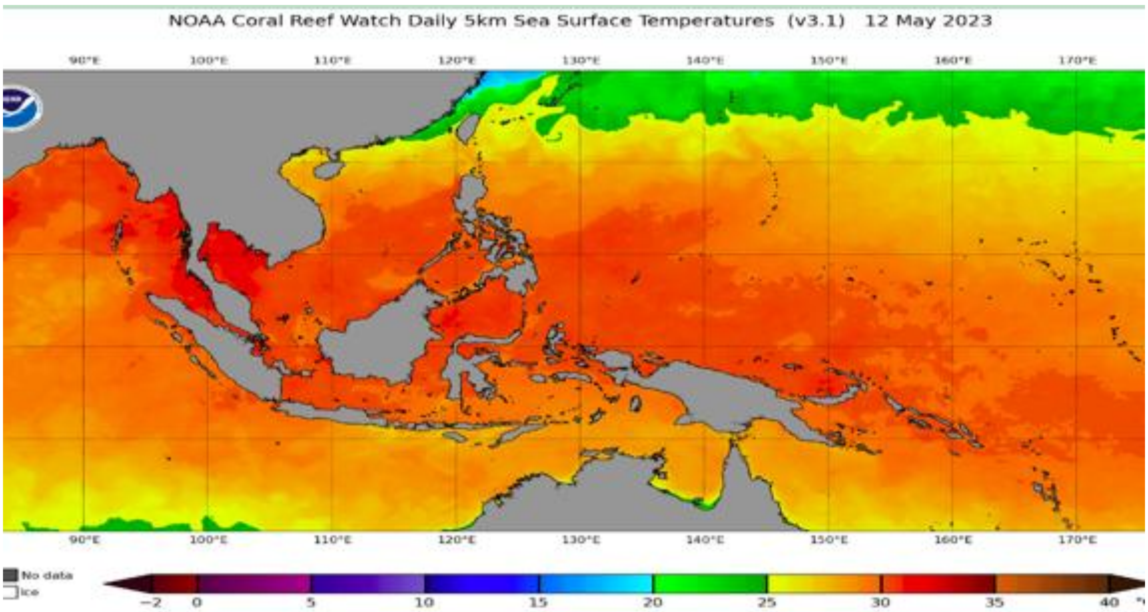
DISCUSSION

Water quality is a critical determinant in the sustainable use and health of aquatic ecosystems. In coastal and marine environments, it plays a vital role in the survival and productivity of essential coastal resources, including seagrasses, reef fishes, and coral reefs. These ecosystems provide numerous ecological benefits, such as habitat provision, biodiversity support, and shoreline protection.

In TRNP, water quality has shown improvement compared to 2014, particularly after the closure of tourism activities due to the 2020 pandemic. Most of the monitored parameters in the 2024 assessment remained within the water quality guidelines, with exceptions of temperature and dissolved oxygen.

According to DAO 2016-08, the pH values for Class SA (marine waters within protected areas) should range between 7 and 8.5. pH, with values lower than 7 indicating the onset of ocean acidification. In TRNP, recorded pH from 2014 to 2024 ranged from 7.05 (WQ02, 2020) to 8.89 (WQ10, 2014). The latest monitoring in 2024 showed a pH range of 7.34 to 8.23, indicating that the waters remain within safe pH levels for marine life, with no signs of ocean acidification.

However, the average temperature in TRNP has been increasing in the past three (3) years, from 29.53°C in 2022 to 34.12°C in 2024. These observations align with the predicted sea surface temperature patterns in the Coral Triangle for 2023 and 2024 (Figure 41).



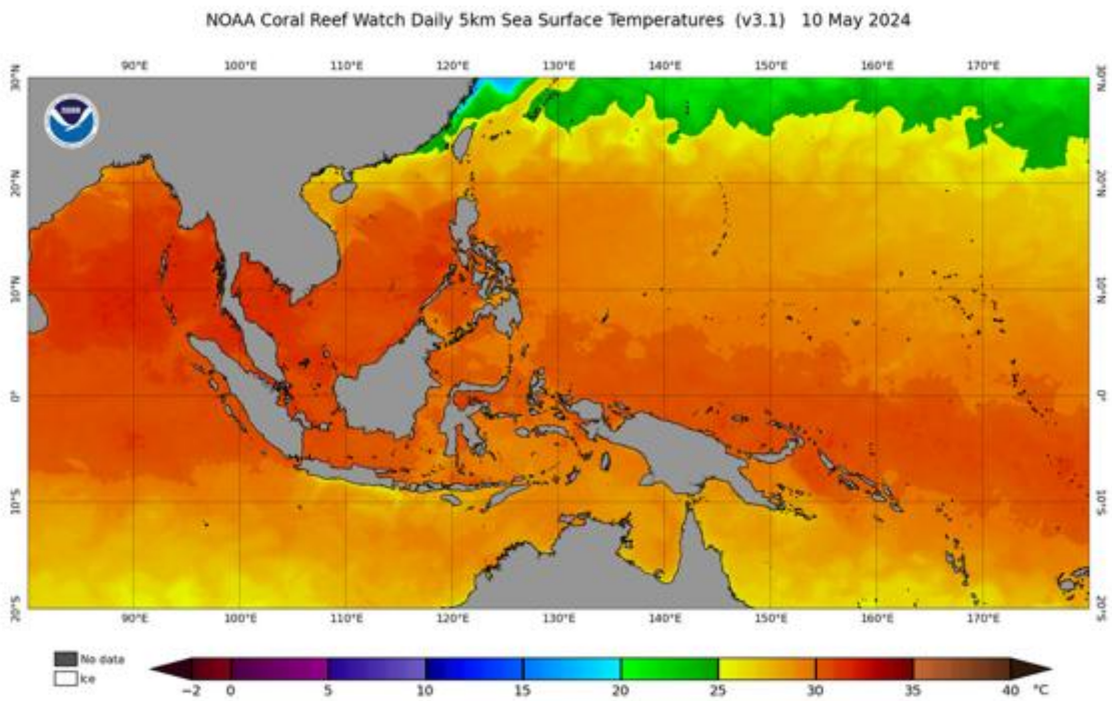


Figure 42. Sea surface temperature projected in Coral Triangle in 2023 (above) and 2024 (below). Source: NOAA Satellite and Information Service. https://coralreefwatch.noaa.gov/product/5km/index.php

Increased sea surface temperatures (SSTs) have significant and detrimental effects on coral reef ecosystems, primarily through coral bleaching. According to Hughes et al. (2017), the frequency and intensity of coral bleaching events have escalated, primarily due to climate change and associated increases in SSTs. Claar et al. (2018) further emphasize that prolonged exposure to elevated temperatures can result to severe mortality rates for coral populations, making recovery increasingly difficult.

Coral reefs are highly sensitive to water temperature changes. The optimal temperature range for coral growth is typically between 22°C and 28°C (Hubbard, 1997), while corals can survive in a wider range from 18°C to 36°C (Khalil, 2019). Research indicates that elevated sea surface temperatures, particularly those above 30°C, can lead to coral bleaching and mortality (Hoegh-Guldberg, 1999). For instance, Guan et al. (2015) found that the average tolerance limits for coral reefs are between 21.7°C and 29.6°C. The increasing sea surface temperatures, projected to rise significantly over the coming decades, ultimately threaten coral health and biodiversity (Szekielda & Guzman, 2021).

The monitoring stations in TRNP indicate that water temperatures exceeded the optimal range for coral growth yet remain within the maximum temperature threshold necessary for their survival. This highlights a concerning trend for coral ecosystems in the region, as sustained high temperatures may impact their health and resilience over time.

Table 23 shows the relationships of physico-chemical variables monitored in TRNP. Correlations can be deduced from the data collected from 2014 to 2024. The moderate negative correlations in this table are between temperature and dissolved oxygen (-0.574), also shown in Figure 43, highlighting that higher temperatures are linked to lower levels of DO. Similarly, a moderate negative correlation between temperature and salinity (-0.4870) was observed, implying that higher temperatures are linked to lower levels of salinity.

Table 23. Correlation between parameters measured on-site in Tubbataha Reefs Natural Park from 2014 to 2024.

	DO	Temp	pH	Salinity
DO	1			
Temp	-0.5745	1		
pH	0.2813	-0.1209	1	
Salinity	0.3997	-0.4870	-0.1595	1

Weak correlations are noted between many of the variables, showing that their relationships are relatively weak or minimal. Positive correlations are generally weaker compared to the more moderate negative correlations observed.

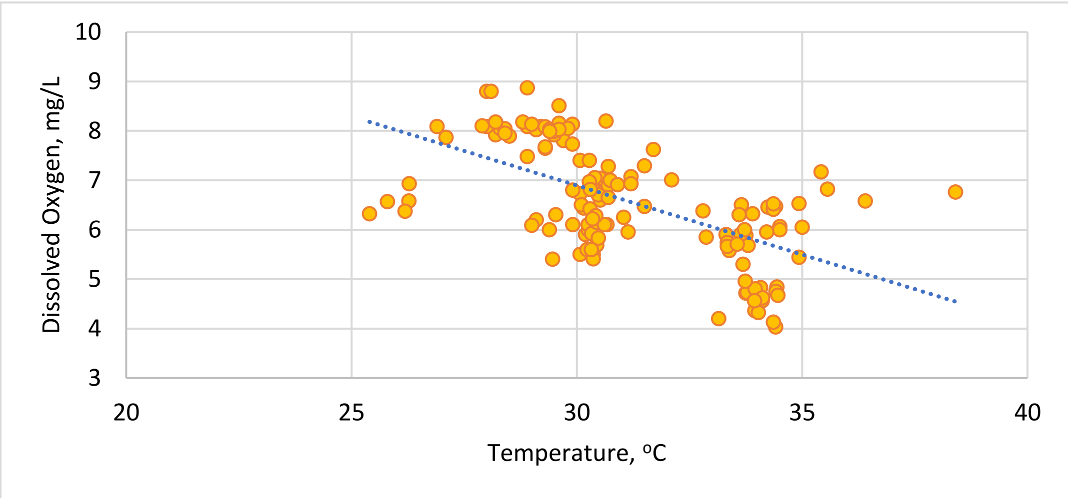


Figure 43. Relationship between dissolved oxygen and temperature measured at all sites in Tubbataha Reefs Natural Park from 2014 to 2024.

The analysis of the relationship of the physico-chemical and microbiological parameters obtained from the samples collected in TRNP showed a moderate positive correlation between oil and grease and fecal coliform (0.5846), suggesting a potential cumulative effects of oil and grease increase and bacterial levels on water quality (Seo et al., 2019). Other parameters such as phosphates (0.2157), showed a weak positive correlation fecal coliform suggesting that other factors besides phosphate levels may be associated with higher levels of fecal coliform. The fecal coliform level in seawater is an indicator of fecal contamination and the potential presence of pathogens. High levels suggest a risk of waterborne diseases. It primarily determines the suitability of the body of water for direct contact recreation such as bathing and swimming.

The key parameters influencing the health of shallow-water coral reefs include temperature, salinity, nutrient levels, light availability, and carbonate ion concentration. Each of these factors interacts intricately to affect coral physiology and resilience. The elevated sea temperatures can lead to coral bleaching, while changes in salinity can disrupt the delicate balance necessary for reef growth and stability. Nutrient overloads can result in harmful algal blooms, which can smother corals and seagrasses, further compromising their survival. Similarly, adequate light is crucial for photosynthetic organisms, which form the foundation of coral reef ecosystems (Couce et al., 2012; Kleypas et al., 1999; Freeman et al., 2013).

The decline of warm-water coral reefs, particularly in tropical regions, has been alarming. Research indicates that these ecosystems have experienced a significant reduction in coverage and biodiversity, with studies revealing a decline of at least 50% in warm-water coral reefs over the past 30 to 50 years (Gardner et al., 2003; Bruno and Selig, 2007). This decline does not only result to loss of biodiversity but also has far-reaching implications for marine life, coastal protection, and local economies that depend on healthy coral reef systems for fishing and tourism.

CONCLUSION

Water quality is essential for the sustainability and health of aquatic ecosystems, particularly in coastal and marine environments where it directly impacts vital resources such as coral reefs, seagrass, and reef fish. The improvements in water quality observed in TRNP since the pandemic-related closure of tourism in 2020 indicate a positive response of these ecosystems to reduced human activity. However, ongoing monitoring reveals concerning trends, particularly regarding rising sea surface temperatures and their correlation with dissolved oxygen and salinity levels.

The recorded increase in average temperatures raises significant concerns about the resilience of coral reefs. With SSTs frequently exceeding optimal growth ranges, the risk of coral bleaching becomes more pronounced, as evidenced by the strong negative correlations between temperature and vital water quality parameters. While TRNP has not yet experienced pronounced ocean acidification, the potential for its onset looms, highlighting the need for vigilant management and conservation efforts.

Concerted efforts must be made to mitigate climate change impacts, monitor water quality, and enforce protective measures in marine areas to ensure the longevity and health of these critical ecosystems. The situation in TRNP reminds us of the intricate connections between human activity, water quality, and ecosystem health, emphasizing the need for an integrated approach to marine conservation that prioritizes sustainability and resilience.

RECOMMENDATIONS

1. Continue the regular monitoring of water quality parameters, including temperature, salinity, pH, and nutrient levels, to detect changes early and inform management decisions. This can be done through installing a continuous/real-time water quality data logger.
2. Improve the technical capacity of staff participating in the collection and handling of water samples.
3. Collaborate with scientific institutions, and establish partnerships with research organizations and universities to leverage expertise in monitoring water quality.
4. Include nitrates and phosphates in succeeding monitoring.

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5| COMPREHENSIVE FISH INVENTORY: YEAR 4

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Overview

Tubbataha Reefs Natural Park, a UNESCO World Heritage Site, is renowned for its rich marine biodiversity, encompassing diverse coral reef systems and a wide range of fish species. Effective conservation and management of this critical ecosystem requires a comprehensive understanding of its biodiversity. While regular fish monitoring provides essential data on species populations and trends, it may not capture the full extent of the park's fish diversity, particularly for less frequently observed species.

This report presents the findings of a Roving Diver Survey (RDS) conducted over four years—2018, 2019, 2023, and 2024. The primary objective of the RDS was to complement existing fish monitoring efforts by enhancing the species list for Tubbataha Reefs to provide a more complete and detailed inventory of fish species within the park. This survey contributes by bridging data gaps and deepening the understanding of the park's fish biodiversity.

Methods

Data Collection

Ten (10) stations were surveyed this year, six (6) of which were dive sites, and four (4) were in the lagoon of the North and South Atolls (see Table 24). Sites previously surveyed are listed in Appendix 14. Overall, 37 sites have been surveyed since this study began.

This study used the roving diver survey (RDS) method to quickly assess species populations. Divers began at approximately 65 ft (20 meters) deep and worked their way toward the reef's shallowest area, noting every species observed during the one-hour dive. The objective was to document as many species as possible. The RDS method provided information on the species, frequency of sightings, and relative abundance.

Table 24. Stations surveyed this year. The station names (i.e., T28-T37) are sequentially assigned based on the count of surveyed stations each year. Since 2018, 37 stations were surveyed in total.

DATE	STATION NAME	LOCATION	REMARKS
23-Jun-24	T28	Lagoon, North Atoll	Lagoon Station, North Atoll about 1 km S of Ranger station to 48' high coral cover, lots of branching corals in shallows.
23-Jun-24	T29	North Atoll	N. Atoll Dive Site Ranger Station. Typical drop off. High coral cover in shallow in areas in spots.
24-Jun-24	T30	Lagoon, North Atoll	Lagoon Station, North Atoll about 2 km S of Ranger station to 80' to 6' high coral cover, shallow a lot of bleaching but lots of fish
24-Jun-24	T31	North Atoll	N. Atoll Dive Site Seafan Alley, very steep dropoff, 90' to 10' high coral cover.
25-Jun-24	T32	South Atoll	S. Atoll southern part near light house Dive Site Delsan Wreck
25-Jun-24	T33	Lagoon, South Atoll	Lagoon Station, S. Atoll, southern part just inside lagoon north of Southwest Wall. Flat sandy area with rock outcrops and lots of long branching corals
26-Jun-24	T34	Lagoon, South Atoll	Lagoon Station, S. Atoll, southern part just inside lagoon near Black Rock Dive Site
26-Jun-24	T35	South Atoll	S. Atoll Dive Site Staghorn North
27-Jun-24	T36	Jessie Beazley	Jessie Beazley, Eastern side to 80'
27-Jun-24	T37	Jessie Beazley	Jessie Beazley, SW side to 80'

The divers took note of the relative abundance by using the following log 10 categories (Schmitt & Sullivan 1996):

Single = 1 individual
Few = 2-10 individuals
Many = 11-100 individuals
Abundant = >100 individuals

Data Processing

The following analyses were patterned after Schmitt and Sullivan (1996). Analysis was performed to assess species diversity, abundance, and sighting frequency from data collected using the Roving Diver Survey method at various stations in Tubbataha across multiple years (2018, 2019, 2023, 2024). Most of the preprocessing and analysis were done in R Studio, while the species accumulation curves were generated using EstimateS software.

Data from all stations were first preprocessed to ensure consistency. This involved merging abundance data with station metadata, which includes the year and location of each survey.

Stations located in the lagoon were excluded from the general analysis to allow for specific lagoon-focused analysis.

Abundance data, originally recorded in qualitative categories (Single, Few, Many, Abundant), were converted into numerical values as follows:

- Single (S) = 1
- Few (F) = 2
- Many (M) = 3
- Abundant (A) = 4

Data Analysis

Sighting Frequency (%SF): For each species, the SF was calculated as the percentage of stations where the species was observed. This was computed using the formula:

$$\%SF = 100 * \frac{S + F + M + A \text{ (for each species)}}{\text{Number of surveys}}$$

Species were then categorized into three groups based on their sighting frequency:

- Frequent (≥70%): Species observed in 70% or more of stations.
- Common (>20% & <70%): Species observed in more than 20% but less than 70% of stations.
- Uncommon/Rare (≤20%): Species observed in 20% or fewer of stations.

Abundance Index: The Abundance Index combined both sighting frequency and density score to give a comprehensive measure of how frequently and densely a species was observed. The formula used was:

$$\text{Abundance Index} = \frac{(S * 1) + (F * 2) + (M * 3) + (A * 4)}{\text{Number of surveys/dives}}$$

Species were further categorized based on their sighting frequency and abundance score into sighting frequency classes (Frequent, Common, and Uncommon) and abundance index ranges:

The abundance index was grouped into ranges to make it easy to categorize species:

0.1 to 2.0 – "smaller numbers"
2.1 to 3.0 – "few but abundant in some"
3.1 to 4.0 – "abundant in most, if not all, stations"

Species Accumulation Curves were generated to evaluate species richness based on the number of stations sampled. These curves reveal how the discovery of new species increased as more stations were surveyed, helping determine if the sampling effort was adequate to capture Tubbataha's biodiversity. To predict the potential increase in species, the analysis used extrapolation by estimating the number of species that could be identified if the current number of sampling stations were doubled.

Results

Outer Reefs

In 2024, 281 species from 51 families were recorded in the outer reefs of Tubbataha, underscoring the rich marine biodiversity and ecological significance of these reef systems. Notably, Station T32, located at the southern tip of the south atoll near the Delsan Wreck dive site, exhibited the highest species richness. Details of all survey stations can be found in Appendix 14. This year, 19 new species were recorded that were not encountered in the previous survey (Appendix 15).

Throughout the study period from 2018 to 2024, a comprehensive survey identified 517 species across 52 families from various locations. Table 25 summarizes the number of species and families observed across the key locations over the four-year study, highlighting that the North Atoll consistently recorded the highest species count.

Table 25. Species and families identified in each location in TRNP surveyed from 2018 to 2024.

