Tubbataha Reefs Natural Park and World Heritage Site

ECOSYSTEM RESEARCH AND MONITORING REPORT

2025

Tubbataha Reefs Natural Park
Ecosystem Research and Monitoring Report 2025

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INTRODUCTION

THE GLOBAL CONTEXT: BREACHING THERMAL THRESHOLDS

Alarm bells were ringing worldwide months ago - it was announced that 2024 has etched itself into environmental history, surpassing 2023 as the hottest year on record and marking a significant shift in ocean thermodynamics (Cheng et al., 2025; Copernicus, 2025, Goreau et al., 2025). These recent studies indicate that we are no longer merely approaching theoretical tipping points; we are crossing them. The ongoing rise in sea surface temperatures (SST) has driven the world into its fourth global coral bleaching event, a crisis that began in 2023 and extended through 2025, affecting about 84% of the world's coral reef ecosystems (NOAA, 2025; ICRI, 2025), including Tubbataha (TMO 2024).

The specific thermal threshold for coral bleaching—typically defined as temperatures exceeding 1°C above the maximum monthly mean—is now regularly surpassed, often for extended periods (Goreau et al., 2025). These thermal anomalies have expanded over larger ocean areas and penetrated deeper into the water column than before, challenging the physiological limits of coral symbiosis worldwide. In this era of "ocean boiling," coral reefs' resilience faces unprecedented thermal stress, making diligent monitoring of marine ecosystems not just an academic task but an urgent necessity for conservation and management.

THE IMPERATIVE OF MARINE PROTECTED AREAS

Given these climate extremes, the importance of Marine Protected Areas (MPAs) has never been more vital. While local protection cannot reduce global ocean temperatures, effective MPAs act as vital "climate refugia." By removing local stressors such as overfishing, destructive gear use, and water pollution, MPAs like Tubbataha enhance the natural resilience of coral reefs, giving them the best chance to survive and recover from thermal anomalies (Queirós et al., 2025).

Tubbataha Reefs Natural Park (TRNP), a UNESCO World Heritage Site and a model of marine conservation in the Philippines, stands as a sentinel in the Sulu Sea. As a verified "seed bank" for the region, the larvae spawned within its boundaries replenish fisheries and reef systems far beyond its borders (Campos et al., 2008). Consequently, the health of Tubbataha is a barometer for the ecological security of the Philippines (Licuanan et al., 2017). Any significant decline in the condition of Tubbataha could therefore have cascading effects on fisheries productivity and marine biodiversity throughout the archipelago. As climate-driven disturbances intensify, sustained monitoring of the Tubbataha ecosystem is essential for assessing ecosystem resilience, informing adaptive management, and safeguarding its role as a source of biodiversity and fisheries replenishment for the Philippines.

TUBBATAHA RESEARCH AND MONITORING OBJECTIVES

The Ecosystem Research and Monitoring Program of TRNP is designed to provide a comprehensive, science-based assessment of the park's biophysical status. Our primary objectives are to:

01. Assess Ecosystem Health

Track long-term trends in key biological indicators to detect changes attributed to natural variability or anthropogenic pressures.

02. Evaluate Management Effectiveness

Determine if current protection measures are sufficient to maintain biodiversity and biomass.

03. Inform Policy

Generate robust scientific data to guide the Tubbataha Protected Area Management Board (TPAMB) in adaptive decision-making.

OVERVIEW OF THE 2025 REPORT

This report synthesizes the data collected during the 2025 survey season, providing a comprehensive view of the park's condition amid a challenging climate.

Fish and Benthos

Presents updated fish biomass estimates and benthos cover data, focusing on potential factors impacting the overall health of the reefs.

Seabirds

The breeding populations on Bird Islet and South Islet are analyzed, highlighting trends in population density and nesting success.

Water Quality

An assessment of physicochemical parameters ensures that the marine environment remains conducive to life.

Sharks and Rays

A targeted survey of elasmobranch density and diversity is presented, emphasizing their critical role as apex predators and indicators of effective enforcement.

Fish Inventory

A targeted survey designed to enhance the park’s existing fish species list and complement the regular monitoring program by documenting species abundance observed outside established monitoring stations.

Furthermore, this report incorporates year-round monitoring efforts by the marine park rangers, which provide high-resolution temporal data that is often overlooked in annual surveys.

Marine Debris

Analysis of waste collected during coastal cleanups and patrols.

Marine Turtles

Data on turtle populations around Tubbataha reefs and islets.

Beach Profiling

Monitoring of shoreline shifts and erosion patterns of the Bird Islet.

This report aims to provide a clear and thorough account of Tubbataha’s status in 2025 to support our ongoing stewardship and management of this invaluable natural heritage.

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CHAPTER 1


Jon Cabiles

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REEF BENTHOS

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, including food provision and coastal protection, to millions of people. These ecosystems have suffered substantial damage, with roughly half of global 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), ongoing threats persist. Monitoring and data-driven management are essential for maintaining coral cover and diversity.

Regular monitoring in the Tubbataha Reefs Natural Park (TRNP) is conducted to assess reef condition and evaluate the effectiveness of management strategies. The 2024 Reef Benthos Monitoring Report found that hard coral cover continued to decline in both shallow and deep areas. This report presents the status of the monitoring stations in TRNP and an analysis of spatio-temporal patterns over the last four years (2022-2025).

MATERIALS AND METHODS

Study Sites and Stations

The Tubbataha Reefs Natural Park (TRNP) was surveyed following a hierarchical sampling design, as described by Green et al. (2011). Each of the six monitoring sites within the TRNP consisted of a pair of monitoring stations (Figure 1) situated approximately 200 m apart on the same reef. Each monitoring station covered a 75-m x 25-m area, with the deepest part located 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, while Stations 5A and 5B have been surveyed annually since 2021 and 2022, respectively.

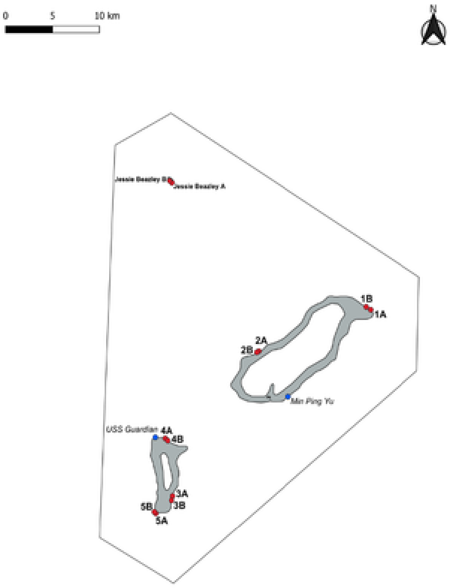

Figure 1. Map of monitoring stations in Tubbataha Reefs.

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. These monitoring stations each consist of three permanent 4-m x 4-m quadrats that 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 1-m 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.

Meanwhile, the reef benthos in the deep areas of the monitoring stations was 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 an aluminum monopod. A total of eighty images were processed from each deep monitoring station.

ll three permanent 4-m x 4-m quadrats in each of the ship grounding sites (USS Guardian and Min Ping Yu) were surveyed via photogrammetry. Flat washers were first distributed across the quadrats to provide scale.

Using a digital camera in an underwater housing, each quadrat was then photographed from a top-down perspective while swimming in a lawnmower pattern and maintaining a distance of 1 m to 1.5 m from the substrate. Photos were taken in succession via timelapse with approximately 80% overlap, ensuring that benthic features were captured in at least 3 to 4 consecutive images.

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 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 was reported for each station.

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

However, the high inter-annual variability of hard coral cover (HCC) estimates in recent years from the fixed plots at the two ship grounding sites necessitated a change in the image processing protocol, beginning with the 2024 images. This variability stemmed from the low cover and the oversampling of the patches of coral, sand, or rubble in the fixed plots. For this report, quadrat images from each 16-m^2 plot in the USS Guardian and Min Ping Yu grounding sites were processed into image orthomosaics using Agisoft Metashape®. Each 4-m x 4-m orthomosaic was cropped into sixteen 1-m × 1-m subsets, which were then scored in CPCe by overlaying 10 random points on each subset to estimate HCC.

Data Analysis

The average hard coral cover (HCC) and coral diversity from the transect data were described at the station, site, atoll, and location (i.e., the whole TRNP) level and categorized according to the national scales introduced by Licuanan et al. (2019). One-way repeated measures analysis of variance (ANOVA) was used to determine if there were statistically significant changes in benthic cover over time. Statistical analyses were performed in Real Statistics Using Excel (Zaiontz, 2025; www.real-statistics.com) and Paleontological Statistics (PAST; Hammer et al., 2001) software. The data were visualized using RStudio and QGIS (QGIS.org, 2024).

To produce a more concise yet comprehensive report, the statistical analyses of the transect data focused on changes since 2022, when the two stations of Site 5 were fully established, resulting in two sites in the North Atoll, three sites in the South Atoll, and one site in Jessie Beazley. Meanwhile, the deep areas utilized the changes beginning in 2018, other years were excluded due to an incomplete dataset or differences in methods used. More detailed analyses at the atoll, site, and station levels were sought only if a statistically significant change was detected by the analysis of data (with the stations as replicates) from the entire TRNP. Further HCC and richness numbers are presented in tables only for the current year and the previous year. However, graphs of HCC and richness data are presented for the entire series from 2012 for the whole TRNP and for each station for shallow areas while, the deep areas utilized time series data starting in 2017, after TMO adopted the phototransect method.

For the USS Guardian and Min Ping Yu grounding sites, two-way fixed-effects analysis of variance was used to seek differences in hard coral cover among the fixed plots in a year and between years. Statistical analyses were performed in Real Statistics Using Excel (Zaiontz, 2025; www.real-statistics.com) and Paleontological Statistics (PAST; Hammer et al., 2001) software. Like in the transect data, the focus was on examining the latest data compared against that of the previous year, and the trend from the last four years.

RESULTS

Shallow Areas

Hard Coral Cover (HCC)

There was no significant change in HCC in 12 stations (including the two stations in Site 5 and the two stations in Jessie Beazley) over the last four years (i.e., from 2022 to 2025; one-way repeated measures ANOVA, p=0.395; see Appendix 2). Hard coral cover remains in Category C. Table 1 summarizes the hard coral cover at each level of the hierarchical sampling design for 2024 and 2025.

The loss in HCC in Jessie Beazley A before 2022, and longer-term declines in the two Site 3 stations, were not covered in the statistical analysis. But these changes are noticeable in the following graphs, which show the time series of the shallow water HCC of the Tubbataha Reefs Natural Park at the location level (Figure 2) and HCC for each reef monitoring station (Figure 3).

Table 1. Summary table for hard coral cover (HCC) for 2024 and 2025 in the shallow areas (North Atoll = Sites 1–2; South Atoll = Sites 3–5).

Note that no statistical tests were made at the atoll and site levels since the one-way repeated measures ANOVA of the station data from the entire Tubbataha Reefs Natural Park revealed no significant change in HCC between years.

	2024		2025	
	Mean % HCC ± SE	HCC Category	Mean % HCC ± SE	HCC Category
TRNP	28.3 ± 1.7	C	30.3 ± 1.7	C
North Atoll	30.7 ± 2.4	C	31.1 ± 2.8	C
South Atoll	25.8 ± 3.3	C	29.8 ± 2.8	C
Site 1	37.2 ± 2.3	B	38.6 ± 3.1	B
Site 2	24.1 ± 3.2	C	23.7 ± 3.2	C
Site 3	10.6 ± 2.2	D	15.8 ± 1.4	D
Site 4	24.9 ± 2.8	C	31.2 ± 2.8	C
Site 5	42.0 ± 1.4	B	42.3 ± 1.7	B
Jessie Beazley	31.1 ± 4.3	C	30.4 ± 4.9	C
Station 1A	31.2 ± 1.4	C	31.5 ± 2.4	C
Station 1B	43.2 ± 1.9	B	45.6 ± 3.8	A
Station 2A	15.3 ± 2.2	D	14.6 ± 1.5	D
Station 2B	33.0 ± 1.4	C	32.8 ± 1.6	C
Station 3A	10.9 ± 3.5	D	17.8 ± 1.8	D
Station 3B	10.4 ± 3.2	D	13.9 ± 2.0	D
Station 4A	18.0 ± 2.8	D	24.7 ± 1.7	C
Station 4B	31.7 ± 2.1	C	37.7 ± 3.4	B
Station 5A	44.4 ± 1.9	A	41.8 ± 3.1	B
Station 5B	39.6 ± 1.6	B	42.8 ± 1.7	B
Jessie Beazley A	22.2 ± 5.8	C	17.6 ± 3.8	D
Jessie Beazley B	40.1 ± 3.3	B	43.2 ± 3.7	B

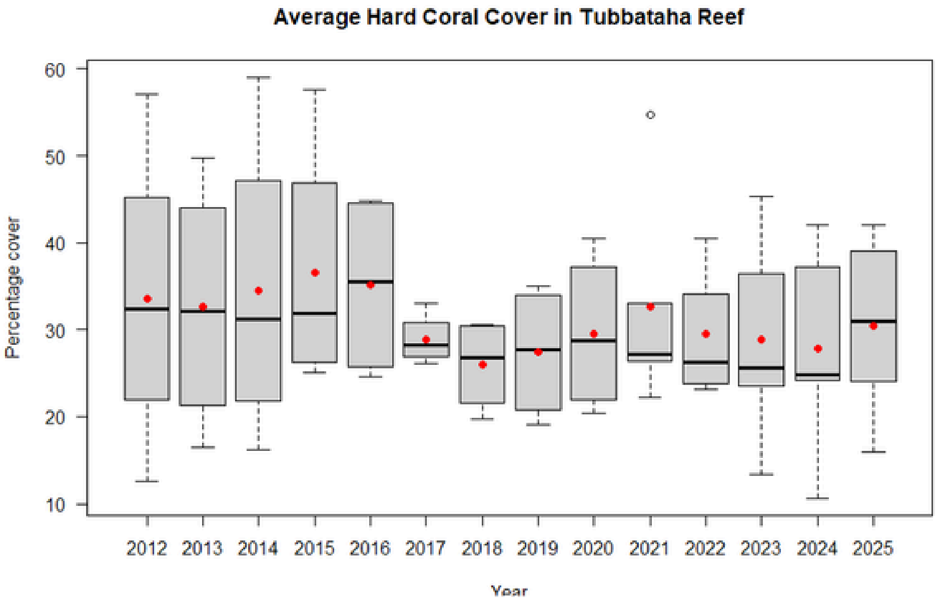

Figure 2. Box plot showing hard coral cover (HCC) in all 12 shallow water monitoring stations of the Tubbataha Reefs Natural Park.

The thick solid line represents the medians, the red dot the averages, the box the 25th and 75th quartiles, and the whiskers (error bars) the minimum and maximum values. Notice the decline of HCC in 2017.

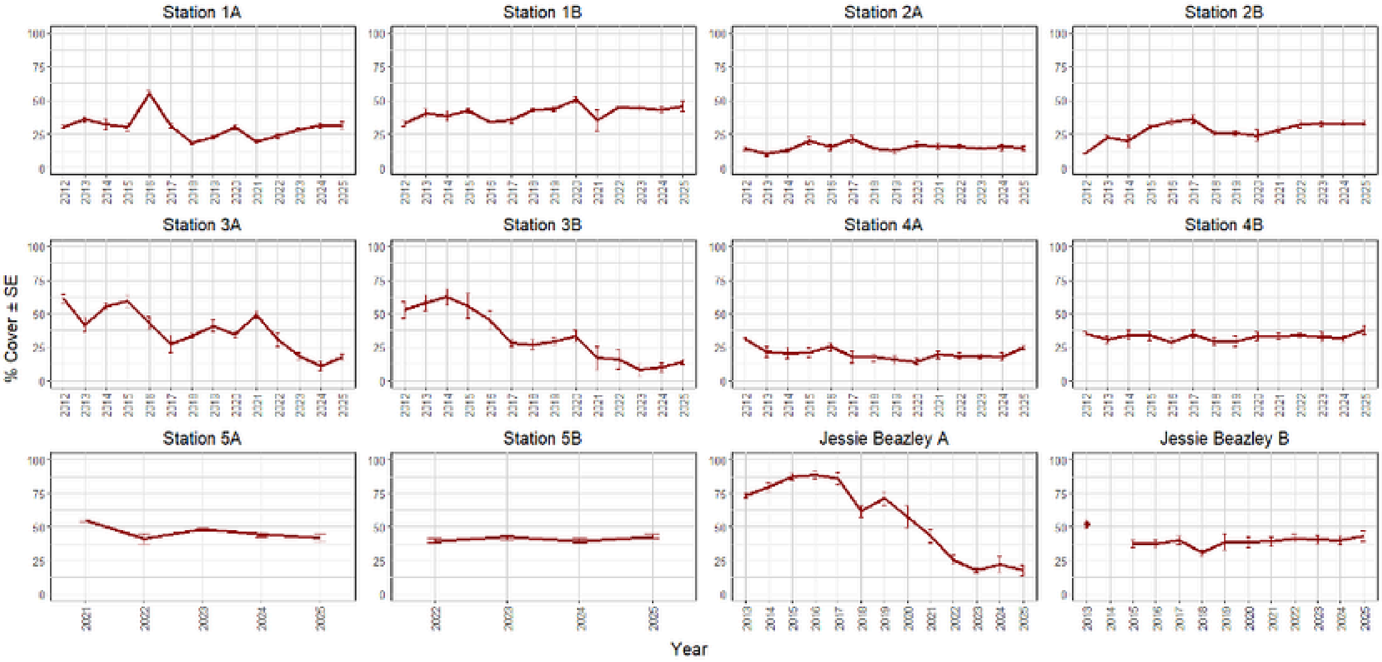

Figure 3. Percent of hard coral cover (HCC) over time in the shallow water monitoring stations of the Tubbataha Reefs Natural Park. Error bars represent ± one standard error (SE).

<u>TAU Richness</u>

There was a statistically significant change in TAU richness across TRNP over the last four years (2022-2025; one-way repeated measures ANOVA, all 12 monitoring stations, p<0.01; see Appendix 3). This result was attributable to the difference between the highest average TAU richness in 2025 (21.6) and the lowest values in 2022 and 2024 (both 19.3; See Figure 4).

Despite this increase, TRNP TAU richness remained in Category C, and thus is above the Philippine fringing reef average. Tukey HSD multiple-comparison tests, and closer examination of Table 2, Figures 4 and 5 show that the increase in TAU richness was widespread, i.e., not driven by changes only in a few sections of the reef. Richness increased at both atolls, all six sites, and most of the stations.

Table 2. Summary table for taxonomic amalgamation units (TAU) richness in the shallow reef monitoring areas (North Atoll = Sites 1–2; South Atoll = Sites 3–5) in 2024 and 2025.

	2024		2025	
	Mean TAU richness ± SE	TAU Category	Mean TAU richness ± SE	TAU Category
TRNP	19.3 ± 0.7	C	21.6 ± 0.7	C
North Atoll	20.3 ± 0.7	C	22.6 ± 1.0	B
South Atoll	19.2 ± 1.3	C	21.6 ± 1.2	C
Site 1	22.2 ± 0.8	B	25.7 ± 0.9	B
Site 2	18.4 ± 0.7	C	19.4 ± 1.1	C
Site 3	13.5 ± 1.7	D	17.2 ± 1.3	D
Site 4	20.4 ± 1.5	C	22.6 ± 1.3	B
Site 5	23.6 ± 0.9	B	25.1 ± 1.3	B
Jessie Beazley	17.4 ± 2.4	D	19.5 ± 2.6	C
Station 1A	21.8 ± 0.7	C	25.2 ± 1.5	B
Station 1B	22.6 ± 1.6	B	26.2 ± 1.0	A
Station 2A	17.2 ± 1.0	D	17.2 ± 1.5	D
Station 2B	19.6 ± 0.9	C	21.6 ± 0.9	C
Station 3A	14.2 ± 2.2	D	18.2 ± 1.2	C
Station 3B	12.8 ± 2.8	D	16.2 ± 2.4	D
Station 4A	18.0 ± 1.8	D	21.2 ± 1.4	C
Station 4B	22.8 ± 2.0	B	24.0 ± 2.3	B
Station 5A	22.4 ± 1.3	B	26.2 ± 1.7	A
Station 5B	24.8 ± 1.0	B	24.0 ± 2.0	B
Jessie Beazley A	10.6 ± 1.4	D	12.2 ± 2.0	D
Jessie Beazley B	24.2 ± 1.1	B	26.8 ± 0.6	A

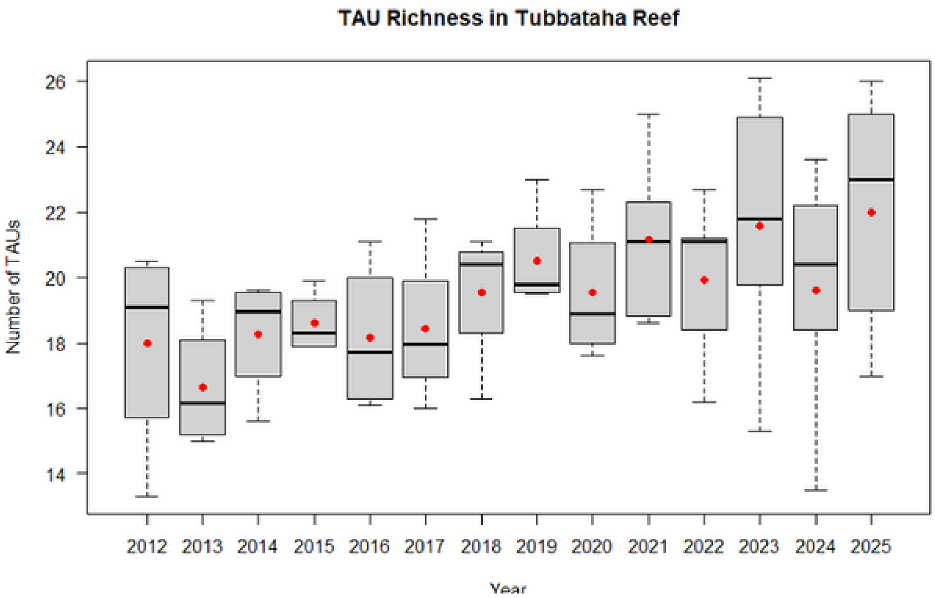

Figure 4. Box plot showing Taxonomic Amalgamation Units (TAU) richness over time in the shallow water monitoring stations of Tubbataha Reefs

The thick solid line represents the medians, the red dot represents the averages, the box represents the 25th and 75th quartiles, and whiskers (error bars) represent the minimum and maximum values.

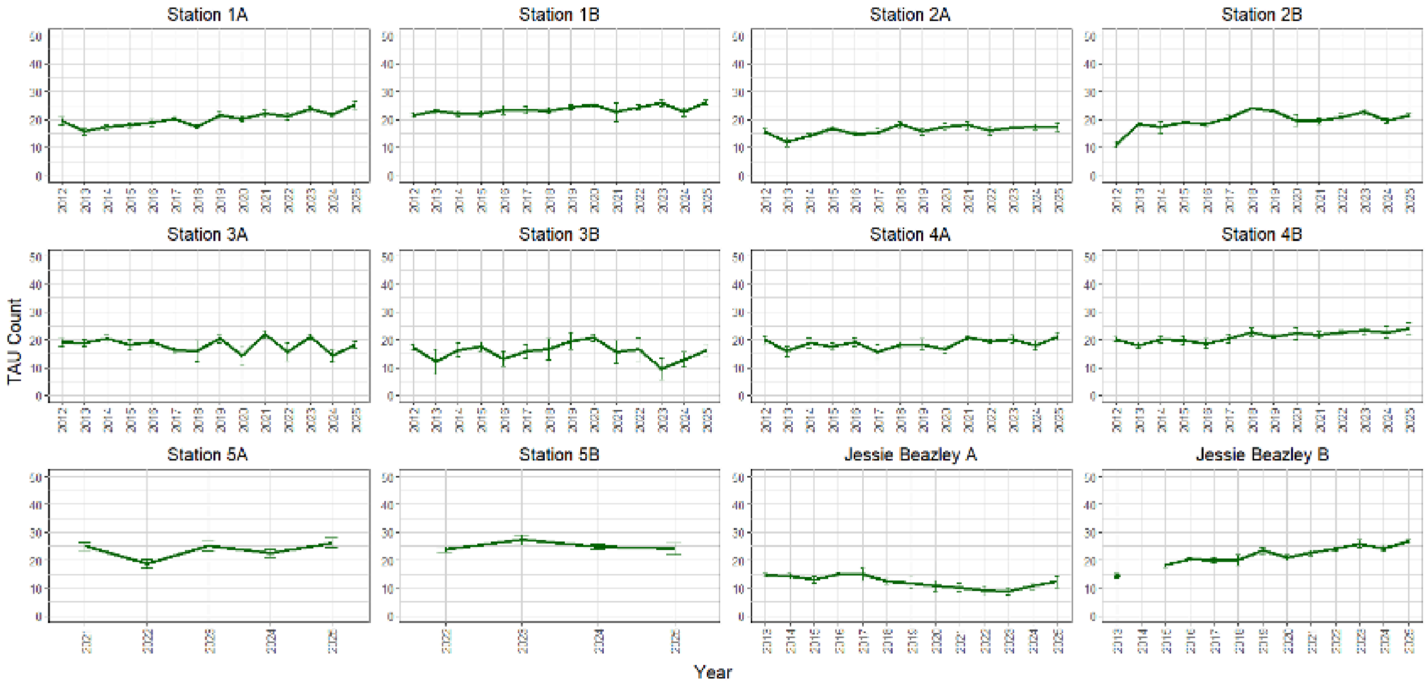

Figure 5. Taxonomic Amalgamation Units (TAU) richness over time in each of the shallow water monitoring stations of the Tubbataha Reefs Natural Park. Error bars represent ± one standard error (SE).

Deep Areas

Hard Coral Cover (HCC)

There was no significant change in HCC in 12 stations (including the two stations in Site 5 and the two stations in Jessie Beazley) over the last four years (i.e., from 2022 to 2025; one-way repeated measures ANOVA, p=0.395; see Appendix 2). Hard coral cover remains in Category C. Table 1 summarizes the hard coral cover at each level of the hierarchical sampling design for 2024 and 2025.

Other years were excluded due to an incomplete dataset or differences in methods used. Between these years, a slight but significant decline was detected (repeated measures ANOVA, all 10 stations, p = 0.012) over the last eight years (i.e., 2018-2025).This was primarily due to the large variability between 2019 and 2022. Due to this significant result, the data was further analyzed at the site and station levels, but no significant results were obtained.

Table 3. Summary table for hard coral cover (HCC) for 2024 and 2025 in the shallow areas (North Atoll = Sites 1–2; South Atoll = Sites 3–5).

	Mean % HCC ± SE	
	2024	2025
TRNP	25.3 (± 1.7)	24.6 (± 2)
North Atoll	29.03 (± 2.2)	26.2 (± 3.6)
South Atoll	23.8 (± 2.3)	24.1 (± 2.7)
Site 1	33.6 (± 3.8)	37.7 (± 4.1)
Site 2	25.4 (± 1.8)	14.7 (± 1.6)
Site 3	22.2 (± 2.8)	19.5 (± 2.5)
Site 4	25.5 (± 3.7)	28.9 (± 4.2)
Jessie Beazley	20.9 (± 5.5)	24.2 (± 4.3)
Station 1A	25.9 (± 5.7)	30.4 (± 4.9)
Station 1B	39.4 (± 2.3)	45 (± 4.5)
Station 2A	23.7 (± 2.3)	13.7 (± 1)
Station 2B	27.1 (± 3)	15.6 (± 3.4)
Station 3A	28.5 (± 2.9)	20.2 (± 4.3)
Station 3B	15.9 (± 1.2)	18.7 (± 3.1)
Station 4A	20.8 (± 5.8)	24.2 (± 8.5)
Station 4B	30.1 (± 4.1)	33.6 (± 2)
Jessie Beazley A	10.9 (± 0.4)	19.5 (± 3.6)
Jessie Beazley B	31 (± 8.6)	24.9 (± 8.2)

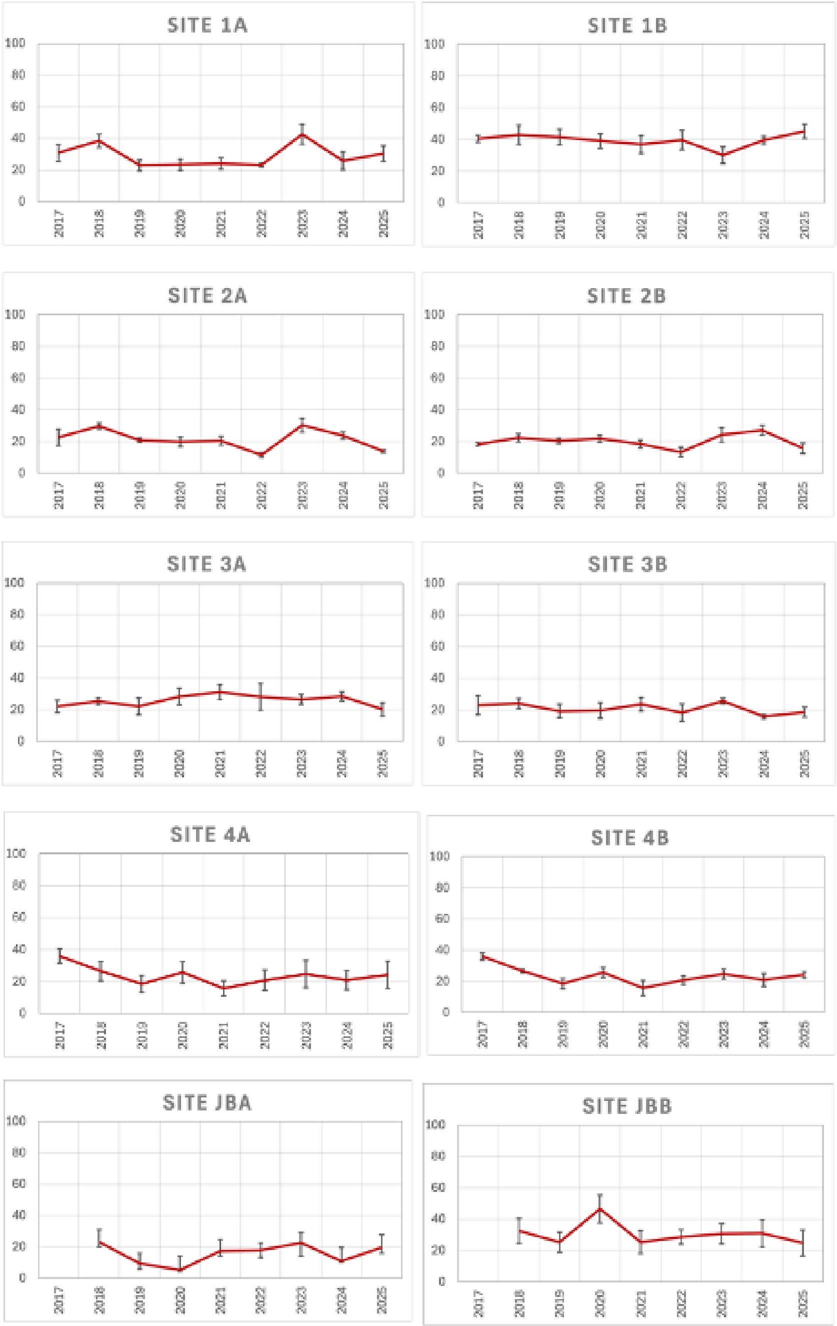

Figure 6. Percent of hard coral cover (HCC) over time in the shallow water monitoring stations of the Tubbataha Reefs Natural Park. Error bars represent ± one standard error (SE).

<u>TAU Richness</u>

There was no significant change in TAU richness from 2024 to 2025, despite a minor decline from 15.75 TAUs in 2024 to 14.9 TAUs in 2025 (paired t-test, p>0.05). Over the last eight years (2018–2025), TAU richness at the location level showed a non-significant upward trend (one-way repeated measures ANOVA for all 10 monitoring stations, p>0.5), as illustrated in Figure 7. At the atoll level, the North and South Atolls nearly had the same values.

Table 4. Summary table for TAU richness and differences among years in the deep areas (North Atoll = Sites 1–2; South Atoll = Sites 3–4, and Jessie Beazley).

