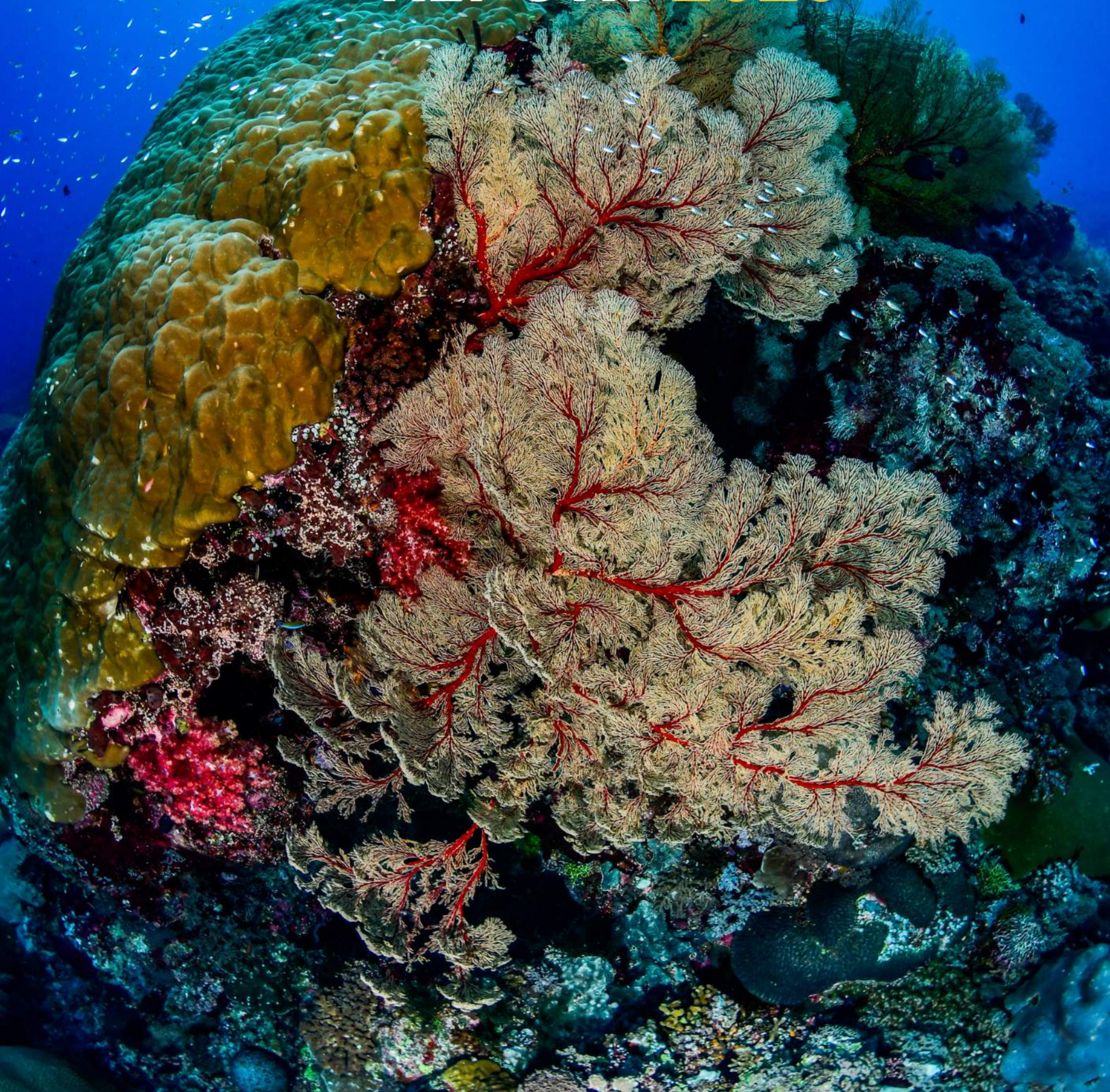
TUBBATAHA REEFS NATURAL PARK
WORLD HERITAGE SITE

ECOSYSTEM RESEARCH & MONITORING REPORT 2023



Tubbataha Reefs Natural Park
Ecosystem Research and Monitoring Report 2023

Editors:

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EXECUTIVE SUMMARY

Tubbataha Reefs Natural Park (TRNP) is the Philippines' largest no-take marine protected area, encompassing 97,030 hectares. It serves as a crucial sanctuary for marine life and supports over 700 species of fish and 360 species of corals. Tubbataha has more than twenty (20) years of fish, coral, and seabird data, providing a critical long-term basis for evaluating reef health and the effectiveness of conservation initiatives. This year, on top of the annual monitoring of benthos, coral recruits, fish, seabirds, and water quality, surveys on cetaceans and marine turtles were also conducted. The sustained monitoring of Tubbataha's ecosystems enables adaptive management, conservation of threatened species, and preservation of its ecological integrity.