Location	Total Species	Total Families
Jessie Beazley	277	37
North Atoll	401	48
South Atoll	371	45

From 2018 to 2023, there was a gradual decline in species diversity recorded, with 2018 showing the highest diversity, with a noticeable drop in 2023. This suggests that species became less evenly distributed over the years, possibly due to environmental changes or disturbances impacting the reef ecosystem. By 2024, there was a slight recovery in diversity,

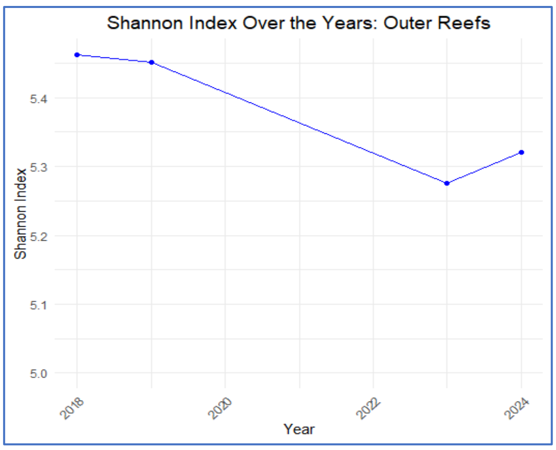

Figure 44. Shannon Diversity Index for Outer Reefs from 2018 to 2024.

which might indicate some improvement in reef conditions or species resilience. Despite this positive shift, diversity levels remained lower than those observed in 2018 and 2019.

Sighting Frequency. The 2024 survey documented 265 species across the reef system, with 61 species categorized as "frequent." These species were observed in at least 70% of the survey stations. This reflects their widespread distribution and dominance within the reef ecosystem. “Frequent” species were noted in at least five stations surveyed in the outer reefs. Among these, 30 species were observed in all six survey sites. This group included a range of species, from small damselfishes and wrasses, which play essential roles in maintaining reef health by controlling algae, to larger predators like groupers and snappers that contribute to balancing the reef's food web (Table 26).

Table 26. These species were present in all stations during the survey this year.

Taxon	Common Names	Taxon	Common Name
Aethaloperca rogaa	Redmouth grouper	*Macolor macularis*	Midnight snapper
Amblyglyphidodon aureus	Golden damselfish	*Melichthys vidua*	Pinktail triggerfish
Arothron nigropunctatus	Blackspotted puffer	*Paracirrhites forsteri*	Freckled hawkfish
Balistapus undulatus	Orange-lined triggerfish	*Parupeneus multifasciatus*	Manybar goatfish
Cephalopholis urodeta	Darkfin hind	*Parupenus crassilabrus*	Doublebar goatfish
Chaetodon kleinii	Sunburst butterflyfish	*Pomacentrus auriventris*	Goldbelly damsel
Chaetodon lunulatus	Oval butterflyfish	*Pseudanthias hutchi*	Red-cheeked fairy basslet
Chaetodon ocellicaudus	Spot-tail butterflyfish	*Pseudanthias smithvanizi*	Princess Anthias
Chromis amboinensis	Ambon chromis	*Pseudanthias tuka*	Yellowstriped fairy basslet
Chromis caudalis	Blue-axil chromis	*Pseudocheilinus evanides*	Striated wrasse
Chromis ternatensis	Ternate chromis	*Pseudocheilinus hexataenia*	Six-line wrasse
Chromis weberi	Weber's chromis	*Pygloplites diacanthus*	Regal angelfish
Ctenochaetus striatus	Striated surgeonfish	*Zanclus cornutus*	Moorish idol
Gomphosus varius	Bird wrasse	Zebrasoma scopas	Brown tang
Labroides dimidiatus	Bluestreak cleaner wrasse	*Zebrasoma veliferum*	Sailfin tang

Most identified species were classified as "common," with 123 species observed in 20% to 70% of the survey stations. These species were typically recorded in two to four stations. In contrast, 79 species were categorized as "uncommon," observed at only one of the six stations. While less prevalent, these species represent groups that have specific habitat preferences.

Between 2018 and 2024, 469 species were documented across 31 stations. Seventy (70) species categorized as "frequent" were observed in at least 22 stations. Among these, *Chaetodon kleinii*, *Chaetodon lunulatus*, *Melichthys vidua*, and *Pygloplites diacanthus* were recorded in all 31, highlighting their consistent presence across different habitats.

The survey identified 152 species as "common," meaning they were recorded in 7 to 21 stations. Notable species under this category was *Cheilinus undulatus* (Humphead wrasse), an IUCN Red List species classified as Endangered, recorded in 18/31 stations, suggesting they thrive in various parts of Tubbataha. Their distribution may indicate suitable microhabitats within the reef, though variations in their sighting frequencies can also reflect possible specific habitat preferences.

Meanwhile, 247 species were classified as “uncommon”. These were the species recorded in one to six stations across the survey periods. Their rarity could be due to natural behavior patterns, while it may indicate specific habitat preferences in others. Most of these were cryptic species, e.g., gobies and blennies, which are rarely recorded in the regular monitoring of TMO.

Abundance Index. This year's survey recorded a total of 161 species falling within the "smaller numbers" category (abundance index range: 0.1–2.0). These species were observed in lower numbers, often as solitary individuals, in pairs, or in small groups. Examples include smaller species, like pygmy gobies *Trimma spp.*, and larger species, such as dogtooth tuna *Gymnosarda unicolor*. This category indicates that these species were generally seen less frequently and in fewer quantities across survey stations.

In the "few but abundant in some stations" category (abundance index range: 2.1–3.0), 60 species were identified. These species were found in moderate numbers across stations, ranging from tens in some locations to nearly a hundred in others. Some species may exhibit higher densities in specific habitats or sites, which explains their classification.

Fifty-three (53) species were categorized as "abundant" (abundance index above 3.0), suggesting that these species were regularly observed in larger groups, often numbering over a hundred individuals. They are commonly seen in schools or large aggregations. The survey highlighted the frequency of damselfishes, fairy basslets, and fusiliers within this group. These species were often seen in reef crests, coral heads, and areas near the reef walls.

Below were the species consistently observed in significant numbers, often exceeding a hundred individuals:

Table 27. Species recorded as "abundant" (Perfect 4 Index) in 2024.

Taxon	Common Name	Taxon	Common Name
Acanthurus thompsoni	Thompson's surgeonfish	*Pomacentrus auriventris*	Goldbelly damsel
Chromis amboinensis	Ambon chromis	*Pomacentrus coelestis*	Neon damselfish
Chromis analis	Yellow chromis	*Pseudanthias dispar*	Dispar Anthias
Chromis atripectoralis	Black-axil chromis	*Pseudanthias hutchi*	Red-cheeked fairy basslet
Chromis caudalis	Blue-axil chromis	*Pseudanthias smithvanizi*	Princess Anthias
Chromis margaritifer	Bicolor chromis	*Pseudanthias tuka*	Yellowstriped fairy basslet

Chromis retrofasciata	Black-bar chromis	*Pterocaesio pisang*	Banana fusiliers
Chromis weberi	Weber's chromis	*Pterocaesio randalli*	Randall's fusilier
Chromis xanthura	Paletail chromis	*Pterocaesio tessellata*	One-stripe fusilier
Dascyllus reticulatus	Reticulated damselfish	*Pterocaesio tile*	Dark-banded fusilier
Heniochus diphretues	Schooling bannerfish	*Pterocaesio trilineata*	Threestripe Fusilier
Heteroconger hassi	Spotted garden eel	*Sphyraena obtusata*	Obtuse barracuda
Pomacentrus alexanderae	Alexander's damsel		

In the 31 stations surveyed from 2018 to 2024, 282 species were found to be in the "smaller numbers" category (abundance index: 0.1–2.0). These species were generally observed in low quantities across survey sites. The consistency in their low abundance over the years suggests that they play more niche or specialized roles in the reef ecosystem, which may depend on specific habitats or micro-environments.

In contrast, 134 species were identified as "few but abundant in some" (abundance index: 2.1–3.0). These species showed a pattern of moderate abundance, often found in higher numbers at particular sites while being less common elsewhere. Such patterns suggest that certain reef areas provide favorable conditions for these species, whether due to habitat features, food availability, or other localized environmental factors. The presence of these species indicates a degree of habitat specialization or selective site attachment.

The "abundant" category (abundance index > 3.0) included 53 species, which consistently appeared in high numbers across the survey years. These species were regularly seen in large schools or aggregations suggesting they thrive in Tubbataha. Their consistent abundance over multiple years signals that the reef system has maintained favorable conditions for these species to flourish. There were seven (7) species categorized in perfect index 4, meaning more than 100 individuals were observed whenever they were present:

Table 28. Species categorized in perfect index 4 (More than 100 individuals present every observation).

Taxon	Common Name
Chromis caudalis	Yellowtail Chromis
Naso lopezi	Lopez's Unicornfish
Pomacentrus armillatus	Bracelet Damsel
Pomacentrus auriventris	Goldbelly Damsel
Pseudanthias tuka	Purple Queen
Sphyraena obtusata	Obtuse Barracuda
Spratelloides delicatulus	Delicate Round Herring

Species accumulation. The initial species accumulation curve (Figure 45) shows a rapid increase in species discovery across 31 sampling sites. As more sites were sampled, the curve began to plateau, indicating a decrease in the rate of new species detection. This suggests that a substantial portion of common species has been recorded, and further sampling within the same habitats may yield fewer additional species unless new or less-explored areas are targeted.

The rarefaction analysis suggests that extended sampling might uncover more species, but the likelihood of discovering new species declines as sampling continues. Projecting the accumulation to 70 sites indicates the potential for continued, though slower, discovery of up to 562 species (Upperbound; Figure 45). This implies that while Tubbataha's biodiversity is not fully documented, additional species are likely to be rarer or more specialized. Focusing future efforts on adding more stations in areas not yet thoroughly surveyed, e.g., the western part of both atolls, may help uncover these less-detected species.

Lagoon

Four stations in the lagoons were surveyed this year, two in North Atoll and two in South Atoll. A total of 164 species were identified in both lagoons this year, demonstrating a considerable variety of species present within these inner reef ecosystems. Within the lagoon in North Atoll, 112 species were identified, while 110 species were recorded in South Atoll. Overall, a total of 192 unique species were recorded in both lagoons.

A total of 83 species were observed in both 2023 and 2024, with 28 species identified in 2023 that were not observed in 2024. Examples include Banded Pipefish (*Corythoichthys intestinalis)*, Sebree's Dwarf goby (*Eviota sebreei)*, and Silver Squirrelfish (*Neoniphon argenteus)*. Meanwhile, 81 species were identified in 2024 that were not present in 2023. Notable additions include Blacktip Squirrelfish (*Neoniphon opercularis)*, several species of *Thalassoma spp*., and goby species. The appearance of these species could be due to either natural variability or other ecological factors affecting their presence. In this survey, 76 species were identified inside the lagoons that are yet to be observed in the outer reefs, highlighting notable differences and unique species compared to the outer reefs. This also emphasizes the importance of the lagoon as a unique habitat that hosts a distinct population assemblage.

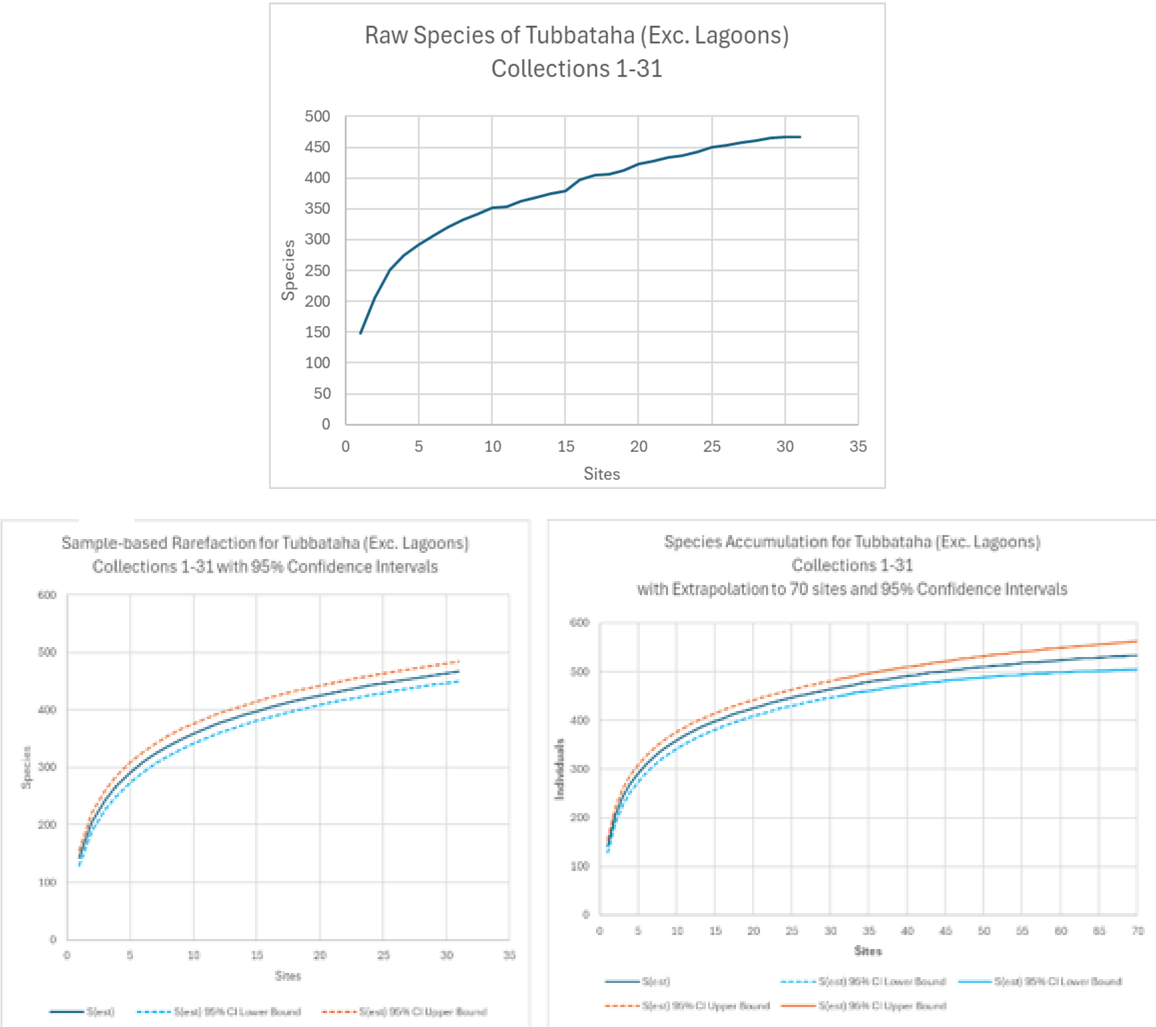

Figure 45. Results of the species abundance analysis in Tubbataha Reefs (2018-2024; excluding lagoons) using EstimateS software: (a) species accumulation curve collected from 31 sites; (b) sample-based rarefaction using data collected from 31 sites with 95%Confidence Intervals (Upper and Lower Bound); and (c) species accumulation in 31 sites with extrapolation up to 70 sites with 95% confidence intervals (Upper and Lower Bound).

Species Accumulation curve. The accumulation curve for Tubbataha lagoons shows a steady increase in species identified as more sites are sampled. This indicates that each new site contributes unique species to the overall species pool. The upward trend in the curve, even after sampling six sites, suggests that species richness has not yet reached a saturation point. As additional sites are sampled, it is likely that more species will be identified, particularly those that are less common or have specific habitat requirements. The confidence intervals widen slightly as more sites are included, indicating variability in species discovery and hinting at the potential for even greater diversity if sampling continues. This suggests the presence of significant undiscovered biodiversity within the lagoons. The extrapolation highlights that the existing sampling has yet to fully capture the range of species, and there remains considerable potential for discoveries. If the sampling is increased by 18 stations, up to 229 species can be potentially identified in the lagoon (Figure 46). The absence of a clear leveling off implies that

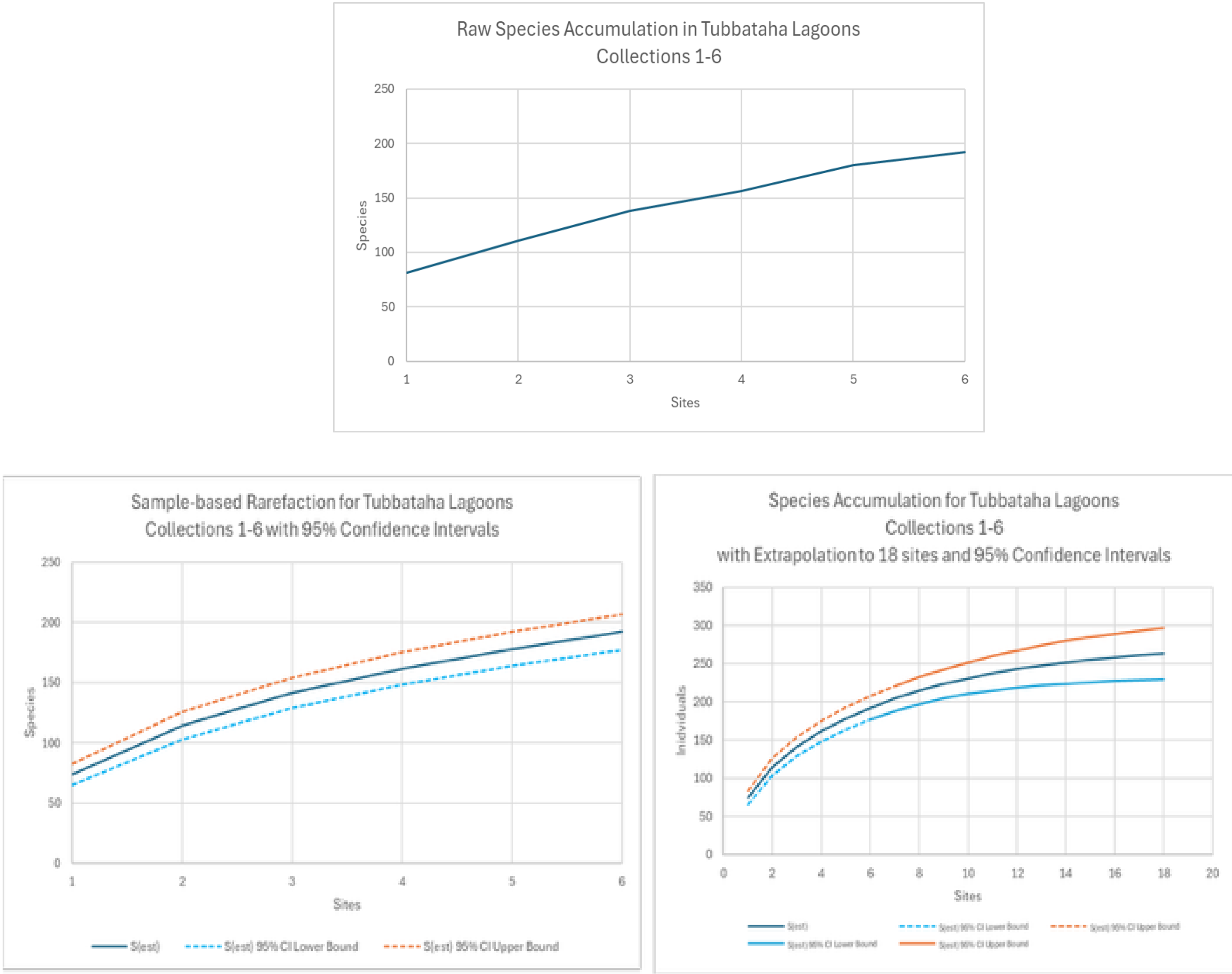

Figure 46. Results of the species abundance analysis in the lagoons of Tubbataha Reefs (2023-2024;) using EstimateS software: (a) species accumulation curve collected from 6 sites; (b) sample-based rarefaction using data collected from 6 sites with 95% Confidence Intervals (Upper and Lower Bound); and (c) species accumulation in 6 sites with extrapolation of up to 18 sites with 95% confidence intervals (Upper and Lower Bound).

additional sampling efforts, especially in different or more remote parts of the lagoons, could reveal new and possibly rare species that have not yet been documented.

Discussion

Overall trends

The multi-year survey data from TRNP revealed notable trends in biodiversity across the outer reefs and lagoons. Between 2018 and 2024, a total of 518 species from 52 families were documented, underscoring the park's status as a marine biodiversity hotspot. However, the trends indicate fluctuations in species diversity over this period, with a general decline from 2018 to 2023, followed by a slight recovery in 2024.