	Mean TAU richness ± SE	
	2024	2025
TRNP	15.75 (± 0.75)	14.9 (± 0.7)
North Atoll	15.4 (± 0.91)	15.4 (± 0.9)
South Atoll	14.87 (± 1.21)	15.9 (±1.2)
Site 1	17.6 (± 1.98)	18.2 (± 0.9)
Site 2	13.5 (± 0.98)	12.5 (± 0.7)
Site 3	13.62 (± 1.6)	15.4 (± 1.3)
Site 4	16.1 (± 1.8)	16.5 (± 2.2)
Jessie Beazley	13.44 (± 1.11)	11.9 (± 0.9)
Station 1A	16.6 (± 1.8)	17.7 (± 1.1)
Station 1B	18.2 (± 1.7)	18.7 (± 0.75)
Station 2A	13.7 (± 2)	13.7 (± 1)
Station 2B	13.25 (± 0.25)	11.2 (±0.63)
Station 3A	17.7 (± 0.62)	15 (± 1.5)
Station 3B	9.5 (± 0.95)	15.7 (± 2.3)
Station 4A	13.5 (± 2.7)	15 (± 3.9)
Station 4B	19 (± 2.16)	18 (± 2.5)
Jessie Beazley A	11.5 (± 0.6)	12.2 (± 1.4)
Jessie Beazley B	15 (± 1.78)	11.5 (± 1.5)

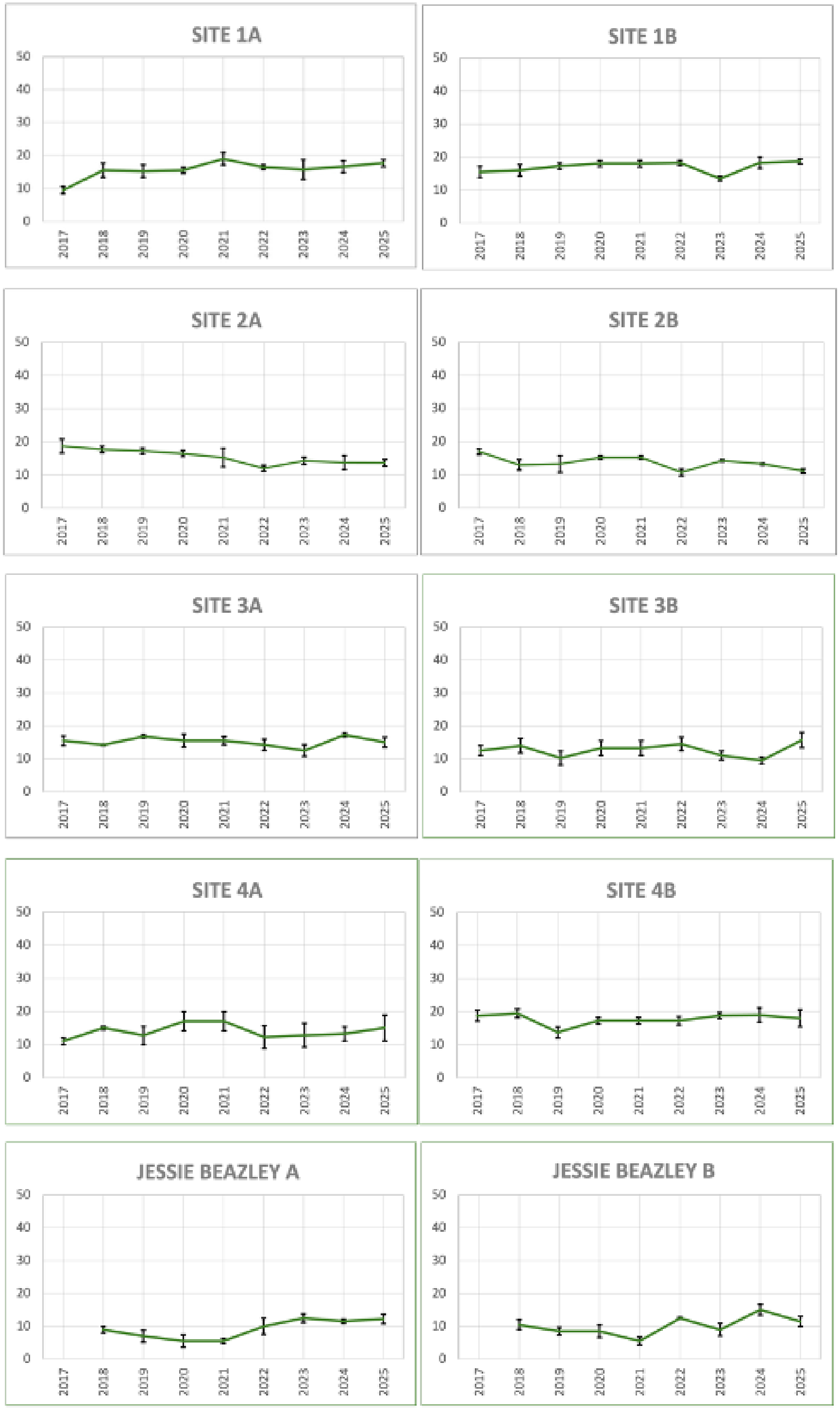

Figure 7. Taxonomic Amalgamation Units (TAU) richness over time in each of the shallow water monitoring stations of the Tubbataha Reefs Natural Park. Error bars represent ± one standard error (SE).

Site 1 had the highest average TAU richness, increasing from 17.6 in 2024 to 18.5 in 2025. Site 3 likewise increased by 1.8 TAUs, but this was not significant. At the station level, both stations in Jessie Beazley declined between 2024 and 2025 (see Table 4); however, the difference was not significant. Multiple comparison tests revealed no significant pairwise differences in results at the location, site, and station levels from 2018-2025 (Tukey's HSD, p > 0.05).

Grounding Sites

There were no significant differences (two-way fixed effects ANOVA, p>0.05) in hard coral cover at the USS Guardian site between the plots, both across plots (ground zero, adjacent control, and impact border plots) within the years 2024 and 2025, and within the same plot between the years (see Figure 8 and Appendix 4). The latter is despite the marked increase in HCC at the ground zero plot and marked decrease at the impact border plot (interaction p>0.05).

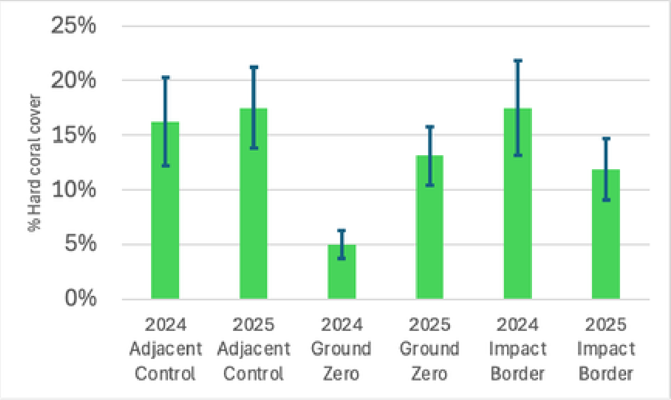

Figure 8. Column chart showing the average hard coral cover in 2024 and 2025 in the three fixed plots of the USS Guardian grounding site. Error bars represent +/- 1 standard error. Note that the data for this chart were derived from orthomosaics.

There were also no significant differences in hard coral cover among four years (2022-2025; Two-way ANOVA, p=0.390) and three plots (ground zero, impact border, and adjacent control; Two-way ANOVA, p=0.116) at the USS Guardian grounding site (see Figure 9 and Appendix 5). Note that the coral cover data for 2022 and 2023 were drawn from 30 randomly chosen images, while cover for 2024 and 2025 (as shown in Figure 8) were derived from orthomosaics.

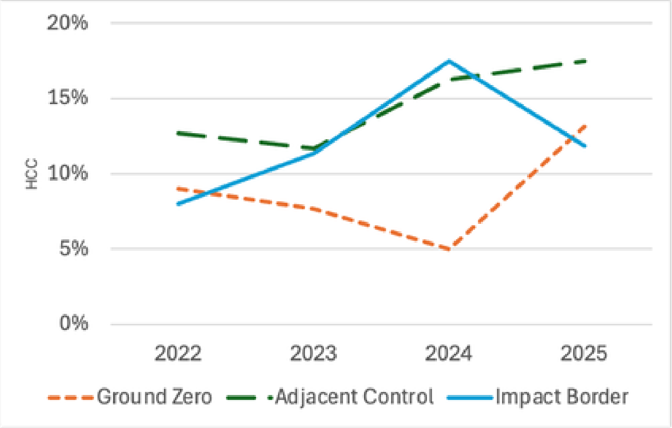

Figure 9. Line chart showing average hard coral cover from 2022 to 2025 in the three fixed plots of the USS Guardian grounding site.

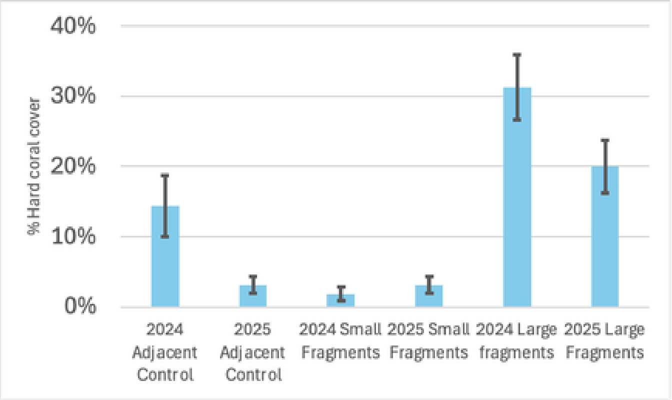

Figure 10. Column chart showing hard coral cover in 2024 and 2025 in the three fixed plots of the Min Ping Yu grounding site. Error bars represent +/- 1 standard error. Note that the small fragments plot was not repositioned correctly in 2025.

Hard coral cover in the large fragments plot at the Min Ping Yu site is significantly different (p<0.01) from the other two plots (adjacent control and small fragments plots) each year for both 2024 and 2025 (see Figure 10). Further, there was a marked decline in coral cover, particularly in the large fragments and adjacent control plots in 2025 (p<0.01). There was no significant interaction between plot and year (p>0.05). The higher hard coral cover in the large fragments plot at the Min Ping Yu site is to be expected, given that this plot is the only one with a predominantly hard substrate suitable for coral settlement and growth. Note that the small fragments plot was not repositioned correctly in 2025.

Like in the USS Guardian, there were no significant differences in hard coral cover between four years (2022-2025; Two-way ANOVA, p=0.784) and three plots (ground zero, impact border, and adjacent control; Two-way ANOVA, p=0.123) at the Min Ping Yu grounding site (see Figure 10 and Appendix 7).

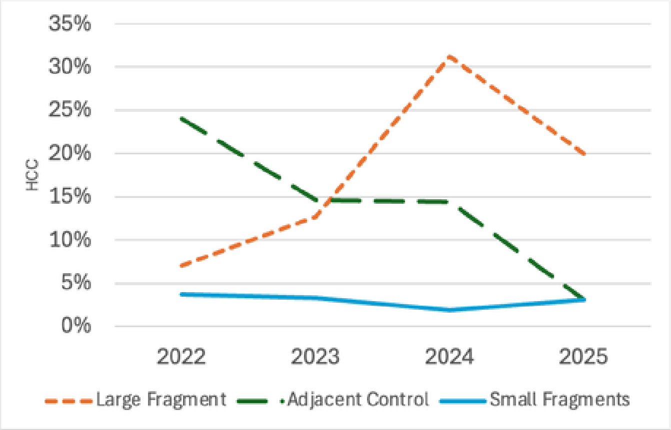

Figure 11. Line chart showing average hard coral cover from 2022 to 2025 in the three fixed plots of the Min Ping Yu grounding site.

In both grounding sites, the low p-values for the between-plot comparisons over four years suggest one plot (the ground zero plot at the USS Guardian, and the large fragments plot at Min Ping Yu) is somewhat different from the other two plots in each grounding site. However, there is high variability in the data, especially between years. Hence, the non-significant results and these tests have likely low statistical power. Adjustments in the field methods and data analyses must be considered in the future (see Discussion).

DISCUSSION

Shallow Areas

The annual monitoring of the ten stations (i.e., five sites) in the North and South Atolls and the two stations (i.e., one site) in Jessie Beazley revealed the lack of statistically significant change in HCC in the Tubbataha Reefs Natural Park from 2022 to 2025. Analysis extending back to older data (14 years, from 2012 to 2025 for eight stations in the North and South Atolls; not shown) also did not reveal statistically significant changes in HCC. However, analysis of the eight stations from the two atolls, plus the two stations in Jessie Beazley from 2015 to 2025 (11 years), revealed a significant change (not shown). These results highlight the slow decline in Stations 3A and 3B from 2015 to 2024, and the more severe loss in Jessie Beazley A from 2017 to 2022 (see Figures 2 and 3).

In contrast, statistically significant increases in TAU richness were found over four years (2022 to 2025) in all 12 stations, including those of JB and Site 5; over 11 years (2015 to 2025) in the eight stations of the North and South Atolls (not shown), and the two stations of Jessie Beazley; and over 14 years (2012 to 2025) for the eight stations of the two atolls (not shown). In all three tests, small increases in richness were found in almost all stations, and thus the results were not driven by large increases in a few monitoring stations (Figure 4).

The somewhat contrasting findings for HCC and TAU richness confirm that the losses in cover were confined to low TAU richness stations, affecting mostly their dominant species – *Montipora spp.* of Jessie Beazley A and *Isopora bruegemanni* of Stations 3A and 3B. These findings, in the light of the results of the 2024 general assessment (Tubbataha Management Office, 2024) and the lack of recent changes in the grounding site plots, further affirm that the TRNP in general remains healthy thus far.

The recent high inter-annual and between-plot variability in the cover data from both USS Guardian and Min Ping Yu requires adjustments in the data collection, processing, and analysis. We recommend the construction of orthomosaics from the images of these plots. Although computationally intensive and time-consuming, the use of orthomosaics will reduce potential oversampling of patches of coral, sand, or bare rock. Non-homogeneous substrate is expected particularly in the adjacent control plots, and as coral cover increases over time, especially when large colonies of coral become established and grow. With orthomosaics, we further recommend that the sizes of all the corals present be measured individually. This is also time-intensive, but it will minimize the effects on the variance due to the random sampling protocol used in earlier reports.

Even with the use of orthomosaics and individual measurements of all corals, variability should still be expected given that the plots being monitored are small, and coral cover will fluctuate more readily with disturbances (e.g., typhoon events) and recruitment pulses. Thus, a longer time series is essential. Images from past monitoring surveys are currently being assembled into orthomosaics.


Eric Madeja

Deep Areas

This year's report only focused on the time-series data from 2018 to 2025.This is due to the difference in method and sites before 2018. The presence of a statistical difference in the time-series at all the monitoring stations highlighted that HCC at the deep monitoring areas showed a gradually declining trend from 2018 to 2025. These significant fluctuations were primarily attributable to sharp declines in the HCC annual average observed in 2019 and 2022, contrasting with the highest average HCC recorded in 2018. This pattern becomes apparent at Sites 3 and 4 in the South Atoll and in Jessie Beazley, which hovers between 20% HCC and 35% HCC.

Over the last eight years, there have been notable fluctuations in HCC in Site 3 and Jessie Beazley, possibly influenced by chronic stressors and localized disturbances.Stations 3A and 3B have maintained low HCC, mostly below 25% from 2018 to 2025. In Site 3, baseline HCC was 24.7% in 2018, declining to 20% in 2019—a 4.7% decrease in one year.Site 3 showed a slight recovery in 2020, returning to 24%, similar to the 2018 baseline. Shortly after the May 2020 monitoring, Site 3 was impacted by coral bleaching. An assessment conducted in July 2020 revealed that the impacts of bleaching on Site 3 were minimal (TMO, 2020). Despite this event, the average HCC in Site 3 peaked at 27% in 2021, suggesting a recovery. However, after 2021, HCC in Site 3 has continued to decline, possibly due to the impacts of typhoons, particularly Typhoon Odette (December 2021), after which the average HCC dropped to 23% in 2022 (TMO, 2022). Two additional typhoons that struck Tubbataha in 2023 may have had lingering effects, which were observed in 2024, when HCC further declined to 22% (TMO, 2024). By 2025, another significant drop in HCC was recorded, likely due to the global mass coral bleaching event in 2024. HCC fell to 19%, marking a net loss of 5.7% since 2018.This pattern suggests that Site 3 is not recovering from past disturbances (i.e., thermal stress, typhoons, and strong waves during the monsoons), which may contribute to the slower growth of hard coral in the area (Hughes et al., 2018).

The HCC at the stations in Jessie Beazley shows the highest degree of inter-annual fluctuation, including a major dip around 2018–2019, followed by a gradual recovery from 2021-2024. The presence of the other biota may have contributed to this change. For example, there has been continuous proliferation of corallimorphs since 2018 in Jessie Beazley B and increasing soft coral cover in Beazley A—both encouraged by strong currents or open spaces from the previous typhoons.These factors may alter local conditions in a way that inhibits and poses threats to coral cover recovery and growth at Jessie Beazley. This high variability indicates Jessie Beazley is highly susceptible to acute disturbances but possesses a strong capacity for recovery due to high turnover or fast-growing coral species (Hughes et.al, 2018; Done, 1992).

Over the course of eight years, Stations 4A and 4B consistently displayed steady HCC levels between 20% and 30%. While these stations experienced smaller and more consistent fluctuations, their recovery process was slower yet more stable compared to the Jessie Beazley.

No statistically significant differences in TAU richness were observed at the location level across all 10 stations from 2018 to 2025. Stations 1A and 4B consistently exhibited higher TAU richness values (approximately 18–20) relative to the other stations. The persistence of these values may indicate that self-seeding mechanisms are influencing TAU richness, thereby reinforcing its status within the park.Additionally, increased proficiency among TMO researchers in coral identification over time could be a contributing factor. In summary, TAU richness remained stable throughout the period, implying that the ecosystem displays a degree of resilience to short-term stressors.

Although Tubbataha's reefs continue to be protected, hard coral cover has gradually declined due to persistent disturbances from 2018 to 2025. In the short-term (2024–2025), some sites showed minor recovery while others declined, likely due to localized events. TAU richness at monitoring sites has remained stable over time. Overall, declines in hard coral cover are limited to specific monitored areas and are likely caused by local stressors, not reflecting the overall state of the park. The park’s resilience remains clear despite these changes.

RECOMMENDATIONS

1. Track coral metrics continuously to ensure that the observed stability is maintained and to provide adaptive strategies related to the intense global stressors (like severe climate change events and storm damage).
2. Conduct further site-specific investigations to pinpoint the local factors driving the significant variability in HCC changes observed between 2024 and 2025. Apply the same statistical methods utilized in this year’s survey to test for differences in HCC alongside other TAU categories (AA, SP, and SC) across years.

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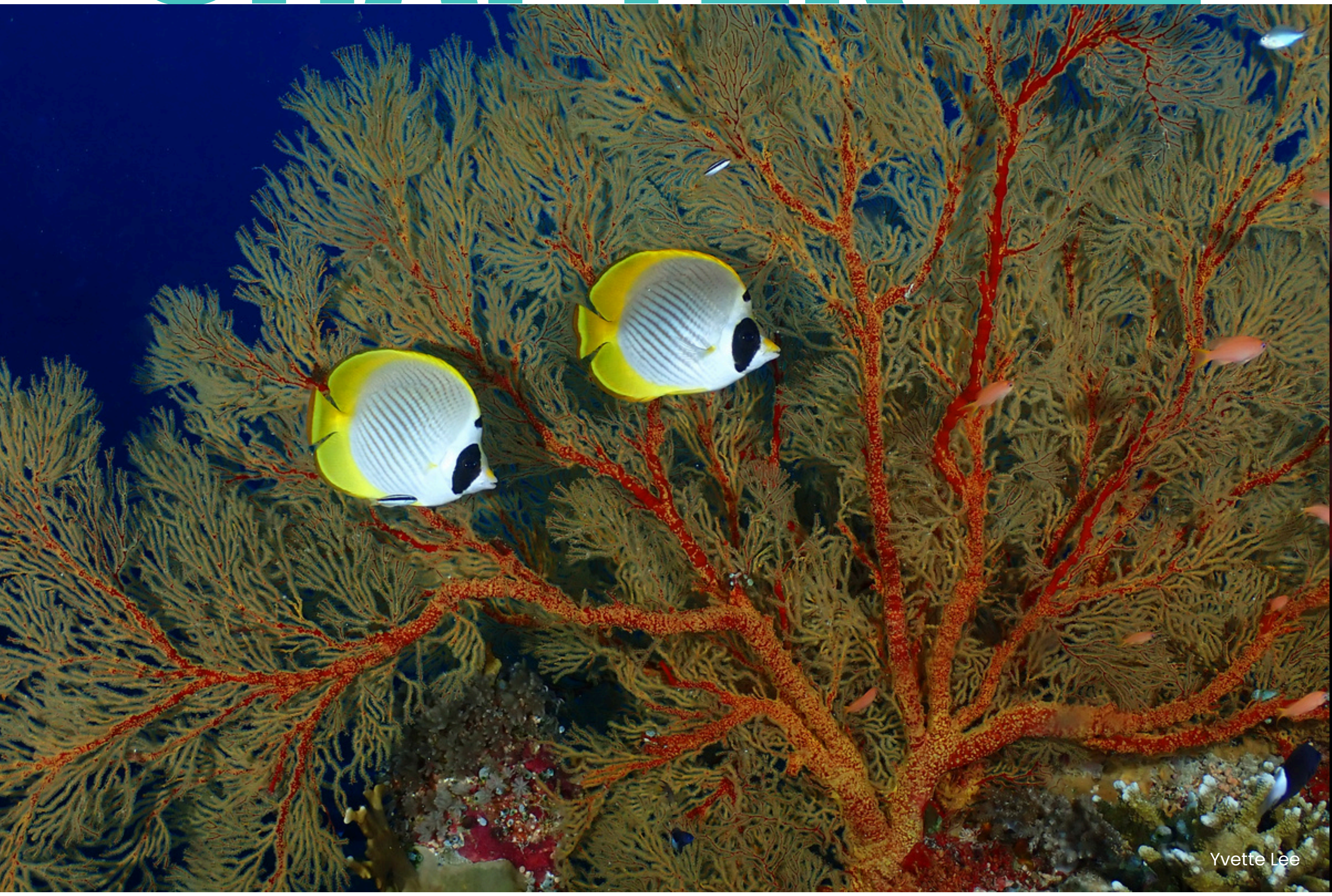
CHAPTER 2



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REEF FISH

OVERVIEW

Fish are a vital part of coral reef ecosystems, performing various ecological roles throughout the food web (Bellwood et al., 2004). They include herbivores that control algae, predators that manage other populations, and species that recycle nutrients. A diverse and abundant fish assemblage, with all functional roles represented, is essential for reef resilience, helping the ecosystem resist and recover from major disturbances.

Monitoring the entire fish assemblage is therefore a primary method for evaluating ecosystem health and the effectiveness of marine protected areas (MPA), like Tubbataha. MPAs are designed to protect the fish community from fishing pressure. Fish biomass and density are key indicators of fish community status and can help track outcomes consistent with effective protection. Recovery of the fish assemblage inside an MPA is a core indicator of conservation success (Halpern, 2003).

This report presents the results of the 2025 fish monitoring program in Tubbataha, focusing on biomass, density, and species richness as key indicators of reef condition. We analyzed location-level and site-level trends, family contributions, and diversity metrics, with dedicated sections on the USS Guardian and Min Ping Yu grounding sites.

The main objectives of this report are to:

- Determine the status of the reef fish community across the park;
- Analyze long-term trends in fish biomass, density, and species richness.

Through this monitoring, TRNP continues to serve as both a benchmark for Philippine reefs and a bellwether of how even the best protected ecosystems respond under mounting global pressures.

MATERIALS AND 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 Processing

All data processing, statistical analysis, and visualization were conducted using the R programming environment (R Core Team, 2025). Key metrics—including species richness, density (individuals/500 m²), and biomass (g/m²)—were calculated for each transect. Fish biomass was estimated from individual fish lengths using the standard length-weight equation, $W=aL^b$, with parameters a and b obtained from FishBase (www.fishbase.org; Froese & Pauly, 2025).

To allow comparison across the entire time series, density and richness data were standardized. Density from the 1999–2014 period was multiplied by two to obtain a standardized value of individuals per 500 m². Biomass was standardized to grams per square meter (g/m²) by dividing the total transect biomass with the corresponding survey area (250 or 500 m²).

For location-level biomass and density estimates, highly migratory families (Scombridae), cryptic families (Muraenidae), and cartilaginous fishes (Carcharhinidae, Dasyatidae) were excluded to minimize variance caused by occasional, high-impact sightings and to focus the analysis on reef-associated species. Lastly, location-level values for richness, density, and biomass were compared against established condition ratings for Philippine coral reefs (Hilomen et al., 2000; Nañola et al., 2006).

Data Analysis

Due to a significant redesign of the sampling protocol in 2013 aimed at improving spatial coverage, all trend analyses are limited to the post-redesign period (2013–2025) to ensure statistical comparability.

The primary analytical approach involved fitting a generalized additive mixed model (GAMM) using the mgcv package (Wood, 2017) to identify potential non-linear temporal patterns of biomass and density..

This model incorporated station as a random effect to account for the hierarchical data structure properly. For reporting purposes, the percentage change was calculated by comparing the GAMM-predicted value for the current year against the baseline year (2013).

We also analyzed the fish population on three categories: based on diet (e.g., herbivore, corallivore, etc.), based on roles in the reefs (target or commercially important species, major, and indicator), and based on association with the reef (i.e., pelagic or demersal).

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 5).

Table 5. Health categories of the reef fish population in the Philippines. Note: $mt/km^2=g/m^2$

Metric	Measure	Category
*Species richness (species per 500m2) Hilomen et al. (2000)	0-23.5 24 -37 37.5 -50 >50	Very poor - Poor Moderate High Very high
*Density (individuals per 500m2) 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/km2) Nañola et al. (2006)	0-10 11-20 21-40 >40	Very low to low Moderate High Very High

RESULTS

Present Conditions

Shallow

Overall averages in shallow area were ~55 spp/500 m^2 (species richness), 103 g/m^2 biomass, and 1,480 ind./500 m^2 density, meeting “very high” benchmarks for richness and biomass, and “high” for density (Table 1; Hilomen et al., 2000). Biomass was distributed primarily among the families of triggerfish (Balistidae), sweetlips (Haemulidae), parrotfish (Scaridae), jacks (Carangidae), and surgeonfish (Acanthuridae). The majority of counts came from small-bodied damselfish (Pomacentridae), followed by fairy basslets (Anthiinae) and wrasses (Labridae), which contributed to the high individual numbers despite moderate biomass.

Site 1 had the highest mean richness (64 sp/500m^2) and mean density; Site 4 led in biomass; Site 3 had the lowest mean richness (47 sp/500m^2) and density. Species richness was highest at Station 2A (64 sp/500m^2) and lowest at Station 3B (46 sp/500m^2); biomass peaked at Station JBB and was lowest at Station JBA; density was highest at Station JBA and lowest at Station 3A (Figure 12).

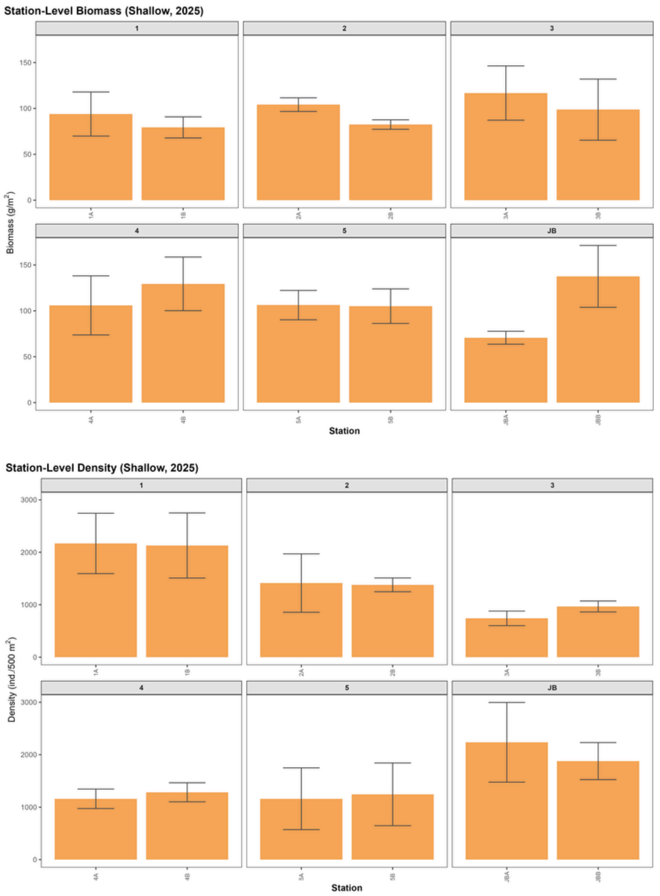

Figure 12. Station level biomass (top) and density (bottom) for shallow areas in 2025.

Deep

The deep area means were ~65 spp/500 m^2 (species richness), 151 g/m^2 biomass, and 1,594 ind./500 m^2 density, classified as “very high” for richness and biomass and “high” for density (Table 5; Hilomen et al., 2000; Nañola et al., 2006). Deep biomass mainly comprised of unicornfishes (Nasinae) and other surgeonfish, with contributions from snappers, parrotfish, triggerfish, and fusiliers. Similar to shallow areas, damselfish and fairy basslets (Anthiinae) contributed significantly to individual counts, with surgeonfish, wrasses, fusiliers, and unicornfish also contributing to the overall density.

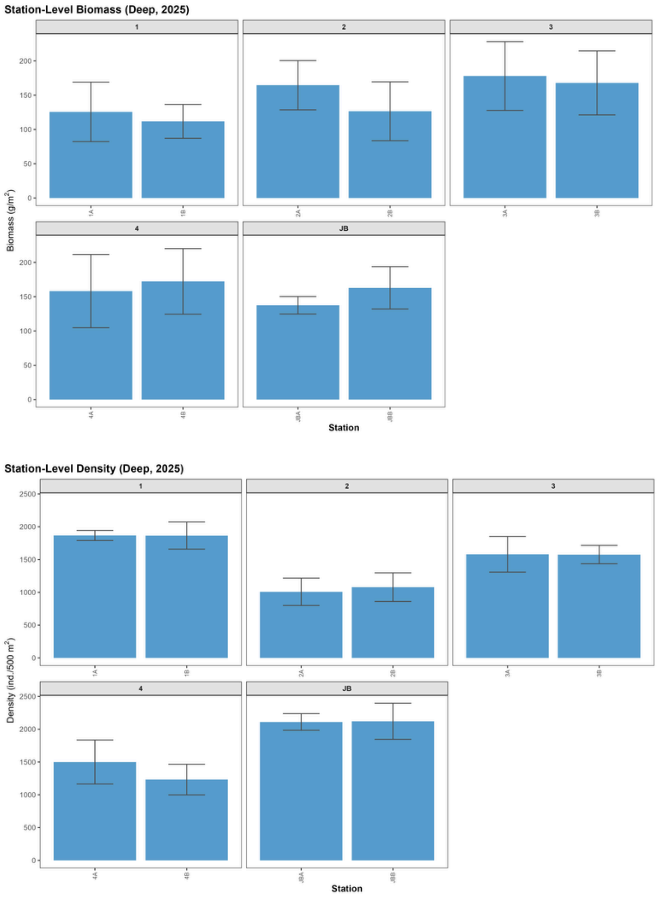

Figure 13. Station level biomass (top) and density (bottom) for deep areas in 2025.

Site 3 had the highest mean richness (72 sp/500m^2) and biomass (172 g/m^2); Site JB had the highest mean density (2,115 ind/500m^2), and Site 2 had the lowest (1043 ind/500m^2). Richness was highest at Station 3B (72 sp/500m^2) and lowest at Station 4A (59 sp/500m^2). Biomass peaked at Station 3A and was lowest at Station 1B; density was highest at Station JBB and lowest at Station 2A (Figure 12 and 13).

Both shallow (55 spp/500 m^2) and deep (65 spp/500 m^2) richness exceed the “very high” threshold (>50 spp/500 m^2) (Hilomen et al., 2000). Biomass at both depths far surpasses the “very high” benchmark (>40 g/m^2; Nañola et al., 2006), at 103 g/m^2 (shallow) and 151 g/m^2 (deep). Mean densities were in the “high” category for both. Shallow areas exhibited a more even biomass distribution among triggerfish, sweetlips, parrotfish, and jacks, while deep areas were dominated by unicornfish and surgeonfish.

Temporal Trends

The following analysis details location-level trends in fish biomass and density across two depths. While the complete time series is presented visually, formal statistical trend analysis focused on 2013-2025 monitoring, following a redesign of the sampling methods.

Location-Level

Shallow

The long-term analysis (2013–2025) confirms a significant increase in fish biomass in shallow areas, accompanied by a significant decrease in density (Figure 1; Appendix 10). The 2025 data showed that biomass reached 102.5 g m^2, exceeding the 2013–2024 average of 85.6 g m^2. The mean density in 2025 was slightly above the 12-year average of ~1,436 individuals per 500 m^2. Species richness, which averaged at 54.1 spp./500 m^2, showed a statistically significant increasing trend. Note that richness is reported from 2015 onward, as the survey area was standardized to 500 m^2 that year.

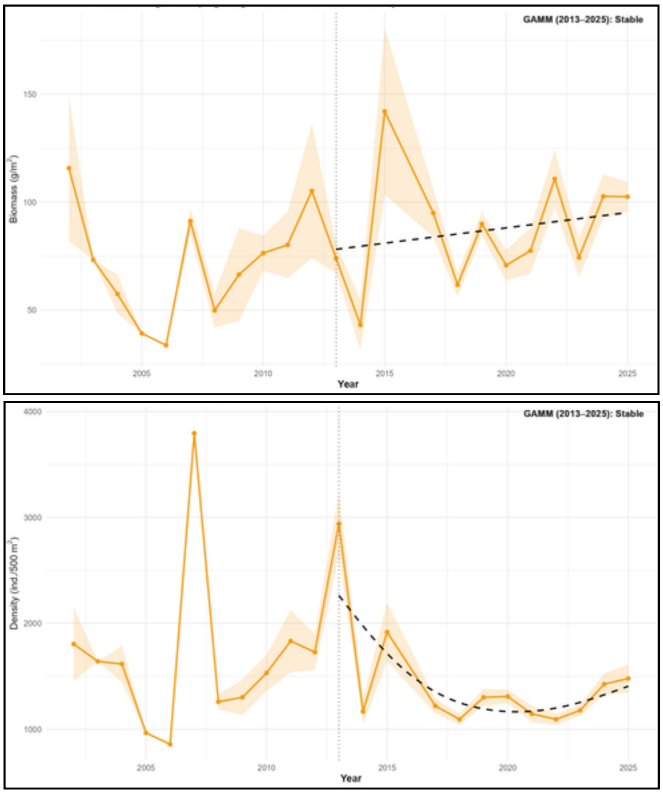

Figure 14. Shallow: Annual mean biomass and density in Tubbataha from 2002 to 2025.