Reef Benthos Monitoring. Hard coral cover in shallow areas of the monitoring sites (25.6%) was significantly lower than the regional average. This value has been declining at a rate of 1.3% annually since 2012. While deeper reef areas showed stable hard coral cover (30.1%), specific shallow sites like Site 3 (near Delsan Wreck) and Jessie Beazley Reef have experienced sharper declines, possibly due to recent typhoons and potential chronic stressors. Further investigation is needed to pinpoint the exact causes of the decline. This may involve establishing monitoring stations within lagoons, measuring juvenile coral health, and collecting additional water quality data.

Coral recruitment. The average density of coral recruits in the shallow areas decreased this year (56.3 ind/m^2), but it has generally increased by 1.76 ind/m^2 annually over the past years. This increase may be due to open spaces created by typhoon damage, providing suitable habitat for new coral growth. In contrast, coral recruit density in the deep areas showed a decline of 5.3 ind/m^2 annually over the past five years. This could be due to limited suitable substrate or factors like strong currents and predators.

Reef Fish Monitoring. Fish populations in TRNP were generally in good condition, with a total of 303 species identified this year. Notably, deep reef areas exhibited higher species richness, fish density, and fish biomass compared to shallow areas. Fish density remained stable across depths for the past eleven (11) years. However, a decline in fish biomass (25.75 g/m^2 annually) in the deep areas was observed, primarily due to fluctuations in encounters with mobile pelagic species. Factors like food availability, predator behavior, and changing environmental conditions likely contribute to these variations.

Further research is recommended to understand seasonal fish population patterns and the potential impacts of declining coral cover and rising sea temperatures, particularly on temperature-sensitive species.

Ship Grounding Sites. The Min Ping Yu grounding site exhibited ongoing recovery, with stable coral recruit density despite the presence of loose rubble in some areas.

Fish biomass remained stable except for a decline in schooling fish in the deep areas, mirroring trends observed in other monitoring sites.

The USS Guardian grounding site showed a slow recovery in hard coral cover, possibly due to broader disturbances. However, coral recruit density increased and is dominated by resilient coral genera like *Favites, Goniastrea*, and *Merrulina*. Fish populations at this site remain stable.

Fish species assessment. A comprehensive fish survey identified 38 new species in Tubbataha, with 25 found exclusively in the North Atoll lagoon. This significantly expanded the record of the park's known fish diversity. Since the first fish inventory in 2018, 103 species have been added to the fish species list in Tubbataha, bringing the total number of fish species to nearly 800. The high species richness within lagoons highlights the need for further exploration of these unique habitats.

Seabird Monitoring. A total of 30,120 adult individuals of seven breeding seabird species were recorded in May 2023. This was 23% lower compared to last year's count. The difference was mainly due to the variation in the breeding period of Sooty Tern and Brown Noddy. The report recommends improved management strategies for these vulnerable species, alongside adjustments to data collection methods.

Water Quality Monitoring. Water quality in TRNP met all national standards for protected waters. This is likely due to park regulations and its designation as a Particularly Sensitive Sea Area. However, sea surface temperatures have been gradually rising over the past three years, potentially linked to the recent Asian Heatwave. Continued monitoring of water quality parameters, including temperature, is crucial to understand its potential impacts on coral health.

Marine Turtle Monitoring. A study of marine turtles in the park revealed a significant decrease in the proportion of juvenile green turtles compared to sub-adults and adults. Only 25 out of 200 captured turtles were juveniles, suggesting potential issues with juvenile recruitment. Possible explanations include by-catch or poaching before the turtles reach TRNP. Collaborative research efforts are needed to investigate the root causes of this decline and ensure the long-term health of the marine turtle population.