The decline in species diversity from 2018 to 2023 likely reflects environmental pressures, including the impacts of climate change, such as elevated sea surface temperatures (SST) and coral bleaching. Similar trends have been documented in other coral reef ecosystems experiencing increased thermal stress and habitat degradation, which disrupt species composition by affecting the health of reef-building corals (Hughes et al., 2017; Hoegh-Guldberg et al., 2019). Declining coral cover and reduced habitat complexity often lead to a decrease in the number of species that reefs can sustain, as many reef fish are closely tied to specific habitats (Wilson et al., 2006).

In April 2024, the fourth global coral bleaching event occurred, marking the second bleaching event within a decade. This extensive bleaching, driven by extreme ocean temperatures, affected reefs across the Atlantic, Pacific, and Indian Oceans, as well as the Red Sea and Persian Gulf. By August 2024, 75% of the world's coral reefs experienced bleaching-level heat stress since January 2023, surpassing the scale of the previous event from 2014 to 2017 (NOAA Coral Reef Watch, n.d.). While a slight recovery in species diversity was observed in 2024, biodiversity levels remain lower than those recorded in 2018, suggesting that the ecosystem might still be under stress and has not fully recovered.

Species Richness and Composition

Species richness was notably high at certain locations, underscoring the ecological significance of the reef's varied habitats. This diversity aligns with studies on coral reef ecosystems, which indicate that structural complexity—such as coral-covered slopes and reef drop-offs—enhances species richness by providing shelter, feeding grounds, and breeding areas for a wide range of marine life (Graham & Nash, 2013; Darling et al., 2017).

The record of 135 species over the years of species not previously listed in the TMO fish database emphasizes the dynamic nature of reef ecosystems and the critical role of ongoing surveys in accurately capturing biodiversity. Reef communities frequently experience shifts in species composition due to environmental changes, recruitment patterns, and migration. Environmental disturbances like coral bleaching alter habitat structure, leading to changes in community assemblages (Hoey et al., 2021; Frontiers, 2021). Recruitment variability and connectivity between populations also drive these dynamics, as seen in multi-decadal studies of Atlantic reef fish and observations of local and regional dispersal patterns (Sale, 2004; Wade et al., 2023).

Such fluctuations highlight that single or sporadic surveys cannot capture the full scope of biodiversity, as many species are influenced by both biotic factors (like recruitment and interspecies interactions) and abiotic factors (such as habitat degradation from climate impacts). Repeated, systematic monitoring enables the detection of these nuanced shifts and provides a comprehensive biodiversity baseline that is essential for effective management and conservation strategies (Mellin et al., 2016). Without regular surveys, we might miss subtle but crucial changes in species assemblages that reflect Tubbataha's health and resilience.

Sighting Frequency and Abundance Patterns

The sighting frequency showed that a core group of "frequent" species was commonly found at multiple survey stations, suggesting they are widely distributed and ecologically stable. Fish species that are frequently sighted are those that play important roles in their ecosystems (e.g. reef health indicator; Bellwood et al., 2004), are more tolerant of environmental changes (Sale, 1991; Wilson et al., 2007), or have broader ecological niches (Sale, 1991; Mumby & Steneck, 2008). Their widespread presence indicates that key habitats within Tubbataha's outer reefs are resilient enough to support these species across various reef zones.

Species categorized as uncommon or rare can serve as indicators of specific habitat preferences and environmental changes. Mouillot et al. (2013) suggest that these rare or uncommon species often occupy distinct positions within an ecosystem's functional space, which reflects unique combinations of traits associated with specialized ecological roles or microhabitats. This also emphasizes their potential as indicators of unique habitat conditions. Therefore, monitoring these uncommon species can provide valuable insights into ecosystem health and help identify habitats that require targeted conservation efforts.

Most species observed were categorized in "smaller numbers," typically seen in low densities across survey sites. This aligns with findings from other coral reefs, where niche-specialist species often exist in lower numbers but play critical ecological roles, such as controlling specific prey populations or contributing to the reef's structural complexity. Research has shown that niche-specialists, despite their low abundance, can exert significant influence on the ecosystem by maintaining prey populations and supporting biodiversity through their specialized interactions (Brandl et al., 2020; Leprieur et al., 2021). These species are often adapted to specific microhabitats, which may explain their patchy, low-density distribution across reef sites (Hemingson et al., 2022).

Species found in moderate densities, categorized as "few but abundant in some stations," likely benefit from favorable localized conditions such as high coral cover or abundant food resources.

Such patterns have been documented in other reef studies, where patchy distributions of species often reflect site-specific habitat features. For example, species abundance has been shown to correlate with habitat complexity and food availability, suggesting that reef fish distributions are closely tied to localized environmental conditions (Wilson et al., 2022; Komyakova et al., 2019). Some studies have also indicated that variations in reef structure can lead to patchy distributions, with some species aggregating in areas that meet specific habitat requirements (Graham & Nash, 2013; Castano et al., 2011).

The "abundant" category highlighted key species that consistently formed large aggregations, reinforcing their importance in the reef's ecosystem structure. For example, schooling species like *Chromis* spp and *Pterocaesio spp* serve as prey for larger predatory fish, contributing to nutrient cycling and energy transfer across the food web (Friedlander & Parrish, 1998). The stability of these aggregations over time suggests favorable conditions for these species to thrive, which is essential for maintaining the ecological balance of Tubbataha's outer reefs.

Overall, the species richness, sighting frequency, and abundance patterns indicate a diverse and well-functioning ecosystem. Continued monitoring is necessary to track changes in these patterns, which will help to inform adaptive management strategies aimed at preserving Tubbataha's biodiversity.

Lagoon Ecosystems

The lagoons of TRNP continue to exhibit a rich and varied species composition, with 76 species uniquely found there. These findings reinforce the ecological importance of lagoons as distinct habitats that support a range of species not commonly found on the outer reefs. In coral reef ecosystems, lagoons often serve as shelter, feeding grounds, and nursery habitats for juvenile fish and species that rely on seagrass beds or sandy substrates (Nagelkerken et al., 2000; Unsworth et al., 2018). The presence of unique species in the lagoons highlights the critical role these habitats play in maintaining biodiversity within the park.

The increase in species observed in 2024 compared to 2023 is likely due to a more comprehensive survey effort. In 2023, only two lagoon stations in North Atoll were surveyed, while in 2024, the survey expanded to include four stations—two in North Atoll and two in South Atoll. This broader coverage likely contributed to the identification of 81 species in 2024 that were not observed in the previous year. The differences in sampling effort demonstrate the importance of surveying multiple locations to capture the full extent of species diversity, as species distribution can vary significantly between different parts of the ecosystem (Mellin et al., 2016). In addition, although habitat information was not quantified, some of the lagoon sites surveyed in 2024 differed significantly in reef structure from the previous years, and this likely contributed to the increase in species observed. It is probable that there are other varied habitats in the lagoon that have not yet been surveyed so increased species richness counts can be expected if these surveys continue.

The absence of 28 species recorded in 2023 but not in 2024 may not necessarily indicate a decline. Rather, it highlights the variability that can arise due to differences in survey locations and seasonal changes in species presence. Continued and consistent monitoring across both North and South Atoll lagoons will be essential to establish clearer patterns of species distribution and better understand the lagoon ecosystem's health.

The steady increase in species identified from lagoon surveys, as indicated by species accumulation curves, suggests that further sampling could uncover additional species. This reinforces the need for comprehensive surveys that include a variety of microhabitats, especially less-explored regions of the lagoons, to capture the full extent of biodiversity within Tubbataha's lagoon ecosystems.

Species Accumulation and Sampling Effort

The species accumulation curves generated from the surveys provide valuable insights into the adequacy of sampling efforts and the overall biodiversity of Tubbataha Reefs. For both the outer reefs and lagoon areas, the curves initially showed a rapid increase in species discovery, which began to level off as more stations were surveyed. This pattern suggests that the majority of common species have been documented, and additional sampling within similar habitats may yield fewer new species. Such trends are consistent with ecological studies, where species accumulation tends to plateau as sampling captures most of the common species present in the area (Gotelli & Colwell, 2001).

The fact that the curves did not completely level off, especially in the lagoons, indicates that the sampling has not yet captured the full extent of biodiversity within Tubbataha. This suggests there are still rarer or more specialized species that could be discovered with further targeted surveys, particularly in less-explored or microhabitat regions of the park. Extending the survey to additional or more remote stations, as well as focusing on underrepresented habitats, could help uncover these species and improve understanding of the ecosystem's complexity (Chao et al., 2014).

Importance of Continued Monitoring

The results from the accumulation curves emphasize the need for continuous and adaptive sampling strategies to monitor the biodiversity of Tubbataha. Sampling designs incorporating diverse habitats and seasonal variations can better account for species that may only appear under specific conditions or at certain times of the year. Comprehensive surveys that regularly assess species richness can provide early warnings of biodiversity loss and inform management actions aimed at preserving the ecological integrity of the reef system.

The curves suggest that there are likely more species in Tubbataha yet to be discovered. This indicates that continued surveys will enhance our understanding of the park's marine biodiversity which would be vital for refining conservation strategies. Adding more stations that are less explored (i.e., lagoons) may reveal rare or specialized species, enriching our overall understanding of Tubbataha's biodiversity.

Conclusions

The Roving Diver Survey conducted across four years has significantly updated the fish species list of Tubbataha. This survey has documented 517 species from 52 families over the years. The findings underscore the ecological richness of the outer reefs and lagoon habitats. This year, 32 previously unlisted species were documented, with 12 species unique to the lagoons. Since the survey's inception, 117 species have been added to the TRNP list.

Species diversity declined from 2018 to 2023, likely due to environmental conditions such as elevated sea surface temperatures. The ongoing fluctuations in species diversity might indicate potential impacts from external factors. Hence, continued monitoring is necessary to detect changes early, understand their causes, and develop adaptive strategies.

The results of this report highlight the importance of comprehensive and regular monitoring to capture the full extent of biodiversity. Enhancing the species list through the RDS improves the understanding of Tubbataha's biodiversity and provides a strong basis for informed conservation actions.

Recommendations

1. **Enhanced Monitoring and Broader Survey Coverage:** Expand the survey to include additional locations within the lagoons and on the western side of the outer reefs. This approach is expected to reveal rare or specialized species that may have previously gone undocumented.

2. **Collaborative Research:** Strengthening partnerships with research institutions and conservation organizations can help us learn more about Tubbataha's ecosystems. Studying species behavior, habitat preferences, and resilience to environmental stress is essential for a comprehensive understanding of the fish population in Tubbataha.

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6| CORAL BLEACHING

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Overview

Climate change and unusually warm ocean temperatures pose a significant threat to coral reefs worldwide. Due to the ongoing El Niño event, ocean temperatures are expected to rise, potentially causing a mass coral bleaching event that could intensify this year (NOAA, 2024). Evaluating the global impacts and variability of coral bleaching is critical for predicting future coral diversity and productivity under climate change (McClanahan et al., 2005). In response, a coral bleaching survey was conducted in Tubbataha to document bleaching episodes in parts of the reefs.

Methods

The survey was carried out at five sites in Tubbataha—three in the North Atoll and two in the South Atoll—from May 30 to June 4, 2024. Using methods introduced by the Wildlife Conservation Society, the survey quantified coral bleaching and its severity within a 50-meter transect at each location. This straightforward and efficient method can be conducted by a single observer with minimal equipment. Additionally, the MERMAID app, an online repository, was used to report the surveys and provide a permanent record of data for each site.

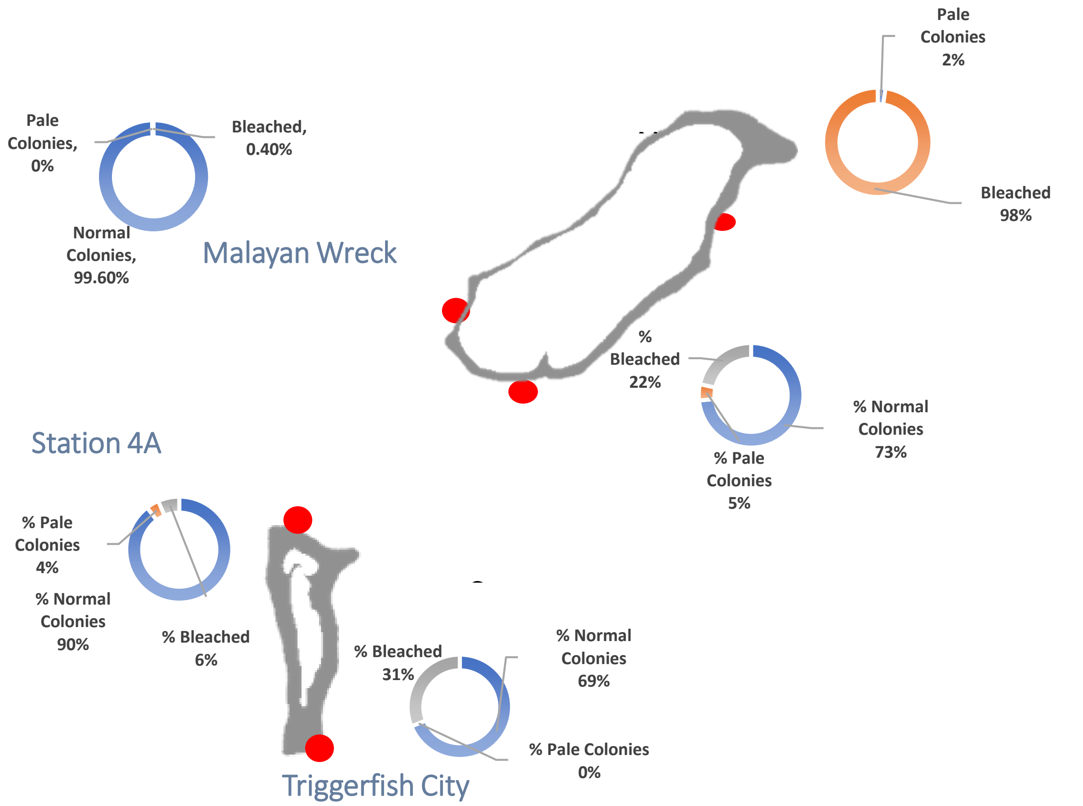

Figure 47. Map of Tubbataha showing the survey sites with corresponding values on the degree of bleaching.

The bleached hard coral cover (HCC) per site in Tubbataha ranged from 0.04% to 43% at depths of 5-7 meters. Among the five surveyed sites, the Elbow Mac site exhibited the highest percentage of bleached HCC at 43%, while the Malayan Wreck site showed minimal bleaching with only 0.04% (Figure 47). Water temperatures during the survey ranged from 29°C to 31°C. Sites on the eastern sides of the reefs showed less bleaching compared to those on the western sides of both atolls. During the survey period, nearly all sites exhibited severe bleaching, with 50-100% of coral colonies affected (Figure 48).

Among the hard corals, those belonging to the genera *Millepora* and *Heliopora* (fire coral species) were the most bleached across nearly all survey sites. These were followed by the known bleaching-sensitive genera *Porites* (branching), *Pocillopora*, and *Seriatopora.* At the West Wall area in the South Atoll, the team observed extensive bleaching of a large bed of the hydroid species *Aglaophenia*, affecting nearly entire colonies (Figure 49).

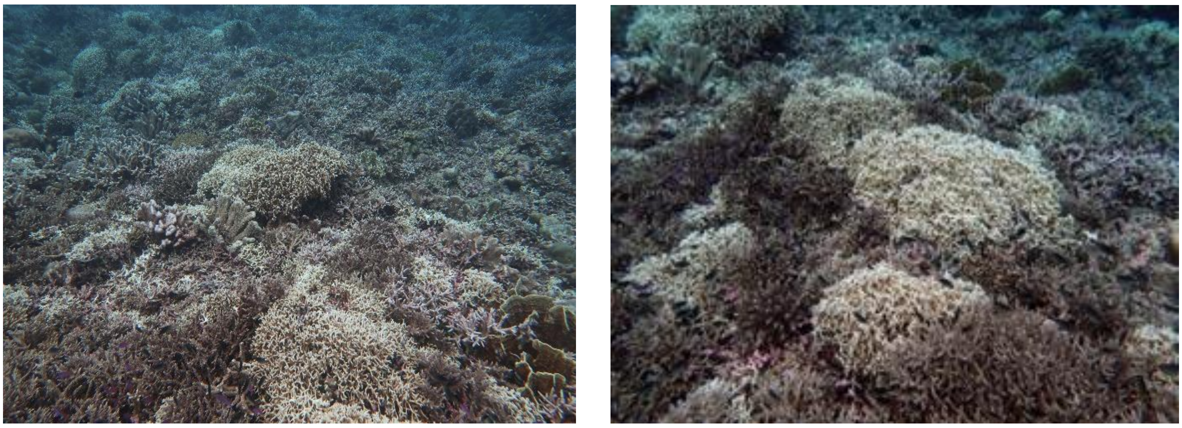

Figure 48. Commonly bleached coral colonies during the survey belong to the genus Millepora, a species of fire coral

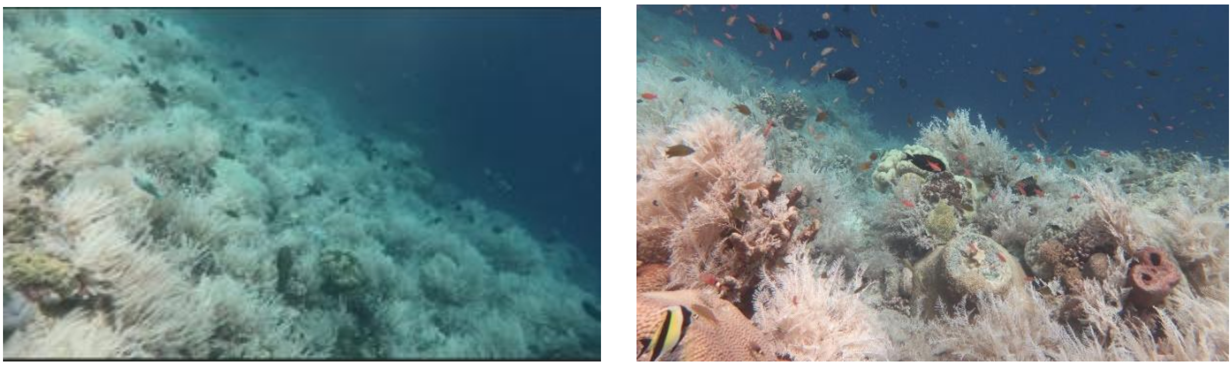

Figure 49. The genus Aglaophenia, commonly known as hydroids, were completely bleached from 5 to 10 meters depth along the reef crest.

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7| BENTHOS ASSESSMENT

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Introduction

The Tubbataha Reef system is a benchmark for pristine reefs in the Philippines and the Coral Triangle (Licuanan et al., 2017). This is because of its remoteness to land-based sources of pollution, the virtual absence of human habitation and consequent impacts, and its being in the center of the Sulu Sea bioregion, the richest in the Philippines (Licuanan et al., 2019). Tubbataha has demonstrated resilience to thermal stress, corallivore outbreaks, human impacts, and other stressors in the past (Dygico et al., 2013; Licuanan et al.,2017; Raymundo et al., 2018; Cadiz et al., 2024). Although long-term monitoring has revealed that hard coral cover and diversity have declined in recent years, particularly at parts of the South Atoll, the declines in coral cover detected often lack statistical power, and the overall trends are still stable (Cadiz et al., 2024). Nutrient enrichment of lagoon waters is suspected, but trends in the cover of spatial competitors of hard corals such as cyanobacteria, sponges, and soft corals show no trends consistent with this hypothesis (Cadiz et al., 2024). However, we must remain vigilant and adopt more sensitive, photogrammetric means of tracking the abundance and distribution of benthic biota to detect changes early enough for the Tubbataha Management Office to respond with measures like the restriction to access of certain portions of the reef based on sustainable carrying capacity determinations.

To complement the long-term monitoring of the benthic biota and other reef-associated organisms in the twelve monitoring stations, regular reef assessments must also be conducted to determine the health of the reef biota outside the monitoring stations. Monitoring seeks precision in tracking trends in fixed points in space over time. On the other hand, assessments seek generality over a larger area of interest at a fixed point in time. The generality is achieved using a stratified random sampling design to select the portions of the reef to survey. Regular assessments and monitoring together provide a more complete picture over space and time. Technical Bulletin No. 2019-04 of the Biodiversity Management Bureau of the Department of Environment and Natural Resources (DENR-BMB) recommends assessments every three (3) years and semi-annual or annual monitoring (barring catastrophic events).