Long-term monitoring of shallow reefs reveals a significant increase in mean fish biomass (above) alongside a significant decrease in fish density (below) between 2013 and 2025 (dashed line = trend line). Points represent annual means, with shaded ribbons indicating standard error.

Deep

Deep areas showed parallel declines in both biomass and density from 2013 to 2025 (Figure 15). By 2025, mean biomass and density had dropped below their 2013–2024 averages (~162.9 g/m^2 and ~1,812.5 individuals per 500 m^2, respectively). These continued declines in deep monitoring areas were already noted in previous TMO monitoring reports. Species richness (2015–2025) averaged ~69.7 spp./500 m^2 and showed an overall increasing trend. Since biomass and density decreased together, this indicates fewer fish overall. This pattern is consistent with a net decline in abundance across size classes, but the underlying demographic drivers (e.g., recruitment or mortality) cannot be determined from these data. In contrast, species richness showed an overall increasing trend, suggesting that while abundance and biomass declined, the number of species remained stable.

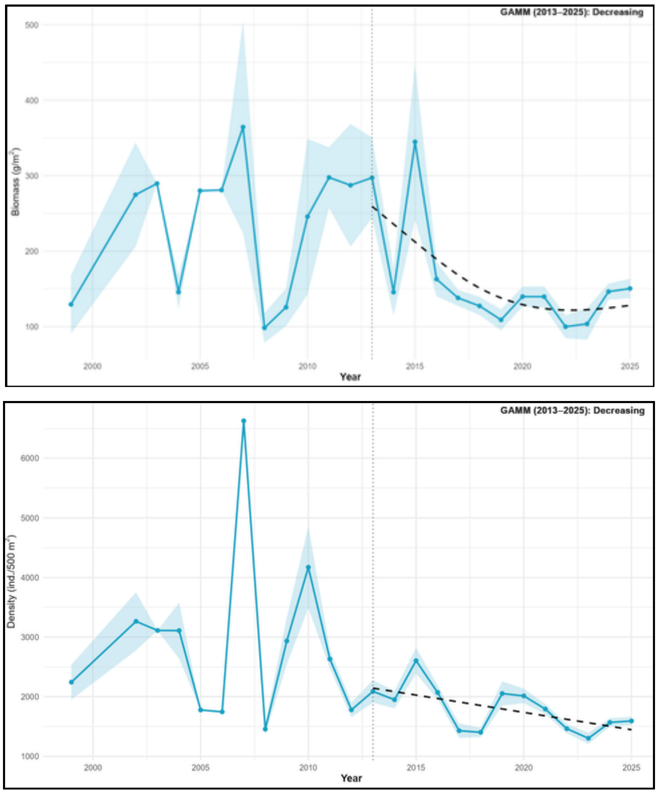

Figure 15. Declining Trends of Biomass (top) and Density (bottom) in Deep Reef Fish Communities (1999–2025).

Long-term data for deep reefs shows significant and parallel declines in both mean fish biomass (left) and density (right) during the 2013–2025 analysis period (dashed line = trend line). Points represent annual means, with shaded ribbons indicating standard error.

The contrasting patterns in shallow versus deep areas indicate that each depth has different patterns. In shallow areas, the increase in biomass alongside a decrease in fish density suggests a shift toward fewer, larger fish.

In deeper areas, both biomass and density decline together, indicating a real decline of the fish community rather than just a change in fish size. Although the density in shallow areas in 2025 is slightly above recent averages, the overall downward trend remains clear.

Site-Level

Shallow

Location-level averages mask a mosaic of site responses. At shallow depths, Sites 1 and 2 showed significant increases in both biomass and density (Table 6), indicating overall growth. Site 3 and Jessie Beazley (JB) exhibited significant increases in biomass, accompanied by substantial declines in density, mirroring the location-level restructuring toward larger individuals. Site 4 was stable for both metrics over the monitoring period. This suggests that the increase is not limited to a single location. Instead, it results from a combination of factors: growth at Sites 1–2, size-up restructuring at Site 3 and JBR (biomass up, density down), and stability at Site 4. The variability suggests that local conditions of each site influence these trends. Understanding how site-specific benthic conditions (Chapter 1) and exposure affect these patterns will help explain why responses differ.

Table 6. Shallow GAMM results: Reef fish biomass and density trends by site (2013–2025).

Values are means ± SE across 2013–2025. Trend Direction indicates modelled temporal trend from 2013 to 2015: ↑ increasing, ↓ decreasing, ↔ no detectable directional change.

SITE	2013-2025 Means	p-value	Trend Direction
	BIOMASS (g/m2)		
1	120.3 ± 37.4	**	↑
2	116.3 ± 29.6	***	↑
3	125.2 ± 34.5	*	↑
4	165.1 ± 46.5	ns	↔
JBR	104.4 ± 27.6	***	↑
	DENSITY (individuals/500m2)		
1	1774.4 ± 231.8	*	↑
2	1187.6 ± 169.8	**	↑
3	1684.5 ± 274.2	***	↓
4	1421.2 ± 222.6	ns	↔
JBR	2100.9 ± 292.8	***	↓

Significance: ns = p ≥ 0.05; * = p < 0.05; ** = p < 0.01; *** = p < 0.001

Deep

Table 7 showed that Sites 2 and 4 experienced significant decreases in both biomass and density. Site 1 exhibited a significant decline in density, with no change in biomass, whereas Site 3 showed a decline in biomass, albeit stable density. Site 1's pattern (density down, biomass steady) suggests a slight shift toward larger individuals. Meanwhile, Site 3 (biomass down, density steady) indicates a loss of the larger-bodied fish community. Among all the sites, only Jessie Beazley Reef (JBR) remained stable for both metrics. The stability at JBR suggests it may have unique local conditions, such as benthic conditions or exposure effects, that protect it from the pressures affecting the other deep areas. The exact factors involved are still unknown and require further research.

Table 7. Deep GAMM results: reef fish biomass and density trends by site (2013–2025).

Values are means ± SE across 2013–2025. Trend Direction: ↑ increasing, ↓ decreasing, ↔ no detectable directional change.

SITE	2013-2025 Means	p-value	Trend Direction
BIOMASS (g/m2)			
1	153.9 ± 51.7	ns	↔
2	145.2 ± 31.9	**	↓
3	162.1 ± 47.9	*	↓
4	211.4 ± 66.9	***	↓
JBR	137.1 ± 39.4	ns	↔
DENSITY (individuals/500m2)			
1	2033.8 ± 259	*	↓
2	1231.1 ± 167.8	*	↓
3	1874.3 ± 239.5	ns	↔
4	1597.1 ± 275.8	*	↓
JBR	2242.2 ± 296.6	ns	↔

Significance: ns = $p \geq 0.05$; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

Functional & Taxonomic Groups

Functional Group

Shallow

Herbivores, piscivores, omnivores, benthic carnivores, and corallivores all increased in biomass, while densities showed a mixed picture—most notably a decrease of small schooling planktivores (Table 8). Demersal, large-sized fish groups dominate shallow communities, while small schooling planktivores thinned. The herbivorous fish group showed the largest increase in biomass. It is well documented (e.g., Burkepile & Hay, 2008; Suchley et al., 2016) that the abundance of herbivorous fish groups typically supports the suppression of macroalgae and enhances reef recovery capacity.

Table 8. Functional guilds in shallow areas.

Trends (2013-2025) in biomass and density of each functional group and the top families representing each. Notes: arrows show direction (↑ increase, ↓ decrease, ↔ no change)

Functional Groups	Biomass Trend (2013-2025)	Density Trend (2013-2015)	Top families (by mean biomass, 2013–2025)
Benthic Carnivore	↑ *	ns	Haemulidae Tetraodontidae
Benthic Invertivore	↑ *	↓ ***	Chanidae Ephippidae
Corallivore	↑ *	ns	Scaridae
Detritivore	↑ *	↑ ***	Acanthuridae Scaridae
Herbivore	↑ ***	↑ **	Kyphosidae Balistidae Nasinae
Omnivore	↑ ***	↑ ***	Belonidae Nasinae
Piscivore	↑ **	↑ ***	Haemulidae Carangidae Epinephelidae
Planktivore	↓ **	↓ **	Caesionidae Balistidae Holocentridae

Deep

The patterns in the deep areas showed significant changes, with broad declines primarily involving planktivores and upper-trophic guilds such as piscivores (Table 9). These losses may be associated with reduced pelagic–benthic coupling and lower energy transfer, which are vital for supporting higher trophic levels. Although there were gains among omnivores and herbivores, these were insufficient to compensate for the overall decline in biomass and density.

Table 9. Functional guilds in deep areas

Functional Groups	Biomass Trend (2013-2025)	Density Trend (2013-2015)	Top families (by mean biomass, 2013–2025)
Benthic Carnivore	ns	ns	Carangidae Haemulidae Lethrinidae
Benthic Invertivore	ns	↓ *	Epinephelidae (Lethrinidae Ephippidae
Corallivore	↓ *	↓ ***	Scaridae (Balistidae Tetraodontidae
Detritivore	↓ ***	↑ ***	Acanthuridae Scaridae
Herbivore	↑ ***	↑ *	Nasinae Kyphosidae Scaridae
Omnivore	↓ ns	↑ *	Nasinae Lutjanidae Acanthuridae
Piscivore	↓ ***	↓ **	Scombridae Carangidae Haemulidae
Planktivore	↓ ***	↓ ***	Balistidae Caesionidae Chaetodontidae

Significance: ns = $p \geq 0.05$; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

Groups (Indicator, Major, Target)

Shallow

These group-level trends are consistent with the location-level pattern of increasing biomass and a shift toward larger individuals in shallow sites. The overall increase in biomass was reflected in the three groups (Table 10). The major group experienced a significant increase in biomass despite a decline in density, providing clear evidence of a shift towards fewer, larger, and heavier fish. Similarly, the commercially valuable "target" group exhibited population growth, characterized by a significant increase in both its biomass and the number of individual fish. Together, these trends within the specific groups confirm the broader conclusion: the shallow reef ecosystem is on a positive trend, accumulating larger fish that are important for both ecological stability and fisheries value.

Table 10. Groups: Indicator, Major, Target (Shallow)

Group	Biomass Trend (2013-2025)	Density Trend (2013-2015)	Top families (by mean biomass, 2013–2025)
Indicator	↑ *	ns	Scaridae Balistidae
Major	↑ ***	↓ ***	Balistidae Ephippidae
Target	↑ ***	↑ ***	Haemulidae Carangidae

Significance: ns = $p \geq 0.05$; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

Deep

In contrast, the decline observed in the deep reef fish community is also clearly reflected in the data for the specific fish groups. The general decrease in biomass across all three groups indicates that the decline in the whole reef system is occurring. This trend was most evident in the target species, where biomass declined significantly while the number of individuals remained stable.

This pattern is consistent with reduced contribution of large-bodied individuals: the deep reef is losing its largest and heaviest fish, but additional data (size spectra / length frequencies) would be needed to confirm.

Table 11. Groups: Indicator, Major, Target (Deep)

Group	Biomass Trend (2013-2025)	Density Trend (2013-2015)	Top families (by mean biomass, 2013–2025)
Indicator	↓ *	↓ ***	Scaridae Balistidae
Major	↓ ***	↓ ***	Balistidae Ephippidae Diodontidae
Target	↓ ***	ns	Scombridae Nasinae Carangidae

Significance: ns = p ≥ 0.05; * = p < 0.05; ** = p < 0.01; *** = p < 0.001

Nature (Demersal and Pelagic)

Shallow

The analysis of the fish community by habitat reinforced the overall trends. In shallow areas, the system is shifting toward being dominated by bottom-dwelling (demersal) fish. The data showed that demersal biomass increased significantly even as the number of individual demersal fish decreased, indicating accumulation of fewer, larger, and heavier fish. In contrast, the pelagic fish populations showed no significant changes. This combination confirms that the shallow areas are developing into a demersal-oriented fish community.

Table 12. Nature: Demersal vs. Pelagic (Shallow)

Nature	Biomass Trend (2013-2025)	Density Trend (2013-2015)	Top families (by mean biomass, 2013–2025)
Demersal	↑ ***	↓ ***	Haemulidae Kyphosidae Chanidae
Pelagic	ns	ns	Carangidae Nasinae Caesionidae

Significance: ns = p ≥ 0.05; * = p < 0.05; ** = p < 0.01; *** = p < 0.001

Deep

In the deep areas, the widespread decline is affecting both demersal and pelagic fish groups, with the biomass of both falling significantly. The loss of pelagic biomass is concerning because it is consistent with the previously noted decline in plankton-eating fish. This pattern is consistent with changes that could affect pelagic-to-reef energy pathways, but this was not directly measured. Planktivorous fishes are key conduits of this oceanic energy, and their decline can therefore weaken the entire ecosystem (Morais & Bellwood, 2019; Siqueira et al., 2021). This loss is especially critical for apex predators, as studies show that offshore pelagic sources can contribute substantially to predator (Skinner et al., 2021). Unlike the shallow areas where gains in bottom-dwelling fish were observed, both components of the deep monitoring areas are declining, indicating a systemic issue affecting this deeper habitat.

Table 13. Nature: Demersal vs. Pelagic (Deep)

Nature	Biomass Trend (2013-2025)	Density Trend (2013-2015)	Top families (by mean biomass, 2013–2025)
Demersal	↓ ***	↓ ***	Caesionidae, Kyphosidae Haemulidae
Pelagic	↓ ***	ns	Scombridae, Nasinae, Crangidae

Significance: ns = p ≥ 0.05; * = p < 0.05; ** = p < 0.01; *** = p < 0.001

In summary, the detailed analysis across different fish categories paints a consistent and starkly contrasting picture of Tubbataha. The shallow areas are thriving, developing a healthier ecosystem characterized by fewer, but significantly larger and heavier, bottom-dwelling (demersal) fish. Conversely, the deep zones are in decline, experiencing concurrent losses in both fish biomass and density. This decline is primarily driven by losses among plankton- and other fish-eating species, suggesting a potential breakdown in the food web linked to offshore energy sources.

Family Level Composition and Trends

Analysis of specific fish families further confirmed the broader trends we have already observed in the shallow and deep areas. Significant increases were observed in shallow areas in both the biomass and density of various fish families, such as surgeonfish, triggerfish, unicorn fish, and snappers. Their increases were the main cause of overall biomass growth. Conversely, the decline in overall fish density was attributed to declines in smaller schooling species, such as anthias and damselfish. This view confirmed that the shallow areas are attracting fewer but heavier fish.

In the deep areas, the family-level data pinpointed the specific groups responsible for the widespread decline. The significant losses in biomass and density were primarily driven by declines in pelagic and schooling families such as fusiliers and jacks (Figure 16). These specific losses directly account for the broader declines observed earlier across the various fish categories.

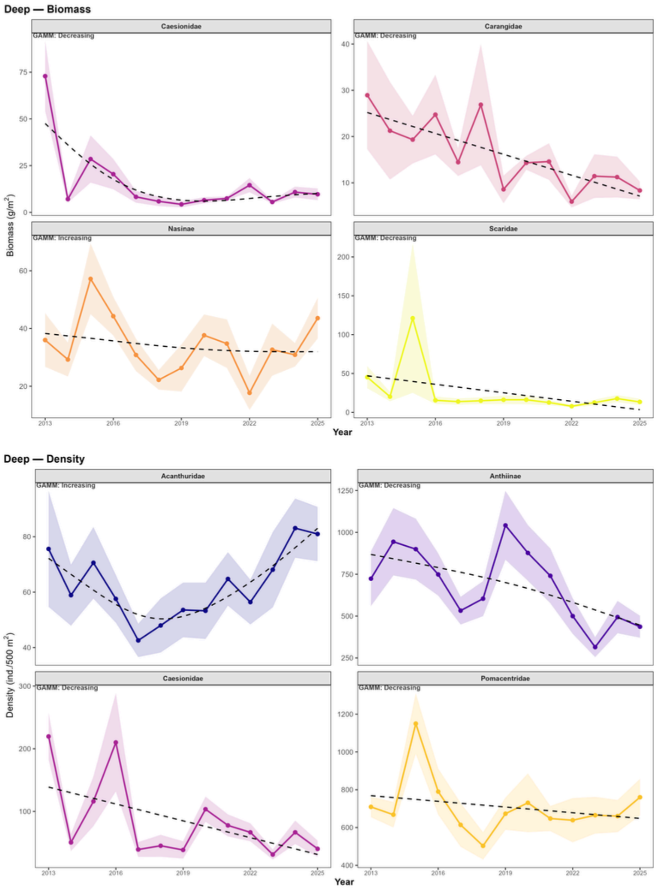

Figure 16. Top 4 families in deep by biomass and density (2013-2025).
Solid lines and points show annual means (±SE ribbons); dashed lines are the GAMM trend line.

Grounding Sites

USS Guardian
Shallow (Impact Site). By 2025, biomass was markedly higher than in 2014, while density was lower, indicating a biomass-led change rather than an abundance-led one. Herbivores, especially surgeonfishes, parrotfishes, and triggerfishes, accounted for most of the biomass in recent years. Carnivores such as groupers and jacks were present but contributed modestly to biomass. In 2025, the shallow area means were 248.73 g/m² (biomass) and 1,244.67 ind./500 m² (density), with species richness of 56.33 sp/500m^2. Both biomass and species richness are considered "very high," and density is "high," per the categories set for Philippine reef fish communities (Hilomen et al., 2000; Nanola et al., 2006, Table 5).

Deep (Adjacent). Compared with previous years, density in the deep areas was relatively stable, while biomass had lower mean values this year. Surgeonfish, triggerfish, parrotfish, and jacks still dominated the family composition at this depth. In 2025, the deep means were 135.59 g/m² (biomass) and 1,315.00 ind./500 m² (density), with a richness of 53.33 sp/500m^2. Overall, USSG showed a contrast between shallow and deep areas in 2025: shallow areas exhibited substantial biomass gain with stable density vs. 2013, while deep areas had lower density with mean biomass comparable to previous years, except 2020.

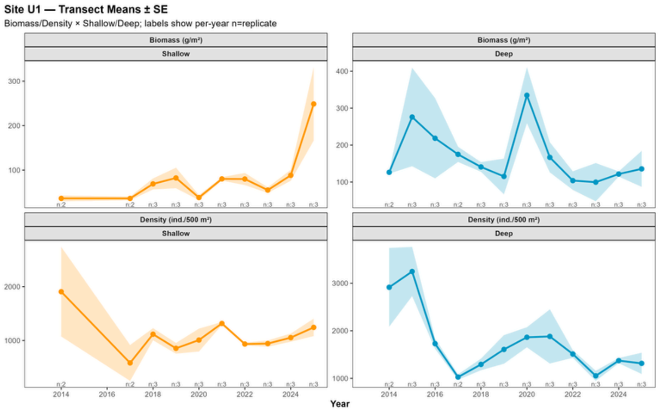

Figure 17. USS Guardian grounding site.

Mean biomass and density in the shallow and deep transects over the years. Points = yearly means across n transects (ribbons = mean ± SE).

Min Ping Yu

Shallow (Impact). Biomass peaked in 2019 and was lower in 2025, while density fluctuated throughout the years (Figure 18). This indicated that biomass was driven by changes in individual fish size rather than by increases in density. The observed contributions of the top families corroborate this. Large-bodied fish such as surgeonfish and triggerfish drove the episodic increases in biomass. Meanwhile, the area had vast numbers of tiny fish, mainly damselfishes (Pomacentridae), but because they weighed so little, their presence had a barely noticeable impact on the total biomass.

Deep (Adjacent). In contrast, both biomass and density at this depth reach their highest values in 2025. The deep biomass is driven primarily by surgeonfishes, with strong contributions at times from schooling planktivores such as fusiliers; high densities were frequently associated with increases in damselfish (Pomacentridae). In 2025, the deep area means were 152.04 g/m^2 and 2,287.33 ind./500 m^2, with a richness of 60 sp/500m^2.

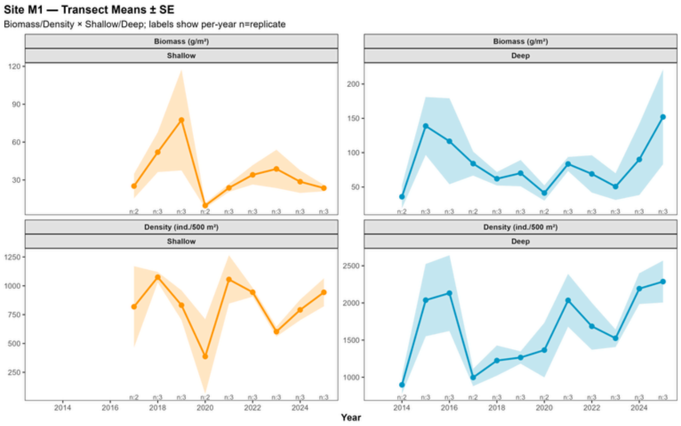

Figure 18. Min Ping Yu grounding site. Mean biomass and density in the shallow and deep transects over the years. Points = yearly means across n transects (ribbons = mean ± SE).

DISCUSSION

Regular monitoring sites

This year's monitoring provided a complex, nuanced view of an ecosystem at a turning point, with shallow and deep areas moving in different directions. While overall, the park still meets or surpasses national standards for healthy coral reefs, a closer look at the data reveals a "tale of two depths" that warrants both celebration and concern.

Location-level patterns and depth contrasts

Shallow sites (~5 m) gained biomass despite flat-to-declining density, while the deeper of the two monitored depths (~10 m) showed concurrent declines in biomass and density. The 2025 snapshot reinforced these trajectories: shallow biomass was above the 10-year mean while density remained below the long-term trend; at ~10 m, both biomass and density were below their 2013–2024 means.

In contrast to declines observed at ~10 m in several sites, Jessie Beazley Reef (JBR) showed relatively stable fish biomass at ~10 m. Carpenter et al. (Chapter 4) reported decrease in the number of fish at JBR extending to ~20 m, which is consistent with the density decline we observed in the shallow monitoring depth. However, in our dataset, the ~10 m layer at JBR did not follow the same declining trajectory seen at ~10 m in other locations. This divergence suggests JBR is a useful candidate for targeted follow-up to examine potential explanatory factors (e.g., hydrodynamic setting, reef geomorphology, or habitat structure).

Mechanisms and ecological interpretation

The observed pattern in the shallow reefs of Tubbataha —characterized by increased fish biomass despite lower fish density— is consistent with a shift in community structure in which biomass is increasingly contributed by larger-bodied taxa. At the family level, these gains are most prominent in large-bodied herbivorous groups, particularly surgeonfishes

(Acanthuridae), while there has been a concurrent decline in smaller planktivorous species.

wo plausible (non-exclusive) mechanisms often discussed could explain this increase in herbivore populations: a "bottom-up" effect, where an increase in their primary food source (algae) fuels population growth, or a "top-down" effect, where the removal of a controlling factor (in the case of Tubbataha, fishing pressure) allows their populations to recover. The available evidence does not strongly support a bottom-up explanation. While the 2025 benthos report (Chapter 1) does not focus specifically on algal cover in its main findings, it shows stable to slightly increasing hard coral cover. A significant disturbance-driven increase in algae would be expected to decrease coral cover over time due to competition for space (McCook et al., 2001). The lack of such a trend in the benthos reports does not provide support for bottom-up driver.

Instead, the data points to the strengthening of "top-down" control is consistent with recovery trajectories reported in no-take reserves. The crucial point here is that this is a gradual recovery, not an abrupt increase. A sudden explosion in herbivore numbers would indeed suggest a response to a disturbance-mediated algal bloom (McClanahan et al., 2011). However, the slow, steady increase in the biomass of large-bodied herbivores observed in TRNP is a pattern often reported of a system recovering from chronic stress from fishing (Russ et al., 2015). This gradual trajectory is the expected ecological response as long-lived species are allowed to grow to their full size and reproductive potential within the protected area (Edwards et al., 2014).

In general, this resurgence of herbivory is fundamental to coral reef resilience. Increased grazing from large-bodied herbivores is a key mechanism that actively manages algal growth, prevents shifts to algal dominance, and maintains open space crucial for coral recruitment and growth (Bellwood et al., 2004; Mumby et al., 2007). By controlling algae, these herbivores promote conditions favorable for coral recovery and ecosystem stability, which is especially important as global stressors like climate change intensify (Hughes et al., 2007).

Therefore, the rising herbivore biomass in TRNP can be interpreted as a potentially positive ecological signal, consistent with patterns reported in well-enforced no-take reserves. Large-bodied herbivores are widely recognized for their role in grazing and limiting algal buildup, but algal dynamics and herbivory rates were not directly assessed in this report. As such, this trend is best presented as consistent with outcomes expected under effective protection, rather than as a definitive measure of management success or ecosystem resilience.

Meanwhile, at ~10 m (the deeper of the two surveyed depths), declines were concentrated in fusiliers, jacks, wrasses, and parrotfishes—schooling planktivores and mid- to upper-trophic fishes—while small gains in Acanthuridae were insufficient to offset these losses. The concurrent reductions in planktivores and pelagic-associated biomass are consistent with changes that could affect pelagic-to-reef trophic pathways and the prey base of larger predators (Morais & Bellwood, 2019; Skinner et al., 2021), but these pathways were not directly measured in this report. Although the proximate drivers remain unclear, the pattern may reflect pressures operating beyond local protection, consistent with evidence that well-managed reserves can still be influenced by broader, climate-linked changes in ocean conditions (Graham et al., 2020).

Connecting Fish Declines to Benthic Habitat

Another plausible factor that may contribute to declines in some fish taxa is change in benthic habitat condition. A previous park report noted declines in shallow hard coral cover (TMO, 2024). Even if the deeper of the two surveyed depths (~10–11 m) did not show a statistically significant decline, habitat change in adjacent shallow areas (~5–6 m) could still influence nearby depths over time, particularly where reef structure is continuous. Loss of structural complexity (e.g., reduced branching coral cover or degradation of crevices and ledges) is widely associated with lower fish abundance and altered community composition, with disproportionate effects on coral- and structure-associated species (Wilson et al., 2010; Pratchett et al., 2011). Consistent with this mechanism, declines in small site-attached taxa (e.g., Pomacentridae) observed in our data may reflect reduced availability of fine-scale refuge, which could also affect higher trophic groups through changes in prey communities. However, benthic complexity and prey dynamics were not directly quantified in this report, so these linkages should be treated as hypotheses for targeted follow-up.

Local protection versus external drivers

TTubbataha's long-standing no-take status, strong enforcement, and remoteness are likely important contributors to its high standing condition (e.g., species richness at or above national "very high" thresholds and biomass above national benchmarks), even as recent trends show declines in some fish groups. Effective protection is generally associated with higher standing biomass, larger body sizes, and greater functional redundancy (Friedlander & DeMartini, 2002; Edgar et al., 2014).

At the same time, local protection cannot fully insulate an ecosystem from external pressures. Major bleaching years and strong storms (e.g., Typhoon Odette, 2021) have been cited in park reports as contributors to coral loss, which can in turn contribute to delayed changes in reef fish communities (Hughes et al., 2018; TMO, 2022; TMO, 2024).

In parallel, processes outside the park boundaries may influence fish populations within TRNP. Regional fishing pressure can reduce highly mobile predators and plankton-feeding fishes at spatial scales larger than the MPA, potentially limiting their numbers even inside protected waters (Kellner et al., 2007). Interannual oceanographic variability may also affect plankton availability and the delivery of pelagic food resources to reef systems, which could contribute to observed declines in planktivores such as fusiliers and anthias that depend heavily on planktonic subsidies (Morais & Bellwood, 2019; Skinner et al., 2021).

Deep Areas as Limited Sanctuaries

While deeper reefs are often seen as potential refuges for shallow reefs, research shows that their reseeding potential for corals is limited and varies by species (Bongaerts et al., 2017). Deep reefs also do not always serve as refuges for shallow reef fish communities; in one case study, shallow-water fish diversity was not fully represented in deeper reefs (Medeiros et al., 2021).

Observations in Tubbataha are broadly consistent with this cautionary framing. Declines were evident at ~10 m, particularly among schooling planktivores and top predators, indicating that changes were not confined to the shallowest sites (~5 m). Rather than acting as a buffer for shallow patterns, the ~10 m layer showed its own downturn. The drivers of these declines cannot be determined from this dataset and were not directly assessed in this report, but the patterns may reflect multiple interacting factors operating within and beyond the park. Overall, these results underscore the complexity of change in Tubbataha and highlight the need for continued monitoring and targeted studies to better understand underlying drivers.

Insights from Grounding Sites

The two grounding sites provide a useful lens for interpreting post-disturbance patterns in reef fish communities and for comparing impacted areas with nearby reference conditions (Graham & Nash, 2013). In many reef systems, fish biomass can rebound ahead of density following disturbance, often reflecting increases in larger-bodied herbivores, while mobile predators and planktivores may recover more slowly (Darling et al., 2017).

At the USS Guardian site, the shallow area shows a pattern similar to the park-wide trend: biomass increased despite lower density, consistent with greater contribution from benthic-associated herbivores and a community of fewer but heavier fish. This suggests that the same broad patterns observed across shallow sites are also present at a location affected by physical disturbance, although the specific drivers of recovery were not examined in this report.

The Min Ping Yu (MPY) site shows a different configuration. The shallow area remained dominated by small damselfish and was characterized by low biomass. In contrast, the ~10 m reference area had high biomass and density in 2025. This contrast is consistent with the importance of habitat structure for supporting diverse and higher-biomass fish communities (Graham & Nash, 2013). While the ~10 m reference area does not, by itself, demonstrate recovery at the impacted shallow site, it provides a benchmark for comparison. Any role in replenishment of the impacted area (e.g., via larval supply or spillover) would require additional evidence on connectivity and habitat suitability.

Management Implications and Path Forward

Despite external pressures such as climate change and regional fishing, dedicated local management remains a central and actionable lever for safeguarding Tubbataha. Evidence from marine reserves globally shows that strong capacity, adequate resourcing, effective enforcement, and sustained monitoring are consistently associated with better ecological outcomes inside protected areas (Edgar et al., 2014; Sala & Giakoumi, 2018; Gill et al., 2017). In TRNP, maintaining a well-supported management team, continuous scientific monitoring, and strict implementation of the no-take policy—strengthened through scientific partnerships—can help sustain high biomass and biodiversity and improve the park's ability to cope with stressors it cannot directly control.lth of this irreplaceable marine protected area.

CONCLUSION

Fish monitoring from 2013–2025 in Tubbataha Reefs Natural Park shows contrasting trends between the two surveyed depths (~5 m and ~10 m). While overall fish biomass remains high, trajectories at these depths differ, highlighting a nuanced picture of change within the park.

In the shallowest sites (~5 m), total biomass increased alongside declining density, a pattern consistent with a community in which biomass is increasingly contributed by larger-bodied individuals. Increases were most evident in key functional groups, including herbivores and some target taxa. These shallow trends are consistent with recovery trajectories reported in well-enforced no-take reserves, although the drivers of change cannot be determined from this dataset alone.

At ~10 m, biomass and density declined in parallel, consistent with an overall reduction in fish abundance rather than a redistribution toward larger individuals. Declines were most apparent in functional groups that include planktivores and piscivores. This pattern may have implications for trophic structure, but potential mechanisms (e.g., habitat change, shifts in pelagic food availability, or broader regional pressures) were not directly assessed and warrant targeted follow-up.

Overall, Tubbataha continues to show high fish biomass and species richness relative to national benchmarks, and shallow-site trends remain consistent with outcomes expected under strong protection. At the same time, the ~10 m declines highlight that even well-managed MPAs can be influenced by pressures operating beyond local control. Sustained enforcement and monitoring, paired with focused studies on drivers of change, will be essential for informing adaptive management.

RECOMMENDATIONS

Below is a non-exhaustive list of recommendations for future research and management actions TMO and its partners can take:

1. Develop a targeted research program to determine the factors driving the decline, investigating potential drivers like ocean warming, deoxygenation, and changes in oceanic productivity (e.g., track satellite Chlorophyll-a as a proxy);
2. Monitor fishing activity just outside the park's boundaries using VIIRS and AIS data to assess if boundary fishing is a contributing factor to the decline in pelagic fish;
3. Conduct acoustic telemetry studies on mobile pelagic species to clarify their residency patterns and determine if a reduction in offshore food sources contributes to the decline;
4. Expand thermal monitoring to depths greater than5 meters, especially in sites with the sharpest declines, to better link local heat events to population declines;
5. Continue and enhance the vigilant protection of the entire park against all direct anthropogenic stressors to support overall ecosystem resilience.

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CHAPTER 3

Kymry Delijero

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SEABIRDS

OVERVIEW

Seabirds are a diverse group of families of birds such as Terns, Boobies, Petrels and Shearwaters that have adapted to life in marine environments. They spend most of their lives at sea, only returning to land to breed on isolated islets, coastal cliffs, or remote islands free of predators. In offshore coral reef ecosystems like Tubbataha, seabirds play crucial ecological roles that extend far beyond their nesting grounds. As top predators in the marine food web, seabirds help regulate fish and invertebrate populations by foraging over wide areas of the ocean. Their nutrient-rich guano (droppings) also contributes significantly to reef productivity by fertilizing nearby waters and even coral cays, supporting both terrestrial vegetation and marine plankton communities. This nutrient input can enhance reef resilience and biodiversity, linking land and sea in a unique biogeochemical cycle.

Their foraging behavior, pelagic migration routes, and reproductive strategies are closely tied to ocean conditions, making them excellent subjects for ecological studies. Because of their sensitivity to changes in the marine environment, seabirds are considered important biological indicators of ocean health. Fluctuations in seabird populations, breeding success, and distribution often reflect changes in prey availability, pollution levels, and the overall state of marine ecosystems.

For example, a decline in seabird breeding may signal overfishing, habitat loss, or ocean warming. Monitoring seabird colonies in offshore coral reefs can therefore provide early warning signs of ecosystem stress, making them vital allies in the conservation and management of these remote and vulnerable marine areas.