Cetacean Survey. Five cetacean species were documented in the recent survey in the park. Among the five, spinner dolphins were the most frequently sighted. Direct comparisons with past surveys were challenging due to changing environmental conditions. Further surveys across different seasons are recommended to understand seasonal patterns affecting their presence in the park. Investigating the low productivity observed in the Sulu Sea may also be valuable for understanding its potential impacts on cetacean presence within TRNP.

Marine Park Rangers' Research Report. Data collected by marine park rangers complements the research and monitoring program in TRNP. Rangers conducted turtle surveys, beach profiling, and coral bleaching monitoring in 2023. These efforts provided valuable insights into trends that may not be captured in the annual monitoring. Below are the highlights of the MPR research report:

- In the turtle surveys in June 2023, 105 turtles were recorded. Most sightings involved single individuals, with some groups of up to four observed;
- Beach profiling in Bird Islet revealed significant sand deposits on the north and southwest sides in November, with minimal change in the south and slight erosion in the northeast;
- Coral bleaching was observed in October-November around the ranger station, primarily affecting branching coral genera like *Acropora* and *Pocillopora*. This coincided with NOAA's "bleaching warning" for the region and was likely caused by extreme low tides. No bleaching was observed elsewhere in the park.

INTRODUCTION

Coral reefs are among the most biodiverse and valuable ecosystems on the planet, covering less than 1% of the ocean floor, but are home to over 25% of all marine species. They provide a wide range of benefits to both humans and nature, including buffering coastlines from storm surges and waves (Guanel et al. 2016; Hongo et al. 2018), providing habitat for numerous marine life crucial for food security and coastal economies (Cabral and Geronimo 2018; Teh et al. 2013), and supporting tourism, recreation, and livelihood (Schmitt 2008; Teh et al. 2013).

However, coral reefs are highly sensitive to the impacts of climate change, which poses the greatest threat to their survival (Schmitt 2008; Berkelmans et al. 2004). Climate change is causing ocean temperatures to rise and ocean acidification to increase (Gleckler et al. 2012), which could damage and kill coral reefs (Bahr et al. 2018; Anderson et al. 2019).

The Kunming-Montreal Global Biodiversity Framework 30x30 agenda is a global initiative to conserve at least 30% of the world's lands and oceans by 2030 (CBD 2022). Target 3 highlights that 30% of marine ecosystems, including coral reefs are effectively managed, conserved, and restored. Protecting coral reefs is essential in addressing the pressing issues of climate change and biodiversity loss in the marine environment (Osborne et al. 2017; Shaver et al. 2022).

Fully protected marine areas (MPAs) are a cost-effective and practical strategy to enhance coral reef resilience against climate change (Simard et al. 2016; Heron et al. 2017; Roberts et al. 2017). MPAs provide a haven for coral reefs and other marine life, allowing them to recover from disturbances and adapt to climate change impacts. Well-managed MPAs can enhance coral reef resilience to environmental stressors, such as those caused by climate change (Bonaldo et al. 2017; Chiriko et al. 2017; Osuka et al. 2021; Rojo et al. 2019). By reducing human stressors and allowing coral reefs to recover, MPAs can help to ensure that these vital ecosystems remain resilient in the face of a changing climate.

Tubbataha Reefs Natural Park (TRNP) is an example of a highly diverse and near-pristine coral reef (Claudino-Sales 2018). The park is an example of how MPAs can be used to create resilient coral reefs that can withstand the impacts of climate change.

TRNP has been conducting ecosystem monitoring since 1999 to determine long-term trends in the condition of the reef and assess its response to changed, such as disturbances like coral bleaching, ship grounding, and storms. The Ecosystem Research and Monitoring strategy of TRNP is specifically aimed at achieving the following goals:

1) determine ecosystem health;
2) generate sound scientific information;
3) provide basis for formulating strategies; and

4) measure biophysical indicators of management effectiveness.

This report presents an analysis of the current condition and temporal trends in fish, benthos, and seabird populations. It also provides an overview of selected water quality parameters that may impact the health of the reef. Additionally, this report details the results of the marine turtle monitoring study conducted with the Marine Research Foundation, led by Dr. Nicholas Pilcher. Finally, we included the results of the cetacean survey, led by WWF – Philippines, conducted after more than a decade.

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1. Reef Benthos

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OVERVIEW

Coral reefs cover only 0.2% of the ocean seafloor, but they support at least 25% of the world's marine species. It is estimated that the ecosystem services coral reefs provide amounts to USD 2.7 trillion per year.