Methods

Data Collection

The assessment of the coral assemblages of the North and South Atolls of Tubbataha was conducted on June 8-12, 2024, by a composite team from the Tubbataha Management Office and the De La Salle University Br. Alfred Shields FSC Ocean Research (ShORe) Center. The same field methods used in the annual monitoring of reef benthos (as described in Licuanan et al. 2017a) were followed. The positions of the survey stations were determined following a stratified (by monsoon exposure) random sampling design described in Technical Bulletin 2019-04 of the DENR-BMB. This stratification was done by dividing the upper reef slopes of the North and South Atolls (Figure 50) into 120 500m long segments (79 in the North Atoll, 41 in the South

Atoll) in Google Earth (www.earth.google.com) using the images from the Allen Coral Atlas (www.allencoralatlas.org; 2024).

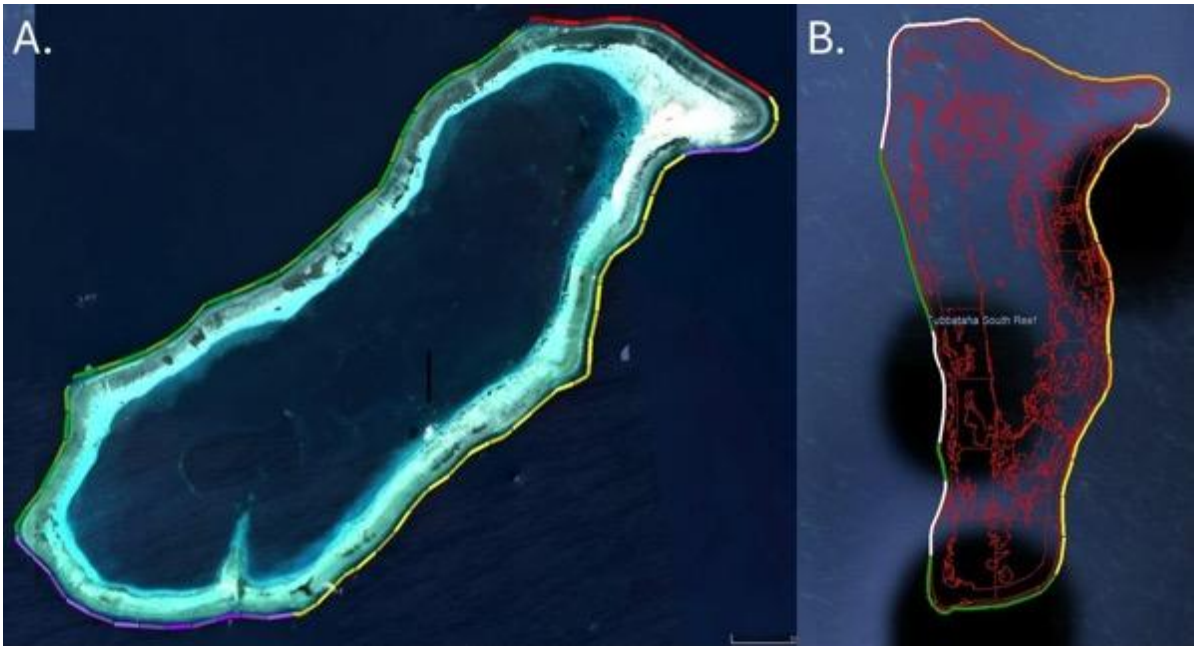

Figure 50. A map of the North (A.) and South (B.) Atolls of the Tubbataha Reefs Natural Park, showing the 500m segments dividing the upper reef slopes that were used in the stratified random sampling to determine the positions of the survey stations.

Segments to be surveyed were chosen using a random number generator in Microsoft Excel®. The number of survey stations in a stratum was allocated based on the number of 500m segments in upper reef slopes facing the northeast (17 segments total, 11 in the North Atoll, 6 in the South Atoll), southwest (17 segments total, 13 in the North Atoll, 4 in the South Atoll), and other directions (86 segments total, 55 in the North Atoll, 31 in the South Atoll). A total of 13 stations were sampled and designated their own Synoptic Investigation of Human Impacts on Nearshore Environments (SHINE) number. These stations were the following: SHINE-1834, SHINE-1836 – 1843, and SHINE-1847 – 1851 (Figure 51).

Figure 51. A map of the assessment stations on the upper reef slopes of the North and South Atolls of the Tubbataha Reefs Natural Park. The strata are the upper reef slopes facing the northeast monsoon, the southwest monsoon, and others (i.e., the North Atoll's N W or SE and the South Atoll's W and E sides).

Data Processing

The transect images from the assessment stations were processed using Coral Point Count with Excel extensions software version 4.1 (CPCe; Kohler and Gill, 2006). Ten random points were overlaid on each of 250 images per survey station. Each point was identified based on the taxonomic amalgamation units (TAUs) described by Licuanan et al. (2019). The benthos were classified into one of six general categories: hard coral (HC), algal assemblage (i.e., bare carbonate rock or carbonate rock with a thin layer of turf algae, recently dead coral, or coralline algae; AA), abiotic material (i.e., sand, silt, or rubble; AB), macroalgae (MA), *Halimeda* (HA), and other biota (i.e. benthic invertebrates other than hard coral; OB). Hard corals were further classified into 59 TAUs representing genus-growth form combinations optimized for the identification of corals in transect images. Additionally, other biota belonging to cyanobacteria and *Terpios* sponges were also identified. The average hard coral cover (HCC) and coral diversity (number of hard coral TAUs; referred to as “coral generic diversity” in Licuanan et al. 2019) of the five transects in each station were reported.

Results

The average hard coral cover (HCC) from the 13 stations of the 2024 assessment was 33.3% (± 5.1 SE). Because of the stratified sampling design used, this average is effectively weighed by the relative areas of the north-facing, southwest-facing, and other upper reef slopes. The average HCC value was at the upper limit of HCC Category C (defined as >22 to 33% HCC; see Licuanan et al., 2019 and Licuanan, 2020 for an explanation of the HCC and diversity scales). Figure 52 shows the HCC in each of the assessment stations.

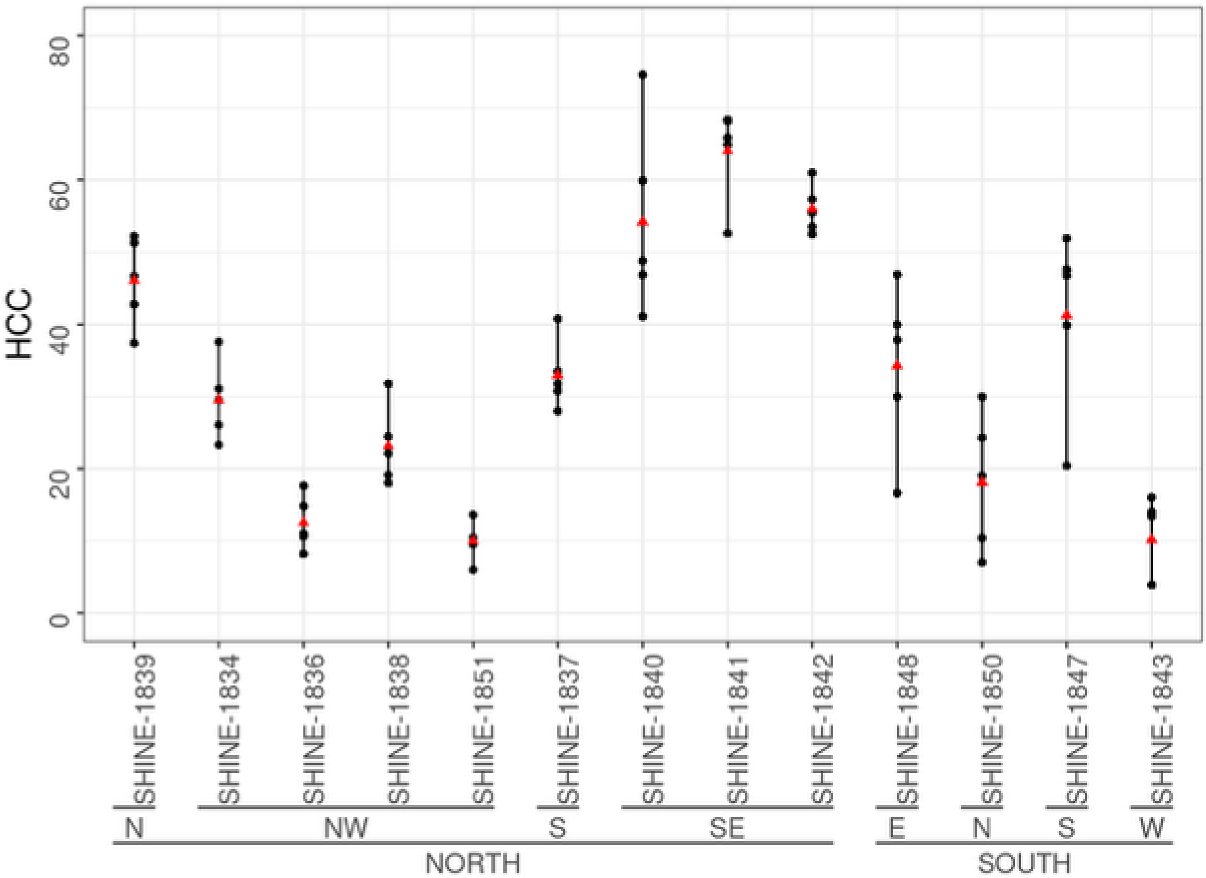

Figure 52. Plot showing the hard coral cover (HCC) of the 13 assessment stations. The black dots represent the average hard coral cover in the five randomly placed 50m photo-transects in each station. The average HCC per station is represented by the red triangle.

The weighted average TAU diversity (properly, TAU richness) was 17.3 (± 1.6 SE). It is at the upper limit of coral TAU Diversity Category D. Figure 53 shows the TAU diversity in each assessment station.

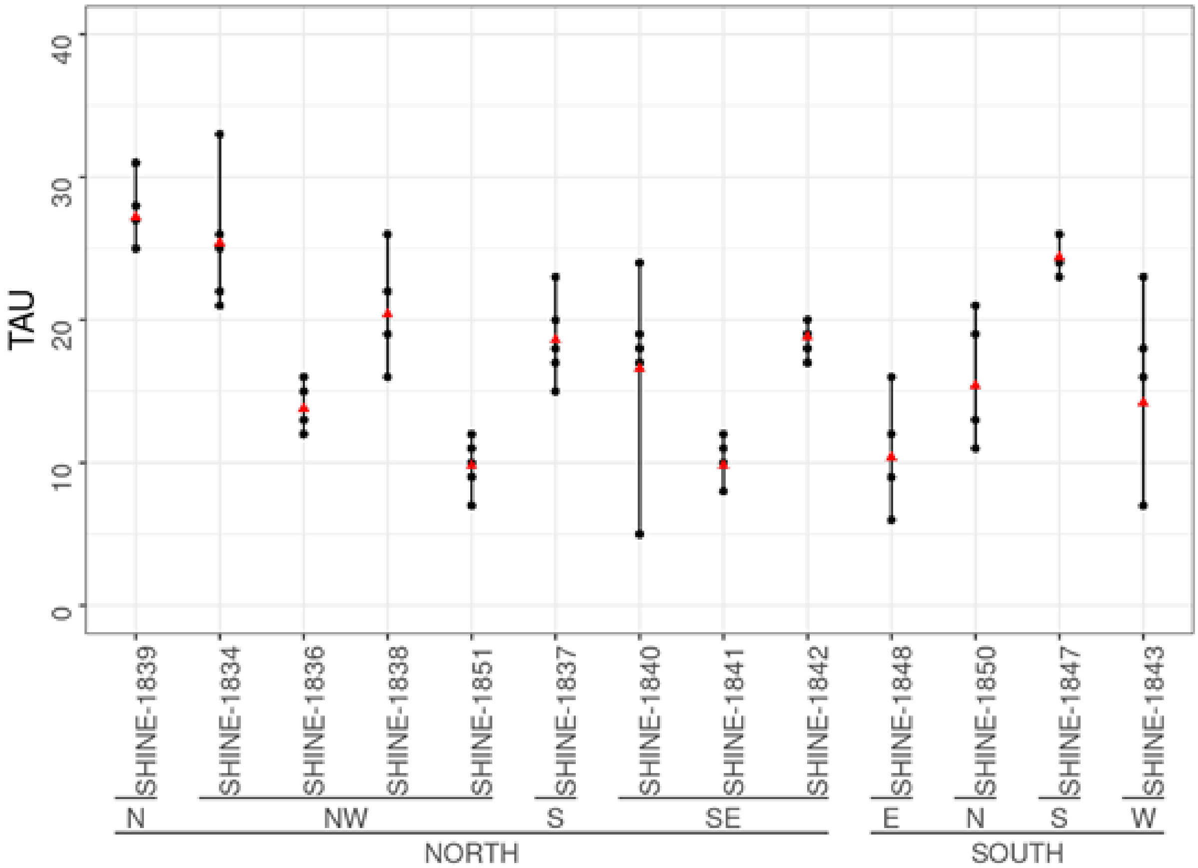

Figure 53. Plot showing the number of coral taxonomic amalgamation units (TAUs) of the 13 assessment stations. Each black dot represents the cumulative number of coral TAUs in each station's five random 50m photo-transects. The red triangle represents the average diversity per station.

Hard coral cover and diversity in the North Atoll (HCC 36.5% ± 6.5, 17.8 ± 2.0 coral TAUs) were higher than in the South Atoll (HCC 26.0% ± 7.2, 16.1 ± 3.0 coral TAUs). However, these differences are not statistically significant (p>0.05 for both parameters).

The three stations on the SE side of the North Atoll had the highest HCC (SHINE-1840 with 54.6% ± 5.6% SE HCC, SHINE-1841 with 64.0% ± 2.9%HCC, and SHINE-1842 with 56.0% ±1.5% HCC) of the thirteen stations. All three stations were HCC Category A (i.e., with HCC >44%). The same stations had relatively low average coral TAU diversity (SHINE-1840 with 16.6 ±3.1 TAUs, SHINE-1841 with 9.8 ±0.8 TAUs, and SHINE-1842 with 18.8 ±0.6 TAUs), putting them at TAU Diversity Category C (for the latter) or at TAU Diversity Category D. The two other stations (SHINE 1851 on the west side of the North Atoll and SHINE 1848 on the E side of the South Atoll) with low TAU diversity are also on sides of the atolls that do not face the NE-SW monsoon system of the country.

Discussion

The overall HCC (33.3% ± 5.1 SE) and TAU diversity (17.3 ± 1.6 SE) values from the assessment are essentially the same as those reported for Tubbataha in Licuanan et al. (2017), which was 34% (± 1.7 SD) and 18 (± 0.9 SD). For comparison, HCC across TRNP (excluding Jessie Beazley) based on the 2024 monitoring surveys was 27.8% ± 4.1%, while coral diversity was 19.6 ± 1.3 TAUs. The 2024 monitoring indicates continuing declines in the monitoring sites and stations. In contrast, the numbers from the 2024 assessment surveys indicate that the overall situation is not bleak. This suggests the declines in the monitoring sites and stations are likely driven by localized disturbances or stressors (e.g., grounding events). Alternatively, the coral communities showing declines (such as Site 3 at the South Atoll) are more sensitive or more prone to succumb to disturbances or stressors such as thermal stress and typhoons, whose influences are widespread.

As stated earlier, the stations with the lowest TAU diversity (SHINE-1841 with 9.8 ± 0.8 TAUs, SHINE-1848 with 12.4 ±2.1 TAUs, SHINE-1851 with 9.8 ± 0.9 TAUs) were on the west or the east of the two atolls and are not facing the monsoon winds (see also SHINE-1836 with 13.8 TAUs and SHINE-1843 with 15.8 TAUs on the west of the North and South atolls, respectively). The west side of the South Atoll doesn't have an appreciable area of upper reef slope. Its reef crest is at the upper edge of a wall and thus does not provide room for coral growth.

In contrast, the three stations with the highest TAU diversity are all on monsoon-facing upper reef slopes, two at the northeast end of the North Atoll (SHINE-1839 facing the NE and SHINE-1834 facing the NW with 27.2 ± 1.1 TAUs and 25.4 ± 2.1 TAUs, respectively) and one (SHINE-1847 with 24.4 ± 0.7 TAUs) on the south end of the South Atoll. All three stations are at TAU Diversity Category B (>22 coral TAUs) and all three have higher than average HCC (HCC Category A, B, or C). The combination of above-average HCC and diversity (N.B. the national average HCC for fringing reefs is 22.8% ± 1.2% SE and 14.5 coral ± 0.5 SE TAUs; Licuanan et al. 2019) coupled with low macroalgae cover (national average macroalgae cover for fringing reefs is 8.7 ± 1.2 SE; Licuanan et al. 2019) means the monsoon-facing coral assemblages in TRNP are likely relatively more resilient to bleaching impacts (Abesamis et al., 2023; Licuanan et al., in prep.).

The three stations at the SE side of the North Atoll (SHINE-1840, SHINE-1841, and SHINE-1842) with the highest HCC and the low coral TAU diversity are the equivalent of Community Type III of Feliciano et al., 2023 (high coral cover but low coral diversity). The coral community in these three assessment stations is dominated by mostly branching species of *Acropora* and *Isopora*, which are (space) competitive corals in the scheme of Darling et al. (2012) but are prone to acute and chronic disturbances such as typhoons, thermal stress, and corallivore outbreaks. Licuanan et al. (in prep.) suggest these communities are the least likely to be climate resilient. They are similar to the coral communities in three monitoring stations at the Tubbataha Reefs Natural Park (Stations 3A and 3B at the South Atoll and Jessie Beazley B; which are also high cover low diversity assemblages). The HCC and diversity at these three monitoring stations continue to decline in 2024 (see the 2024 monitoring report). Notice that monitoring Stations

3A and 3B are also on the SE side of the South Atoll suggesting that similar environmental regimes prevail in this side of the reef (e.g., same level of exposure to monsoon-generated waves). The three assessment stations at the SE side of the North Atoll cluster out in a classification of coral TAU composition (Figure 53) showing that these stations are not just distinct in terms of high HCC and low TAU diversity.

The rest of the assessment stations cluster together in Figure 54, including all the stations on the northwest of the North Atoll (SHINE-1838, SHINE-1834, SHINE-1836, SHINE-1851), west of the South Atoll (SHINE-1843), SW of the North Atoll (SHINE-1837), and N and S of the South Atoll (SHINE-1850, SHINE-1847). This large cluster includes the three stations with the highest TAU diversity, similar to the Type I community type of fringing reefs in Feliciano et al. (2023).

There are two outliers. One is SHINE-1839 which is northeast of the North Atoll and expected to be the most exposed to the NE monsoon, like the Type II community type of Feliciano et al. (2023). The second outlier is SHINE-1848, which is east of the South Atoll, and closest to monitoring Site 3. HCC decline is fastest in the latter.