METHODS

The fieldwork was conducted on 1-7 May 2025. South Islet was surveyed on May 2 while Bird Islet was visited on May 3-6. The team was headed by PASu Angelique Songco and included TMO staff, marine park rangers (MPRs), Tubbataha avifauna consultant, Arne Jensen, and volunteers (Appendix 1). One highlight of this year's monitoring was the capacity building of TMO staff on the installation of satellite trackers on 15 seabirds in Bird Islet. The activity that uses satellites to determine the location and movements of seabird species was led by Dr. Autumn-Lynn Harrison of the Smithsonian Institution and was funded by the Foundation for the Philippine Environment and WWF-Philippines.

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 and their offspring represent a combination of different count methods:

- direct daytime inventories of adults, immatures, juveniles, pulli, eggs, and nests;
- in-flight count of adult and immature 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 15.1 (June 2025) and Wild Bird Club of the Philippines Checklist of Birds of the Philippines 2025.

Calculation of land area and vegetative cover

Photos of permanent photo documentation sites in Bird Islet and South Islet were taken (Appendix 18). 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 (preferably at 1 meter for comparability with other years).

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 19 presents a photographic documentation of the most common beach forest species in Tubbataha. The 2025 vegetation inventory was conducted using the same methodology as in previous years, allowing for a reliable comparison of trends over time.

Figure 19. (top) *Heliotropium foertherianum* (tree heliotrope), and (bottom) *Pisonia grandis* (Anuling, bird-catcher tree/lettuce tree). Photos: Teri Aquino, 2014

Calculation of breeding populations

This report includes data from August 2024 to August 2025. 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 adult Brown Booby (*Sula leucogaster)* and Red-footed Booby (*Sula sula)* populations at the 'Plaza' and the adjacent area;
- In-flight data of adult and immature 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.

In May, inventory counts are based on whichever is higher: the number of adults or the number of nests. Below are the formula used for obtaining these values per species:

Number of adults during daytime counts + inflight counts	Number of nests (with eggs, pullus, juveniles, and empty but active nests) Multiplied by 2
*The higher number will be considered for the inventory in May	

From this, the annual population estimate per species is obtained using the following formula:

Annual population estimate	= May inventory count + (number of eggs and pulli in February and August x 2)

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 2024 to May 2025. The data from 1981 to 2013 were analyzed in detail by Jensen and Songco (2016). Other analyses are found in the 28-year seabird population development data published in 2004 to 2006, and in the 2009 to 2024 seabird monitoring reports (see Jensen 2004 to 2006 and 2009 to 2016, Jensen et al. 2017-2023, and TMO, 2024).

RESULTS AND DISCUSSION

Monitoring of Changes in Land Area and Habitats

Two independent sets of measurements were collected using separate GPS units. These readings were recorded at high tide (~1 meter) along the shoreline, as the vegetation line previously used as a reference had disappeared. As a result of this change in methods, data sets from 2016 onward are not directly comparable to those from the prior years. This year, new GPS units with higher accuracy rates were used, which might cause slight differences in results compared to the results from previous years.

Bird Islet. The land area of Bird Islet decreased by 22%, from 16,905 sqm in 2024 to 13,232 sqm in 2025. The islet's current measurement is similar to its size in 2022 and 2023. Mapping software shows that the islet reduced in size on all sides. This may indicate differences in tidal conditions at the time of measurement as data collection occurred during high tide. As a result, the islet's circumference decreased by 16% in 2025. The "Plaza", an area of compact barren soil in the center of Bird Islet, also shrank by 10%. Plaza measurements are based on the edges of vegetation and may vary annually due to changes in vegetation distribution.

In May, 22 trees, measuring three to 10 feet, were recorded in Bird Islet. Five individuals were in poor condition and were not enclosed in protective bamboo tree guards. Among the saplings placed inside tree guards, only one was in good condition, six individuals were in fair condition, and 10 individuals were in poor condition.

South Islet. South Islet was previously part of a large sandbar before a concrete seawall was constructed in the 1980s for the installation of a lighthouse (Kennedy 1982). Modifications in 2019, including a new seawall and lighthouse, resulted in changes to the islet's dimensions. After the completion of the new seawall in 2020, the circumference of the islet increased from 230 meters in 2018 to 307 meters, and its land area expanded from 2,884 m^2 to 5,222 m^2.

A total of 12 saplings, measuring three to five feet, were recorded in South Islet in May. The saplings were in poor condition and were not enclosed in tree guards. In addition, three coconut trees, 10 to 15 ft high, were recorded in fair condition.

Avifauna Inventory Results

A total of thirty-four (34) bird species, including breeding seabird species, have been recorded this year (see Appendix 17). Over time, 125 avifauna species—predominantly migratory and mostly in single number—have been documented within TRNP. Notably, eight seabird species breed in TRNP: Brown Noddy (*Anous stolidus*, Black Noddy (*Anous minutus*), Greater Crested Tern (*Thalasseus bergii*), Sooty Tern (*Onychoprion fuscata)*, Masked Booby (*Sula dactylatra)*, Red-footed Booby (*Sula sula)*, Cocos Booby (*Sula brewsteri)*, and Brown Booby (*Sula leucogaster)*. Additionally, three other species breed in the park: the Pacific Reef-Egret (*Egretta sacra)* breeds annually, the Barred Rail (*Gallirallus torquatus*) breeds irregularly, and the Eurasian Tree Sparrow (*Passer montanus)* is now only infrequently observed but assumed to breed.

Among the breeding seabirds, the Masked Booby is classified as Critically Endangered, while both the Brown Booby and Black Noddy are listed as Endangered. The Brown Noddy, Greater Crested Tern, and Sooty Tern are designated as Vulnerable (DENR 2019). Furthermore, the Philippine subspecies worcesteri of the Black Noddy is included in Appendix II of the Convention on Migratory Species, underscoring the necessity for international conservation and management measures. The Cocos Booby, a newly recorded resident seabird species in the Philippines, has now been added to the park's list of breeding seabirds.

At TRNP, booby species exhibit year-round breeding activity, whereas tern species have an annual breeding season of approximately nine months (Heegaard and Jensen 1992; Manamtam 1996; Kennedy et al. 2000; Jensen 2009; Jensen and Songco 2016). Consequently, the April/May inventory represents only the breeding population present during that specific timeframe.

In May 2025, a total of 42,677 adult individuals from eight breeding seabird species were recorded, with about 50% of the population in each islet – 21,135 in Bird Islet and 21,542 in South Islet (Table 14). The 2025 seabird count is 215% higher than the baseline counts recorded in 1981 (Kennedy 1982).

Table 14. Total count numbers of adult resident seabirds present on Bird Islet and South Islet in May 2025 compared to the inventory result of May 2024.

Species / Numbers	2024			2025			% Change
	Bird Islet	South Islet	Total	Bird Islet	South Islet	Total	
Brown Noddy	1,332	189	1,521	1,378	577	1,955	29%
Black Noddy	1,580	832	2,412	2,336	>1,050	>3,386	40%
Greater Crested Tern	11,065	5,972	17,037	10,246	7,460	17,706	4%
Sooty Tern	>320	760	1,080	2,800	11,706	14,506	1243%
Masked Booby	4	0	4	2	0	2	
Red-footed Booby	346	156	502	150	187	337	-33%
Brown Booby	8,117	622	8,739	4,222	560	4,782	-45%
Cocos Booby				1	2	3	
Total	22,764	8,531	31,295	21,135	21,542	42,677	36%

Compared to the 2024 inventory, the seabird population on Bird Islet decreased by -7%, whereas South Islet saw a 152% increase. This increase in South Islet population is attributed to the Sooty Terns, whose population increased by 1440% from 2024 (760 individuals) to 2025 (11,706 individuals). Despite this increase in the Sooty Tern population, the Greater Crested Tern remained to be the most abundant species, representing 41% of the total May 2025 count.

This increase in the 2nd quarter breeding population is mainly attributed to the increase in Sooty Terns in South Islet. The number of Black Noddy also increased by 40%, from 2,412 in 2024 to 3,386 this year.

Review of Marine Park Rangers Data

Since the inventory in May 2024, MPRs made three (3) inventories in Bird Islet and three (3) in South Islet until February 2025. In-flight counts for Brown and Red-footed Boobies were also carried out on Bird Islet in November 2024.

By April 2025, the MPRs had conducted 11 distance counts on Bird Islet and 11 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 15 below).


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Table 15. Highlights of MPR distance and direct counts from June 2024 to April 2025 with notes from August 2025

Species	Bird Islet	South Islet
Brown Noddy	Since 2017, changes in phenology have been observed among overwintering Brown Noddies. Monthly distance counts of MPRs indicated that Brown Noddies were present throughout the year, with breeding activity peaking in August 2024, when 496 eggs and 39 pulli were recorded. In contrast, the May 2024 counts documented 8 eggs and 1 juvenile.	Brown Noddy was observed in South Islet year-round. According to distance estimates, their numbers were greater in South Islet than in Bird Islet from December 2024 to March 2025. Quarterly direct counts indicate that Brown Noddy now breeds throughout the year, as eggs were reported in each quarter.
Black Noddy	Black Noddy was observed year-round, with breeding documented in August and November 2024, and February 2025.	Previously absent from November to February, this species is now observed year-round. Breeding has been documented in August and November 2024, and February 2025.
Greater Crested Tern	There were no individuals present from November to December 2024. Non-breeding adults started arriving in January 2025, with an initial count of 20 adults noted. The population increased to approximately 2,700 by April 2025.	No individuals were on the islet from October to December 2024. Fifty adults arrived in January 2025, rising to 2,580 by April 2025.
Sooty Tern	Breeding activity reached its peak in August 2024, with 6,300 adults and 2,980 eggs recorded. A small number of individuals remained through November and December 2024; however, no individuals were observed from January to February 2025. In March, the population began to return, with 800 individuals documented.	No individuals were recorded from June to July 2024. In August, arrivals commenced with a count of 350 individuals. Breeding activity was initiated in September with 1,650 adults present, resulting in the observation of 989 juveniles by November.
Masked Booby	On 26 July 2024, MPRs documented the incubation of two eggs by a single adult identified with ring no. 446. In a subsequent visit on 25 July 2024, they observed four adults present in Bird Islet, all with tag (plastic rings: 446, 256, 017, and 912). On 19 September 2024, only one egg was noted under incubation. However, in their succeeding visits, MPRs confirmed that the egg did not hatch. On 7 February 2025, two eggs were being incubated, with two adults present; on this occasion, the incubating individual was ring no. 256. This breeding pair successfully produced one juvenile, recorded on 3 May 2025 during second quarter monitoring. On 11 July 2025, the juvenile was tagged with a steel ring (no. 0710).	No breeding population
Red-footed Booby	The adult population remained low, with fewer than 200 individuals recorded in most months. Similarly, the number of active nests was consistently below 50, typically yielding very few offspring.	Fewer than 200 adult individuals are present year-round. The nesting rate is low, with a maximum of 24 active nests recorded in February 2025.
Brown Booby	The species is present year-round, with the highest adult count observed in November 2024 (4,873 individuals, with 1,057 active nests). In February 2025, the number of active nests increased to 1,453, comprising 689 juveniles, 411 pullus, and 353 eggs.	The population of adults and active nests was lower than that observed on Bird Islet, with a monthly average of 226 individuals recorded during this period. The number of active nests peaked in February 2025, comprising 98 pullus and 16 eggs.
Cocos Booby		On 23 April 2025, a pair with two eggs was found breeding on South Islet.
Pacific Reef-egret	Six (6) observed in November 2024 and February 2025	Six (6) observed in August 2024
Barred Rail	Not observed	Not observed
Eurasian Tree Sparrow	Not observed	Not observed
Ruddy Turnstone	Two (2) observed in November 2024	Not observed
Frigatebird sp.	Not observed	Fourteen (14) individuals observed in August 2024

Species Account of Breeding Birds

Brown Noddy (Conservation Status - Philippine Red List: Vulnerable): Fluctuating population. The total estimated annual population is 4,345 individuals. This value is 101% more than the 2024 annual population estimate.

The second quarter breeding counts are presented in Figure 20. The breeding population in May 2025 is 1,955 individuals representing the adult daytime and inflight counts. This number is 29% higher than in May 2024 (1,521 individuals). This year, most of the Brown Noddy bred in Bird Islet, nevertheless, it is important to note the 205% increase in the number of breeders in South Islet compared to 2024.

The species is normally absent in TRNP from November to February. However, similar to 2024, a portion of the adult population overwintered and bred on Bird and South Islets.

Despite the overall increase in adult population, the breeding numbers in May 2025 were notably low, with only eight (8) eggs and nine (9) juveniles for both islets. The low numbers in February and May 2025 and the higher turnout in August 2025 may suggest changes in the breeding cycle of the Brown Noddy in Tubbataha.

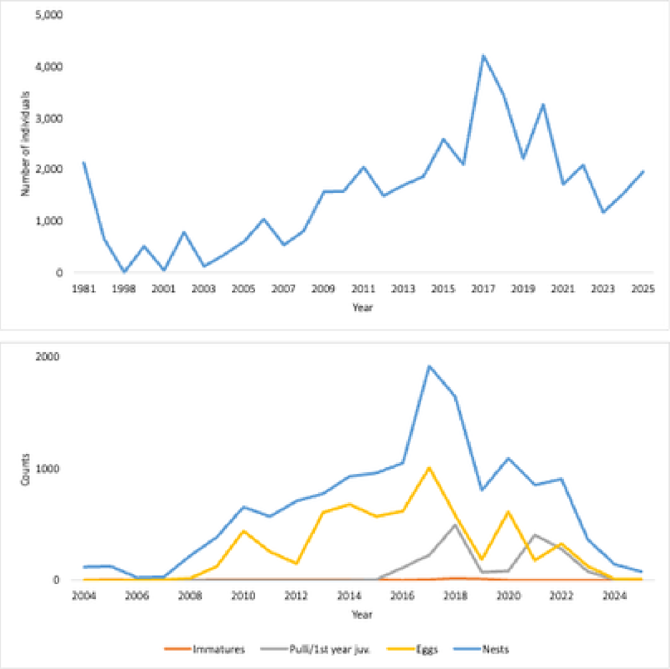

Figure 20. Population trend (top) and breeding data (bottom) of Brown Noddy

Black Noddy (Conservation Status – Philippine Red List: Endangered): Declining population. The estimated annual adult population is 5,418, a 45% increase from the 2024 estimate of 3,730 adults (Figure 21).

The Black Noddy is classified as Endangered by the Department of Environment and Natural Resources (DENR, DAO 2019-09) and listed as a conservation-dependent species under Appendix II of the Convention on Migratory Species. Currently, only 50% of the original population of 10,656 adult birds recorded in 2013 remains. This significant decline is primarily attributed to the loss of natural breeding habitat.

To help mitigate this decline, MPRs began constructing artificial nesting structures on Bird Islet in 2017 and on South Islet in 2019, providing alternative breeding areas for the species. These efforts aim to support the recovery and long-term survival of the Black Noddy population in Tubbataha.

In May 2025, the adult population was recorded at 3,386 individuals, representing a 40% increase from the May 2024 counts. This year's adult counts were based on the number of nests multiplied by 2 (representing 2 adults per nest) on both islets. It should be noted that this figure likely underrepresents the actual total in South Islet, as nests located in the upper sections of the nesting structures were excluded from the count due to limited access to appropriate equipment, e.g., ladder.

Similar to last year, the species now breeds year-round, as eggs, juveniles, and pulli were observed during each quarterly inventory, with the numbers peaking in August. Historically absent from November to February, the Black Noddy overwintered and bred on both islet in November 2024.

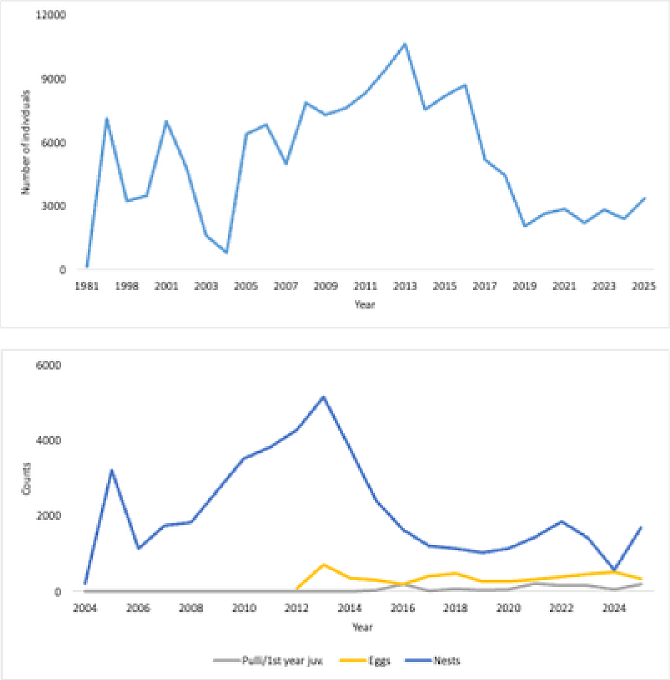

Figure 21. Population trend (top) and breeding data (bottom) of Black Noddy

The Black Noddy continue to utilize 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 structures have been 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. However, these structures caused the death of two (2) adults which got stuck between the bamboo slices.

Greater Crested Tern (Conservation Status - Philippine Red List: Vulnerable): Stable population. The estimated annual adult population is 17,728, which closely matches the 2024 estimate of 17,037.

As shown in Figure 22, the Greater Crested Tern population continue to increase. This year's count represent the number of nests multiplied by 2 (one nest equals 2 adults).

Compared to May 2024, the population in May 2025 only increased by 4%. A -7% decline in South Islet was recorded, but this was compensated by the 25% increase in Bird Islet. This year, Bird Islet hosted 58% of the population.

Adults arrived in January 2025 with breeding possibly commencing in March to April, as suggested by the pullus and eggs recorded in May 2025. Among all seabirds breeding in Tubbataha, the Greater Crested Tern, together with Brown Booby, remains one of the most stable breeding populations.

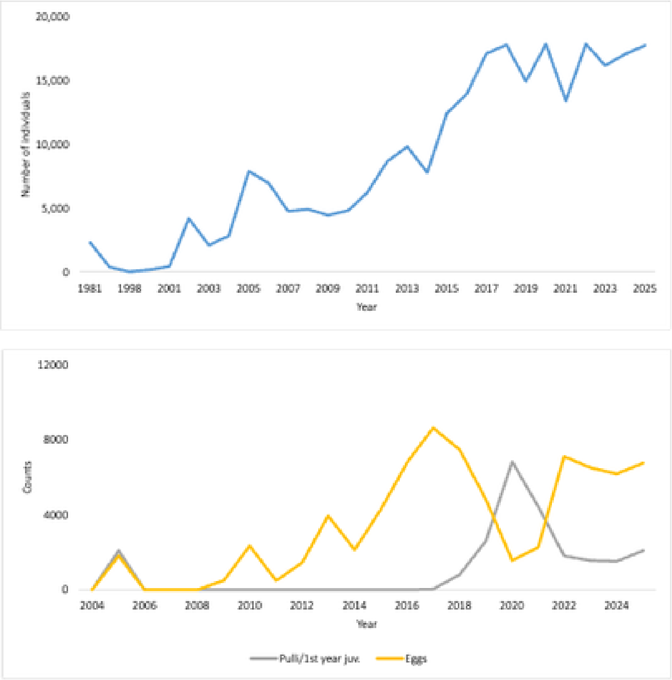

Figure 22. Population trend (top) and breeding data (bottom) of Greater Crested Tern

Sooty Tern (Conservation Status – Philippine Red List: Vulnerable): Stable population. This year's adult population estimate is 14,814, a 23% increase from last year's 12,056.

As seen in Figure 22, Sooty Tern exhibits the most variable breeding cycle among all the seabirds in the park. Despite this, the species reached its highest adult counts (14,506 individuals), suggesting a stable population despite the variation in breeding cycle. This count represents a combination of the number of eggs multiplied by two (2) in South Islet and the nighttime estimate in Bird Islet.

Unlike last year, when the Sooty Tern began breeding in December 2023, this year's breeding cycle likely began in January 2025 in South Islet, with 71 pullus and 57 eggs recorded in February. In Bird Islet, breeding likely began in April with four (4) pulli and 420 eggs recorded in May. Since this number was low compared to previous years, the standard protocol is to conduct a nighttime estimate of adults to account for the population which has just began their breeding cycle. The team estimated 2,800 adults inside the plaza in Bird Islet.

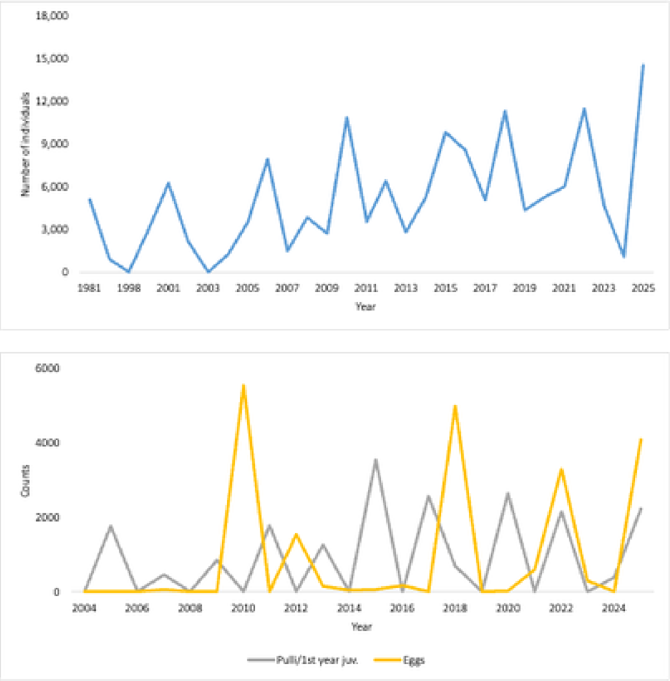

Figure 23. Population trend (top) and breeding data (bottom) of Sooty Tern

Notable this year is the very high number of breeding population in South Islet, with 2,201 pulli and 3,743 eggs.

Masked Booby (Conservation Status - Philippine Red List: Critically Endangered): Increasing population – 4 adults. 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 camera was installed near their nest on Bird Islet to observe their breeding cycle. Since the first breeding on June 2020, the pair has laid eggs 15 times. During the May counts, one juvenile was recorded and was tagged with a color band (320). This juvenile was one of the two eggs recorded by MPRs in February 2025.

The rangers have closely monitored the population development of the Masked Boobies. The original breeding pair successfully raised three fledglings, one each in 2022, 2024, and 2025. Apart from this breeding pair, another pair of adults were recorded by the MPRs in July 2024.

Figure 24. A juvenile raised by the original pair of Masked Booby was tagged with color band no. 320 in May 2025. Photo: Kymry Delijero

All four (4) adults are now tagged with either a plastic or steel rings. In 11 July 2025, the juvenile tagged with color band (320) in May was tagged with steel ring no. 0710. This juvenile was being raised by the original pair with band numbers 446 and 256.

Red-footed Booby (Conservation Status - Philippine Red List: Least Concern): Declining population. The total estimated annual population is 455 adult individuals, which is 25% less than last year (604 individuals).

The adult population in May 2025 was recorded at 337 individuals, which represent a -33% decrease compared to May 2024. This year's count was taken from the number of adults present during the day plus the inflight counts in both Islet.

The number of active nests in May 2025 was still low, with only 119 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. At least five (5) pairs with nests on the ground at South Islet were observed during the May counts.

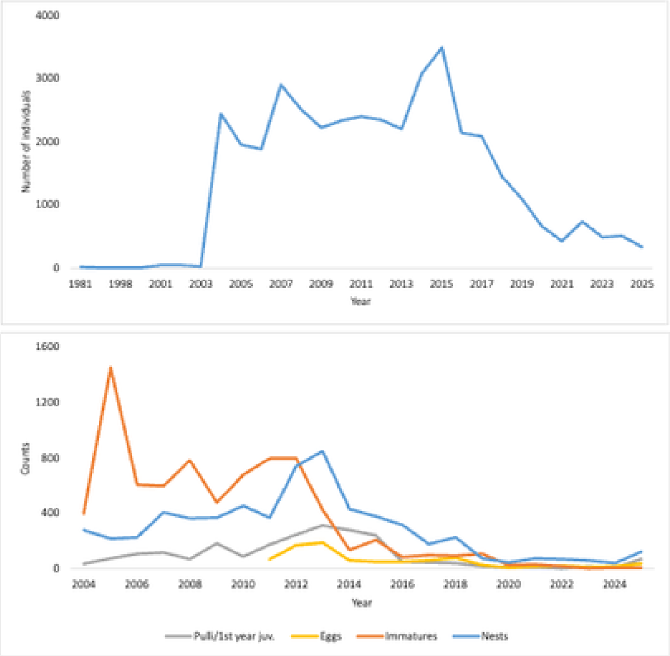

Figure 25. Population trend (top) and breeding data (bottom) of Red-footed Booby.

Brown Booby (Conservation Status - Philippine Red List: Endangered): Increasing population. The total estimated annual population is 6,558, which is 39% less than the 2024 estimate of 10,830 individuals.

The number of adults in May 2025 is comparable to the 2022 and 2023 counts, suggesting that the May 2024 count might be an outlier, mainly influenced by the unusually high number of inflight count, compared to the previous years. Overall the Brown Booby population exhibits an increasing trend.

The May 2025 counts of Brown Booby represents adults during the daytime counts plus the inflight counts on both islets.

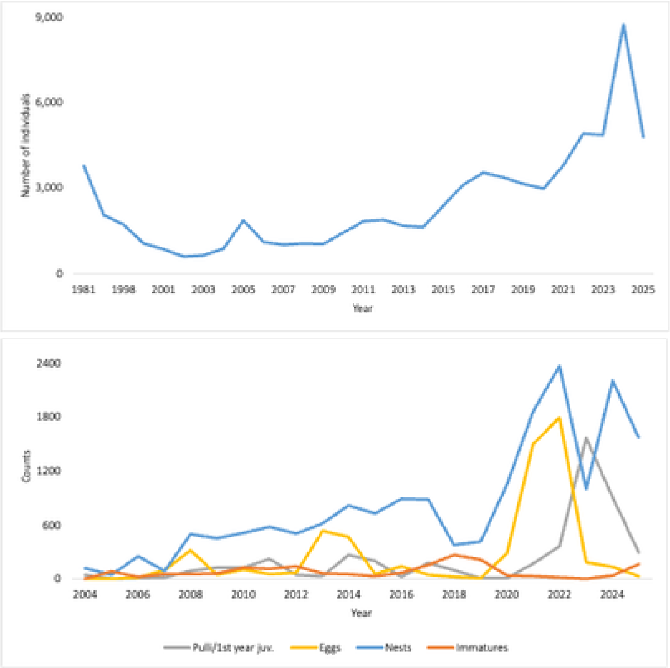

Figure 26. Population trend (top) and breeding data (bottom) of Brown Booby

The May 2025 breeding data which is represented by 294 pulli/1st year juvenile and 31 eggs is lower compared to the February 2025 counts by the rangers with 1,181 pulli/1st year juvenile and 386 eggs. Ranger data shows that the peak in the number of eggs and pulli is in February. This highlights the importance of the quarterly monitoring of the MPRs.

The first documented record of an albino Brown Booby in Tubbataha Reefs Natural Park was made in 2025, with an individual first observed on South Islet on 16 April and later re-sighted on Bird Islet in May.

Figure 27. Albino Brown Booby reported by MPRs in South Islet on 16 April 2025. Photo: Segundo Conales, Jr.

Cocos Booby. This species, now classified as *Sula brewsteri*, was considered a subspecies of the Brown Booby until 2024. Historically, the Cocos Booby bred in Mexico's Gulf of California and on islands in the Pacific Ocean from Nayarit, Mexico, to southwestern Colombia and is expanding its population westward in the Pacific Ocean (Mlodinow et al., 2024). The species was first documented in the park on 20 May 2020, when Theresa Aquino, DVM, recorded it on Bird Islet. The pale individual, initially described as showing possible nutritional deficiency, is now recognized as belonging to the brewsteri taxon of the Brown Booby (Figure 28); only one such individual was recorded (TMO, 2020).

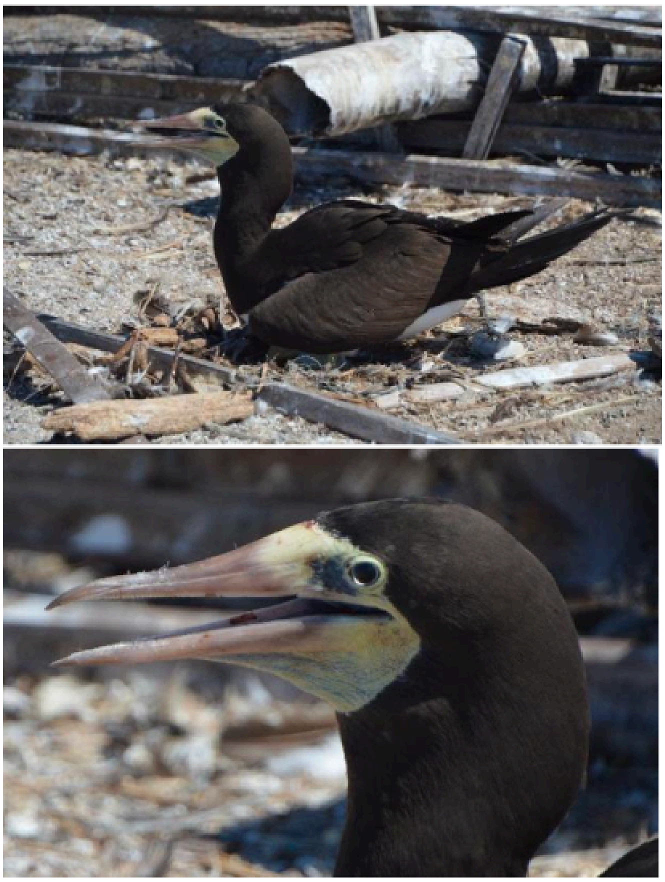

Figure 28. Photos of a Cocos Booby in Bird Islet on 20 May 2020. Photo: Teri Aquino.

In 2025, a pair with two eggs was found breeding on South Islet on 23 April by MPR Segundo Conales, Jr. (Figure 29). On 2 May 2025, a male Cocos was tagged with steel ring number 1000 and colored band 296. A single male was first observed by Arne Jensen among Brown Boobies on 3 May 2025 at North Islet (Figure 29). On 2 December 2025, a female Cocos Booby in South Islet was tagged with steel ring number 0929 and plastic band 027.

Figure 29. Male Cocos Booby incubating an egg in South Islet on 23 April 2025. Photo: Seconds Conales, Jr.

Figure 30. Male Cocos Booby in Bird Islet on 3 May 2025. Photo: Lisa Paguntalan-Marte

RECOMMENDATIONS

Land area at Bird Islet and South Islet

1. Continue to produce and update 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.
2. 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 was scheduled for 2025, but has yet to be completed.
3. During inventories and when the birds are in their breeding period, limit the number of people on the island to reduce human-induced stress among birds and separation of pulli from their parents.

Species

4. Black Noddy
- Continue to maintain a sufficient number of breeding structures for at least 4,000 noddies.
- Each member of the monitoring team (MPRs, TMO, and volunteers) must bring a pair of scissors to remove plastic items dangling in the nests.
- When observed, previously banded Black Noddy and Brown Booby should be recaptured, and ring numbers read for analysis.

5. Red-footed Booby: Nests without eggs in the artificial breeding structures, on tree guards, or directly on the ground should be regularly removed.
6. Procure steel rings and colored bands for Masked and Cocos Boobies.
7. Closely monitor Masked Booby and Cocos Booby breeding activities.

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CHAPTER 4


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WATER QUALITY

OVERVIEW

Water quality is an important indicator of reef health, as trend shifts in fundamental parameters such as temperature, pH, salinity, etc., can detect ecological stressors. Despite being a no-take zone, TRNP is not immune to the effects of climate change. The threat of rising sea surface temperatures (SST) and ocean acidification needs to be monitored more frequently as their effects on coral reefs (e.g., coral bleaching) are evident now more than ever.

Water quality is monitored annually in TRNP across 20 stations to assess the health of the reef and waters as a whole. Monitoring began in 2014 and has been done nine times since then. This study aims to update the TRNP water quality data and track long-term trends to identify possible anomalies happening in the park.

METHODS

Seven (7) stations are located in the South Atoll, three (3) of which are located inside of the south lagoon (Table 1). Nine (9) stations are in the North Atoll, five (5) of which are located within the north lagoon. WQ19 is located on the Southwest side of Jessie Beazley Reef (JBR). Three (3) stations are in the buffer zone of TRNP, adjacent to each reef formation. WQ8 is adjacent to the South Atoll, WQ18 is adjacent to the North Atoll, and WQ20 is adjacent to JBR.