From 2009 to 2018, 14% of the world's coral reefs were degraded due to recurring large-scale coral bleaching events, storms, coastal development, pollution, and unsustainable fishing. The 2020 Status of Coral Reefs of the World Report of the Global Coral Reef Monitoring Network (Souter et al. 2021) revealed that among all regions assessed, only the Coral Triangle Region, containing 30% of the world's coral reefs, has shown recovery from past disturbances, e.g., coral bleaching events. Nevertheless, threats to coral reefs remain, and in order to increase the probability of recovering from future environmental impacts, high coral cover and diversity must be maintained.

Regular reef monitoring is one approach implemented in the Tubbataha Reefs to determine overall reef health and assess the efficacy of management actions. In the 2022 TRNP Reef Benthos Monitoring Report, declines in hard coral cover in the monitoring stations were recorded for both shallow and deep areas. This report presents the current status of the monitoring stations in TRNP and the spatio-temporal patterns since 2012.

METHODS

Study Sites

TMO monitors a total of five sites in the North Atoll, South Atoll, and Jessie Beazley Reef to assess fish and benthic communities. Twelve monitoring stations are surveyed following a hierarchical scheme described by van Woesik et al. (2019) (Figure 1). Each site has two stations about 200 meters apart. Ten of the 12 monitoring stations have been surveyed annually since 2012, while Stations 5A and 5B were surveyed in 2021 and 2022, respectively. For station locations, refer to Figure 1.

To study reef conditions at different depths, the shallow (~5 meters) and deep (~10 meters) sections of each station were surveyed, except at Stations 5A and 5B, where only shallow stations were established due to reef characteristics. Unlike the other sites, Site 5 was distant from the walls, preventing the establishment of transects at 10 meters. Since 2013, TMO monitored the Min Ping Yu (MPY) and USS Guardian (USSG) ship grounding sites to track changes in fish and benthos over time.

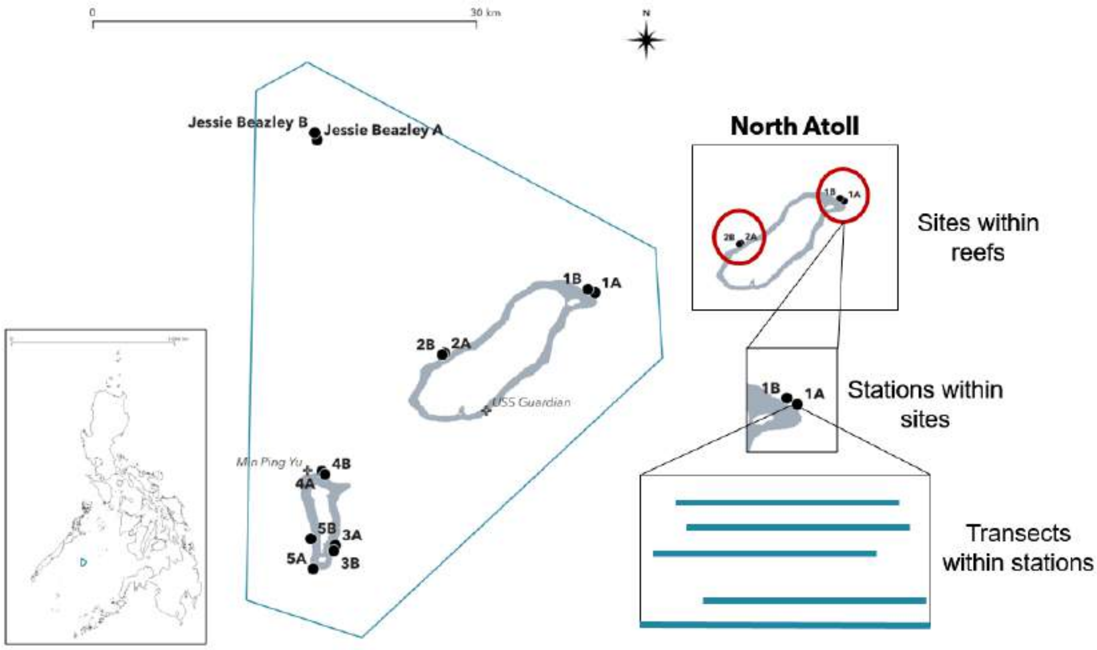

Figure 1. Map of Tubbataha showing the hierarchical sampling method of van Woesik et al. (2019).