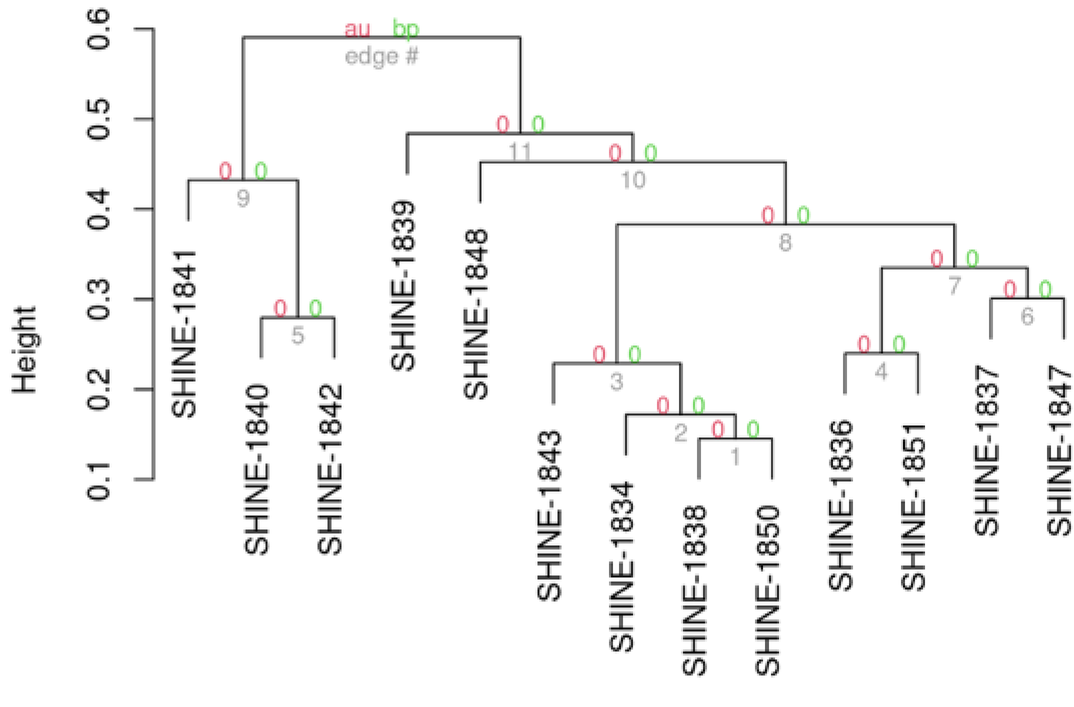

Figure 54. A dendrogram summarizing the results of an unweighted pair group method with arithmetic mean (UPGMA) cluster analysis (using the Bray-Curtis dissimilarities) of benthic composition data using Taxonomic Amalgamation Units

It is recommended that the trajectories of monitoring stations of Site 1 (Stations 1A and 1B), and Site 5 (Stations 5A and 5B) be tracked as a test of the hypothesis about the climate resilience of coral assemblages or communities on slopes facing the northeast-southwest monsoon system. We also recommend another assessment be conducted in three years.

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8| RANGER REPORT

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Overview

Marine Park Rangers are essential to the research and monitoring of Tubbataha since they can collect data during offseason. They collect the following data throughout their tours of duty:

- Seabirds- monthly distance and quarterly direct counts (analysis included in the seabird report)
- Marine turtles- biannual islets and atoll counts
- Beach profiling- biannual in Bird Islet
- Marine Debris – Every tour of duty (TOD)
- Other Observations – Coral bleaching watch, large marine vertebrate sightings, etc.

This report documents the research results from surveys conducted by the rangers. The data they collect on wildlife, such as the seabird census, is important to monitor breeding populations throughout the year. Beach profiling is conducted biannually as Bird Islet's shoreline changes with the monsoons. Marine debris and other observations during the off-season would be non-existent if not collected by the rangers.

METHODS

Marine Turtles

Marine turtle boat surveys are conducted biannually, in June and November. Straight line transects are conducted in smaller sites such as Bird Islet, South Islet, and the ranger station. Surveys conducted in the shallow regions of the reef flats of the north and south atolls follow a zig-zag pattern to cover a broader area (Figure 55). Both surveys follow predetermined coordinates to guarantee the method's replicability. All turtles observed within 10 meters on either side of the boat are recorded, and the boat's position is pinpointed using a GPS.

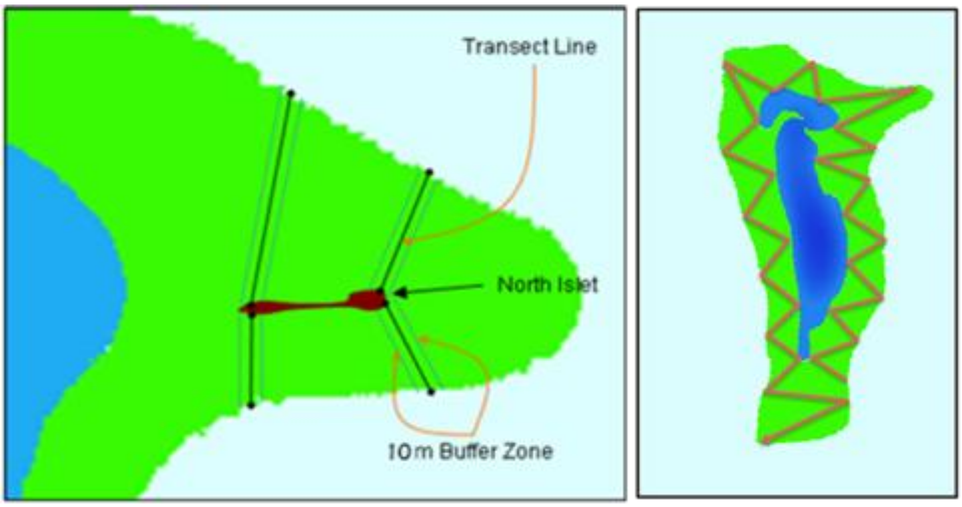


Figure 55. Illustration of transects surveyed by marine park rangers on the islets (left) and over the reef flats (right).

Beach Profiling

Beach profiling is performed biannually to record the erosion or deposition of sand at Bird Islet during the Northeast and Southwest monsoons. This year's beach profiling survey was conducted in July, coinciding with low tide. The four (4) permanent monitoring locations were reexamined, and the distance and elevation of the contours from the monitoring points to the water line were measured (Figure 56).

Figure 56. Marine Park Rangers conduct beach profiling in Bird Islet.

RESULTS

Marine Turtle

The figures below show the plotted coordinates of the turtle sightings during the survey in June 2024. A total of 61 sightings were recorded across all the straight-line transects, compared to 27 in 2023. Bird Islet accounted for 36 sightings, South Islet had 24, and only one sighting occurred at the ranger station.

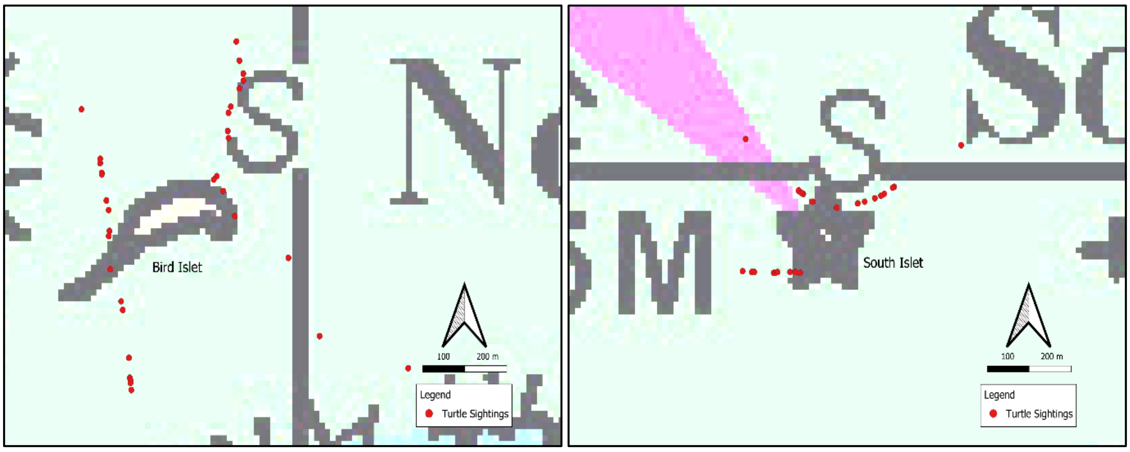


Figure 57. Turtle sightings recorded in the straight line transects in Bird Islet (left) and South Islet (right).

A total of 70 individuals were recorded in the survey over the reef flats in the North and South Atolls, which is only nine more than those observed in the straight-line surveys near the islets. This year’s total sightings on the atolls were also eight less than those in 2023. Across all transects in the June 2024 survey, a total of 131 individuals were recorded, which is 26 more than the 105 sightings recorded in 2023.

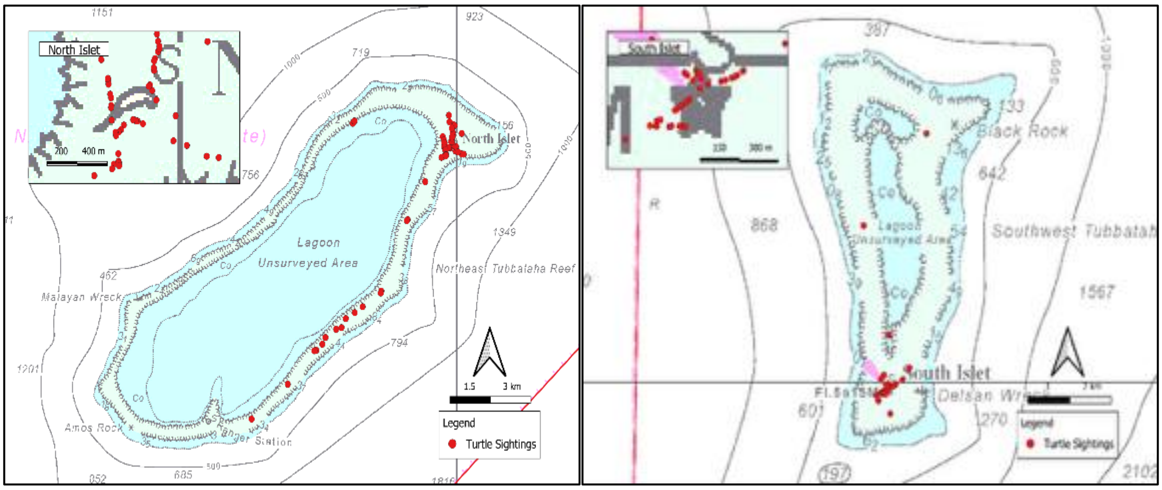
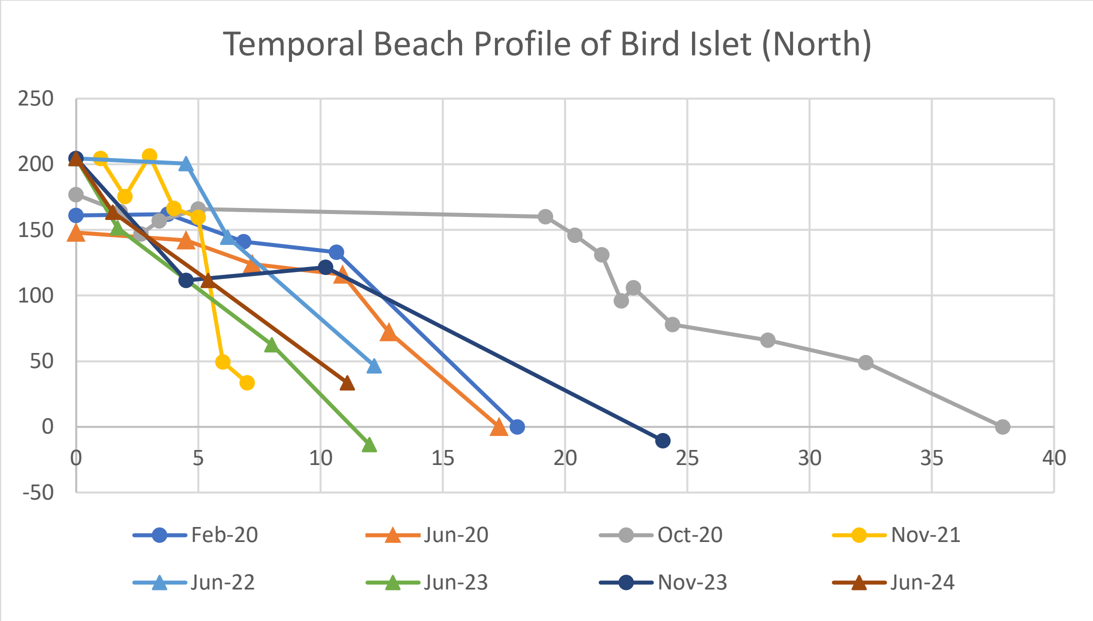


Figure 58. Turtle sightings recorded over reef flats in North and South Atoll.

Bird Islet Beach Profiling

Figure 59 shows the temporal data of the beach profiles of the north and south monitoring points on Bird Islet from February 2020 to June 2024. The northern marker experienced a significant sand deposition in October of 2020 and has decreased since then. The southern marker experienced a more consistent temporal profile, with the only erratic change in November 2021.



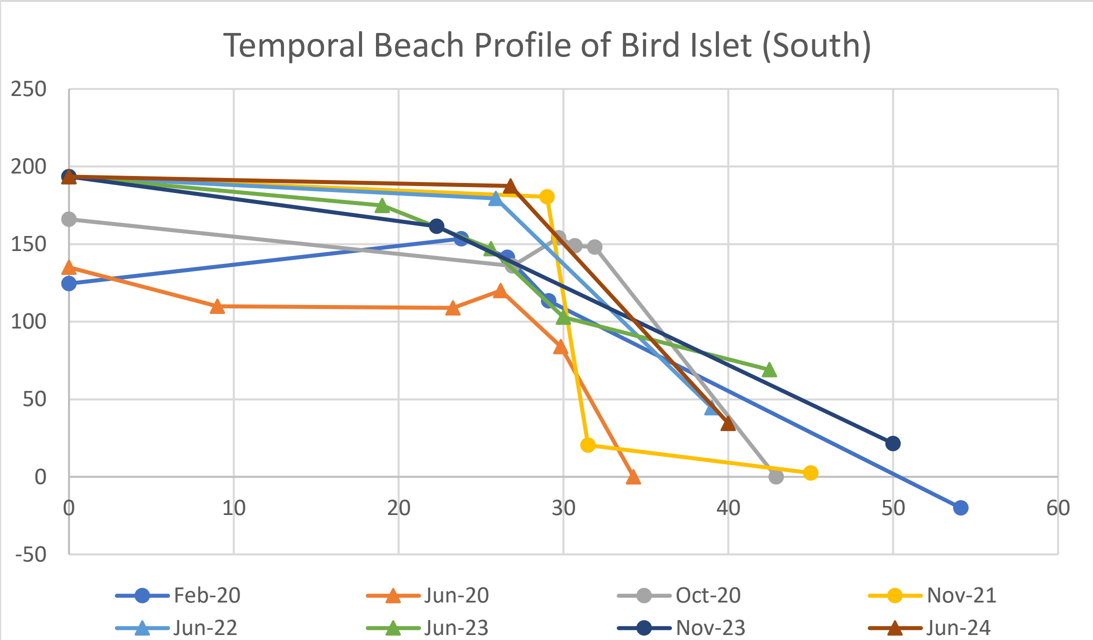
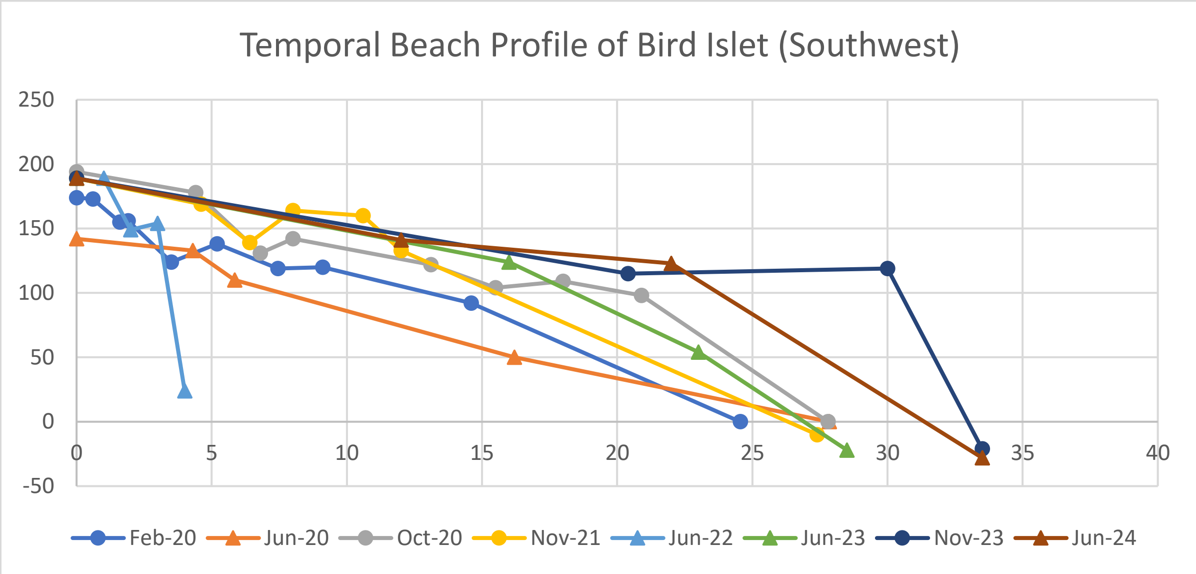


Figure 59. Scatterplot graphs showing the beach profiles of the north and south markers on Bird Islet. (Triangle markers represent surveys conducted during Habagat and circle markers represent Amihan)

There was a drastic change in sand deposition in the southwest marker from June 2022 to November 2023. The change in monsoons could be the main factor. The northeast side of Bird Islet has seen a slight increase in sand deposition over the years and is much more stable compared to the southwest marker.



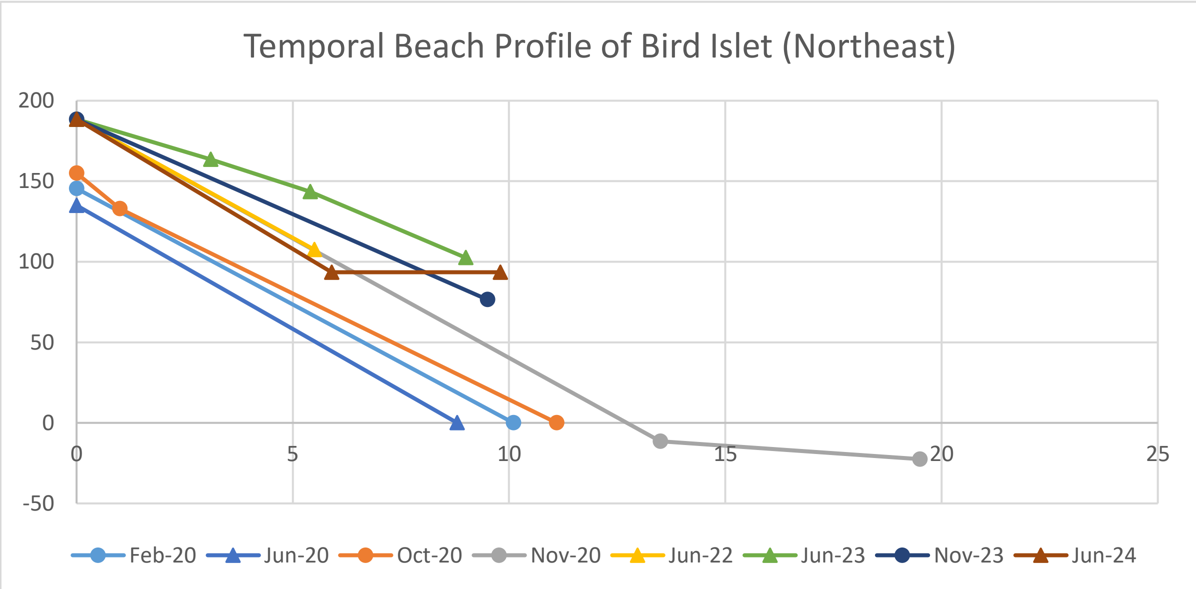


Figure 60. Scatterplot graphs showing the beach profiles of the northeast and southwest markers on Bird Islet. (Triangle markers represent surveys conducted during Habagat and circle markers represent Amihan).

Marine Debris

The majority of marine debris gathered by the MPR's are mostly found during their beach cleanups in Bird Islet (Figure 61). Floating debris is collected on the Ranger Station sandbar or during their regular patrols around the atolls. The standardization of data on marine debris started in 2016, where they weigh and categorize the different forms of pollution. The amount of debris is measured by kilograms and categorized by the following:

- Assorted Garbage
- Composite Materials
- Glass Items
- Metal
- Nylon
- Other Plastic Items
- Plastic Container
- Plastic Food Wraps
- Rigid Plastic Items
- Rubber
- Styrofoam

Figure 61. MPRs conducting beach cleanup on Bird Islet

The total weight of marine debris collected from January to July 2024 was 713.3 kg, a 1110% increase from the collected debris in 2023 (the lowest total collected weight since 2017). A large portion of the accumulated debris can be attributed to metal collected in March and July 2024, each weighing around 300kg. All other categories of marine debris had low weight relative to prior years (Table 29).