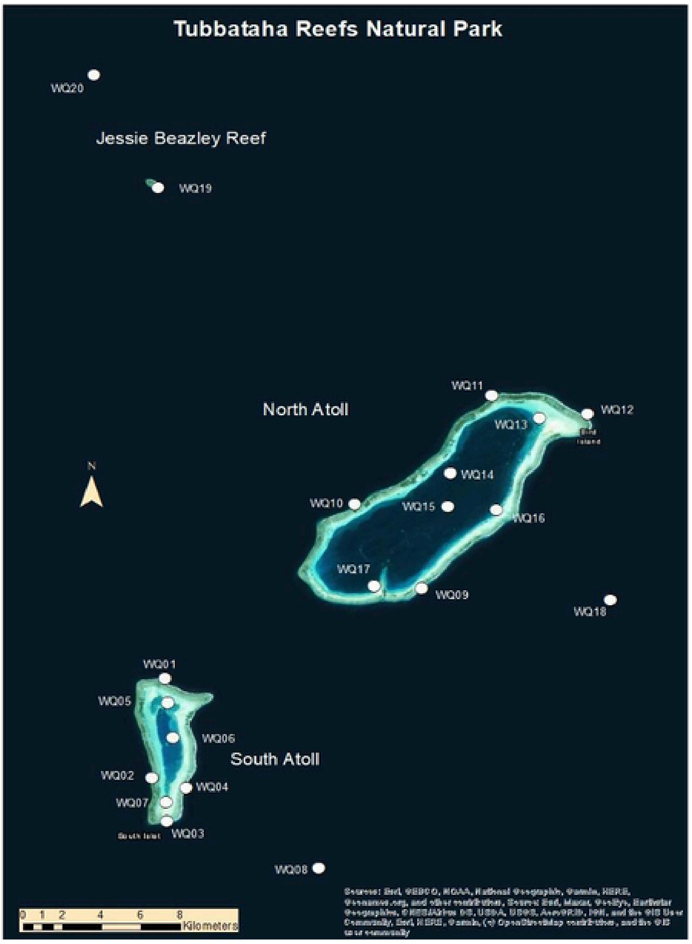


Figure 31. Map of Water Quality Monitoring Stations in Tubbataha

Table 16. Water Quality Stations with corresponding coordinates and descriptions

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
WQ20	N9.09834	E119.78648	Original water quality site; buffer zone; deep waters

Table 17. Water quality parameters and their corresponding threshold for Class SA

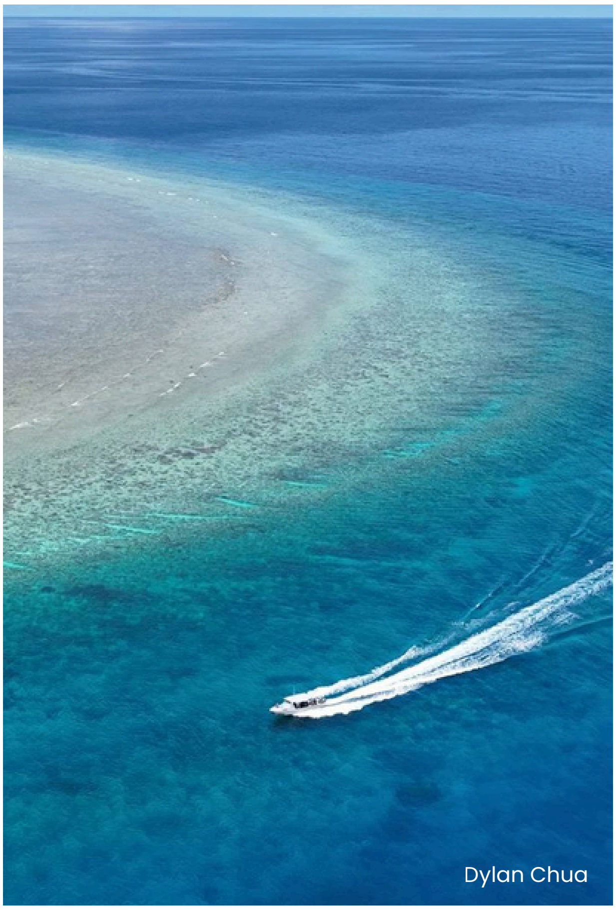
Parameter	Significance	Unit of Measurement	WQ Guideline * (Class SA)
pH	Measures the acidity or alkalinity of water. Most aquatic organisms thrive within a specific pH range. Deviations can indicate pollution or affect the availability of nutrients and metals.		7 – 8.5
Temperature	Affects the solubility 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.	°C	26oC – 30oC
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.	mg/L	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.	NTU	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.	ppt	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.	mg/L	none
Specific Gravity	Refers to the density of substance compared to fresh water.		none

Table 17 presents the key water quality parameters, their significance, and WQ guidelines. Data was collected in situ using a HORIBA multiprobe meter. Data was compared to the Water Quality Guidelines (WQG) in DENR Administrative Orders (DAO) 2016-08 and DAO 2021-19. Class SA indicates the standard of protected waters designated as national or local marine parks, reserves, sanctuaries, or similar areas established by law or declared as such by relevant government agencies, local government units (LGUs), and other authorities.

RESULTS

Present Conditions

Table 18 shows all stations and their measurements taken from May to June 2025. Depths of measurements varied from 0.68 meters in the lagoon, to 6.6 meters in the buffer zone.



Dylan Chua

Table 18. 2025 Water Quality results

Parameters	Habitat	Temperature °C	pH	Conductivity	Turbidity (NTU)	DO (mg/L)	TDS (mg/L)	Salinity (ppt)	Specific Gravity
South Atoll									
WQ1	Top of reef	33.11	8.09	44.9	0	7.79	27.4	29.03	16.4
WQ2	Top of reef	33.01	8.16	44.7	0	8.89	27.3	28.88	16.3
WQ3	Top of reef	32.96	8.28	45.4	0	8.22	27.7	29.38	16.7
WQ4	Top of reef	33.01	8.1	45.4	0	8.05	27.7	29.38	16.7
WQ5	Lagoon	32.76	8.13	44.4	0	7.15	27.1	28.69	16.2
WQ6	Lagoon	33.09	8.11	44.5	0	6.55	27.2	28.73	16.2
WQ7	Lagoon	33.44	8.18	42.8	0.61	7.45	26.1	27.51	15.1
North Atoll									
WQ9	Top of reef	33.15	8.8	44.7	0	7.79	27.3	28.88	16.3
WQ10	Top of reef	33.71	8.48	45	0	8.5	27.4	29.09	16.2
WQ11	Top of reef	32.94	8.11	44.2	0	7.74	27	28.49	16
WQ12	Top of reef	32.88	8.76	44.7	0	8.62	16.4	28.58	16.4
WQ13	Lagoon	33.93	8.98	44.7	0	6.97	27.3	28.87	16.4
WQ14	Lagoon	33.74	8.21	44.9	0	8.22	27.4	29.94	16.1
WQ15	Lagoon	33.75	8.27	45.5	0	8.33	27.8	29.43	16.5
WQ16	Lagoon	33.76	8.25	45.6	0	8.16	27.8	29.52	16.5
WQ17	Lagoon	33.73	8.24	44.4	0	6.59	27.1	28.63	15.7
Jessie Beazley									
WQ19	Top of reef	32.82	8.22	44.7	0	6.81	27.2	28.81	16.3
Buffer Zone									
WQ8	Buffer zone	32.96	8.26	45.1	0	9.14	27.5	29.13	16.5
WQ18	Buffer zone	33.06	8.02	44.8	0	12.8	27.4	28.92	16.3
WQ20	Buffer zone	32.83	7.86	44.1	0	8	26.9	28.39	16
Average		33.23	8.28	44.7	0.03	8.09	26.8	28.91	16.24
Water Quality Guideline		Fail	SA			SA			

Figure 32 shows that the mean pH level in TRNP fell within the water quality guidelines for Class SA (DAO 2016-08), with the highest reading of 8.98 at station WQ13 on the top reef of the North Atoll. The North Atoll (reef) habitat averaged the highest pH level in TRNP (8.54), slightly exceeding the maximum threshold, while the buffer zone had the lowest (8.05).

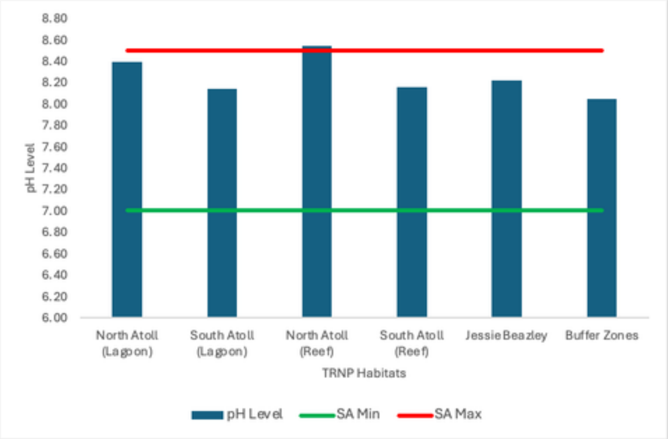


Figure 32. The average pH level per TRNP habitat with the minimum and maximum thresholds for Class SA guidelines.

Dissolved oxygen (DO) also exceeded the minimum requirement of 6 mg/L, averaging at 8.09 mg/L. (Figure 33). shows that the buffer zone had the highest average DO among all the TRNP habitats (9.98 mg/L), while JBR yielded the lowest (6.81 mg/L). Station WQ18 (buffer zone) had the highest DO in TRNP at 12.8 mg/L.

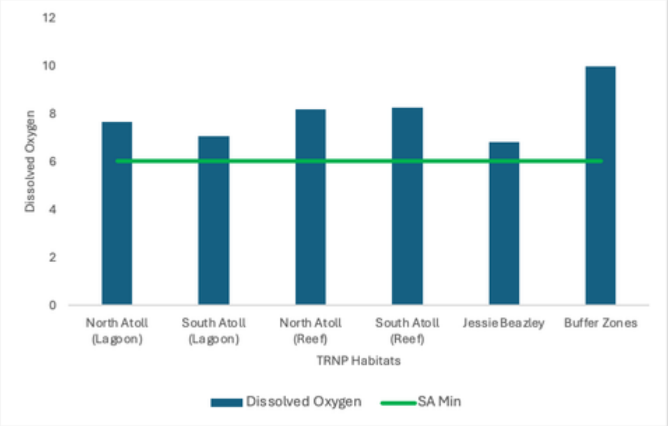


Figure 33. The average dissolved oxygen per TRNP habitat with the minimum threshold for Class SA guidelines.

Sea surface temperatures exceeded the maximum acceptable threshold of the Class SA WQG in all stations, with a mean of 33.23°C (Figure 34). The North Lagoon was the hottest area with an average of 33.78°C. The lowest average temperature was recorded at Jessie Beazley Reef at 32.82°C. JBR and the buffer zone were the only areas below 33°C. The station with the highest temperature was WQ13, near Bird Islet (33.93°C).

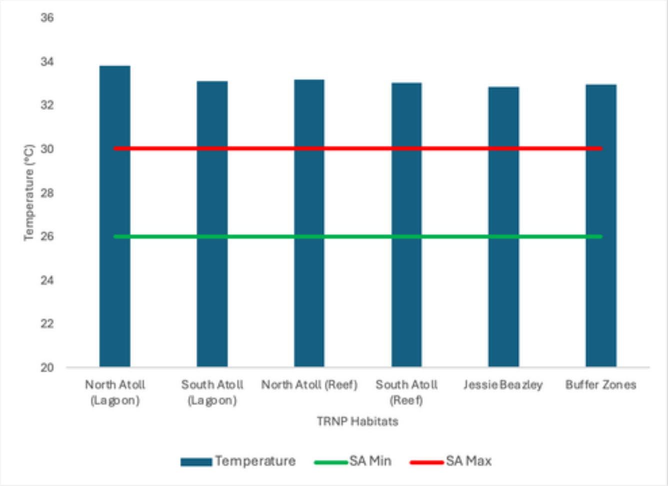


Figure 34. The average temperature per TRNP habitat with the minimum and maximum thresholds for Class SA guidelines.

Temporal Trends

pH Level

The highest average pH level was recorded in 2017 at 8.77. Since then, it has only exceeded the maximum threshold once in 2022 (8.53). Overall, the trendline shows that pH levels in TRNP remain stable.

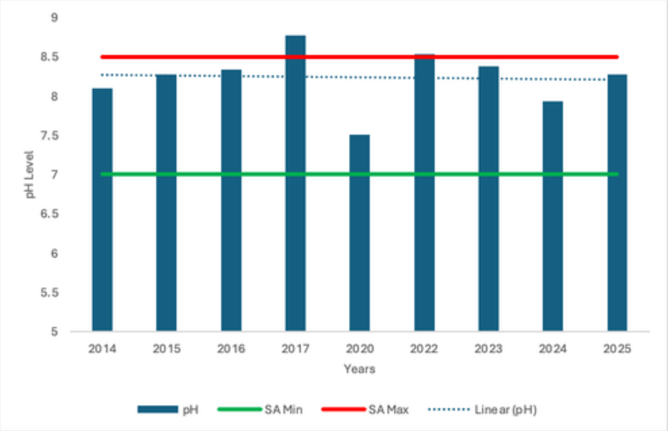


Figure 35. Average pH level in TRNP per year

Dissolved Oxygen

In 2025, the average dissolved oxygen reached 8.09 mg/L, the highest recorded since 2014. This is a drastic increase from 2024, which not only recorded the lowest level but also was the only year that failed to meet the Class SA standard.

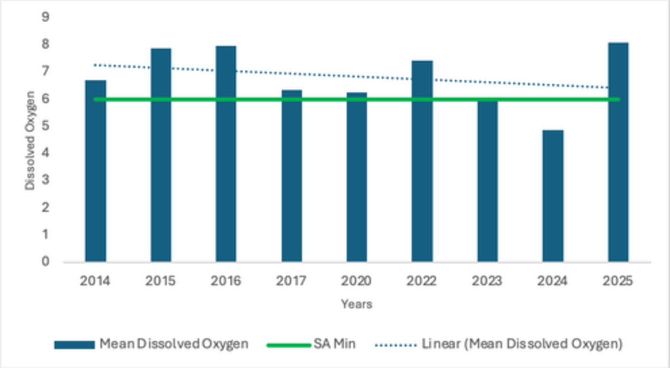


Figure 36. The average dissolved oxygen in TRNP per year

Temperature

TRNP exceeded the Class SA threshold six times out of the last nine surveys since 2014. The last three years (2023-2025) have been the highest readings ever recorded, peaking in 2024 (34.12°C). The lagoons had the highest temperatures in the last three years, notably the South Atoll (lagoon) with the highest reading of 35.12°C in 2023. The trendline in Figure 37 shows a significant increasing trend.

Figure 37. The average temperature in TRNP per year

DISCUSSION

TRNP has mostly exhibited healthy levels of pH in 2025, with exception to the North Reef habitat going slightly above the accepted range. Data from 2014 shows that pH levels have been very stable and within the Class SA guidelines. High pH levels can be detrimental to marine life, as it can weaken the calcium carbonate structures of marine organisms. The observed stability in TRNP's pH levels may provide useful insights into the park's potential resilience to future ocean acidification despite elevated SST (Doney et al., 2020).

All habitats in TRNP had high amounts of dissolved oxygen in 2025, surpassing the Class SA guideline. Dissolved oxygen usually has an inverse relationship with rising SST (Garcia-Soto et al., 2021; Song et al., 2019), which was the case in the 2024 results (ERM 2024). The drastic decrease of DO in 2024 and the return to normal levels in 2025 despite the elevated SST may indicate a sampling error, as opposed to the idea of SST as a cause.

Since 2023, the average SST has been well over the acceptable limit of 30°C. Coral bleaching was widespread in TRNP during the fourth global bleaching event declared in 2024 (NOAA, 2024; Reimer et al., 2024), which was also the highest average SST in TRNP. High amounts of dissolved oxygen can offset the detrimental effects of elevated SST by supplying additional oxygen to marine organisms whose metabolic rates increase at higher temperatures (Giomi et al., 2019; Jiang et al., 2021).

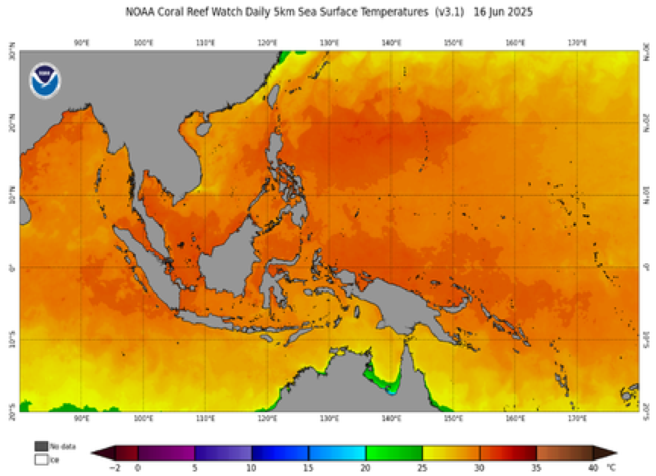


Figure 38. Sea Surface Temperature of Coral Triangle during month of sampling (June). Source: NOAA Satellite and Information Service. *https://coralreefwatch.noaa.gov/product/5km/index.php#data_access*

CONCLUSION

The effect of rising SST has already been documented in TRNP (TMO 2024). Although the results of pH levels and dissolved oxygen meet the Class SA standard, the threat of global warming and climate change will not go unnoticed. As discussed, these findings point to resilience to ocean acidification and oxygenation-mediated buffering of elevated SST, though the longevity of these effects remains unclear.

RECOMMENDATIONS

1. Install real-time data loggers, i.e., pH and temperature in TRNP, to obtain long-term data and anomalies throughout the year
2. Collaborate with scientific institutions to seek expertise and increase technical capacity in data analysis and data collection to avoid sampling error
3. Continue in situ collection of water samples every three years, as the current annual sampling through the ten-year time frame shows little to no deviation in results

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CHAPTER 5

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SHARKS

OVERVIEW

Sharks of the subclass Elasmobranchii occupy many levels and niches of reef trophic structures. Some reef sharks, like the whitetip reef shark (*Triaenodon obesus*), hunt for crustaceans in the crevices of the reef, while the Tiger shark (*Galeocerdo cuvier*) is an apex predator that can control the populations of mesopredators. Sharks are indicators of reef health because their absence may imply disturbance or inadequate prey in the area. However, their population has been facing declines, mainly due to overfishing and bycatch. Their long life span and low fecundity have led to some species reaching the endangered status, prompting the need for conservation efforts such as the ban on targeting protected species and establishing marine protected areas (MPAs).

Data on sharks in Tubbataha date back to 2005 when Walker and Abesamis conducted a top predator study in the park. Alava conducted the first ever shark inventory in 2010, revealing the high density of reef sharks in TRNP. Data was only collected via SCUBA until 2015, when the Large Marine Vertebrates Research Institute Philippines (LAMAVE) conducted the most comprehensive study on sharks to date. Using baited remote underwater video surveys (BRUVS) to compliment the SCUBA surveys, they showed that TRNP had the highest density of whitetip and grey reef sharks in the world.

This study intends to update data on the TRNP shark population after the first in-house survey led by Tubbataha Management Office in 2021.

METHODS

The Underwater Visual Survey (UVS) method in the 2021 shark survey modeled from LAMAVE (2015-2017) was utilized in this year's survey. There were two groups of three divers, which consisted of one recorder and two spotters per group. The recorders were situated at a depth of 15 meters and the two spotters would be 5m above and below the recorder (10m and 20m, respectively). The spotters identified and counted sharks and signal to the recorder to verify the sighting. Divers followed the current's direction for about 40 minutes and count sharks passing within the 30-meter wide transect. Sharks that passed the divers from behind were not included in counts to avoid double counts but were taken note of, as well as sharks observed beyond the 30-meter transect.

The eight (8) sites surveyed by LAMAVE and the newly added site in 2021 were revisited (Table 19). Transect start coordinates were determined upon entry, marked by a researcher on the boat. End coordinates were marked when the divers signaled the end of the survey by deploying a Surface Marker Buoy (SMB). Each site had two replicates, surveyed two hours apart to minimize the disturbance of sharks in the area.

Table 19. Descriptions of shark survey sites

Dive Number	Dive Site	Start Coordinates	End Coordinates	Distance Covered (meters)
1	Malayan Wreck	N08°53.3017' E119°53.8238'	N08°53.1671' E119°53.3929'	843
2	Wall Street	N08°51.9508' E119°52.9950'	N08°51.5917' E119°52.7641'	808
3	Malayan Wreck	N08°53.3869' E119°54.0713'	N08°53.2195' E119°53.5212'	1071
4	Wall Street	N08°52.0529' E119°53.0525'	N08°52.5059' E119°53.2927'	965
5	Shark Airport	N08°55.6343' E120°00.8194'	N08°56.0254' E120°00.9274'	820
6	Seafan Alley	N08°56.7796' E119°59.6903'	N08°56.5930' E120°00.0206'	698
7	Shark Airport	N08°55.5465' E120°00.6078'	N08°55.7101' E120°00.9299'	671
8	Seafan Alley	N08°56.7745' E119°59.6981'	N08°56.4771' E120°00.1608'	1015
9	South Park	N08°50.8215' E119°55.6850'	N08°50.7479' E119°55.4383'	464
10	South Park	N08°50.9725' E119°56.0832'	N08°50.7944' E119°55.6795'	814
11	Kook	N08°48.5213' E119°48.4105'	N08°48.5788' E119°48.8611'	845
12	Black Rock	N08°47.8091' E119°50.2391'	N08°48.0961' E119°50.5283'	808
13	Black Rock	N08°47.5241' E119°49.9717'	N08°47.8099' E119°50.2760'	786
14	Kook	N08°48.5173' E119°49.1366'	N08°48.5542' E119°48.7211'	804
15	Delsan Wreck	N08°44.7644' E119°49.6590'	N08°44.4577' E119°49.4327'	738
16	Triggerfish City	N08°44.3987' E119°49.1975'	N08°44.3638' E119°48.6739'	962
17	Delsan Wreck	N08°45.2467' E119°49.6880'	N08°44.7878' E119°49.6828'	869
18	Triggerfish City	N08°44.3924' E119°49.1164'	N08°44.4035' E119°48.6622'	841

The survey area was determined by using the mapping software QGIS v3.30.2, by plotting start and end waypoints and following the contour of the reef. The approximate distance was then multiplied by the 30-meter transect width. The estimated total survey area was used to calculate mean density, or number of individuals per hectare (ind/ha) per species.

RESULTS

A total of 18 UVS dives were completed across nine (9) sites. A distance of 14.8 kilometers was covered with a survey area of 44.5 hectares. A total of 282 sharks of 5 species were recorded with an overall mean density of 6.12 ind/ha. The two most abundant shark species were the grey reef shark (*Carcharhinus amblyrhynchos*) and the whitetip reef shark (*Triaenodon obesus*) (Table 19), which made up 96% of the total encounters. Only 10 blacktip reef sharks (*Carcharhinus melanopterus*) were recorded in this census. The tiger shark (*Galeocerdo cuvier*) and the whale shark (*Rhincodon typus*) were only observed once. Ray sightings were infrequent, recording only nine individuals (Table 19). The most abundant being the spotted eagle ray (*Aetobatus ocellatus*) and reef manta ray (*Mobula alfredi*), each with three sightings.

Table 20. Count and mean density of recorded species. ns = not significant

Species	Total Count	Density (ind/ha)
Sharks		
Carcharhinus amblyrhynchos	190	4.21
Triaenodon obesus	80	1.91
Carcharhinus melanopterus	10	0.19
Galeocerdo cuvier	1	0.02
Rhincodon typus	1	0.02
Rays		
Aetobatus ocellatus	3	0.09
Mobula alfredi	3	0.07
Taeniurops meyeni	2	0.04
Taeniura lymma	1	0.02

Triggerfish City had the highest number of sharks recorded (Figure 39). Grey reef sharks comprised 91% of all sightings in Triggerfish City. Shark Airport had the second most sharks with a total of 49 individuals (32 white tips, 17 grey reefs). Wall Street had the fewest sightings, recording only nine (9) sharks. The tiger shark was observed in Black Rock and the whale shark was seen in South Park.

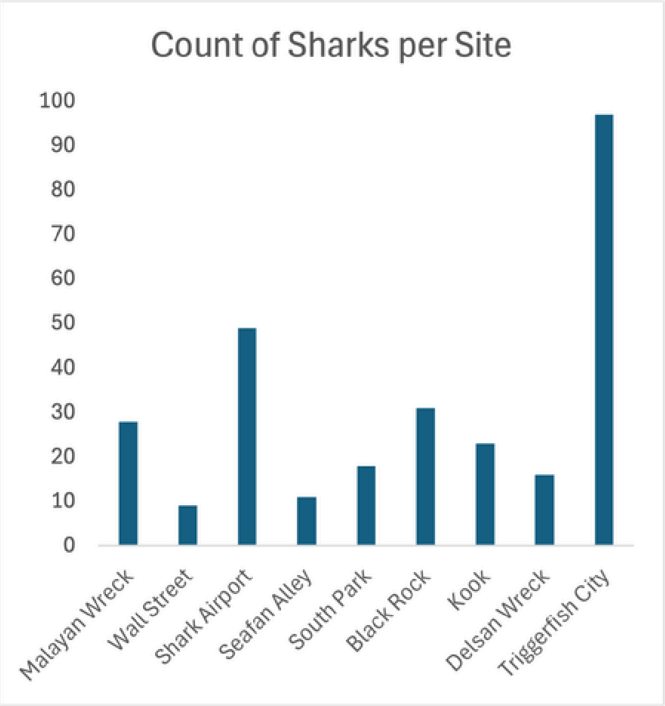

Figure 39. Bar graph of shark counts per site

DISCUSSION

The grey reef shark had more than double the encounters of whitetip reef sharks (Figure 40). Previous surveys by LAMAVE in TRNP 2015-2017 reported a higher density of whitetip reef sharks rather than grey reef sharks during their UVS (Murray, 2019). Schools of grey reef sharks were frequently sighted by researchers, the largest being a school of ~26 individuals at Triggerfish City. The UVS method could undercount whitetips as they are nocturnal and rest in caves or on reef tops compared to the more mobile grey reef shark with large aggregations near reef crests (Randall, 1977 and Economakis et al., 1998).

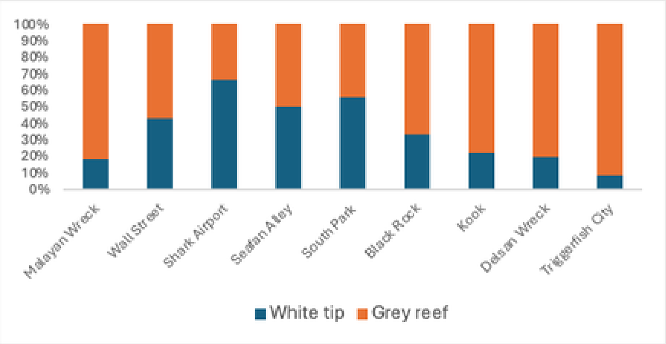

Figure 40. Percentage of grey reef shark encounters vs. whitetip reef shark encounters

The overall mean density of 6.12 ind/ha is much lower than the 2021 survey which had a mean density of 10.4 ind/ha. The higher density in 2021 may be attributed to the absence of tourists in TRNP during the COVID-19 pandemic. However, it is still lower than the initial mean density of 7.32 ind/ha reported by Alava in 2010 and 7.17 ind/ha in 2015 to 9.2 ind/ha in 2017 by LAMAVE (Murray et al., 2019), which were the highest reported densities of whitetip and grey reef sharks in the world.

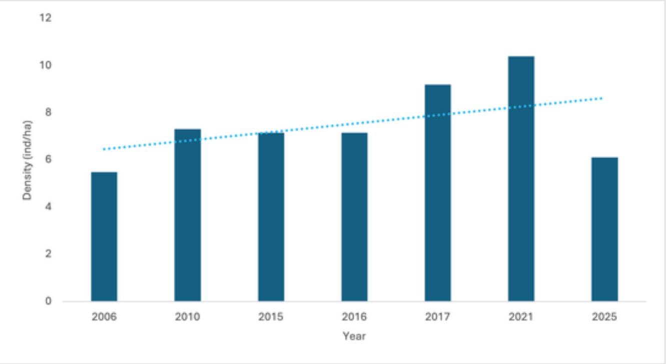

Figure 41. Mean shark density in TRNP from 2006 to 2025

Large MPAs isolated from anthropogenic activity with effective protection like TRNP could be the last remaining habitats for megafauna to thrive (Juhel et al., 2017). Proper enforcement can deter illegal, unreported, and unregulated (IUU) fishing inside the park, but cannot protect against external fishing pressure near the boundaries. Grey reef sharks have been observed to migrate well outside MPA boundaries, even in pelagic waters (White et al., 2017).

Environmental pressures such as rising sea surface temperatures (SST) could also affect reef sharks. The fourth global bleaching event was confirmed in 2024 (NOAA, 2024; Reimer et al., 2024), which caused coral bleaching in TRNP (TMO, 2024). Reef sharks depend primarily on reef fishes as prey, and the declines in fish populations in Tubbataha (Chapter 2) could have also cascaded to their populations by reducing food availability. Increased environmental stress can lead to a decline in prey sources for apex predators and can reduce their residency in coral reefs (Brandl et al., 2020; Williamson et al., 2024).

CONCLUSION

The decrease in mean density from 2021 to 2025 although drastic, is not comparable. The absence of divers in TRNP could have impacted the shark density to some degree. The use of multiple methods could complement UVS to gain a better understanding of the shark population in TRNP. Acoustic telemetry can highlight the site fidelity and vertical migration while BRUVS can corroborate the population density from the UVS and possibly record additional species. More frequent shark censuses could better monitor the long-term trends of the community, as it has only been the second shark survey since 2017.

RECOMMENDATIONS

1. Conduct more frequent shark surveys to better track fluctuations in the population
2. Explore utilizing different methods such as BRUVS and acoustic tagging to better represent the shark population and track horizontal and vertical migration
3. Maximize citizen science efforts to gather additional data, especially in years when monitoring is not conducted

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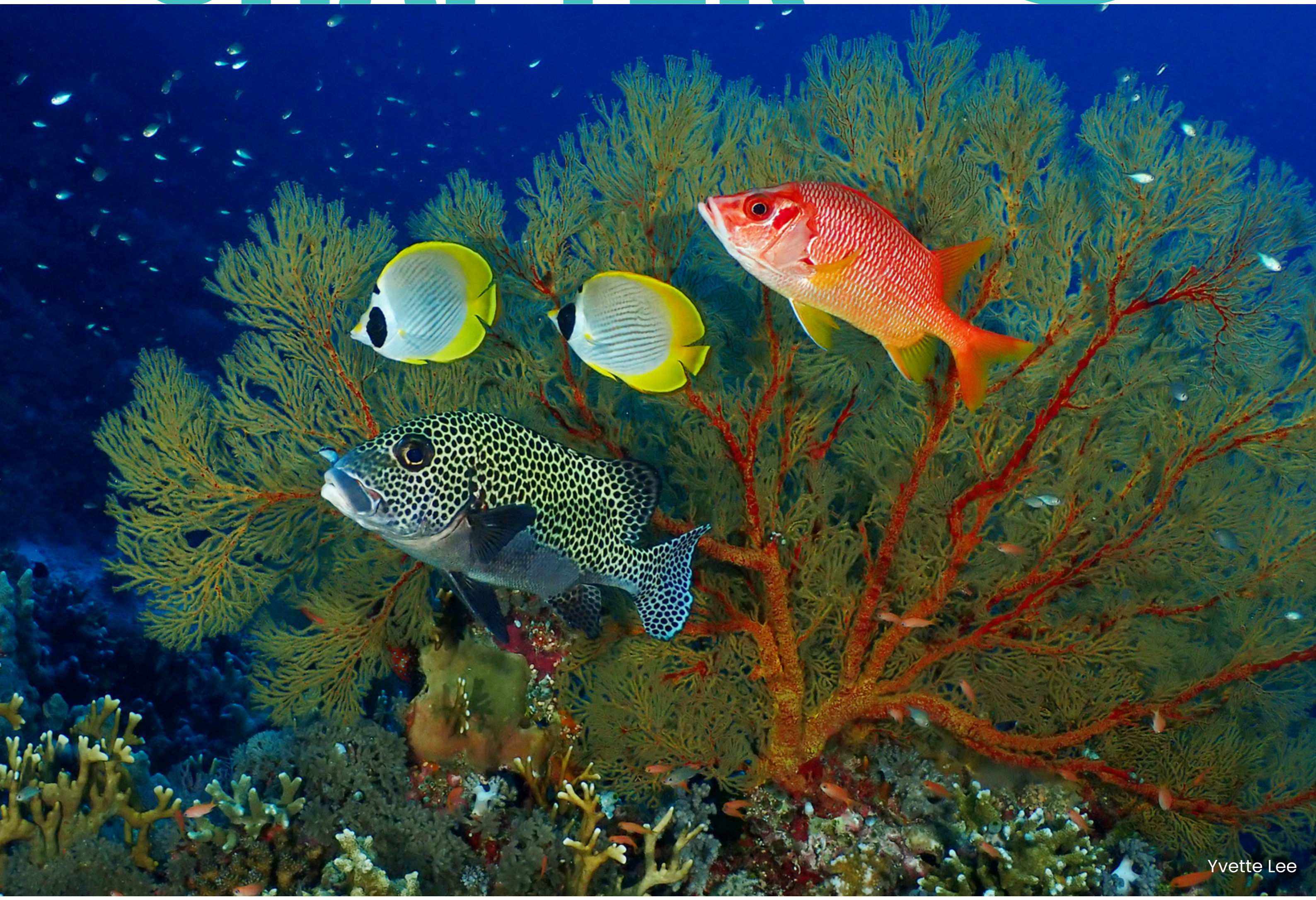
CHAPTER 6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FISH INVENTORY

OVERVIEW

This marks the fifth time the fish inventory initiative was conducted, which aims to update the existing fish list of Tubbataha. Over the past years, we have documented more than 100 previously unrecorded fish species, bringing the total of Tubbataha's existing list to 800 species. Lagoons of both atolls were also surveyed, opening the possibility of discovering fish species unique to these sheltered habitats.

While the main goal was achieved, it also allowed the researchers to gather data on abundance in sites outside the TMO monitoring stations. This provides a snapshot of the overall diversity and abundance of the reefs beyond our current monitoring scope. It serves as a valuable addition to the efforts led by TMO.

In this report, we aim to present the eight-year trends (2018-2025) in diversity and abundance within the reef structure and in the lagoons, including an assessment of the sampling efforts conducted.