Data collection

Shallow monitoring stations were 75m x 25m in area, located on the shallow upper reef slope at a depth range of 2 to 6 meters, and were sampled using the photo-transect method detailed in Luzon et al. (2019). The deepest limit of each station was defined by deploying a 75-m belt transect (transect 1) following the reef's contour. Four 50-m transects were then deployed on the shallower side of transect 1 following randomized x,y-meter-coordinates, where the transects were deployed parallel to one another and at least 1-m distance from the preceding transect. At least 50 photographs were taken at 1-m intervals along the shallow side of each transect using a Sony Alpha camera enclosed in an Ikelite underwater housing and mounted on a 1-m x 1-m x 1.2m aluminum monopod. A randomized x-coordinate (in meters) was used to determine the starting point for the 50 photographs taken along transect 1. A total of 250 photographs were processed from each monitoring station.

Additional photos of the reef, coral colonies, non-coral benthos, and abiotic substrates were taken to aid in the description and documentation of the monitoring stations. Photographs documenting coral recruits and turf algae were also taken for future processing and analysis. At least one permanent 4m x 4m quadrat was annually photographed at each monitoring site. This year, a new permanent quadrat was established in Station 5B.

Reef benthos in deep areas of the monitoring stations (10-m depth) were sampled by deploying four 20-meter transects, 5 meters apart, along the same depth and following the reef contour. Photographs were taken at 1-m intervals on the shallower side of each transect using Canon G7X cameras, enclosed in underwater housings, mounted on 1-m x 1-m x 1.2m aluminum monopods. A total of 80 images were processed from each deep monitoring station.

The USS Guardian grounding site in the South Atoll and the Min Ping Yu grounding site in the North Atoll (see Figure 1) have been monitored annually since 2014, a year after the two grounding incidents occurred. Three 4-m x 4-m fixed quadrats were established in each ship grounding site to represent an area directly impacted by the grounding incident, an adjacent area with less impact, and a control plot within the same reef area.

Each quadrat was photographed using the same camera-monopod set-up as the shallow monitoring stations. The entire quadrat was photographed in a lawnmower pattern, with images having at least 50% overlap. Thirty images from each quadrat were randomly selected for processing and analysis. For future processing and analysis efforts, each quadrat was also photographed in a lawnmower pattern using the Timelapse function (1 photo per second) of two GoPro Hero 9 units mounted on an aluminum base 1-m apart from each other.

Data processing

Reef benthos in transect and quadrat images were identified using Coral Point Count with Excel extensions (CPCe) 4.1 (Kohler and Gill 2006). Ten random points were overlaid on each image, where the benthos beneath each point were identified and scored into one of six benthic categories: hard coral (HC), algal assemblage (i.e., carbonate rock with thin layers 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 (OB). Hard corals were further classified into 59 hard coral Taxonomic Amalgamation Units (TAUs), which are genus-growth form combinations optimized for the identification of corals in transect images. Percent cover of benthos and average coral TAU diversity (referred to as "coral generic diversity" in Licuanan et al. 2019) were reported.

Data analysis

Hard coral cover (HCC) and coral TAU diversity categories were described at the station, site, atoll, and location level, following the scales introduced by Licuanan et al. (2019; Figure 2). Significant changes in benthic cover over time were identified using simple linear regression (LR) and one-way repeated measures analysis of variance (ANOVAR). LR was also used to determine the direction and rate of change (i.e., slope) of HC, AA, and sponge (SP) cover from 2012 to 2023. RStudio (RStudio Team 2020) and PAST 3.26 (Hammer et al. 2001) were used to perform statistical analyses. The data were visualized using RStudio (RStudio Team 2020) and QGIS (QGIS.org 2022).

RESULTS

Present conditions

Shallow areas

At the location level, the reefs of Tubbataha (Sites 1, 2, 3, and 4) had an average HCC of 25.6% and an average TAU density of 19.8 TAUs in 2023 (Table 1). The HCC and TAU density values are less than the average (HCC – 28.4%; TAU density – 20.8) reported for fringing reefs in the Sulu Sea bioregion (Licuanan et al. 2019).

At the atoll level, the North Atoll (Sites 1 and 2) had higher HCC and more TAUs than the South Atoll (Sites 3 and 4) (Table 1). Additionally, the South Atoll HCC moved down from Category C in 2022 (24.7%) to Category D (19.5%) in 2023.