Table 29. Marine debris collected in 2023 and 2024

	2023	2024
Composite Materials	0.8	5
Glass items	21.8	0.3
Metal	2.3	605.2
Nylon	10	54.7
Other Plastic Items	1.2	1
Plastic Container	5.9	6.9
Plastic Food Wraps	1	1
Rigid Plastic Items	2.6	0.5
Rubber	11.85	2.4
Styrofoam	1.5	36.3
Total Weight	**58.6**	**677**

There was an insurgence of marine debris in 2018 (Figure 62) mainly due to the accumulation of nylon, weighing 1,363.7 kg in 2018 alone. There is a decreasing trend in the total collected marine debris per year as indicated by the downward sloping trendline in the figure below. The COVID-19 global pandemic may have been a factor in the decrease of marine debris in 2020 and 2021 followed by a rise in 2022 when operations resumed to normal. However, this does not explain why 2023 had the least amount of debris collected since 2016. Another factor could be the difference in effort by the rangers, which is influenced by weather conditions.

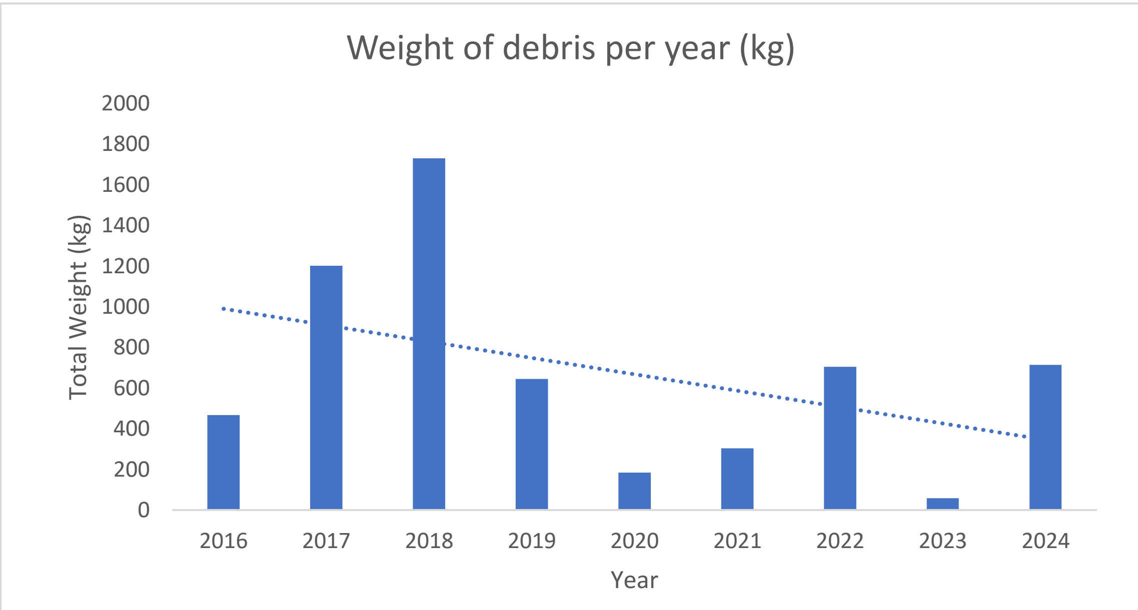
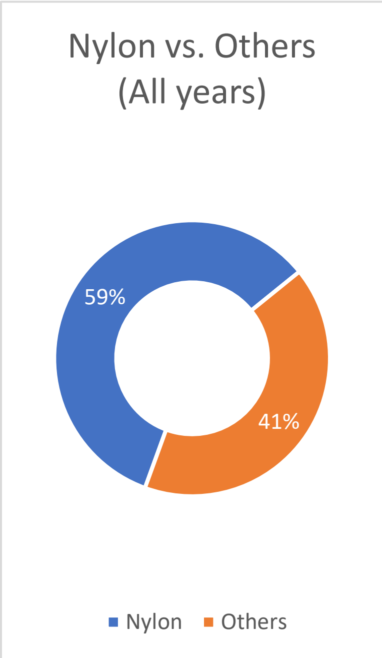


Figure 62. Weight of marine debris collected per year from 2016 to 2024

Nylon was by far the largest contributor of marine debris collected since 2016 (3,122 kg), outweighing all other categories combined (Figure 63, left). The largest amount of nylon collected in a single tour of duty was in August to October 2018, weighing around 1,200 kg. In both 2017 and 2022, there were numerous occasions when the gathered fishing nets and ropes weighed 300kg or more. The second heaviest material was metal, with a total weight of 709 kg, the majority of which was collected in 2024. Plastic containers were the heaviest among all the plastic categories, excluding nylon (Figure 63, right). Water bottles were a large factor in the total weight of plastic containers and were estimated to weigh 124 kg since 2017.



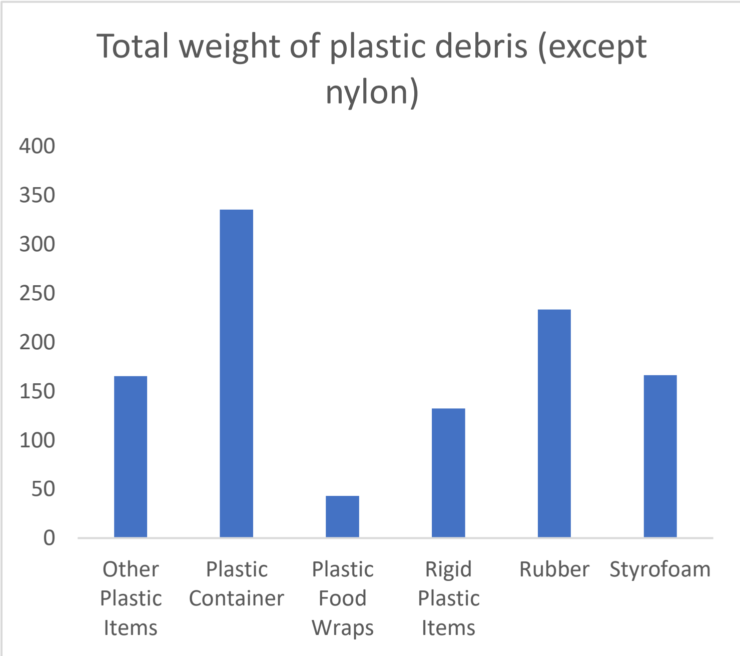


Figure 63. Total weight of nylon from 2016 to 2024 compared to all other collected marine debris combined (left) and total weight of plastic debris per categories from 2016 to 2024 (right).

Other Observations

Coral Bleaching

There were numerous reports of coral bleaching all over Tubbataha, even inside the lagoons. Many photos were sent in by dive professionals and marine park rangers documenting the extent of the bleaching. This confirms the occurrence of the 4th global bleaching event announced by NOAA in February. The event continued throughout the remainder of the diving season but has subsided since June. Minimal bleaching was observed after July of 2024. Researchers returned in November 2024 and have also seen minimal bleaching in the reefs.

Figure 64. Protected Area Superintendent Angelique Songco inspecting the extent of coral bleaching in Tubbataha. Photo by Dylan Chua/TMO.

Large Predator Sightings

The rangers regularly note sightings of large predators during their tours of duty. Two pods of spinner dolphins were observed at Jessie Beazley Reef. The first pod, estimated to have 30 individuals, was seen in April 2024. The second pod, an estimated 50 individuals was seen in August. Two tiger sharks were seen on separate occasions near the ranger station in May and August, while three tiger sharks were seen roaming the shallows near Bird Islet in May and July. Green sea turtles were regular visitors around the ranger station. They were seen every day, often as many as 30 individuals at a time during high tide. Lastly, two porcupine rays were noted east of the ranger station.

APPENDICES

Appendix 1. 2024 Research Team

Fish and Benthos

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Appendix 2. Mean density (ind/500m^2) and mean biomass (g/m^2) of fish families in deep and shallow stations

Family	Common Name	Mean density		Mean biomass	
		Shallow	Deep	Shallow	Deep
Acanthuridae	Surgeonfish	110.3	83.1	10.84	11.84
Acanthuridae/Nasinae	Unicornfish	12.6	30.0	9.71	30.89
Anthiadidae	Fairy basslets	128.6	494.0	0.40	1.63
Apogonidae	Gobies	0.0	2.2	0.00	0.00
Aulostomidae	Trumpetfish	0.0	0.0	0.00	0.00
Balistidae	Triggerfish	91.4	33.3	22.90	9.63
Belonidae	Needlefish	0.1	0.0	0.14	0.00
Blenniidae	Blennies	0.2	0.3	0.00	0.00
Caesionidae	Fusiliers	0.6	62.1	0.19	10.21
Carangidae	Jacks and Trevallies	4.4	3.8	8.27	11.01
Carcharhinidae	Sharks	0.0	0.1	0.00	0.86
Chaetodontidae	Butterflyfish	16.1	31.9	1.82	4.16
Cirrhitidae	Hawkfish	5.0	1.6	0.03	0.02
Dasyatidae	Ray	0.0	0.0	0.08	0.00
Ephippidae	Batfish	0.3	0.5	0.52	0.47
Epinephelidae	Groupers	0.0	0.1	0.00	0.44
Fistulariidae	Cornetfish	0.1	0.0	0.04	0.00
Gobiidae	Goby	1.1	0.0	0.01	0.00
Haemulidae	Sweetlips	2.0	1.7	7.04	2.64
Holocentridae	Bigeye	0.5	22.6	0.18	4.87
Kyphosidae	Rudderfish	0.4	0.9	0.22	0.82
Labridae	Wrasses	167.7	44.4	3.81	4.80
Lethrinidae	Emperorfish	3.7	20.9	4.03	8.74
Liopropomatidae	Soapfish	0.0	0.0	0.00	0.01
Lutjanidae	Snappers	5.9	19.6	3.83	11.40
Malacanthidae	Tilefish	0.0	0.0	0.01	0.00
Monacanthidae	Filefish	0.3	0.1	0.03	0.01
Mullidae	Goatfish	1.4	1.4	0.25	0.29
Muraenidae	Moray eels	0.0	0.0	0.00	0.04
Nemipteridae	Breams	0.1	0.0	0.01	0.00
Ostraciidae	Boxfish	0.1	0.0	0.01	0.00
Pinguipedidae	Sandperch	0.0	0.0	0.00	0.00
Plotosidae	Garden eels	1.1	0.0	0.01	0.00
Pomacanthidae	Angelfish	12.8	12.4	0.43	1.29
Pomacentridae	Damselfish	769.7	660.6	2.84	5.76
Ptereleotridae	Dartfish	8.3	1.8	0.02	0.00
Scaridae	Parrotfish	16.6	18.9	15.75	17.66
Serranidae	Hinds and Groupers	20.1	13.3	4.81	5.93

Siganidae	Rabbitfish	0.8	1.5	0.25	0.69
Tetraodontidae	Pufferfish	0.6	0.2	0.14	0.05
Zanclidae	Moorish Idol	6.1	6.2	1.20	1.05
Average		**1388.9**	**1569.6**	**99.81**	**147.22**

Appendix 3. Mean density (ind/500m^2) and mean biomass (g/m^2) in the shallow and deep areas of the USS Guardian grounding site this year.

Family	Common Name	Mean Density		Mean Biomass	
		Shallow	Deep	Shallow	Deep
Acanthuridae	Surgeonfish	114.67	44.00	14.78	10.21
Acanthuridae/Nasinae	Unicornfish	9.33	10.00	6.90	17.41
Anthiadidae	Fairy basslets	93.67	440.00	0.19	1.55
Balistidae	Triggerfish	95.00	109.67	23.10	17.68
Caesionidae	Fusiliers	0.00	17.00	0.00	4.85
Carangidae	Jacks and trevallies	6.67	3.33	9.73	3.96
Chaetodontidae	Butterflyfish	10.67	12.33	0.87	1.32
Cirrhitidae	Hawkfish	5.33	2.00	0.03	0.01
Ephippidae	Batfish	0.33	0.00	0.42	0.00
Epinephelidae	Groupers	0.00	0.33	0.00	0.42
Haemulidae	Sweetlips	1.00	3.67	2.38	7.50
Holocentridae	Bigeyes	0.67	16.67	0.83	5.47
Labridae	Wrasses	261.00	67.33	3.17	9.90
Lethrinidae	Emperorfish	1.00	11.00	0.89	4.30
Lutjanidae	Snappers	2.33	2.33	2.03	1.34
Muraenidae	Moray eels	0.33	0.00	0.64	0.00
Ostraciidae	Boxfish	1.00	0.00	0.37	0.00
Pomacanthidae	Angelfish	7.67	13.00	0.18	2.21
Pomacentridae	Damselfish	397.33	588.00	1.81	3.53
Ptereleotridae	Dartfish	1.33	0.00	0.01	0.00
Scaridae	Parrotfish	16.33	14.00	13.87	25.42
Scorpaenidae	Scorpionfish	0.00	0.33	0.00	0.08
Serranidae	Hinds and groupers	13.33	11.67	3.15	3.07
Siganidae	Rabbitfish	1.33	0.00	0.54	0.00
Tetraodontidae	Pufferfish	1.00	0.33	0.24	0.28

Appendix 4. Approximate changes in the land area of Bird Islet from 1911 to 2024

Year	Land area (length x width)/ circumference (m)	Land area (high tide) (m²)	Open area ("Plaza") (m²)	Major sandbars position and condition	Erosion area
1911	400 x 150	60,000	No data	>40,000 m² (?)	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	No erosion

				SE: One stable and one expanding sandbar	
2021 [6]	513	>14,009	3,253	NW: stable sandbars SE: Stable sandbars	Northeast coast
2022	494	13,334	7,014	NW: one stable sandbar SE: One stable sandbar	Northern coast
2023	540	13,993	5,435	NW: One stable sandbar SE: One stable sandbar	Northeast coast
2024	591	16,905	6,842	NE: One sandbar SW: Two sandbars	Northeast coast

Source: Worcester 1911, Kennedy 1982, Heegaard and Jensen 1992, Manamtam 1996, WWF Philippines 2004 and Tubbataha Management Office 2004 to 2024.

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.

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

Condition of vegetation on Bird Islet, May 2006 (baseline year), and 2022 to 2024

Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2006	2022	2023	2024	2006	2022	2023	2024	2006	2022	2023	2024	2006	2022	2023	2024	2006	2022	2023	2024
Dead trees																	82	ND	ND	ND
Mature, live trees (> 3 feet)	10	0	0	8	49	5	5	0	11	0	0	0	70	5	5	8				
Small, live trees (2- 3 feet)	109	0	0	0	0	2	0	0	0	1	0	0	109	3	0	0				
Seedlings (< 1 foot)	50	0	0	0	0	0	2	0	0	0	0	0	50	0	2	0				
Total	169	0	0	4	49	7	7	0	11	1	0	0	229	8*	7*	8*	82	ND	ND	ND

Notes:
In 2021 planting took place only after the May inventory, e.g., 16 mostly Anuling as of August 2021 and in June 2022, 20 saplings
*All plants placed in protective bamboo boxes
Coco Palms: 2018: 3, 2019: 2, 2020: 0, 2021: 0, 2022: 3, 2023: 0, 2024: 0

Condition of vegetation on South Islet May 2011 (baseline year), and 2022 to 2024

Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2011	2022	2023	2024	2011	2022	2023	2024	2011	2022	2023	2024	2011	2022	2023	2024	2011	2022	2023	2024
Dead trees																	16	ND	ND	ND
Mature, live trees (> 3 feet)	70	0	0	0	28	0	0	0	5	0	0	0	103	0	0	0				
Small, live trees (2- 3 feet)	2	19	0	1	0	0	0	0	0	0	0	0	2	35	19	1				
Seedlings (< 1 foot)	19	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0				
Total	91	19	0	4	28	0	0	0	5	0	0	0	124	35	19	1	16	ND	ND	ND

Notes:

In 2021 planting took place only after the May inventory, e.g. 35 mostly Anuling as of August and again in August 2022.

Coco Palms 2011: 13, 2016: 6, 2017:6, 2018:10, 2019:6, 2020:7, 2021: 3, 2022: 5, 2023: 4, 2024: 5

Appendix 6. Population results and population trend of breeding seabirds in TRNP April to June 1981 – 2024

Inventory baseline years are underlined. Source: Kennedy 1982, Manamtam 1996, WWF Philippines 1998-2004, and TMO 2004-2024

Year/Species	Ground-breeders	Masked Booby	Brown Booby	Brown Noddy	Great Crested Tern	Sooty Tern	Tree-breeders	Red-Footed Booby	Black Noddy	TOTAL
1981	13,388	150	3,768	2,136	2,264	5,070	156	9	147	13,544
1995	3,949	1	2,060[1]	643	335	910[1]	7,128	0	7,128	11,077
1998	1,744	0	1,716	0	0	28	3,250	0	3,250	4,994
2000	4,695	0	1,045	500	150	3,000	3,502	2	3,500	8,197
2001	7,529	0	850	37	414	6,228	7,042	44	6,998	14,571
2002	7,635	0	577	775	4,160	2,123	5,003	43	4,860	12,638
2003	2,804	0	623	115	2,064	2	1,630	20	1,610	4,434
2004	5,200	0	856	336	2,808	1,200	3,240	2,435	805	8,440
2005	13,825	0	1,877	590	7,858	3,500	8,353	1,947	6,406	22,178
2006	16,957	0	1,108	1,035	6,894	7,920	8,727	1,877	6,850	25,684
2007	7,746	0	1,016	530	4,700	>1,500	7,902	2,902	> 5,000	15,648
2008	10,534	0	1,059	800	4,875	3,800	10,403	2,513	7,890	20,937
2009	9,721	0	1,018	1,570	4,433	2,700	9,525	2,220	> 7,305	19,246
2010	18,669	0	1,438	1,575	4,790	10,866	9,975	2,331	7,644	28,644
2011	13,592	0	1,846	2,042	6,160	3,544	10,746	2,395	8,351	24,338
2012	18,383	0	1,879	1,492	8,653	6,359	11,776	2,340	9,436	30,159
2013	15,988	0	1,690	1,688	9,794	2,816	12,858	2,202	10,656	28,846
2014	16,448	0	1,632	1,862	7,730[2]	5,224[3]	10,630	3,074	7,556	27,078
2015	27,193	0	2,403	2,583	<12,387	9,820[4]	11,718	3,492	8,226	38,911
2016	27,654	1	3,122	2,096	13,880	8,555	11,101	2,141	8,716	38,549
2017	29,940	1	3,535	4,209	17,097	>5,098	7,278	2,087	5,191	37,218
2018	35,878	1	3,367	3,470	17,752	11,288	5,916	1,443	4,473	41,794
2019	24,569	1	3,138	2,208	14,880	4,342	3,152	1,080	2,072	27,721
2020	29,323	2	>2,977	3,262	17,810	>5,272[5]	3,310	660	2,650[8]	32,633

2021	24,880	2	3,800	1,702[6]	13,376	6,000[7]	3,298	422	2,876[9]	28,178
2022	35,994	2	4,906[10]	2,084[11]	17,812	11,448[12]	2,950	736	2,214[13]	39,202
2023	26,789	2	4,854	1,162	16,156	4,615	3,331	489	2,842	30,120
2024	28,381	4	8,739	1,521	17,037	1,080	2,914	502	2,412	31,295
Trend (%)		-97%	132%	-29%	653%	-79%		-79%	-66%	131%

Notes:

1) End of March data
2) Based on MPR distance count 1 June 2014
3) Based on MPR count 9 August 2014
4) Based on MPR Rangers egg count 14 Feb 2015
5) Annual total 12,530, if 7,258 breeding individuals counted by MPR Feb 2020 is added
6) May represent change in breeding phenology. February 2021 count was 2,728
7) Annual total 8,063, if 2,063 breeding individuals counted by MPR Feb 2021 is added
8) Annual total 3,128 breeding individuals, if 478 actively breeding individuals counted by MPR Feb 2020 is added
9) Annual total 3,636 breeding individuals, if 760 actively breeding individuals counted by MPR Feb 2021 is added
10) 5,130 individuals, if 224 actively breeding birds with juveniles, pulli and eggs in February 2022 is added
11) Represents change in phenology. Total 3,200 breeding individuals, if 1,116 actively breeding individuals with eggs, pulli and juveniles in February 2022 is added
12) If the population breeding numbers is based on eggs laid in February 2022(3,814 eggs) and eggs present during the April inventory, the population of this species would be 18,506 adult individuals
13) Total 3,026 breeding individuals, if 812 actively breeding individuals with eggs counted in February 2022 is add