METHODS

Data Collection

This year, nine (9) stations were surveyed, including seven (7) outer reefs and two (2) in the lagoon of the North and South Atolls (see Table 20). Appendix 19 lists the previously surveyed sites. In total, 46 sites have been surveyed since the study began (Appendix 19).

Researchers used the roving diver survey (RDS) method to quickly estimate the populations of various species. Divers started at around 20 meters deep and worked their way up to the reef's shallowest area, noting every species they encountered during the one-hour dive. The goal was to record as many species as possible. The RDS method gave them information on the species, how often they were seen, and how abundant they were.

Table 21. Sites surveyed this year. The station names (i.e., T38-T46) are sequentially assigned based on the count of surveyed stations each year. Since 2018, 46 sites have been surveyed in total. No survey was conducted from 2020 to 2022 due to COVID-19.

Date	Code	Location	Description
Jun 22	T38	North Atoll	Amos Reef, N. Atoll, not too far from the Ranger station
Jun 22	T39	North Atoll	Ranger Buoy No. 2, North Atoll
Jun 23	T40	North Atoll	Washing Machine
Jun 23	T41	North Atoll	Seafan Alley
Jun 24	T42	North Atoll	Wall Street (southeastern part of North Atoll)
Jun 24	T43	South Atoll	Black Rock, northeastern South Atoll
Jun 24	T44	Lagoon, South Atoll	Southern part of the lagoon in the South Atoll. Max depth 25' abundant staghorn coral, rock outcroppings and fine sand
Jun 24	T45	Lagoon, South Atoll	Southern part of the lagoon, North Atoll. Max depth 45', abundant staghorn coral, rock outcroppings, and fine sand.
Jun 24	T46	Jessie Beazley Reef	Jessie Beazley, northwest side

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 R statistical software (version 4.4.1, R Core Team 2024) was used for all analyses, along with the following packages: dplyr (v1.1.4; Wickam et al., 2023) for data manipulation and vegan (v2.7.1; Oksanen et al., 2025) for community ecology analysis.

First, the raw survey data, organized with species as rows and stations as columns, was cleaned to remove non-species entries. We then converted the categorical abundance codes (S, F, M, A) to their corresponding numerical lower bounds (1, 10, 100, 1000). Next, data for community analysis were prepared by transposing the matrix into a wide-format site-by-species matrix, with stations as rows and species as columns. During this step, duplicate species entries were aggregated by summing their abundances.

A corresponding metadata file was created, linking each station to its survey year and location, such as North Atoll or South Lagoon. This made it possible to separate the data into "Reef" and "Lagoon" subsets for more targeted analyses.

Data Analysis

Alpha Diversity Trends. Alpha diversity, a measure of biodiversity within a habitat, was evaluated using two key metrics for each station: Species Richness (the total number of species) and Shannon's Diversity Index (H'), which considers both richness and evenness. To examine temporal trends while adjusting for uneven sampling efforts between years, the annual mean of each metric was calculated for each location.

A linear regression model was then applied to these annual means, testing the relationship between the diversity metric (response variable) and survey year (predictor variable). A trend was considered statistically significant if the p-value was less than 0.05.

Species-Level Metrics. Two metrics were used to pinpoint the most common and dominant species at the reef sites to give a complete picture of each species' contribution to the community. These formulas were adapted from Schmitt and Sullivan (1996).

1. Sighting Frequency (%SF): The percentage of reef stations where a species was present. This was calculated as:

$$\%SF = \left(\frac{\text{Number of stations with species}}{\text{Total number of reef stations}}\right) \times 100$$

2. Abundance Index (AI): A composite measure reflecting both how often and in what numbers a species was seen. Abundance categories were scored (S=1, F=2, M=3, A=4), and the index was calculated as:

$$AI = \frac{\text{Sum of abundance scores}}{\text{Total number of reef stations}}$$

Newly Recorded Species. To track the progress of the species inventory, the cumulative species list from all previous surveys (2018-2024) was compared to the species list from the 2025 survey. Any species recorded in 2025 that had not been previously documented was identified as a new record.

Species Accumulation Curve. To assess the completeness of sampling effort in the outer reefs and lagoons, we generated species accumulation curves using the iNEXT (v3.0.2; Chao et al., 2014) package with the Chao incidence-based estimator (q = 0). This method utilizes presence–absence data across stations to model sample-based rarefaction and extrapolation, thereby providing an estimate of the expected species richness under increased sampling effort. Curves were calculated separately for outer reefs and for each lagoon, with extrapolations extended to 80 stations for reefs and 10 stations for each lagoon. The solid portion of each curve represents the observed accumulation (interpolation), while the dashed portion shows predicted richness with additional sampling. Shaded bands represent 95% confidence intervals, allowing evaluation of whether current sampling adequately captures total fish biodiversity.

RESULTS

Since 2018, 46 sites have been surveyed across Tubbataha's outer reefs and lagoons. In 2025, surveys covered nine (9) stations: seven reef sites (North Atoll, South Atoll, Jessie Beazley Reef) and two lagoon sites (one in each atoll).

The long-term monitoring program has documented a total of 696 fish species (excluding shark and rays) across all surveyed habitats in Tubbataha between 2018 and 2025. The majority of this diversity was recorded at the outer reef sites, which yielded a cumulative total of 481 species. Two hundred fifteen (215) species were identified in the less-explored lagoons of the two atolls. This year, 15 species that were not recorded in 2018-2024 were identified in Tubbataha. Fourteen species (14) in the outer reefs, and one (1), i.e., Threadfin Cardinalfish *Zoramia leptacantha* (Figure 42), in the lagoon.

Outer Reefs

Sighting Frequency and Abundance

Analysis of the reef sites from 2018-2025 showed a consistent group of core species that define the fish community (Table 21). Seven species were seen in over 97% of all surveys, showing they are widespread throughout the park's reef habitats. Notably, Klein's Butterflyfish (*Chaetodon kleinii*) was recorded in 100% of all surveys (Table 21).

While some species are often seen, others are more notable for their high abundance when present. The Yellowtail Damselfish (*Pomacentrus auriventris*), Golden Damselfish (*Amblyglyphidodon aureus*), and Yellowstriped fairy basslet (*Pseudanthias tuka*) had the highest Abundance Index scores (3.84, 3.63, and 3.61, respectively), showing they were consistently observed in large numbers ("Many" to "Abundant" categories). This contrasts with other common species like the Regal Angelfish (*Pygoplites diacanthus*), which was seen frequently but usually in smaller numbers (Abundance Index of 2.16).

Figure 42. Threadfin cardinalfish (Zoramia leptacantha) recorded from the lagoon. Photo grab from fishbase.org.

Table 22. Top 20 most frequently sighted species at reef sites from 2018-2025, with their corresponding Sighting Frequency (%SF) and Abundance Index.

Species	Common Name	Sighting Frequency	Abundance Index	Remarks
Chaetodon kleinii	Sunburst butterflyfish	100	2.66	Frequent, few but abundant in some
Pomacentrus auriventris	Goldbelly damsel	97.37	3.84	Frequent, abundant in most, if not all, stations
Macolor macularis	Midnight snapper	97.37	3.08	Frequent, abundant in most, if not all, stations
Balistapus undulatus	Orange-lined triggerfish	97.37	2.55	Frequent, few but abundant in some
Caranx melampygus	Bluefin trevally	97.37	2.53	Frequent, few but abundant in some
Pygoplites diacanthus	Regal angelfish	97.37	2.16	Frequent, few but abundant in some
Chaetodon lunulatus	Oval butterflyfish	97.37	1.97	Frequent, smaller numbers
Amblyglyphidodon aureus	Golden damselfish	94.74	3.63	Frequent, abundant in most, if not all, stations
Melichthys vidua	Pinktail triggerfish	94.74	2.79	Frequent, few but abundant in some
Cephalopholis argus	Peacock hind	94.74	2.26	Frequent, few but abundant in some
Halichoeres hortulanus	Checkerboard wrasse	94.74	2.26	Frequent, few but abundant in some
Pseudanthias tuka	Yellowstriped fairy basslet	92.11	3.61	Frequent, abundant in most, if not all, stations
Chromis weberi	Weber's chromis	92.11	3.55	Frequent, abundant in most, if not all, stations
Thalassoma lunare	Moon wrasse	92.11	2.76	Frequent, few but abundant in some
Zanclus cornutus	Moorish idol	92.11	2.74	Frequent, few but abundant in some
Lutjanus bohar	Two-spot red snapper	92.11	2.58	Frequent, few but abundant in some
Acanthurus pyroferus	Mimic surgeonfish	92.11	2.5	Frequent, few but abundant in some
Cephalopholis urodeta	Darkfin hind	92.11	2.21	Frequent, few but abundant in some
Pseudocheilinus hexataenia	Sixline wrasse	92.11	1.97	Frequent, smaller numbers
Chromis caudalis	Blue-axil chromis	89.47	3.58	Frequent, abundant in most, if not all, stations

Sighting Diversity

Fish diversity, as measured by the Shannon's Diversity Index, showed a statistically significant change at two of the three reef locations between 2018 and 2025. Significant downward trends were observed at Jessie Beazley Reef ($p = 0.031$) and the North Atoll ($p = 0.021$), indicating a lesser number of species identified since 2018. While a downward trend was also observed at the South Atoll, it was not statistically significant ($p = 0.108$) (Figure 43).

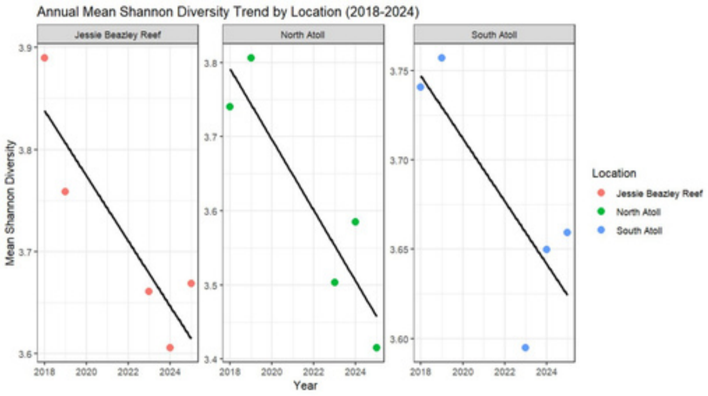

Figure 43. Annual mean Shannon's Diversity Index for the three reef locations from 2018 to 2024. Each point represents the average diversity for a given year and location.

Lagoon Fish Communities

Surveys conducted in the lagoon habitats from 2023 to 2025 have documented a total of 215 species. The North Lagoon, which has more sampling sites over this period, yielded a higher cumulative richness of 178 species. In contrast, the South Lagoon, with fewer surveys, has so far yielded 137 species.

Furthermore, a comparative analysis between lagoon and outer reef habitats reveals that the lagoons host a unique fish assemblage. A total of 46 species were found to be exclusive to the lagoon, meaning they have not been recorded at any of the 38 outer reef sites across all survey years (2018-2025). This highlights the unique ecological features of the lagoon systems and their value to the park's overall biodiversity.

In the North Lagoon (Figure 44), the abundance decreased from 2023 to 2025, while species richness and diversity both increased. This means fewer individuals were recorded overall, but they were spread across more species and with greater evenness (i.e., reduced dominance by a few species). The South Atoll lagoon shows a similar pattern between its first survey in 2024 and 2025: abundance decreased but diversity remained stable, indicating a comparable and evenly distributed species mix despite lower counts. Note that 2024 serves as the baseline year for the South Atoll lagoon.

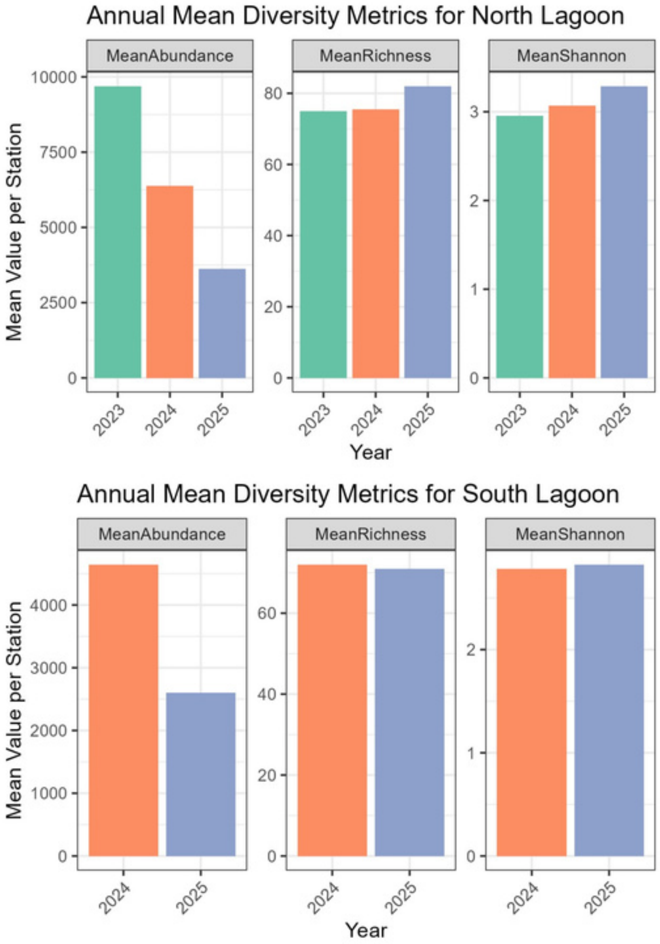

Figure 44. Alpha diversity in the lagoons of North (top) and South (bottom) Atolls. Lagoon in South atoll was first surveyed in 2024.

Lagoon Fish Communities

In the outer reefs, the Chao rarefaction curve rises gradually and begins to taper near the current effort (38 sites). Extrapolating to 80 sites indicates modest additional gains: the predicted richness is ~544 species, or ~+57 species beyond what is expected at 38 sites (Figure 45a).This suggests that most readily detectable reef species are already recorded, and further reef sampling yields diminishing returns.

In the lagoons, curves remain steeply increasing, consistent with under-sampling and high discovery potential. From the current effort - North Lagoon: 5 sites; South Lagoon: 3 sites - extrapolation to 10 sites predicts ~232 species for the North Lagoon (~+54 spp) and ~196 species for the South Lagoon (~+59 spp). Thus, adding ~5 stations in each lagoon is expected to yield >50 additional species per lagoon (Figure 45b & c).

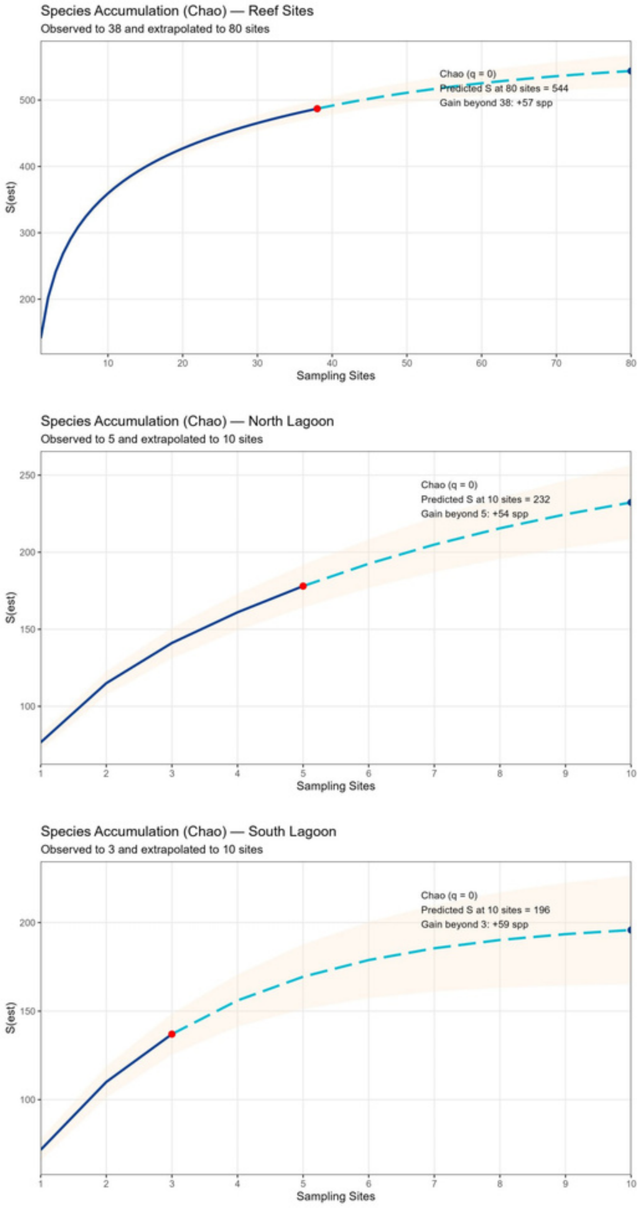

Figure 45. Sample-based species accumulation and Chao (q = 0) rarefaction/extrapolation curves with 95% confidence intervals for (a) outer reef sites, (b) North Lagoon, and (c) South Lagoon. The solid dark-blue line shows interpolated richness across the observed number of stations (red dot at 38 reef, 5 North Lagoon, and 3 South Lagoon). The dashed light-blue line shows the extrapolated richness to the study endpoints (blue dot at 80 reef sites and 10 sites per lagoon). Shaded bands depict 95% bootstrap CIs. Curves were computed from presence–absence (incidence) data using iNEXT with Chao (q = 0), which is appropriate for non-repeated stations.

DISCUSSION

This inventory survey reveals several critical insights into the state of fish communities in Tubbataha Reefs Natural Park. First, downward trend fish diversity has been statistically confirmed at two of the three major reef systems, Jessie Beazley Reef and the North Atoll. Second, despite these trends, the park's species inventory continues to grow substantially, with the 2025 survey adding 15 new species to the cumulative list, the majority of which were found in the outer reefs. Finally, species accumulation curve analysis indicates that while the current sampling effort is robust, the full extent of fish biodiversity, particularly in the lagoons, has not yet been completely documented.

Interpreting the Shifting Reef Communities

The statistically significant change in Shannon's Diversity at Jessie Beazley Reef and the North Atoll between 2018 and 2025 might suggest a change in these systems. The concurrent and significant change in diversity at Jessie Beazley Reef suggests a more pronounced environmental stressor at this location.

Potential drivers for these change are likely multifactorial. Without inferring causality, several non-exclusive mechanisms may explain these trajectories: (i) changes in coral habitat and condition that shift available niches; (ii) variable recruitment, with cohort pulses that fail to persist; (iii) environmental anomalies (e.g., heat waves, storms) affecting sensitive fish groups; and/or (iv) predator–prey shifts or fishing near park boundaries that influence highly mobile species.In fact, in the last eight years (2018-2025), TMO noted four (4) bleaching and two (2) storm events in the park (see TRNP Ecosystem Research and Monitoring Reports, tubbatahareefs.org) that could have impacted the reefs on which most of the fish rely. The combination of these environmental factors could be contributing to the changes we are seeing in the Jessie Beazley.

Figure 46. A rubble area in the Jessie Beazley. Suspected causes that reduced this area to the photo above include compounding environmental factors, such as bleaching and storms. Screen grab from video taken by Segundo Conales Jr.

The State of Tubbataha's Fish Inventory and the Importance of Lagoon Habitats

The lagoons remain a critical biodiversity reservoir within Tubbataha. Between 2023 and 2025, they contributed substantially to the expansion of the Park’s species list, including several taxa not yet recorded from the outer reefs. These new records highlight that lagoon habitats support distinct assemblages, reinforcing the need to treat them as important ecological units for long-term monitoring and strict protection. The fact that additional effort in the lagoons continues to produce new records underscores their potential as biodiversity hotspots.

Patterns in diversity metrics suggest subtle but important ecological dynamics. In the North Atoll Lagoon, species richness and diversity increased steadily from 2023 to 2025, while mean abundance per station declined. This points to a more even distribution of species, with communities becoming richer and more balanced but at lower overall densities. The South Lagoon showed a comparable level of richness, but with slightly higher diversity in 2025, further emphasizing the role of lagoons in maintaining unique and varied fish communities.

Species accumulation analyses strengthen these observations. For reef sites, the accumulation curve approaches an asymptote, with extrapolation indicating that additional effort will yield new species but at a diminishing rate of return. By contrast, curves for both lagoons continue to rise steeply, confirming under-sampling and high discovery potential. Strategic expansion of lagoon sampling, particularly in microhabitats such as patch reefs, rubble–sand interfaces, bommies, and across different tidal conditions, is likely to generate the largest biodiversity gains per unit of effort, and should be prioritized in future monitoring.

CONCLUSION

This eight-year study uncovers a significant divergence in the ecological health of Tubbataha's marine habitats. The outer reefs, especially Jessie Beazley and the North Atoll, are experiencing ongoing and statistically significant changes in fish diversity. Conversely, the park's lagoons are proving to be unique and a vital sanctuary for biodiversity. They continue to expand the park's species list and harbor distinct fish assemblages that are still not fully documented.

As the species inventory for the outer reefs approaches completion, the lagoons remain a frontier for discovery where further survey efforts are likely to provide additional fish species.

RECOMMENDATIONS

1. Continue Roving Diver Survey: Given that the RDS is essential for documenting new species and tracking broad ecological patterns, it should be formally integrated into the park's long-term monitoring plan. To ensure financial and logistical feasibility, conducting the comprehensive survey once every two or three years would be efficient to track long-term trends.
2. Prioritize future surveys in lagoon habitats, as species accumulation curves indicate these areas are under-sampled. Focus RDS on diverse lagoon microhabitats to better capture biodiversity, while maintaining protection of this distinct ecosystem.

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CHAPTER 7


Eric Madeja

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REEF RUGOSITY

OVERVIEW

Coral reef rugosity refers to the structural complexity of a reef, defined by the three-dimensional configuration of the reef surface relative to a flat plane (Graham & Nash, 2013; Darling et al., 2017). Rugosity describes the variations in reef topography composed of diverse microhabitats such as ridges, crevices, overhangs, and holes that collectively form the physical structure of coral reef habitats (Ticzon et al., 2012). It is therefore a key indicator of reef structural complexity and is closely linked to the composition and condition of coral communities, particularly the size, abundance, and morphology (lifeforms, morphotypes) of reef-building corals (Ticzon et al., 2012; Darling et al., 2017). As such, rugosity measurements provide a valuable baseline for evaluating reef condition and guiding adaptive management in marine protected areas.

METHODS

Data Collection

Rugosity was quantified on the reef slope using the Chain Intercept Transect (CIT) method following Hill & Wilkinson (2004). Measurements were taken in the 75-meter transect tape at each monitoring station. Along this transect, a 3-meter lightweight, flexible metal chain was carefully laid directly on the substrate, ensuring that it followed the natural relief and benthic topography without spanning gaps or being suspended above the substrate.

The starting position for each chain placement was determined using a series of randomly generated distances (in meters) to avoid observer bias and to ensure a representative sampling of the reef's structural complexity.

At each randomly selected point, the chain was laid along the reef surface following the coral growth and contours until its full 3-meter length was reached. The linear distance between the chain's start and end points (i.e., the projected distance along the transect tape) was recorded to compute rugosity indices (e.g., the ratio of chain length to linear distance). This procedure was repeated 12 times per monitoring station, yielding a total of 144 rugosity measurements across all stations in Tubbataha. These measurements provided a quantitative estimate of small-scale habitat complexity, which is an important descriptor of reef structure and potential habitat availability.
Rugosity Index (RI) was determined for each station following Ticzon et al., (2012) and Graham & Nash, (2013), using the formula:

$$RI = linear/surface$$

where;

linear (l) is the distance covered when the chain or tape was pulled out and,

surface (s) is the linear distance between the start and end of the chain or tape when it was draped over the contours of the substrate.

A Rugosity Index of 1 indicates that the substrate is flat (Ticzon et al. 2012; Hill and Wilkinson, 2004). Furthermore, the rugosity index was classified into ordinal categories (Low, Medium, High) using the relative rugosity index across all stations, with thresholds determined from the lowest and highest measurements recorded:

Table 23. Threshold in determining the relative rugosity Index.

Category	Rugosity Index (RI)
Low	0 to 1.10
Medium	1.11 to 2.67
High	2.68 to 4.25

RESULTS

The rugosity index (RI) values across surveyed stations in Tubbataha ranged from 1.34 to 1.75, with all stations classified as having "Medium" rugosity (Table 24). Station 4B (RI = 1.75) recorded the highest rugosity, followed by Station 3A (RI = 1.68), indicating relatively more complex reef structures compared to other stations. In contrast, Jessie Beazley A (RI = 1.34) and Station 1A (RI = 1.39) had the lowest complexity.

Table 24. Rugosity index and threshold (low, medium, high) across all stations in Tubbataha Reefs Natural Park.

Stations	**Rugosity Index (l/s)**	**RI Threshold**
Station 1A	1.39	Medium
Station 1B	1.52	Medium
Station 2A	1.48	Medium
Station 2B	1.64	Medium
Station 3A	1.68	Medium
Station 3B	1.45	Medium
Station 4A	1.39	Medium
Station 4B	1.75	Medium
Station 5A	1.48	Medium
Station 5B	1.65	Medium
Jessie Beazley A	1.34	Medium
Jessie Beazley B	1.49	Medium
Average	*1.57*	*Medium*

Overall, the consistency of medium rugosity across stations suggests a generally intact reef framework, characterized by moderate topographic relief and sufficient coral growth forms to support diverse reef communities.

DISCUSSION

The observed medium rugosity across all stations implies that Tubbataha Reefs maintain a balanced structural state—neither flattened nor excessively degraded—despite exposure to local and global stressors (e.g., typhoons and frequent bleaching events). Medium rugosity values are commonly associated with reefs dominated by branching, massive, and sub-massive coral assemblages, which contribute to vertical and horizontal relief without extreme surface irregularity (Darling et al 2017).

Some studies have demonstrated that even moderate levels of rugosity enhance fish abundance, species richness, and functional diversity, which may relate to the present condition of the reef in Tubbataha as compared to low-complexity reefs (e.g., a completely flat, sandy bottom or intricate reef crest). The study of Risk (1972), originally emphasized rugosity as a practical proxy for habitat complexity, while later studies confirmed its strong positive relationship with reef fish assemblages and ecological performance (Luckhurst & Luckhurst, 1978; Graham & Nash, 2013).

In the context of TRNP, the uniform classification of medium rugosity across sites reinforces the effectiveness of long-term protection and management interventions. It also provides a baseline condition against which future structural changes—whether due to bleaching events, typhoons, or anthropogenic pressures—can be quantitatively assessed. Monitoring trends in rugosity over time will be critical in detecting early signs of reef flattening, which has been linked to declines in ecosystem function and fisheries productivity.

RECOMMENDATIONS

Building on the current dataset, further analyses need to be conducted to enhance understanding of reef structural complexity and ecological relationships, including spatial patterns and associations with benthic communities and reef fish assemblages. As this represents the first application of rugosity measurements, and observations were limited to a single depth, future monitoring efforts would benefit from collecting rugosity data across multiple transects. Expanding spatial coverage will better capture natural variability in reef structure, improve comparability among sites, and provide a more representative assessment of habitat reef complexity.

The current rugosity values indicate that Tubbataha Reefs retain sufficient structural complexity to sustain key ecological functions. Moving forward, management efforts can build on this condition by prioritizing continued protection from physical damage, such as vessel grounding and anthropogenic impacts. Sustained, long-term monitoring of rugosity alongside coral cover and diversity, benthic composition, and fish assemblages will provide a comprehensive picture of reef condition over time. Integrating structural complexity metrics into routine reef health assessments will further strengthen evidence-based decision-making.

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CHAPTER 8


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RANGER REPORTS

OVERVIEW

The marine park rangers (MPR) of Tubbataha rotate tours of duty every two months. In addition to enforcing environmental laws in the park, they also conduct research to provide vital data during the off-season. This report serves to present the data on beach profiling, marine turtles, and marine debris collected by marine park rangers between June 2024 to June 2025.

BEACH PROFILING

Data is collected biannually to monitor Bird Islet's beach profile during different monsoons (northeast and southwest). Four (4) permanent markers are located in the North, Northeast, South, and Southwest corners of Bird Islet (Figure 47). The direction of the transect starting from the permanent marker is determined using a compass and is measured until it reaches the tide. Data collected in November 2024 and June 2025 is presented in this report

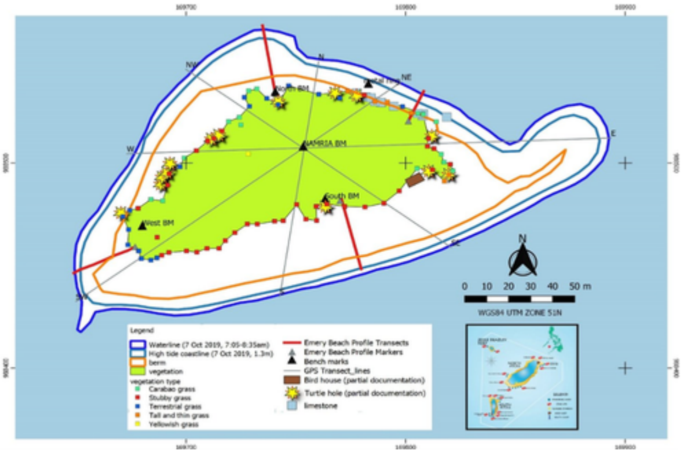

Figure 47. Map of Bird Islet showing the location of permanent markers and direction of transects (red lines). Illustration by Dr. John Ong, Dr. Caroline Jaraula, and Ms. Angelique Doctor.

This survey follows the beach profiling method presented by Emery (1961), where the difference in the alignment of two rods marked in centimeters determines the slope of the shore (Figure 48).

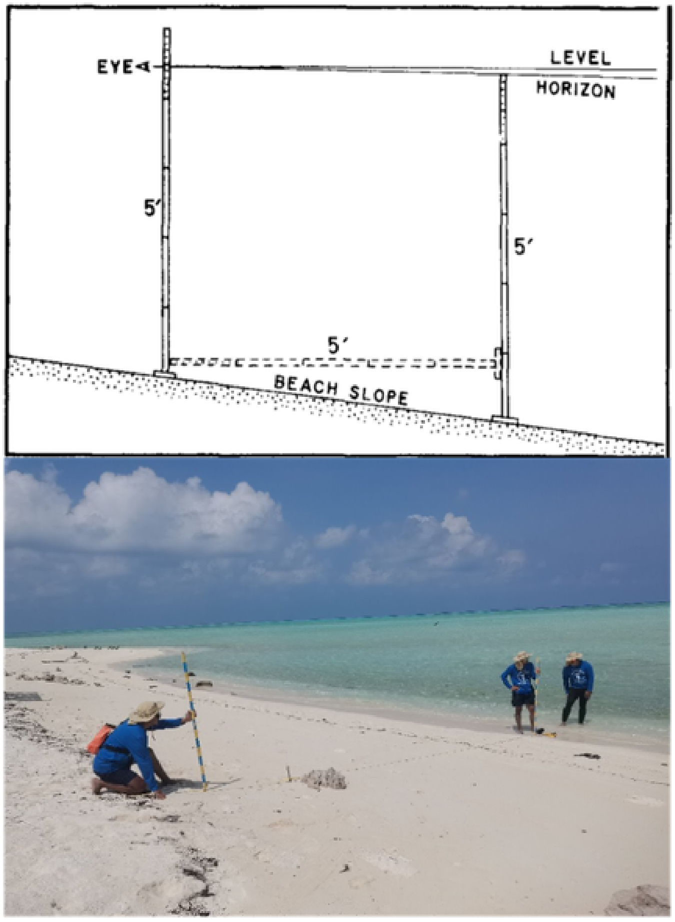

Figure 48. Sketch of the Emery beach profiling method (Emery, 1961) (top). Marine park rangers collecting the beach profile measurements (bottom) Photo by: Segundo Conales/TMO

Results from the June 2025 survey showed that the North, Northeast, and Southwest corners of Bird Islet have decreased in distance from the permanent marker since November 2024. This could indicate erosion in these corners (Figure 49). The South marker experienced a deposition of sand in June 2025, resulting in an elevation higher than in November 2024, even though the distance from the permanent marker remained similar.

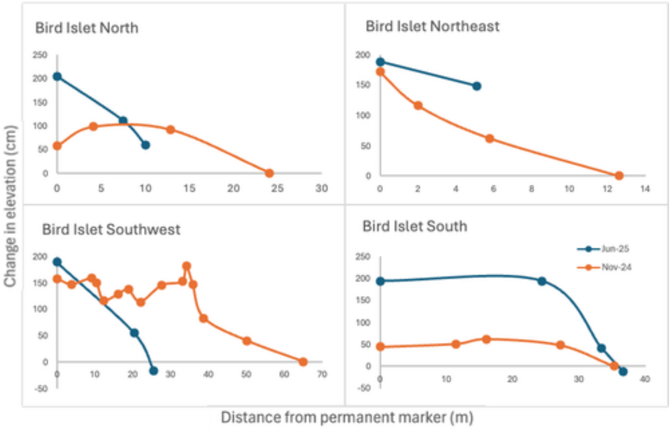

Figure 49. Bird Islet beach profile in November 2024 and June 2025.

Annual beach profiles of Bird Islet during the Northeast monsoon (October/November) showed that the distance from the permanent marker and elevation of the North has decreased, with a significant cavity at the start of the 2024 (Figure 50). The cavity may be attributed to sea turtle tracks as they frequently nest in that area. The Northeast corner had similar slopes from 2020.The Southwest corner increased in elevation and distance since 2020, suggesting an accretion of sand. The South corner was more erratic through the years, with a steep drop after 30m from the marker in 2021 and a decrease in elevation in the 2024 transect.