Appendix 7. Seabird breeding data from Bird and South Islets, 2nd Quarter (mainly May) 2004-2024

Species/Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Red-footed Booby											
Immatures	398	1,455	606	597	780	477	677	795	799	426	134
Pulli/1st year juv.	> 35	71	105	116	69	180	88	171	243	312	277
Eggs	+	+	+	+	+	+	+	68	>166	>185	>57
Nests	279	217	225	404	361	367	451	369	739	848	431
Brown Booby											
Immatures	0	81	26	55	55	61	126	110	140	62	51
Pulli/1st year juv.	43	2	7	12	91	126	125	225	46	28	266
Eggs	1	0	18	95	317	48	106	52	69	532	466
Nests	117	43	250	89	497	453	513	575	507	618	816
Brown Noddy											
Immatures	0	2	0	0	0	4	1	1	2	3	5
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	0	0
Eggs	0	0	0	3	17	126	438	253	>147	>607	679
Nests	115	124	20+	25+	218	384	653	571	709	771	931
Black Noddy											
Immatures	0	0	0	0	0	0	0	0	0	0	0
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	0	0
Eggs	ND	+	0	+	+	430	+	+	>80	>700	>351
Nests	208	3,203	1,131	1,734	1,824	2,680	3,525	3,827	4,282	5,156	3,778
Great Crested Tern											
Immatures	0	1	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
Eggs	0	1,829	0	0	0	515	2,341	498	1,456	3,939	2,120
Sooty Tern											
Immatures	0	0	0	0	0	0	0	0	0	0	0
Pulli/1st year juv.	0	1,750	0	458	0	846	0	1,764	0	1,258	0
Eggs	9	0	0	63	2	3	5,515	2	1,534	146	37

Species/Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Red-footed Booby										
Immatures	206	80	97	89	104	24	30	12	0	3
Pulli/1st year juv.	240	49	43	39	14	8	8	0	13	4
Eggs	>46	> 49	55	74	26	>7	14	18	11	12
Nests	379	315	177	223	72	43	73	68	57	38
						Note 1		Note 8		
Brown Booby										
Immatures	28	66	157	264	218	35	27	13	2	37
Pulli/1st year juv.	200	22	175	95	8	8	172	360	1,562	907
Eggs	55	144	43	25	6	286	1,496	1,792	187	136
Nests	726	887	886	376	412	1,054	1,861	2,369	1,002	2,203
						Note 2	Note 6	Note 9		
Brown Noddy										
Immatures	2	0	2	14	9	0	0	0	0	0
Pulli/1st year juv.	6	109	223	493	68	79	406	279	77	1
Eggs	571	620	1,005	581	183	615	177	326	124	8
Nests	960	1,048	1,917	1,644	805	1092	851	907	363	138
						Note 3	Note 7	Note 10		
Black Noddy										
Immatures	0	0	0	0	0	o	0	0	0	0
Pulli/1st year juv.	30	193	8	74	39	40	207	161	149	41
Eggs	>299	>191	406	468	254	269	323	380	463	516
Nests	2,397	1,634	1,205	1131	1036	1,135	1,438	1,852	1,421	557
						Note 4		Note 11		
Great Crested Tern										
Immatures	0	0	0	0	0	0	0	0	0	0
Pulli/1st year juv.	0	0	29	832	2610	6,813	4,447	1,807	1,572	1,527
Eggs	4,280	6,800	8,620	7,461	4830	1,568	2,292	7,099	6,506	6,165
						Note 5				
Sooty Tern										
Immatures	0	1	0	0	0	0	0	0	0	0
Pulli/1st year juv.	3,538	0	2,549	680	11	2,622	1	2,150	3	378
Eggs	52	166	0	4,964	3	14	593	3,284	287	3

Source: WWF Philippines 2004 and TMO 2004 to 2024

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

Appendix 8. In-flight to roost statistics of boobies and noddies on Bird Islet 2005 to 2024

Species/ Numbers	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	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
	Red-footed Booby									
Adult: Daytime	823	655	631	1,241	686	982	1,011	382	830	950
In-flight	960	1,171	2,082	1,272	1,534	1,259	1,259	1,680	779	813
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
%-in-flight population	55	65	78	51	69	56	55	81	48	46
Average In-flight (%)	60.4									
Immature: Daytime	514	>205	275	239	179	194	106	174	125	61
In-flight	588	401	295	541	298	483	483	249	149	5
Adjusted to 2-hour period	941	419	322	-	-	-	-	-	-	-
Total	1,455	>606	597	780	477	677	589	423	274	66
%-in-flight population	65	69	54	69	63	71	82	59	54	8
Average In-flight (%)	59.4									
	Brown Booby									
Adult: Daytime	629	405	660	691	650	930	1,338	1,060	968	834
In-flight	360	225	326	368	368	508	508	819	722	798
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
%-in-flight population	48	37	35	35	36	35	28	44	43	49
Average In-flight (%)	39									
Immature: Daytime	22	20	21	20+?	22	30+	96	81	30	13
In-flight	37	6	31	34	39	96	14	59	32	39
Adjusted to 2-hour period	59	6	34	-	-	-	-	-	-	-
Total	81	26	55	54	61	126	110	140	64	51
%-in-flight population	73	23	62	63	64	76	13	42	50	76
Average In-flight (%)	54.2									
	Brown Noddy									
Adult: Daytime							618	607	1,004	1,045
In-flight							1,124	525	142	239
Total							1,742	1,132	1,146	1,284
%-in-flight population							65	46	12	19
Average In-flight (%)	35.5									
	Black Noddy									
Adult: Daytime							421	1,098	2,243	1,506
In-flight							1,334	1,124	272	318
Total							1,755	2,222	2,515	1,824
%-in-flight population							76	51	11	17
Average In-flight (%)	38.8									

Species/ Numbers	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
	May 9: 16.30- 18.30	May 11: 16:30 – 18.30	May 10: 16.30 – 18.30	May 14: 16.30 – 18.30	May15: 16.30 – 18.30	May19: 16.30 – 18.30	May27: 16.30 – 18.30	April 26: 16.30 – 18.30	May 10: 16.30 – 18.30	May 9: 16.30 – 18.30
	Red-footed Booby									
Adult: Daytime	1,499	248	343	470	362	131	97	279	63	346
In-flight	602	367	527	356	282	309	224	131	195	114
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	-	-
Total	2,101	615	870	826	644	430	321	410	285	460
%-in-flight population	29	25	25	43	44	72	70	32	76	25
Average In-flight (%)	44.1									
Immature: Daytime	111	8	29	24	27	5	5	3	3	1
In-flight	37	17	40	20	34	16	20	0	2	6
Adjusted to 2-hour period	-	-	-	-	-	-	-	-		
Total	148	25	69	44	61	21	25	3	5	7
%-in-flight population	25	25	25	45	56	76	80	0	40	85
Average In-flight (%)	45.7									
	Brown Booby									
Adult: Daytime	1,505	1,920	2,257	1,295	2,212	888	1,556	3,560	1,274	8117
In-flight	848	1,202	1,278	2,072	727	1,640	1,352	1,172	1,790	5,569
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	-	-
Total	2,353	3,122	3,535	3,367	2,939	2,528	2,908	4,732	3,064	13,686
%-in-flight population	36	25	25	62	25	65	47	25	58	41
Average In-flight (%)	40.9									
Immature: Daytime	1	25	74	127	187	16	3	0	0	26
In-flight	25	41	78	105	30	19	18	3	2	12
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	-	-
Total	26	66	152	232	217	35	21	3	2	38
%-in-flight population	96	62	51	45	14	26	86	0	100	46
Average In-flight (%)	52.6									
	Brown Noddy									
Adult: Daytime	1,031	992	2,953							
In-flight	378	358	51							
Total	1,409	1,350	3,004							
%-in-flight population	27%	27%	2%							
Average In-flight (%)	28.3									
	Black Noddy									
Adult: Daytime	2,412	711	800							
In-flight	132	84	9							
Total	2,544	795	809							
%-in-flight population	5%	11%	1%							
Average In-flight (%)	24.6									

Appendix 9. In-flight to roost statistics of boobies and noddies on South Islet May 2014 to 2024

Species/ Numbers	2014	2015	2016	2017	2018	2019	2020	2022	2023	2024
Red-footed Booby										
	May 8: 16.30 - 17.30	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12: 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	Apr 30 16.30 - 18.30	May 12: 16.30 - 18.30	May 12: 16.30 - 18.30
Adult: Daytime	401	366	508	584	262	154	32	41	84	156
In-flight	910	1,020	1,018	633	355	282	198	285	147	58
Adjusted to 2-hour period	1,820	-	-	-	-	-	-	-	-	-
Total	2,221	1,386	1,526	1,217	617	436	230	326	231	214
% in-flight population	82.0	73.6	66.7	52.0	57.5	64.7	86.1	12.6	64	27
Average	58.62									
Immature: Daytime	68	58	32	27	22	43	5	6	7	2
In-flight	1	No count	21	1	23	27	4	2	0	3
Adjusted to 2-hour period	2	-	-	-	-	-	-	-	-	-
Total	70	> 58	63	28	45	70	9	8	7	5
% in-flight population	2.9	-	33.3	3.6	51.1	38.6	44.4	25.0	0	60
Average	28.8									

Species/ Numbers	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
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 31: 16.30 - 18.30	April 29: 16.30 - 18.30	May 12: 16.30 - 18.30	May 12: 16.30 - 18.30
Adult: Daytime	7	22	40	31	160	41	73	81	174	219	622
In-flight	2	28	24	11	144	158	376	20	109	130	185
Adjusted to 2-hour period	4	-	-	-	-	-	-	-	-	-	-
Total	11	50	64	42	304	199	449	101	174	349	807
% in-flight population	18.2	56.0	37.5	26.2	47.4	79.4	83.7	19.8	62.6	37.2	23
Average	44.6										
Immature: Daytime	0	2	0	4	32	1	16	3	0	18	11
In-flight	0	No count	No count	1	0	4	16	2	1	0	0
Adjusted to 2-hour period	0	-	-	-	-	-	-	-	-	-	-
Total	0	>2	0	5	32	5	32	5	1	18	11
% in-flight population	0	-	-	20.0	0	80.0	50.0	40.0	50.0	0	0
Average	30										

Species	Black and Brown Noddy							
	Year	2015	2016	2017	2018	2019	2022	2023
	(Note 1)	(Note2)	(Note 3)		(Note 4)	(Note 5)		
	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	30 April: 16.30 - 18.30	12 May: 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	0	-	-	-
Adjusted to 2-hour period	4,678	-	-	-	-	-	-	-
Total	11,534	7,921	6,192	3,514	0	-	-	-
% in-flight population	40.6	44.2	33.4	38.0	-	-	-	-
Average	39.0							
	Brown Noddy							
Adult: Daytime			2,921	1,347	0	427	1,270	1,162
In-flight			1,461	681	0	249	176	104
Adjusted to 2-hour period			-	-	-	-	-	-
Total			4,382	2,028	0	676	1,446	1,266
% in-flight population			33.3	33.6	0	36.8	12.2	8
Average	20.65							
	Black Noddy							
Adult: Daytime			1,205	832	60	948	1,125	2,842
In-flight			605	654	19	171	113	168
Adjusted 2-hour period			-	-	-	-	-	-
Total			1,810	1,486	79	1,119	1,238	3,010
% in-flight population			33.4	44.0	24.0	15.3	9.1	5.6
Average	21.9							

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 10. Systematic list of other avifauna than resident seabirds observed at Bird Islet, South Islet, and Ranger Station, Tubbataha Reefs Natural Park from May 8 to May 13, 2024

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 *Hypotaenidia torquata*	6	Bird Islet	9-11 May 2024
Resident Locally Common LC	Slaty-breasted Rail *Lewinia striata*	1	Bird Islet	10 May 2024
Migrant Uncommon LC	Ruddy Turnstone *Arenaria interpres*	3	Bird Islet	9-11 May2024
Migrant Uncommon NT	Grey-tailed Tattler *Tringa brevipes*	3	Ranger Station	11 May 2024
Accidental Rare LC	White-tailed Tropicbird *Phaethon lepturus*	Adult 1	North Atoll at Shark Airport	13 May 2024
Migrant Uncommon LC	Lesser Frigatebird *Fregata ariel*	Male ad 2 Female ad 1 Immature 1	Bird Islet	9-11 May 2024
Migrant Uncommon LC	Great Frigatebird *Fregata minor*	Male 4 Female > 1	Bird Islet	9-11 May 2024
		Male 4 Female 3 Juvenile 1	South Islet	12-13 May 2024
Migrant Locally rare Vulnerable	Christmas Frigatebird *Fregata andrewsi*	Juv 1	Bird Islet	9-11 May 2024
Resident Uncommon LC	Pacific Reef-egret *Egretta sacra*	1	Amos Rock	11 May 2024
		5	Bird Islet	9-11 May 2024.
		5	South Islet	12-13 May 2024
		1	Ranger Station	8 May 2024
Migrant Common LC	Lanceolated Warbler *Locustella lanceolata*	1	Ranger Station	8 May 2024
Resident Very Common LC	Eurasian Tree Sparrow *Passer montanus*	4	Bird Islet	9-11 May 2024 Species last seen alive in in May 2020 at Ranger Station
		1	South Islet	12 May 2024

Taxonomic treatment and sequence follows IOC/Wild Bird Club of the Philippines 2024. Threat status follows DENR Administrative Order No 2019 – 09: Updated National List of Threatened Philippine Fauna and Their Categories.

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

Appendix 11. Comparison of the landscape and habitats seen from the Permanent Photo Documentation Sites on Bird and South Islets, May 2004 and 2024

Bird Islet

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

Photo name code: B1 01
Comments: 6 shots (Stitched by Microsoft ICE)
Date: 11 May 2024
Photo credit: Rowell Alarcon
Coordinates: N8.92961° E119.99879°

Viewing angle for photo: facing NE 038º

Film no: 27, 28

Photo no (camera):

Photo name code: BI 02

Photo no (negative):

Comments: 2 shots good angle

Date: May 7, 2004

Photo Doc Site NI No. 02- 2004

Photo name code: BI 02

Comments: 4 shots

Date: 11 May 2024

Photo credit: Rowell Alarcon

Viewing angle for photo: facing S 165º
Comments: 3 shots panoramic view
Photo name code: BI 03
Film no: 22, 23, 24
Date: May 7, 2004
Photo no (camera):

Photo name code: BI 03
Photo credit: Rowell Alarcon
Date: 11 May 2024
Coordinates: N8.93130° E119.99701°

Photo Doc Site NI No. 04- 2004

Viewing angle for photo: facing E 067º
Film no: 14
Photo name code: BI 04
Comments: 1 shot Plaza
Date: May 7, 2004

Photo name code: BI 04
Photo credit: Rowell Alarcon

Date: 11 May 2024
Coordinates: N8.93005° E119.99656°

South Islet:

Viewing angle for photo: facing S 060º
Comments: shot includes view of the old lighthouse at the background
;
Photo taken behind the old nipa hut
Photo name code: SI 01

Photo name code: SI 01
Date: 12 May 2024
Comments: single shot including new lighthouse at the background;
Coordinates for new photo doc site was taken in 2019
Photo no (camera): IMG_3352
Photo credit: Rowell Alarcon
Coordinates: N8.74901° E119.81967°

Appendix 12. Field data sheets during water quality monitoring on 12 – 13 May 2024

PALAWAN COUNCIL FOR SUSTAINABLE DEVELOPMENT STAFF
PCSD Environmental Laboratory
FIELD DATA SHEET

Sample Source: Tubbataha Reefs Natural Park, Cagayancillo, Palawan
Date of Sampling: 12 May 2024
Sampling Team: Rowell Alarcon, Dylan Chun, Cresencio Cammay, Rogel Gopalango, Segundo Conales, Gerlie Gedon

PARAMETERS	SAMPLING SITE/STATION			
Sampling Site Description (name)	WQ01 top of the reef	WQ04	WQ08 (buffer de core zone)	WQ03 (top of the reef
Sample Description (see reference below)	Seawater	Seawater	Seawater	Seawater
GPS Coordinate	N 08°46.572' E 119°49.127	N 08°45.365' E 119°49.722	N 08 43.047' E 119°53.397'	N 08°44.398' E 119°49.185'
Time of Sample Collection	11:50 AM	12:09 PM	12:23 PM	12:36 PM
Weather Condition (see reference below)	Sunny	Sunny	Sunny	Sunny
Water Appearance (see reference below)	1A	1A	1A	1A
Other Observations (Odor, human activities in the river, communities, etc)				
ON-SITE MEASUREMENTS				
Temperature, °C	34.41	34.08	34.46	34.44
pH	7.77	8.06	7.88	7.84
Conductivity, mS/cm	49.4	49.0	48.9	49.2
Turbidity, NTU	0.00	0.08	0.60	0.07
Dissolved Oxygen, mg/L	5.47	4.83	4.67	4.84
TDS, g/L	30.2	29.9	29.8	30.00
Salinity, ppt	32.32	31.74	31.0	32.37
Specific gravity, σt	18.3	18.2	18	18.2
Water depth, m	1.1	1.1	1.05	1
Preservation Techniques Done				
Container Type				
Sampling Methods	Grab Sampling	Grab Sampling	Grab sampling	Grab sampling
Analysis Requested				
(This portion to be filled up by Lab. Staff)		*Job Order No.:*		
Lab. Sample Number				
Sample(s) Received by				

Remarks:

Sample Description
1 - Riverwater
2 - Seawater
3 - Brackishwater
4 - Groundwater
5 - Effluent
6 - Tapwater
7 - Others (Pls Specify)

Physical Appearance of Water
1A - Crystal clear, transparent water
1B - Transparent water colored by dissolved organic matter
2 - Not quite crystal clear, cloudy white, gray, or light brown
3 - Cloudy brown due to high sediment levels
4 - Green due to algal growth; indicative of excess nutrients
5 - Cloudy brown from sediment and green from algae growth
6 - Others (Pls describe)

Types of Weather:
1 - Sunny
2 - Cloudy
3 - Partly Cloudy
4 - Intermittent Rain
5 - Windy
6 - Rainy

Samples Collected By:

Name/Affiliation/Signature
Gerlie Gedoria, TMO
Rowell Alarcon, TMO
Michael Dylan Chua, TMO
Segundo Conales Jr., TMO
Cresencio Cammay Jr., TMO
Rogel Gopalango, LGU

Name/Affiliation/Signature

PALAWAN COUNCIL FOR SUSTAINABLE DEVELOPMENT STAFF
PCSD Environmental Laboratory

FIELD DATA SHEET

Sample Source: Tubbataha Reefs Natural Park, Cagayancillo Palawan

Date of Sampling: 12 May 2024

Sampling Team: Rowell Alarcon, Dylan Chua, Segundo Conales, Cresencio Caranay, Gerlie Gedoria

PARAMETERS	SAMPLING SITE/STATION			
	N 08°44.914' E 119°49.142			
Sampling Site Description (name)	WQ7 (lagoon)	WQ02 (reef)	WQ06 (lagoon)	WQ05 (
Sample Description (see reference below)	Seawater	Seawater	Seawater	Seawater
GPS Coordinate	N° 08°44.915' E 119° 49.142'	N° 08°45' 659' E° 119°46 793	N° 08°46.823' E 119°49.366'	N° 08°47 624' E 119° 49.227
Time of Sample Collection	11:10 AM	11:21 AM		11:42 AM
Weather Condition (see reference below)	Sunny	Sunny	Sunny	Sunny
Water Appearance (see reference below)	1A	1A	1A	1A
Other Observations (Odor, human activities in the river, communities, etc)				
ON-SITE MEASUREMENTS				
Temperature, °C	~~27.29~~ 34.93	34.90	34.50	34.42
pH	~~7.46~~ 8.23	8.02	7.98	7.91
Conductivity, mS/cm	~~12.5~~ 48.4	48.9	49.1	49.4
Turbidity, NTU	~~9.46~~ 5.83	0.00	0.37	1.892
Dissolved Oxygen, mg/L	~~4.71~~ 5.44	6.37	6.06	4.75
TDS, g/L	~~9.7~~ 29.5	29.8	30	30.01
Salinity, ppt	~~9.5~~ 31.78	31.88	32.10	32.37
Specific gravity, σt	17.8	18.2	18.2	18.3
Water depth, m	0.85	1.05	1.1	1.1
Preservation Techniques Done				
Container Type				
Sampling Methods	Grab sampling	Grab sampling	Grab sampling	Grab sampling
Analysis Requested	TMO	TMO	TMO	TMO
(This portion to be filled up by Lab. Staff)		*Job Order No.:*		
Lab Sample Number				
Sample(s) Received by				

Remarks:

Sample Description
1 - Riverwater
2 - Seawater
3 - Brackishwater
4 - Groundwater
5 - Effluent
6 - Tapwater
7 - Others (Pls Specify)

Physical Appearance of Water
1A - Crystal clear, transparent water
1B - Transparent water colored by dissolved organic matter
2 - Not quite crystal clear, cloudy white, gray, or light brown
3 - Cloudy brown due to high sediment levels
4 - Green due to algal growth, indicative of excess nutrients
5 - Cloudy brown from sediment and green from algae growth
6 - Others (Pls describe)

Types of Weather:
1 - Sunny
2 - Cloudy
3 - Partly Cloudy
4 - Intermittent Rain
5 - Windy
6 - Rainy

Samples Collected By:

Name/Affiliation/Signature
Rowell Alarcon, TMO
Dylan Chua, TMO
Segundo Conales, TMO
Cresencio Caranay, TMO

Name/Affiliation/Signature
Gerlie Gedoria, TMO
Reed Gapilango, TMO

PALAWAN COUNCIL FOR SUSTAINABLE DEVELOPMENT STAFF
PCSD Environmental Laboratory
FIELD DATA SHEET

Sample Source: Tubbataha Reefs Natural Park, Cagayancillo, Palawan
Date of Sampling: 13 May 2023
Sampling Team: Rowell Alarcon, Dylan Chua, Segundo Corales, Cresencio Caranay, Leo Jagto, Winston Alaska

PARAMETERS	SAMPLING SITE/STATION			
Sampling Site Description (name)	WQ10 (top of the reef)	WQ19 (top of the reef)	WQ20 (outside core zone)	WQ11 (top of the reef)
Sample Description (see reference below)	Seawater	Seawater	Seawater	Seawater
GPS Coordinate	N 08°52.764' E 119°53.940	N 09°02.698 E 119°48.954	N 09°05.902 E 119°47.198	N 08°56.651 E 119°58.147
Time of Sample Collection	6:52 AM	7:30 AM	7:42 AM	8:25 Am
Weather Condition (see reference below)	~~Seawater~~ Sunny	Sunny	~~Sunny~~ Cloudy	~~Sunny~~ Cloudy
Water Appearance (see reference below)	1A	1A	1A	1A
Other Observations (Odor, human activities in the river, communities, etc)				
ON-SITE MEASUREMENTS				
Temperature, °C	33.75	33.74	33.94	33.78
pH	8.11	8.15	8.14	7.34
Conductivity, mS/cm	49.9	48.7	49.7	49.4
Turbidity, NTU	0	0.46	0	0.06
Dissolved Oxygen, mg/L	4.72	4.96	4.56	4.73
TDS, g/L	30.5	29.7	30.3	30.1
Salinity, ppt	32.66	31.75	32.52	32.24
Specific gravity, σt	18.8	18.2	18.7	18.5
Water depth, m	1m	1.05	1.05	1.15
Preservation Techniques Done				
Container Type				
Sampling Methods	Grab sampling	Grab sampling	Grab sampling	Grab sampling
Analysis Requested				

(This portion to be filled up by Lab. Staff)			*Job Order No.:*	
Lab. Sample Number				
Sample(s) Received by				

Remarks:

Sample Description
1 - Riverwater
2 - Seawater
3 - Brackishwater
4 - Groundwater
5 - Effluent
6 - Tapwater
7 - Others (Pls Specify)

Physical Appearance of Water
1A - Crystal clear, transparent water
1B - Transparent water colored by dissolved organic matter
2 - Not quite crystal clear, cloudy white, gray, or light brown
3 - Cloudy brown due to high sediment levels
4 - Green due to algal growth; indicative of excess nutrients
5 - Cloudy brown from sediment and green from algae growth
6 - Others (Pls describe)

Types of Weather:
1 Sunny
2 Cloudy
3 Partly Cloudy
4 Intermittent Rain
5 Windy
6 Rainy

Samples Collected By:

Name/Affiliation/Signature
Rowell Alarcon TMO
Michael Dylan Chua TMO
Segundo Corales Sr. TMO
Cresencio Caranay Jr. TMO
Genie Gedoria, TMO
Leo Mark Jagto WWF
Winston Alaska PGD-Pal

Name/Affiliation/Signature
~~Bartolome Aldano, LGU~~
Luciban Bonales, LGU

PALAWAN COUNCIL FOR SUSTAINABLE DEVELOPMENT STAFF
PCSD Environmental Laboratory
FIELD DATA SHEET

Sample Source: Tubbataha Reefs Natural Park, Cagayancillo, Palawan
Date of Sampling: 13 May 2024
Sampling Team: Rowell Alarcon, Segundo Conales, Cresencio Coranay Jr., Dylan Chua, Leo Jagto, Winston Alasko, Gerlie Gedona,

PARAMETERS	SAMPLING SITE/STATION			
Sampling Site Description (name)	WQ12 (top of the reef)	WQ18 (outside core zone)	WQ09 (top of the reef)	WQ17 (back of the ranger station)
Sample Description (see reference below)	Seawater	Seawater	Seawater	Seawater
GPS Coordinate	N 08°55.305' E 119°59.700	N 08°50.769 E 120°01.404	N 08°51.100', E 119°56.203'	N 08°57.104', E 119°55.025'
Time of Sample Collection	9:50	10:06 AM	10:21 AM	10:35AM
Weather Condition (see reference below)	Partly cloudy	Cloudy	Partly Cloudy	Cloudy
Water Appearance (see reference below)	1A	1A	1A	1A
Other Observations (Odor, human activities in the river, communities, etc)				
ON-SITE MEASUREMENTS				
Temperature, °C	33.95	34.12	34.11	33.96
pH	7.78	7.95	7.73	7.77
Conductivity, mS/cm	49.4	49.7	48.7	48.7
Turbidity, NTU	0	0	0.85	3.21
Dissolved Oxygen, mg/L	4.35	4.62	4.56	4.8
TDS, g/L	30.2	30.3	29.7	29.7
Salinity, ppt	32.29	32.45	31.7	31.72
Specific gravity, σt	18.5	18.6	18.	18.1
Water depth, m	1.1	1.05	1.05	1.05
Preservation Techniques Done				
Container Type				
Sampling Methods	Grab sampling	Grab Sampling	Grab Sampling	Grab Sampling
Analysis Requested				
(This portion to be filled up by Lab. Staff)			*Job Order No.:*	
Lab. Sample Number				
Sample(s) Received by				

Remarks:

Sample Description
1 - Riverwater
2 - Seawater
3 - Brackishwater
4 - Groundwater
5 - Effluent
6 - Tapwater
7 - Others (Pls Specify)

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5 - Cloudy brown from sediment and green from algae growth
6 - Others (Pls describe)

Types of Weather:
1- Sunny
2- Cloudy
3- Partly Cloudy
4- Intermittent Rain
5- Windy
6- Rainy

Samples Collected By:

Name/Affiliation/Signature
Rowell Alarcon, TMO
Segundo Conales Jr. TMO
Gerlie Gedona, TMO
Winston Alasko, TMO

Name/Affiliation/Signature
Michael Dylan Chua, TMO
Cresencio Coranay Jr. TMO
Leo Mark Jagto, NFW
Bartolome Atillano, LGU

PALAWAN COUNCIL FOR SUSTAINABLE DEVELOPMENT STAFF
PCSD Environmental Laboratory

FIELD DATA SHEET

Sample Source: Tubbataha Reefs Natural Park, Cagayancillo, Palawan

Date of Sampling: 13 May 2024

Sampling Team: Rowell Alarcon, Segundo Conales, Cresencio Caranay, Dylan Chua, Leo Jagto, Winston Alaska, Gerlie Gedona

PARAMETERS	SAMPLING SITE/STATION			
Sampling Site Description (name)	WQ13 (North atoll lagoon)	WQ14 (North atoll lagoon)	WQ15 (North atoll lagoon)	WQ16 (North atoll lagoon)
Sample Description (see reference below)	Seawater	Seawater	Seawater	Seawater
GPS Coordinate	N 08°55.784 E 119°54.729	N 08°54.480 E 119°57.009	N 08°53.461 E 119°56.942	N 08°53.363 E 119°58.273
Time of Sample Collection	8:46 AM	9:08 (am)	9:17 AM	9:28
Weather Condition (see reference below)	Partly Cloudy	Partly cloudy	Partly cloudy	Partly cloudy
Water Appearance (see reference below)	1A	1A	1A	1A
Other Observations (Odor, human activities in the river, communities, etc)				
ON-SITE MEASUREMENTS				
Temperature, °C	33.15	34.41	34.36	34.03
pH	7.71	8.16	8.00	8.19
Conductivity, mS/cm	48.7	48.	49.8	47.9
Turbidity, NTU	0.80	0.22	0.24	0.00
Dissolved Oxygen, mg/L	4.20	4.03	4.13	4.32
TDS, g/L	29.7	29.3	30.4	29.2
Salinity, ppt	31.75	31.26	32.53	31.18
Specific gravity, σt	18.4	17.6	18.5	17.6
Water depth, m	0.60	1.05	1.05	1.0
Preservation Techniques Done				
Container Type				
Sampling Methods	Grab sampling	Grab sampling	Grab sampling	Grab sampling
Analysis Requested				
(This portion to be filled up by Lab. Staff)		*Job Order No.:*		
Lab. Sample Number				
Sample(s) Received by				

Remarks:

Sample Description
1 - Riverwater
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7 - Others (Pls Specify)

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6 - Others (Pls describe)

Types of Weather:
1 - Sunny
2 - Cloudy
3 - Partly Cloudy
4 - Intermittent Rain
5 - Windy
6 - Rainy

Samples Collected By:

Name/Affiliation/Signature
Rowell Alarcon TMO
Michael Dylan Chua TMO
Segundo Conales Jr. TMO
Cresencio Caranay Jr. TMO
Leo Mark Jagto NFW
Winston Alaska CRD-Pal
Gerlie Gedona TMO

Name/Affiliation/Signature
Bucabar Rondes, LGU

Appendix 13. Description of the stations surveyed from 2018 to 2024

YEAR	STATIONS	LOCATION	DATE	REMARKS
2018	T1	North atoll	25-Apr-18	Site 4 Station A. Malayan wreck; southern tip of North Atoll; SW North Atoll; 08.89236oN; 119.90627oE
2018	T2	North atoll	25-Apr-18	Site 1 Station A. South of Ranger station. S tip of North Atoll
2018	T3	North atoll	26-Apr-18	Site 3 Station A. Shark airport; Northern part of North Atoll
2018	T4	North atoll	26-Apr-18	Site 2 Station A. Seafan alley, northern North Atoll
2018	T5	South atoll	27-Apr-18	Site 5, Station A southern South Atoll
2018	T6	South atoll	27-Apr-18	Site 6 Station A. Near Delsan wreck. South Atoll
2018	T7	South atoll	28-Apr-18	Site 7, Station A. T-Wreck
2018	T8	Jessie Beazley	29-Apr-18	Site Jessie Beasley Reef, Station A.
2019	T9	South atoll	18-Apr-19	Dive site 'Staghorn Point' S of lighthouse island; drop off high coral cover
2019	T10	South atoll	18-Apr-19	Dive Site 'Delson Wreck
2019	T11	South atoll	19-Apr-19	Dive Site Ko-ok, northern part of S Atoll
2019	T12	South atoll	19-Apr-19	Dive Site T-Wreck, northern part of S Atoll
2019	T13	South atoll	20-Apr-19	Dive Site Black Rock, northern part of S Atoll
2019	T14	North atoll	20-Apr-19	Dive Site Malayan Wreck, southern part of N. Atoll, right in front of wreck, starting and ending at submerged part of wreck in 3 m.
2019	T15	North atoll	21-Apr-19	Dive Site Seafan Alley (at first buoy), northern part of N. Atoll.
2019	T16	North atoll	21-Apr-19	Dive Site Shark Airport, over long sand flat and drop off, northern part of N. Atoll
2019	T17	Jessie Beazley	22-Apr-19	Dive Site Jessie Beazley, directly in front of Island
2019	T18	Jessie Beazley	22-Apr-19	Dive Site Jessie Beazley, opposite side of reef from island
2023	T19	Lagoon, north	20-Jun-23	Lagoon Station, North Atoll about 1 km N of Ranger Station, Dive buddies Rangers Manny + and Klaus Steifel
2023	T20	North atoll	20-Jun-23	North Atoll, South Park Dive Station 72' to 10'
2023	T21	North atoll	21-Jun-23	North Atoll, Northern area, Shark Airport
2023	T22	Lagoon, north	21-Jun-23	North Atoll, Lagoon, about 1 km S of Bird Island
2023	T23	South atoll	22-Jun-23	South Atoll, Delsan Wreck
2023	T24	South atoll	23-Jun-23	South Atoll, Ko-Ok Dive site
2023	T25	South atoll	23-Jun-23	South Atoll, Southwest Wall Dive Site
2023	T26	Jessie Beazley	24-Jun-23	Jessie Beazley, NE Side
2023	T27	Jessie Beazley	24-Jun-23	Jessie Beazley, NE Side but different part than first dive
2024	T28	Lagoon, north	23-Jun-24	Lagoon Station, North Atoll about 1 km S of Ranger station to 48' high coral cover, lots of branching corals in shallows.
2024	T29	North atoll	23-Jun-24	N. Atoll Dive Site Ranger Station. Typical drop off. High coral cover in shallow in areas in spots.
2024	T30	Lagoon, north	24-Jun-24	Lagoon Station, North Atoll about 2 km S of Ranger station to 80' to 6' high coral cover, shallow a lot of bleaching but lots of fish
2024	T31	North atoll	24-Jun-24	N. Atoll Dive Site Seafan Alley, very steep dropoff, 90' to 10' high coral cover.
2024	T32	South atoll	25-Jun-24	S. Atoll southern part near light house Dive Site Delsan Wreck

2024	T33	Lagoon, south	25-Jun-24	Lagoon Station, S. Atoll, southern part just inside lagoon north of South West Wall. Flat sandy area with rock outcrops and lots of long branching corals
2024	T34	Lagoon, south	26-Jun-24	Lagoon Station, S. Atoll, southern part just inside lagoon near Black Rock Dive Site
2024	T35	South atoll	26-jun-24	S. Atoll Dive Site Staghorn North
2024	T36	Jessie beazley	27-jun-24	Jessie Beazley, Eastern side to 80'
2024	T37	Jessie beazley	27-jun-24	Jessie Beazley, SW side to 80'

Appendix 14. List of species previously unrecorded in Tubbataha

No	Scientific name	No	Scientific name	No.	Scientific name	No	Scientific name
1	*Aioliops novaeguineae*	*30*	*Dischistodus prosopotaenia*	*59*	*Gymnothorax zonipectus*	*89*	*Ptereleotris randalli*
2	*Amblyeleotris arcupinna*	*31*	*Enneapterygius nanus*	*60*	*Halichoeres solorensis*	*90*	*Remora sp*
3	*Amblyeleotris guttatus*	*32*	*Epinephalus maculatus*	*61*	*Hemiglyphidodon plagiometopon*	*91*	*Rhabdamia gracilis*
4	*Amblyeleotris randalli*	*33*	*Epinephelus miliaris*	*62*	*Istigobius regilis*	*92*	*Saurida nebulosa*
5	*Amblyeleotris steinitzi*	*34*	*Epinephelus quoyanus*	*63*	*Koumansetta hectori*	*93*	*Scolopsis affinis*
6	*Amblyeleotris yanoi*	*35*	*Escenius bimaculatus*	*64*	*Labropsis alleni*	*94*	*Sethojulis bandanensis*
7	*Amblyglyphidodon sp. cf1 Kuiter*	*36*	*Escenius tricolor*	*65*	*Lethrinus amboinensis*	*95*	*Sethojulis trilineata*
8	*Amblygobius nocturnus*	*37*	*Eviota ancora*	*66*	*Lotilia klausewitzi*	*96*	*Siphamia elongata*
9	*Amblygobius phalaena*	*38*	*Eviota atriventris*	*67*	*Lutjanus bengalensis*	*97*	*Sphaeramia nematoptera*
10	*Asterropteryx striatus*	*39*	*Eviota fallax*	*68*	*Meiacanthus geminatus*	*98*	*Sphyraena obtusata*
11	*Blenniella chrysospilus*	*40*	*Eviota guttata*	*69*	*Mulloidichthys flavolineatus*	*99*	*Spratelloides delicatulus*
12	*Bothus pantherinus*	*41*	*Eviota lachdeberei*	*70*	*Myriptistis pralinia*	*100*	*Synodus jaculum*
13	*Bryaninops loki*	*42*	*Eviota latifasciata*	*71*	*Naso caesius*	*101*	*Taeniamia fucata*
14	*Bryaninops natans*	*43*	*Eviota minuta*	*72*	*Oplopomus oplopomus*	*102*	*Taeniamia zosterophora*
15	*Bryaninops yongei*	*44*	*Eviota nebulosa*	*73*	*Ostorhinchus apogonoides*	*103*	*Tomiyamichthys oni*
16	*Centropyge multifasciatus*	*45*	*Eviota nigriventris*	*74*	*Ostorhinchus chrysopomus*	*104*	*Trimma anaima*
17	*Cephalopholis maculatus*	*46*	*Eviota sebreei*	*75*	*Ostorhinchus dispar*	*105*	*Trimma benjamini*
18	*Cephalopholis polleni*	*47*	*Eviota shimadai*	*76*	*Ostorhinchus nanus*	*106*	*Trimma cheni*
19	*Chrysiptera springeri*	*48*	*Eviota sp? Sandcolor*	*77*	*Ostorhinchus neotes*	*107*	*Trimma emeryi*
20	*Cirrhilabrus ryukyuensis*	*49*	*Eviota zebrina*	*78*	*Ostorhinchus nigrofasciatus*	*108*	*Trimma erdmanni*
21	*Cirripectes imitator*	*50*	*Eviota prasites*	*79*	*Ostorhinchus novemfasciatus*	*109*	*Trimma nasa*
22	*Corythoichthys intestinalis*	*51*	*Exyrias bellisimus*	*80*	*Ostorhinchus monospilus*	*110*	*Trimma naudei*
23	*Cryptocentrus cinctus*	*52*	*Fusigobius melacron*	*81*	*Ostracion nasus*	*111*	*Trimma preclarum*
24	*Cryptocentrus cyanospilotus*	*53*	*Fusigobius signipinnis*	*82*	*Parapercis xanthozona*	*112*	*Trimma taylori*
25	*Cryptocentrus strigilliceps*	*54*	*Genicanthus melanospilos*	*83*	*Pleurosicya elongata*	*113*	*Trimma yanoi*
26	*Ctenogobiops feroculus*	*55*	*Genicanthus watanabei*	*84*	*Pleurosicya micheli*	*114*	*Trimma stobbsi*
27	*Decapterus russelli*	*56*	*Gnatholepis cauerensis*	*85*	*Psecuochromis bitaeniata*	*115*	*Valenciennea puellaris*
28	*Diademichthys lineatus*	*57*	*Gobiodon okinawae*	*86*	*Pseudochorus yamashiroi*	*116*	*Valenciennea sexguttata*
29	*Dischistodus perspicullatus*	*58*	*Gymnocranius cf. superciliosus*	*87*	*Pseudochromis marshallensis*	*117*	*Vanderhorstia nannai*
				88	*Psuedocheilinus octotaenia*	*118*	*Zoramia viridiventer*