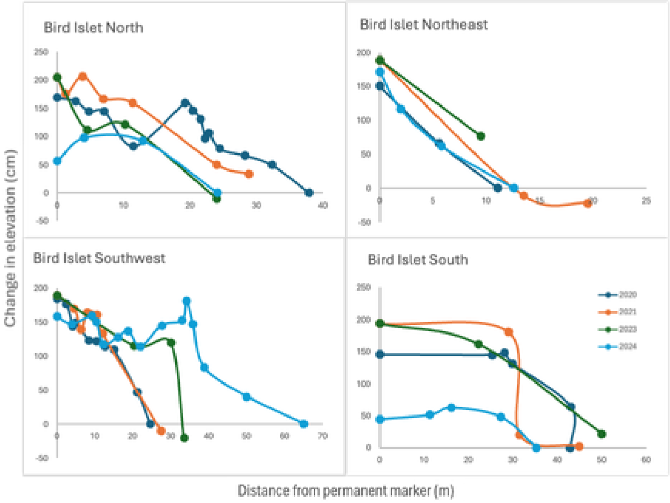

Figure 50. Annual Bird Islet beach profiles during the Northeast monsoon.

The annual beach profiles of Bird Islet during the Southeast monsoon have shown mostly stable slopes with increasing elevations since 2020. The Northeast, South, and Southwest corners have all increased in elevation since 2020. The Northeast corner increased in elevation at the marker but has decreased in horizontal distance possibly indicating accretion of sand near the marker but a closer waterline.

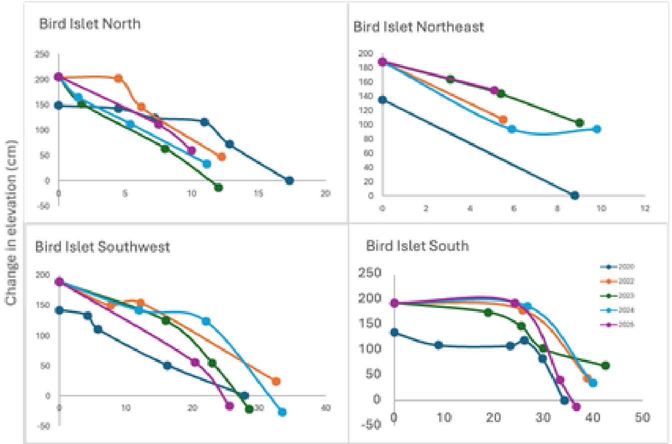

Figure 51. Annual Bird Islet beach profiles during the Southwest monsoon.

The Southwest monsoon seems to have more stable positive trends rather than the decreasing trends during the Northeast monsoon, as the latter experiences more erratic slopes in most corners of Bird Islet compared to the similar trends during the Southwest monsoon.

The second beach profiling of 2025 will be conducted in November during the Northeast monsoon and will be included in the 2026 ERM Report.

MARINE TURTLES

Marine turtle boat surveys are conducted biannually during the different monsoons. Straight line transects are conducted around Bird Islet, South Islet, and the ranger station. Surveys conducted in the shallow area of the reef flats of the north and south atolls follow a zigzag pattern to cover a broader area. 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 marked using a GPS equipment.

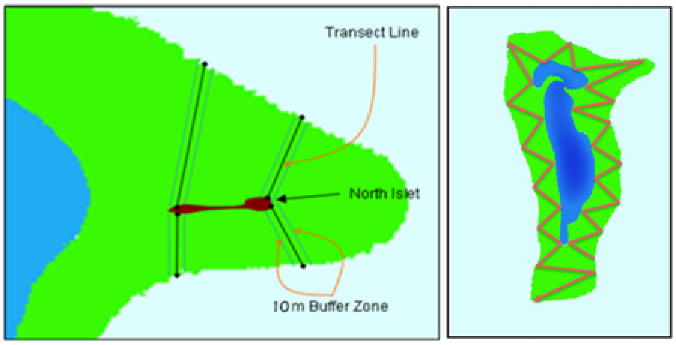

Figure 52. Illustration of transects surveyed by marine park rangers on the islets (left) and over the reef flats (right).

The June 2025 survey recorded a total of 155 individuals across both islet and reef flat areas, five (5) less sightings compared to the October 2024 survey. The counts between zigzag and straight-line surveys are mostly consistent except for the June 2024 count. June 2024 had the most zigzag sightings but had the least straight-line sightings compared to the next two surveys.

Table 25. Turtle counts from June 2024 to June 2025 using zigzag and straight line surveys

	Jun 2024	Oct 2024	Jun 2025
Zigzag Survey			
North Atoll	39	35	42
South Atoll	31	26	22
Zigzag Total	70	61	64
Straight line Survey			
North Islet	36	49	35
South Islet	24	47	40
RS Sandbar	1	3	16
Straight line Total	61	99	91
Grand Total	131	160	155


Segundo Conales, Jr.

MARINE DEBRIS

Marine debris collected in TRNP is sorted and weighed by material type. Sampling effort is irregular and opportunistic as some debris are retrieved floating on the surface during ranger patrols. Debris is also collected during beach cleanups on Bird Islet.

A total of 1073.9 kg was collected from July 2024 to July 2025 (Table 23). The heaviest category was nylon with 484.4 kg collected. Metal was the second heaviest category with 321.2 kg.

Table 26. Total weight (kg) of marine debris categories from July 2024 to July 2025.

Categories	Total Weight (kg)
Cans	20
Composite Materials	8
Glass items	26
Metal	321.2
Nylon	484.4
Other Plastic Items	42.5
Plastic Container	52.65
Plastic Food Wraps	6.5
Rigid Plastic Items	29.1
Rubber	43
Styrofoam	40.6
Grand Total	1073.9

Figure 53 shows the total weight of marine debris collected in TRNP since 2015. The year with the most collected debris by weight was 2018 with a total of 1,711.8 kg. 2024 had the second highest with a total of 1,413.4 kg, followed by 2017 with 1,002.95 kg. The large amount of debris in 2018 can be attributed to the collection of 1,200kg of nylon during the August to October tour of duty.

Fish aggregating devices (FADs), fishing nets, and rope were the main contributors to the 2024 totals. A FAD weighing nearly 300 kg was collected in July 2024. Nylon fishing nets and rope were collected in December 2024, weighing 400 kg. These debris could possibly come from commercial fishing vessels outside of TRNP.

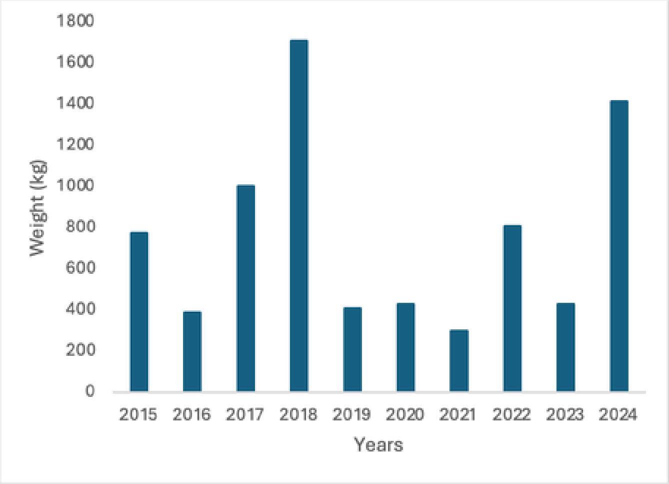

Figure 53. Total weight (in kg) of marine debris collected per year.

Marine debris poses a serious threat to marine life. Large fishing nets can entangle pelagic species such as this whale shark (Figure 54, left), which was observed caught in the same discarded nets that are collected within TRNP. This season during the shark survey, a grey reef shark was seen also entangled in a nylon rope (Figure 54, right). This hinders their movement and slowly cuts away at their flesh, mortally wounding them. Sacks of rice or grain are sometimes collected from smothered coral heads, restricting them of light absorption and potentially killing the coral. Sea turtles also often mistake plastic floating in the water column as potential food, obstructing their digestive system or drowning them in the process.

The collection of marine debris is not only vital for research but is a duty to protect Tubbataha and the marine life that seek refuge in the park.

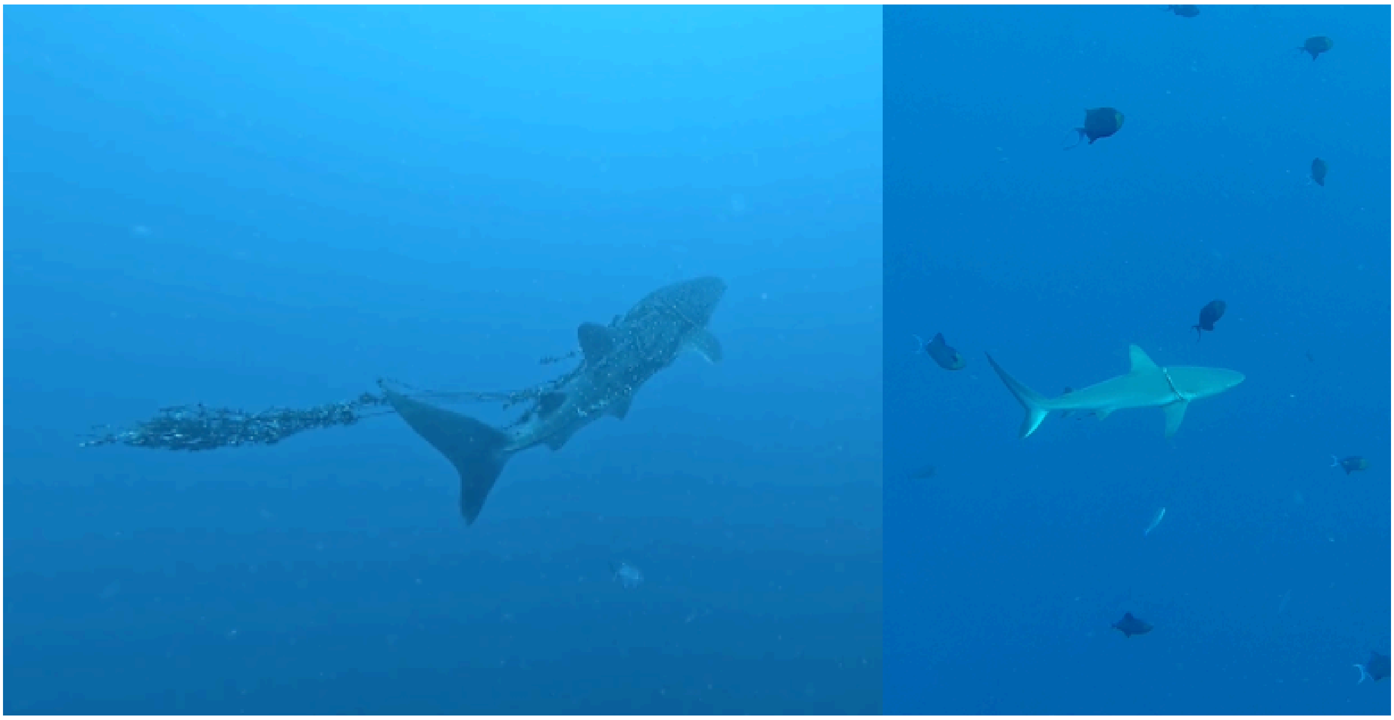

Figure 54. Whale shark entangled in a fishing net (left), grey reef shark entangled in nylon rope (right). Photos by M/Y Infiniti (left), Dylan Chua (right).

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APPENDICES

Appendix 1. 2025 Research Teams

Fish and Benthos Monitoring
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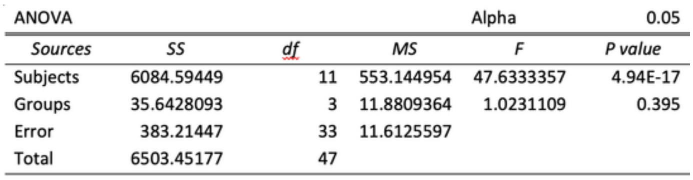
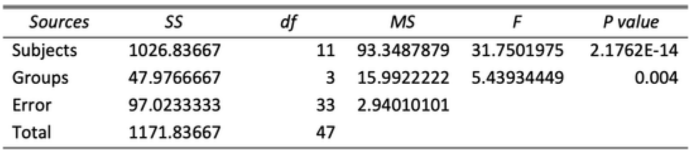
Jeffrey David, TMO
Erika Korosi, CI
Ryan Moyer, Terra Carbon
Scott Settelmyer, Terra Carbon
Benjamin Jimenez, Volunteer
Dominic Manuel, Volunteer
Marvi Trudeau, Friends of Tubbataha
Kymry Delijero, WWF

Appendix 2. ANOVA results for hard coral cover from shallow transects, 2022–2025.



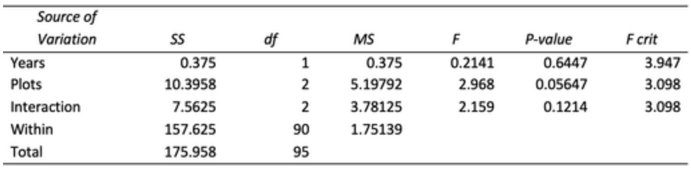
ANOVA				Alpha	0.05
Sources	*SS*	*df*	*MS*	*F*	*P value*
Subjects	6084.59449	11	553.144954	47.6333357	4.94E-17
Groups	35.6428093	3	11.8809364	1.0231109	0.395
Error	383.21447	33	11.6125597		
Total	6503.45177	47			

Appendix 3. ANOVA results for TAU richness from shallow transects, 2022–2025.



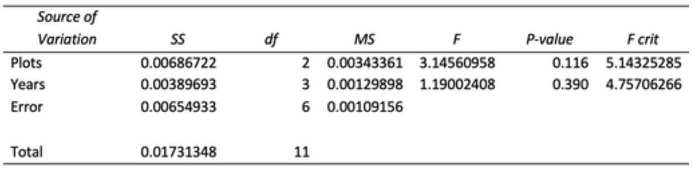
Sources	*SS*	*df*	*MS*	*F*	*P value*
Subjects	1026.83667	11	93.3487879	31.7501975	2.1762E-14
Groups	47.9766667	3	15.9922222	5.43934449	0.004
Error	97.0233333	33	2.94010101		
Total	1171.83667	47			

Appendix 4. ANOVA results for hard coral cover in the USS Guardian fixed plots, 2024–2025.



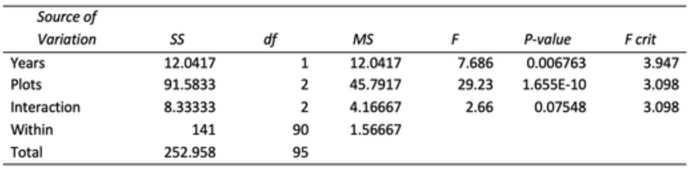
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Years	0.375	1	0.375	0.2141	0.6447	3.947
Plots	10.3958	2	5.19792	2.968	0.05647	3.098
Interaction	7.5625	2	3.78125	2.159	0.1214	3.098
Within	157.625	90	1.75139			
Total	175.958	95				

Appendix 5. ANOVA results for hard coral cover in the USS Guardian fixed plots, 2024–2025.



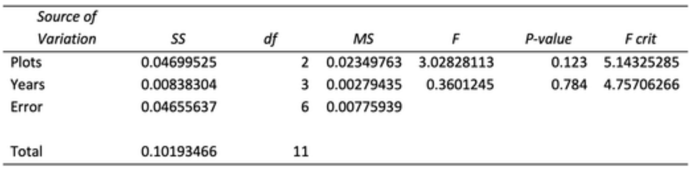
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Plots	0.00686722	2	0.00343361	3.14560958	0.116	5.14325285
Years	0.00389693	3	0.00129898	1.19002408	0.390	4.75706266
Error	0.00654933	6	0.00109156			
Total	0.01731348	11				

Appendix 6. ANOVA results for hard coral cover in the Min Ping Yu fixed plots, 2024–2025.



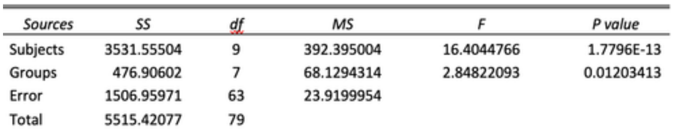
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Years	12.0417	1	12.0417	7.686	0.006763	3.947
Plots	91.5833	2	45.7917	29.23	1.655E-10	3.098
Interaction	8.33333	2	4.16667	2.66	0.07548	3.098
Within	141	90	1.56667			
Total	252.958	95				

Appendix 7. ANOVA results for hard coral cover in the Min Ping Yu fixed plots, 2022–2025.



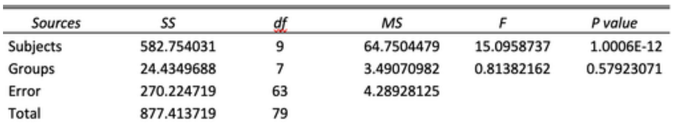
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Plots	0.04699525	2	0.02349763	3.02828113	0.123	5.14325285
Years	0.00838304	3	0.00279435	0.3601245	0.784	4.75706266
Error	0.04655637	6	0.00775939			
Total	0.10193466	11				

Appendix 8. ANOVA results for hard coral cover from shallow transects, 2018–2025.



Sources	*SS*	*df*	*MS*	*F*	*P value*
Subjects	3531.55504	9	392.395004	16.4044766	1.7796E-13
Groups	476.90602	7	68.1294314	2.84822093	0.01203413
Error	1506.95971	63	23.9199954		
Total	5515.42077	79			

Appendix 9. p ANOVA results for TAU richness from shallow transects, 2018–2025.

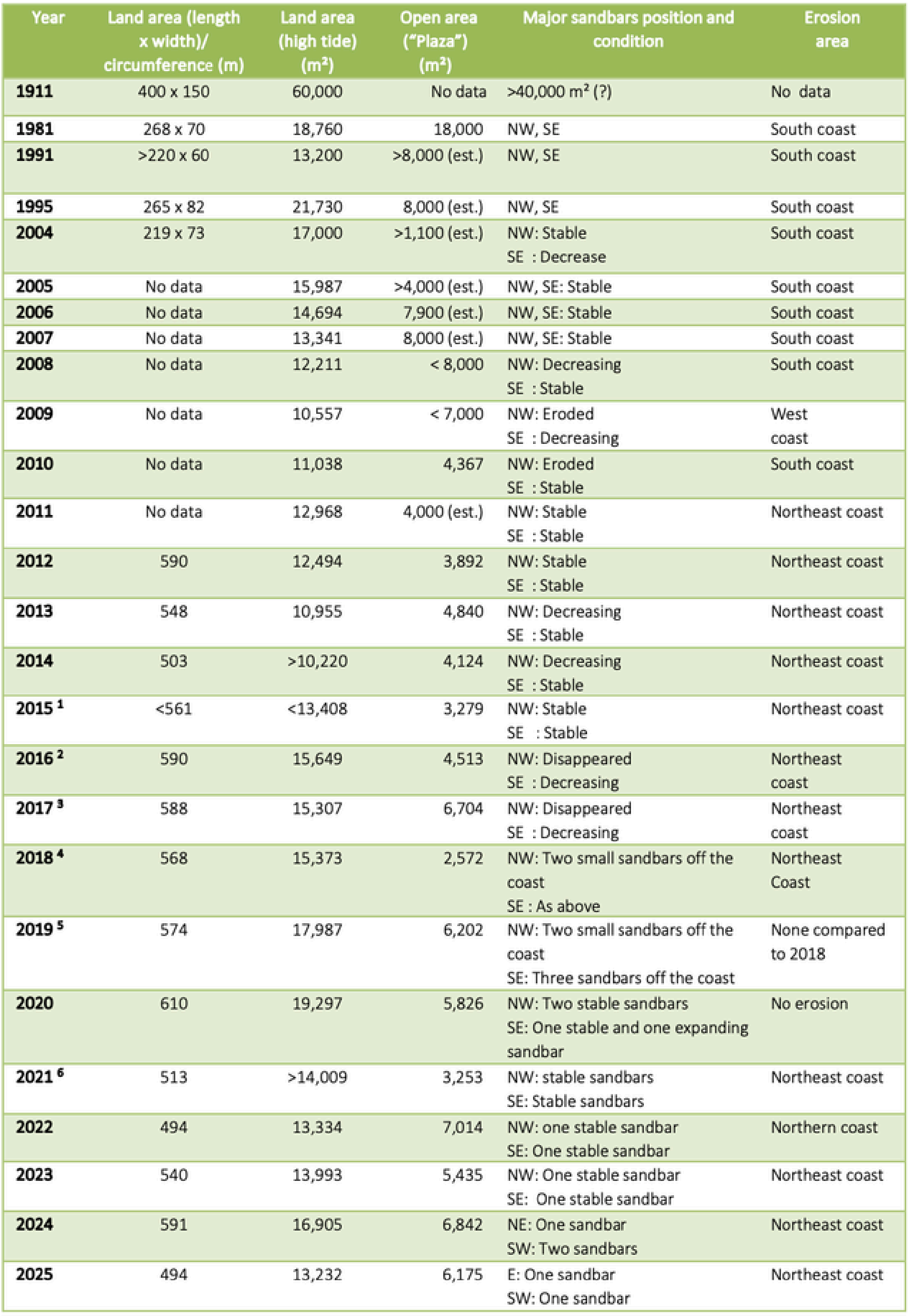


Sources	*SS*	*df*	*MS*	*F*	*P value*
Subjects	582.754031	9	64.7504479	15.0958737	1.0006E-12
Groups	24.4349688	7	3.49070982	0.81382162	0.57923071
Error	270.224719	63	4.28928125		
Total	877.413719	79			

Appendix 10. Temporal trends (2013-2025) of fish community metrics in TRNP at location and site levels, with results from three statistical models.

Site	**Depth**	**Generalized Additive Mixed Models (p-value) significance levels**	**GAMM Trend Direction**
Location -level	Deep	***	Decreasing
Location -level	Shallow	***	Increasing
1	Shallow	**	Increasing
2	Shallow	***	Increasing
3	Shallow	*	Increasing
4	Shallow	ns	Stable
JBR	Shallow	***	Increasing
1	Deep	ns	Stable
2	Deep	**	Decreasing
3	Deep	*	Decreasing
4	Deep	***	Decreasing
JBR	Deep	ns	Stable
Location-level	Deep	***	Decreasing
Location-level	Shallow	***	Decreasing
	Shallow	*	Increasing
2	Shallow	**	Increasing
3	Shallow	***	Decreasing
4	Shallow	ns	Stable
JBR	Shallow	***	Decreasing
1	Deep	*	Decreasing
2	Deep	*	Decreasing
3	Deep	ns	Stable
4	Deep	*	Decreasing
JBR	Deep	ns	Stable
Location-level	Deep	***	Increasing
Location-level	Shallow	***	Increasing
	Shallow	***	Increasing
2	Shallow	***	Increasing
3	Shallow	**	Increasing
4	Shallow	ns	Stable
JBR	Shallow	***	Increasing
1	Deep	***	Increasing
2	Deep	ns	Stable
3	Deep	**	Increasing
4	Deep	ns	Stable
JBR	Deep	**	Increasing

Appendix 11. Approximate changes in the land area of Bird Islet from 1911 to 2025



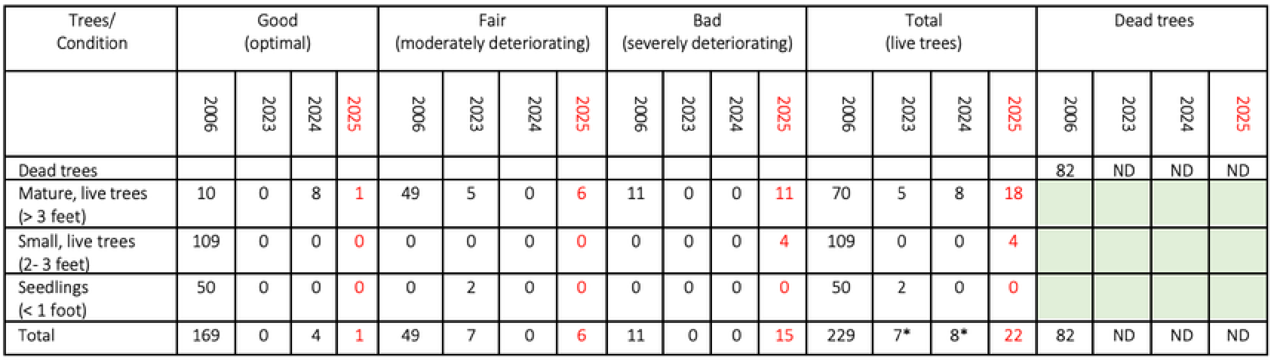
Year	Land area (length x width)/ circumference (m)	Land area (high tide) (m²)	Open area ("Plaza") (m²)	Major sandbars position and condition	Erosion area
1911	400 x 150	60,000	No data	>40,000 m² (?)	No data
1981	268 x 70	18,760	18,000	NW, SE	South coast
1991	>220 x 60	13,200	>8,000 (est.)	NW, SE	South 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 SE: One stable and one expanding sandbar	No erosion
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
2025	494	13,232	6,175	E: One sandbar SW: One sandbar	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 12. Condition of vegetation on Bird Islet and South Islet

Condition of vegetation on Bird Islet, May 2006 (baseline year), and 2023 to 2025



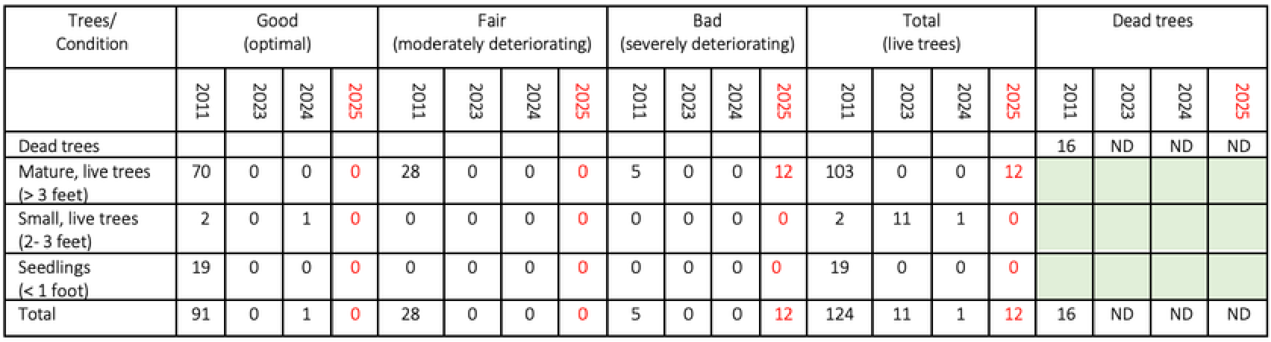
Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2006	2023	2024	2025	2006	2023	2024	2025	2006	2023	2024	2025	2006	2023	2024	2025	2006	2023	2024	2025
Dead trees																	82	ND	ND	ND
Mature, live trees (> 3 feet)	10	0	8	1	49	5	0	6	11	0	0	11	70	5	8	18				
Small, live trees (2- 3 feet)	109	0	0	0	0	0	0	0	0	0	0	4	109	0	0	4				
Seedlings (< 1 foot)	50	0	0	0	0	2	0	0	0	0	0	0	50	2	0	0				
Total	169	0	4	1	49	7	0	6	11	0	0	15	229	7*	8*	22	82	ND	ND	ND

Notes:

**All plants placed in protective bamboo boxes*

Coco Palms: 2018: 3, 2019: 2, 2020: 0, 2021: 0, 2022: 3, 2023: 0, 2024: 0, 2025: 0

Condition of vegetation on South Islet May 2011 (baseline year), and 2023 to 2025



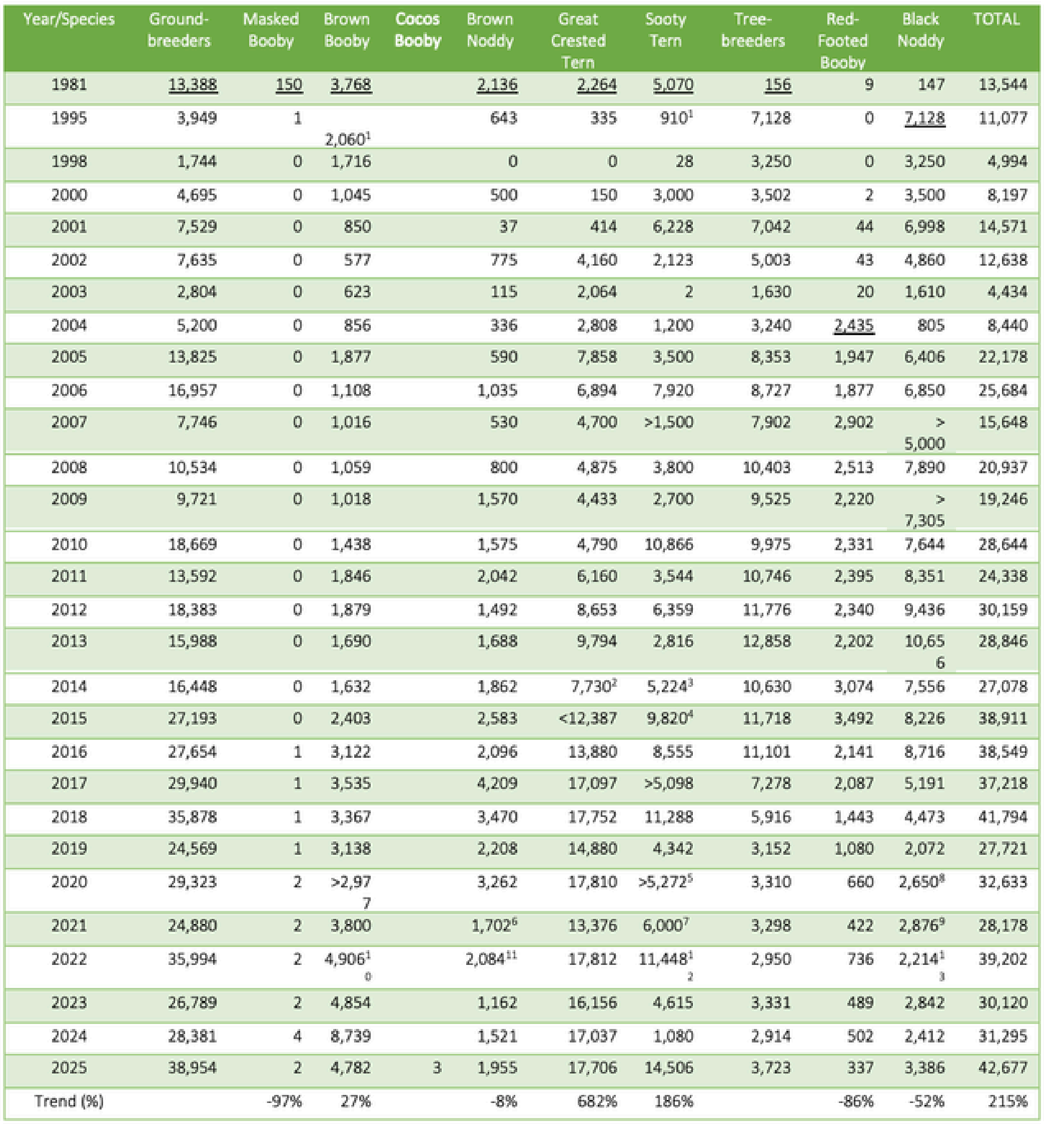
Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2011	2023	2024	2025	2011	2023	2024	2025	2011	2023	2024	2025	2011	2023	2024	2025	2011	2023	2024	2025
Dead trees																	16	ND	ND	ND
Mature, live trees (> 3 feet)	70	0	0	0	28	0	0	0	5	0	0	12	103	0	0	12				
Small, live trees (2- 3 feet)	2	0	1	0	0	0	0	0	0	0	0	0	2	11	1	0				
Seedlings (< 1 foot)	19	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0				
Total	91	0	1	0	28	0	0	0	5	0	0	12	124	11	1	12	16	ND	ND	ND

Notes:

Coco Palms 2011: 13, 2016: 6, 2017:6, 2018:10, 2019:6, 2020:7, 2021: 3, 2022: 5, 2023: 4, 2024: 5, 2025: 3

Appendix 13. Population results and trend of breeding seabirds in TRNP April to June 1981 – 2025

Inventory baseline years are underlined. Source: Kennedy 1982, Manamtam 1996, WWF Philippines 1998-2004, and TMO 2004-2025

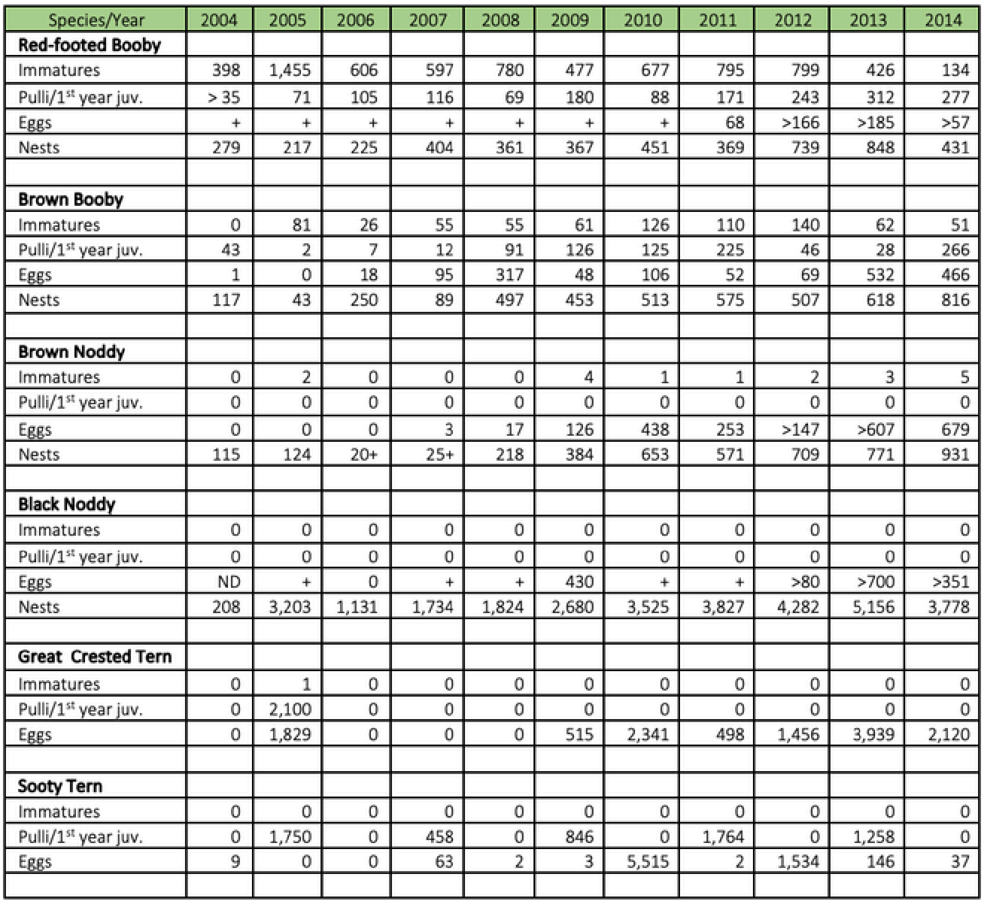


Year/Species	Ground-breeders	Masked Booby	Brown Booby	**Cocos Booby**	Brown Noddy	Great Crested Tern	Sooty Tern	Tree-breeders	Red-Footed Booby	Black Noddy	TOTAL
1981	13,388	150	3,768		2,136	2,264	5,070	156	9	147	13,544
1995	3,949	1	2,060[1]		643	335	910[1]	7,128	0	7,128	11,077
1998	1,744	0	1,716		0	0	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
2025	38,954	2	4,782	3	1,955	17,706	14,506	3,723	337	3,386	42,677
Trend (%)		-97%	27%		-8%	682%	186%		-86%	-52%	215%

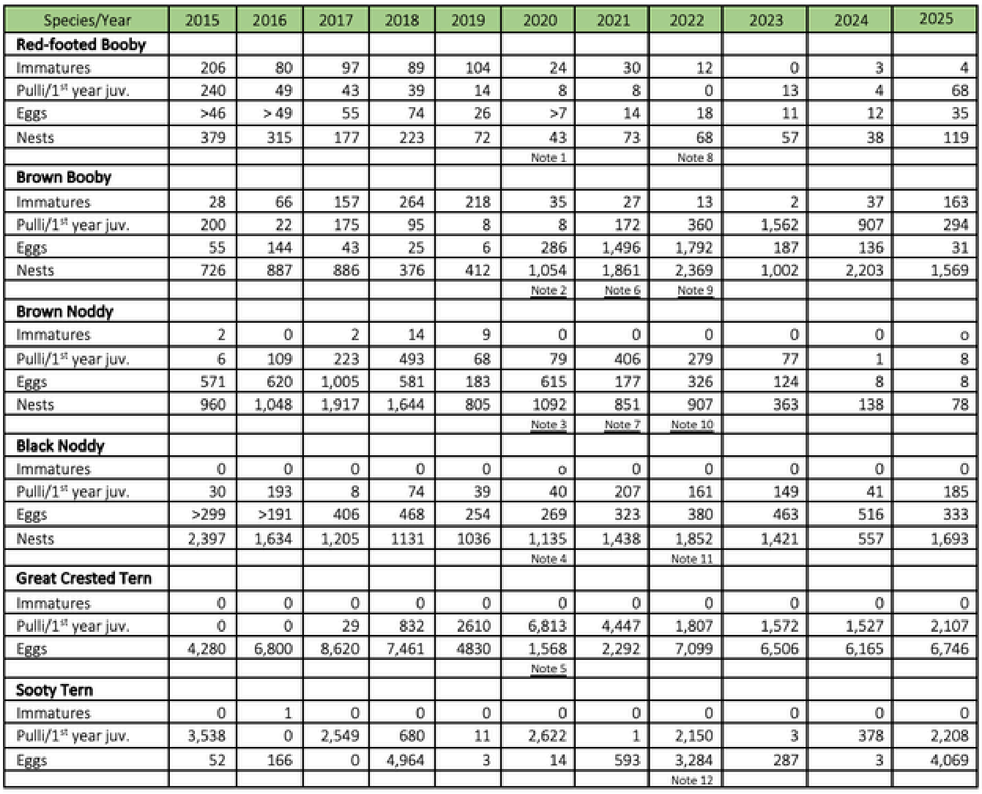
Notes:

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

Appendix 14. Seabird breeding data from Bird Islet and from South Islet, 2nd Quarter (mainly May) 2004-2025



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	2025
Red-footed Booby											
Immatures	206	80	97	89	104	24	30	12	0	3	4
Pulli/1st year juv.	240	49	43	39	14	8	8	0	13	4	68
Eggs	>46	> 49	55	74	26	>7	14	18	11	12	35
Nests	379	315	177	223	72	43	73	68	57	38	119
						Note 1		Note 8			
Brown Booby											
Immatures	28	66	157	264	218	35	27	13	2	37	163
Pulli/1st year juv.	200	22	175	95	8	8	172	360	1,562	907	294
Eggs	55	144	43	25	6	286	1,496	1,792	187	136	31
Nests	726	887	886	376	412	1,054	1,861	2,369	1,002	2,203	1,569
						Note 2	Note 6	Note 9			
Brown Noddy											
Immatures	2	0	2	14	9	0	0	0	0	0	o
Pulli/1st year juv.	6	109	223	493	68	79	406	279	77	1	8
Eggs	571	620	1,005	581	183	615	177	326	124	8	8
Nests	960	1,048	1,917	1,644	805	1092	851	907	363	138	78
						Note 3	Note 7	Note 10			
Black Noddy											
Immatures	0	0	0	0	0	o	0	0	0	0	0
Pulli/1st year juv.	30	193	8	74	39	40	207	161	149	41	185
Eggs	>299	>191	406	468	254	269	323	380	463	516	333
Nests	2,397	1,634	1,205	1131	1036	1,135	1,438	1,852	1,421	557	1,693
						Note 4		Note 11			
Great Crested Tern											
Immatures	0	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	2,107
Eggs	4,280	6,800	8,620	7,461	4830	1,568	2,292	7,099	6,506	6,165	6,746
						Note 5					
Sooty Tern											
Immatures	0	1	0	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	2,208
Eggs	52	166	0	4,964	3	14	593	3,284	287	3	4,069
								Note 12			

Source: WWF Philippines 2004 and TMO 2004 to 2025

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

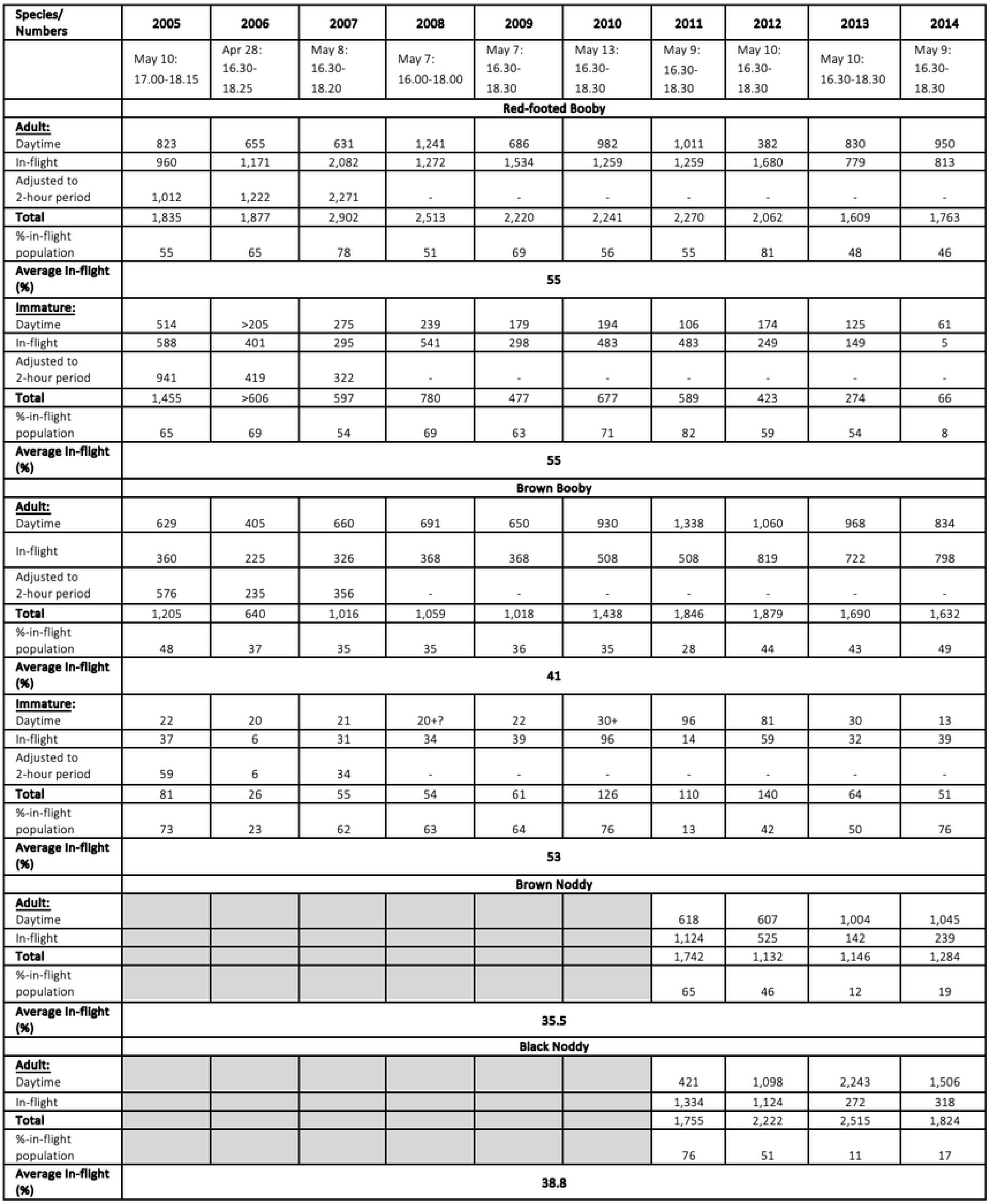
Note 9: 13 and 17 Feb 2021: MPR counted 1 juvenile, 29 pulli and 114 eggs

Note 10: 13 and 17 Feb 2021: MPR counted 140 juvenile, 46 pulli and 372 eggs = 1,116 active breeding adults

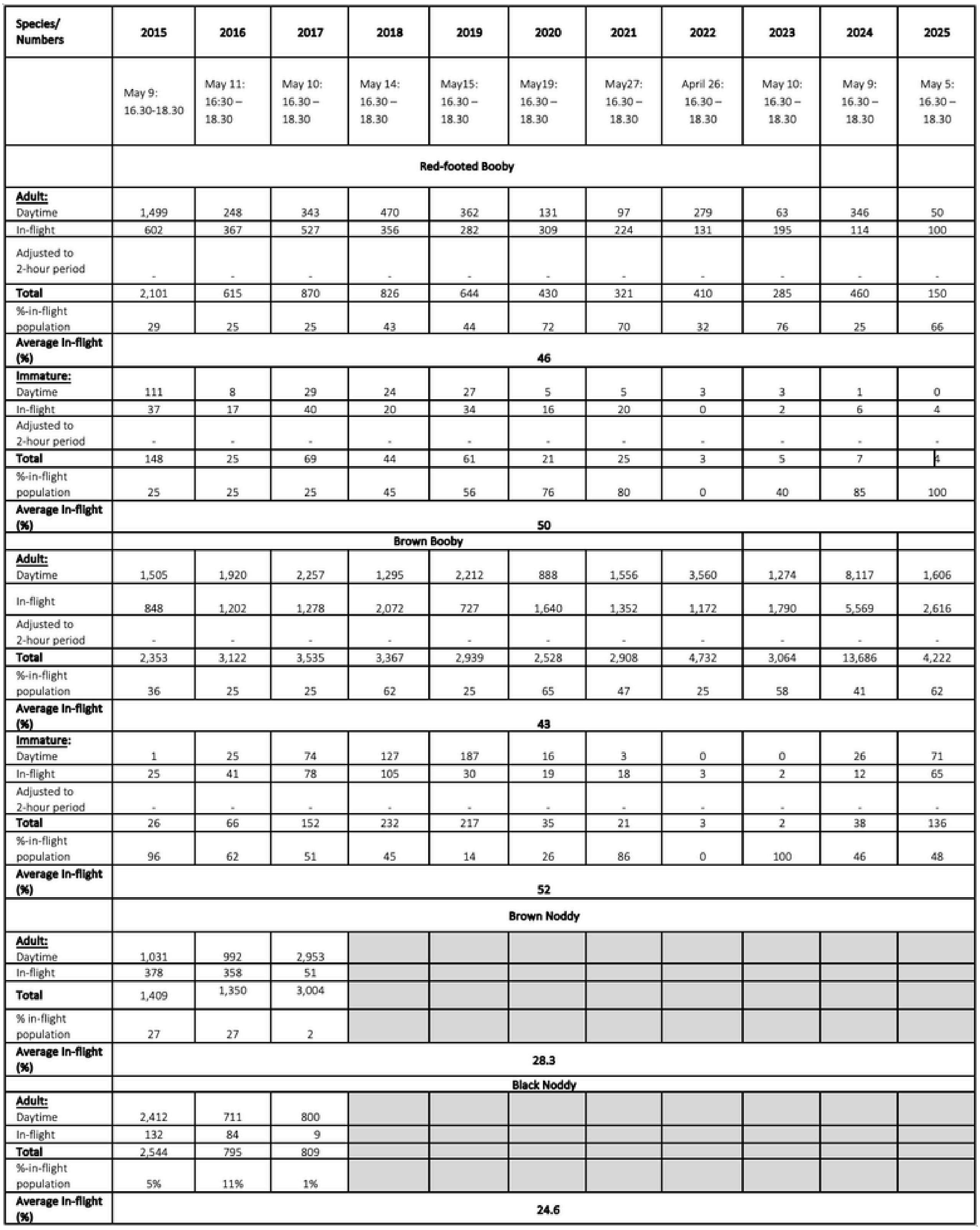
Note 11: MPR counted on 13 and 17 Feb 20221 81 pulli and 325 eggs= 812 active breeding adults

Note 12: MPR counted on 13 and 17 Feb 2022 3,814 eggs, 4 pulli and 1 juvenile = 7,638 adults

Appendix 15. In-flight to roost statistics of boobies and noddies on Bird Islet 2005 to 2025

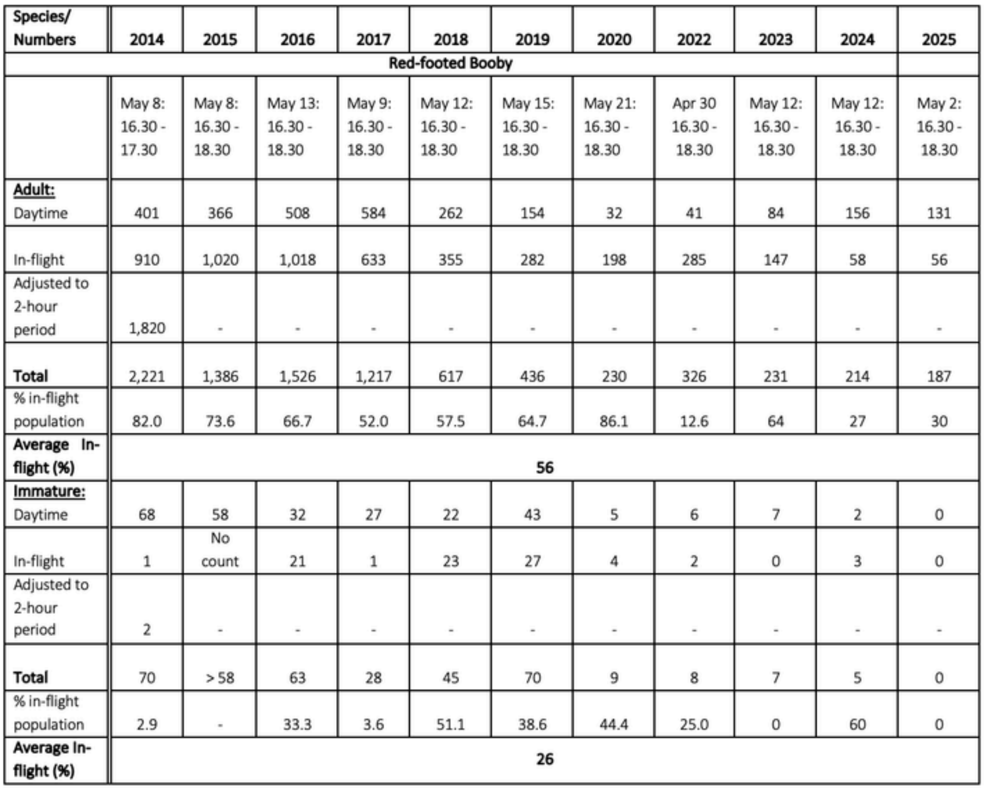


Species/ Numbers	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
	May 10: 17.00-18.15	Apr 28: 16.30-18.25	May 8: 16.30-18.20	May 7: 16.00-18.00	May 7: 16.30-18.30	May 13: 16.30-18.30	May 9: 16.30-18.30	May 10: 16.30-18.30	May 10: 16.30-18.30	May 9: 16.30-18.30
	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 (%)	**55**									
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 (%)	**55**									
	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 (%)	**41**									
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 (%)	**53**									
	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**									

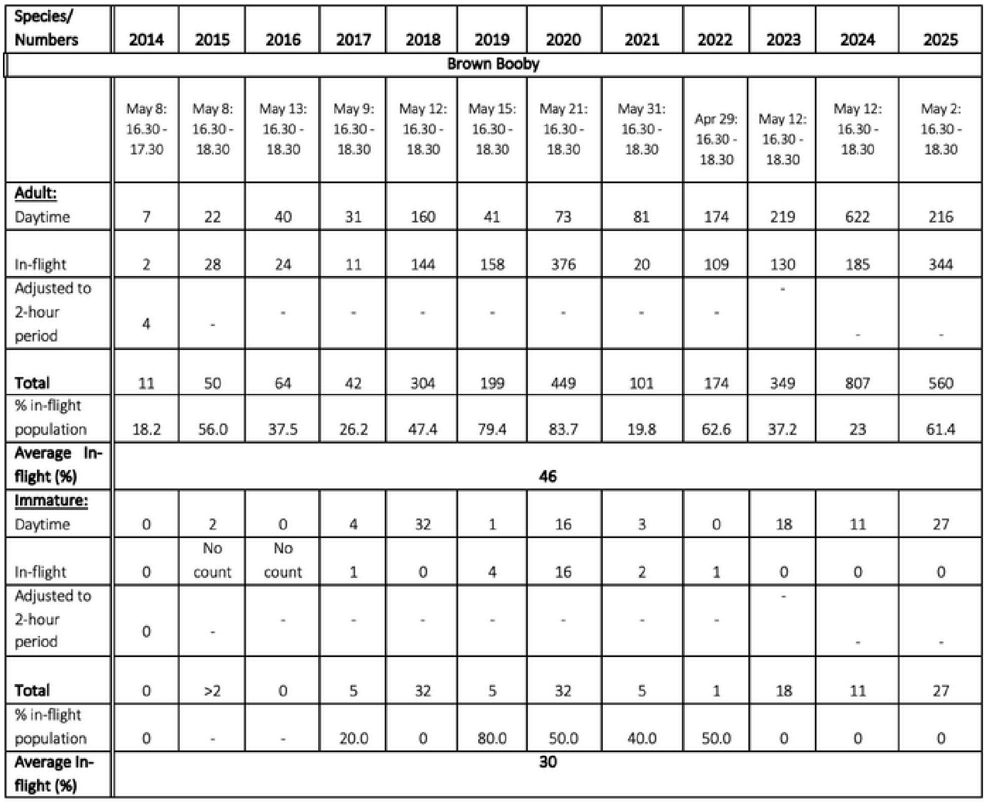


Species/ Numbers	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
	May 9: 16.30-18.30	May 11: 16:30 – 18.30	May 10: 16.30 – 18.30	May 14: 16.30 – 18.30	May15: 16.30 – 18.30	May19: 16.30 – 18.30	May27: 16.30 – 18.30	April 26: 16.30 – 18.30	May 10: 16.30 – 18.30	May 9: 16.30 – 18.30	May 5: 16.30 – 18.30
	Red-footed Booby										
Adult: Daytime	1,499	248	343	470	362	131	97	279	63	346	50
In-flight	602	367	527	356	282	309	224	131	195	114	100
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	-	-	-
Total	2,101	615	870	826	644	430	321	410	285	460	150
%-in-flight population	29	25	25	43	44	72	70	32	76	25	66
Average In-flight (%)	**46**										
Immature: Daytime	111	8	29	24	27	5	5	3	3	1	0
In-flight	37	17	40	20	34	16	20	0	2	6	4
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	-	-	-
Total	148	25	69	44	61	21	25	3	5	7	4
%-in-flight population	25	25	25	45	56	76	80	0	40	85	100
Average In-flight (%)	**50**										
	Brown Booby										
Adult: Daytime	1,505	1,920	2,257	1,295	2,212	888	1,556	3,560	1,274	8,117	1,606
In-flight	848	1,202	1,278	2,072	727	1,640	1,352	1,172	1,790	5,569	2,616
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	4,222
%-in-flight population	36	25	25	62	25	65	47	25	58	41	62
Average In-flight (%)	**43**										
Immature: Daytime	1	25	74	127	187	16	3	0	0	26	71
In-flight	25	41	78	105	30	19	18	3	2	12	65
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	-	-	-
Total	26	66	152	232	217	35	21	3	2	38	136
%-in-flight population	96	62	51	45	14	26	86	0	100	46	48
Average In-flight (%)	**52**										
	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**										

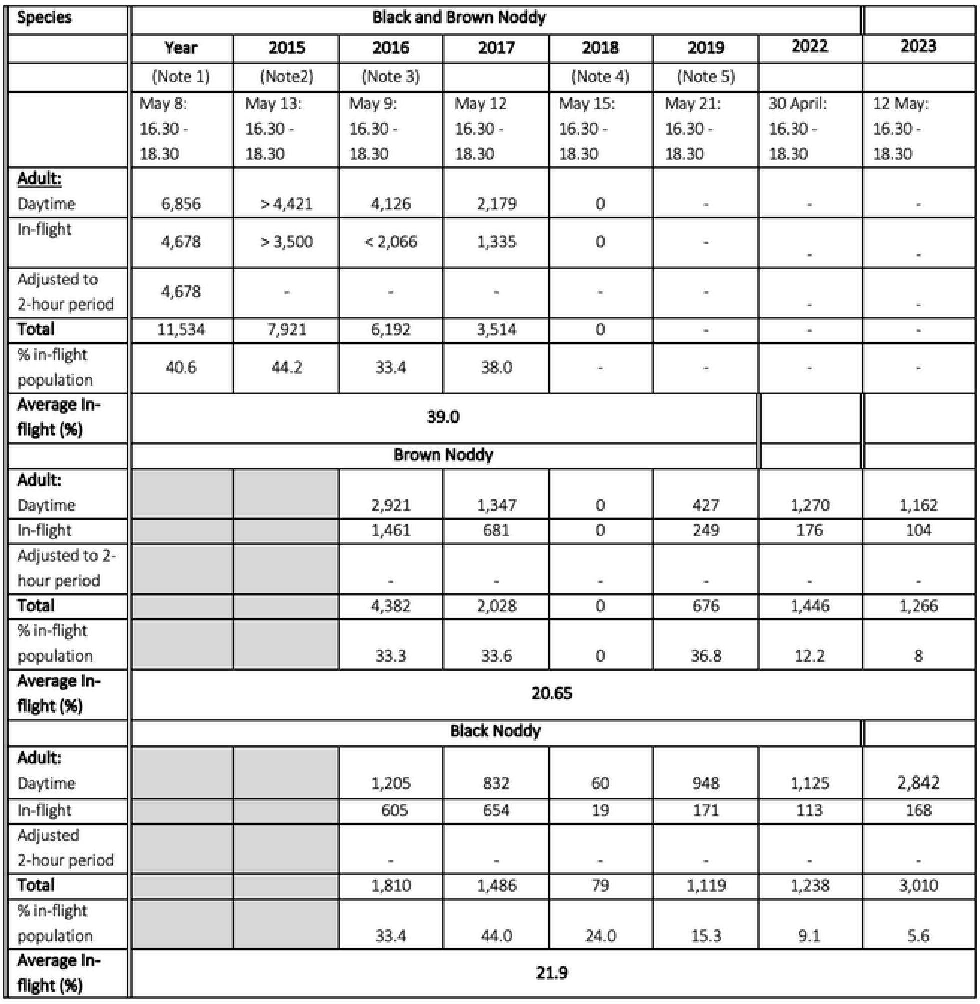
Appendix 16. In-flight to roost statistics of boobies and noddies on South Islet May 2014 to 2025



Species/ Numbers	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2022**	**2023**	**2024**	**2025**
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	May 2: 16.30 - 18.30
Adult: Daytime	401	366	508	584	262	154	32	41	84	156	131
In-flight	910	1,020	1,018	633	355	282	198	285	147	58	56
Adjusted to 2-hour period	1,820	-	-	-	-	-	-	-	-	-	-
Total	2,221	1,386	1,526	1,217	617	436	230	326	231	214	187
% in-flight population	82.0	73.6	66.7	52.0	57.5	64.7	86.1	12.6	64	27	30
Average In-flight (%)	**56**										
Immature: Daytime	68	58	32	27	22	43	5	6	7	2	0
In-flight	1	No count	21	1	23	27	4	2	0	3	0
Adjusted to 2-hour period	2	-	-	-	-	-	-	-	-	-	-
Total	70	> 58	63	28	45	70	9	8	7	5	0
% in-flight population	2.9	-	33.3	3.6	51.1	38.6	44.4	25.0	0	60	0
Average In-flight (%)	**26**										



Species/ Numbers	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
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	Apr 29: 16.30 - 18.30	May 12: 16.30 - 18.30	May 12: 16.30 - 18.30	May 2: 16.30 - 18.30
Adult: Daytime	7	22	40	31	160	41	73	81	174	219	622	216
In-flight	2	28	24	11	144	158	376	20	109	130	185	344
Adjusted to 2-hour period	4	-	-	-	-	-	-	-	-	-	-	-
Total	11	50	64	42	304	199	449	101	174	349	807	560
% in-flight population	18.2	56.0	37.5	26.2	47.4	79.4	83.7	19.8	62.6	37.2	23	61.4
Average In-flight (%)	**46**											
Immature: Daytime	0	2	0	4	32	1	16	3	0	18	11	27
In-flight	0	No count	No count	1	0	4	16	2	1	0	0	0
Adjusted to 2-hour period	0	-	-	-	-	-	-	-	-	-	-	-
Total	0	>2	0	5	32	5	32	5	1	18	11	27
% in-flight population	0	-	-	20.0	0	80.0	50.0	40.0	50.0	0	0	0
Average In-flight (%)	**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 In-flight (%)	**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 In-flight (%)	**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 In-flight (%)	**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 17. Systematic list of other avifauna than resident seabirds observed at Bird Islet, South Islet, and Ranger Station, Tubbataha Reefs Natural Park from May 2 to 6, 2025

Taxonomic treatment and sequence follows IOC/Wild Bird Club of the Philippines 2025. Threat status follows DENR Administrative Order No 2019 – 09: Updated National List of Threatened Philippine Fauna and Their Categories.

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

Status and Abundance (within Sulu Sea) Threat Status (IUCN and National Red List)	Species name	Number of individuals	Locality	Notes
Resident Common LC	Slaty-legged Crake *Rallina eurizonoides*	1	Bird Islet	3-4 May 2025
Resident Common LC	Barred Rail *Hypotaenidia torquata*	4	Bird Islet	3-4 May 2025
Resident Uncommon LC	Watercock *Gallicrex cinerea*	1 female	South Islet	5 May 2025
		1 female	Bird Islet	3 May 2025
Migrant/ Resident Common LC	Black-winged Stilt *Himantopus himantopus*	2	Bird Islet	3-4 May 2025
Migrant Uncommon LC	Ruddy Turnstone *Arenaria interpres*	1	Bird Islet	3-4 May 2025
Migrant Uncommon NT	Grey-tailed Tattler *Tringa brevipes*	1	Ranger Station	3-4 May 2025
		4	Bird Islet	5 May 2025
Migrant Common LC	Common Sandpiper *Actitis hypoleucos*	1	Bird Islet	3-4 May 2025
Migrant Common NT	Red-necked Stint *Calidris ruficollis*	1	Bird Islet	5 May 2025
Migrant Scarce LC	White-winged Black Tern *Chlidonias leucopterus*	1 migrating north	Bird Islet	3-4 May 2025
Resident Uncommon LC	Black-naped Tern *Sterna sumatrana*	4	Bird Islet	3-4 May 20255
Migrant Uncommon LC	Little Tern *Sternula albifrons*	2 passing by	Bird Islet	3-4 May 2025
		2	Ranger Station	2 May 2025

Migrant Common LC	Whiskered Tern	2 (2nd year) bird	Bird Islet	3- 4 May 2025
Migrant Uncommon LC	Lesser Frigatebird *Fregata ariel*	2 adult male 1 adult female 1 immature	Bird Islet	3-4 May 2025
Migrant Uncommon LC	Great Frigatebird *Fregata minor*	1 male 2 female	Bird Islet	4 May 2025
		1 male 1 female 1 juvenile	South Islet	5 May 2025
Migrant	Frigatebird, unidentified *Fregata sp*	6	South Islet	5 May 2025
		2 juvenile	Bird Islet	4 May 2025
Resident, Migrant Common LC	Striated Heron *Butorides atricapilla*	1	Bird Islet	4 May 2025
Resident Uncommon LC	Pacific Reef-egret *Egretta sacra*	5 dark phase 1 nest inside tree cage	Bird Islet	3-4 May 2025
		6 dark phase	South Islet	5 May 2025
Migrant Uncommon VU	Chinese Egret *Egretta eulophotes*	1	Bird Islet	3-4 May 2025
Resident/Migrant Common LC	Little Egret *Egretta garzetta*	1	Bird Islet	3-4 May 2025
Resident/ Migrant Common LC	Eastern Cattle Egret *Ardea coromanda*	1	Bird Islet	3-4 May 2025
Resident Common LC	Collared Kingfisher *Todiramphus chloris*	1	South Islet	5 May 2025
Migrant Common LC	Arctic Warbler/ Kamchatka Leaf Warbler *Phylloscopus borealis/ examinandus*	1	South Islet (on board Navorca)	5 May 2025
Migrant Common LC	Lanceolated Warbler *Locustella lanceolata*	1	Ranger Station	3-4 May 2025
Migrant Common LC	Eastern Yellow Wagtail *Motacilla tschutschensis*	2	South Islet	5 May 2025
		2	Bird Islet	3-4 May 2025
Migrant Common LC	Grey Wagtail *Motacilla cinerea*	1	Bird Islet	3-4 May 2025
Resident Very Common LC	Eurasian Tree Sparrow *Passer montanus*	6	Bird Islet	3-4 May 2025

Appendix 18. Comparison of the landscape and habitats seen from the Permanent Photo Documentation Sites on Bird Islet and South Islet, May 2004 and May 2025

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: 5 May 2025

Photo credit: Kymry Delijero

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 name code: BI 02

Comments: 4 shots

Date: 11 May 2024

Photo credit: Rowell Alarcon

Coordinates: N8.92972° E119.99637°

Viewing angle for photo: facing S 165º

Film no: 22, 23, 24

Comments: 3 shots panoramic view

Date: May 7, 2004

Photo name code: BI 03

Photo no (camera):

Photo name code: BI 03

Date: 5 May 2025

Photo credit: Kymry Delijero

Coordinates: N8.93130° E119.99701°

Photo Doc Site NI No. 04 - 2004

Viewing angle for photo: facing E 067º

Film no: 14

Photo no (negative):

Photo name code: BI 04

Photo no (camera):

Comments: 1 shot Plaza

Date: May 7, 2004

Photo name code: BI 04

Photo credit: Rowell Alarcon

Date: 11 May 2024

Coordinates: N8.93005° E119.99656°

South Islet:

Date: May 2004

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 no (camera): 01

Date: 2 May 2025

Comments: single shot including new lighthouse at the background;

Coordinates for new photo doc site was taken in 2019

Photo no (camera): IMG_7302

Photo credit: Rowell Alarcon

Coordinates: N8.74901° E119.81967°

Appendix 19. 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, Soutwest 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 Southwest 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'
2025	T38	North Atoll	22-Jun-25	Amos Reef, N. Atoll, not too far from the Ranger station
2025	T39	North Atoll	22-Jun-25	Ranger Buoy No. 2, North Atoll
2025	T40	North Atoll	23-Jun-25	Washing Machine
2025	T41	North Atoll	23-Jun-25	Seafan Alley
2025	T42	North Atoll	24-Jun-25	Wall Street (southeastern part of North Atoll)
2025	T43	South Atoll	24-Jun-25	Black Rock, northeastern South Atoll
2025	T44	Lagoon, South Atoll	25-Jun-25	Southern part of the lagoon in the South Atoll. Max depth 25' abundant staghorn coral, rock outcroppings and fine sand
2025	T45	Lagoon, South Atoll	25-Jun-25	Southern part of the lagoon, North Atoll. Max depth 45', abundant staghorn coral, rock outcroppings, and fine sand.
2025	T46	Jessie Beazley Reef	26-Jun-25	Jessie Beazley, northwest side