At the site level, Site 1 had the highest HCC (36.5%) and TAU density (24.9 TAUs) among the sites (Table 1), while Site 3 had the lowest of both (13.3% HCC and 14.3 TAUs) and had the largest decline in HCC over one year. Site 1 qualified as a Category B reef in 2023 in terms of HCC, an improvement from its 2022 Category C classification. Meanwhile, Sites 3 and Jessie Beazley declined one category in terms of HCC to Category D and Category C, respectively.

At the station level, Station 5A had the highest HCC (48.3%), while Station 3B had the lowest HCC (8.3%) among the stations in 2023 (Table 1, Figure 2). Station 5A, which improved in terms of HCC category from 2022, and Station 1B were the only sites to qualify as Category A reefs. Meanwhile, three stations declined one category in terms of HCC: Stations 3B and Jessie Beazley A to Category D and Station 4B to Category C. In terms of TAU density, Station 5B had the highest TAU density (27.2 TAUs) among the stations, while Station Jessie Beazley A had the lowest (8.8 TAUs) (Table 2, Figure 2). Notably, while Station 3B declined in terms of HCC, its TAU density improved to qualify for Category C from Category D in 2022. Additionally, three other stations improved in terms of TAU density: Stations 2B and 5A from Category C to Category B and Station 5B from Category B to Category A. The rest of the monitoring stations remained the same in terms of HCC and TAU density categories (Figure 2).

Table 1. Summary table for hard coral over (HCC), TAU density, rates of change in HCC, and differences in HCC among years in the shallow areas. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated. ns = not significant (p>0.05)

	Average % HCC (± SE) 2023		Average TAU richness (± SE) 2023		Rate of change in HCC (Linear Regression) 2012-2023	Difference among years in HCC (ANOVAR; p<0.05 is significant) 2012-2023
	% HCC	Category	TAU Richness	Category		
TUBBATAHA (with JB without Site 5)	25.6 ± 1.8	C	19.8 ± 1.0	C	⬇ (-1.3%)	p < 0.001
TUBBATAHA (without JB, Site 5)	24.7 ± 1.9	C	20.5 ± 1.0	C	⬇ (-0.9%)	p < 0.001
ATOLL Level						
North Atoll	30.0 ± 2.5	C	22.3 ± 0.9	C	ns	ns
South Atoll (without Site 5)	19.5 ± 2.5	D	18.6 ± 1.6	C	⬇ (-2.1%)	p < 0.001
SITE Level						
Site 1	36.5 ± 2.8	B	24.9 ± 0.8	B	ns	ns
Site 2	23.5 ± 3.1	C	19.8 ± 1.1	C	⬆ (+0.6%)	p < 0.05
Site 3	13.3 ± 2.9	D	14.3 ± 2.7	D	⬇ (-3.7%)	p < 0.001
Site 4	25.6 ± 3.1	C	21.8 ± 1.0	C	ns	ns
Jessie Beazley	29.1 ± 4.2	C	17.3 ± 3.0	D	⬇ (-3.7%)	p < 0.001
STATION Level						
Station 1A	28.5 ± 0.7	C	23.8 ± 0.9	B	⬇ (-1.1%)	p < 0.005
Station 1B	44.4 ± 2.1	A	26.0 ± 1.3	B	⬆ (+0.8%)	p < 0.05
Station 2A	14.5 ± 1.1	D	17.0 ± 0.3	D	ns	ns
Station 2B	32.5 ± 1.5	C	22.6 ± 1.2	B	⬆ (+1.1%)	p < 0.001
Station 3A	18.4 ± 2.3	D	21.0 ± 1.1	C	⬇(-1.1%)	p < 0.001
Station 3B	8.3 ± 4.4	D	9.6 ± 3.9	D	⬇(-4.7%)	p < 0.001
Station 4A	18.4 ± 1.9	D	20.2 ± 1.4	C	⬇(-0.9%)	p < 0.005
Station 4B	32.8 ± 3.5	C	23.4 ± 1.3	B	ns	ns
Station 5A	48.3 ± 1.0	A	25.0 ± 1.8	B	ns	ns
Station 5B	42.3 ± 1.7	B	27.2 ± 1.8	A	ns	ns
Jessie Beazley A	17.7 ± 2.0	D	8.8 ± 1.2	D	⬇(-5.0%)	p < 0.001
Jessie Beazley B	40.4 ± 3.1	B	25.8 ±1.4	B	ns	ns

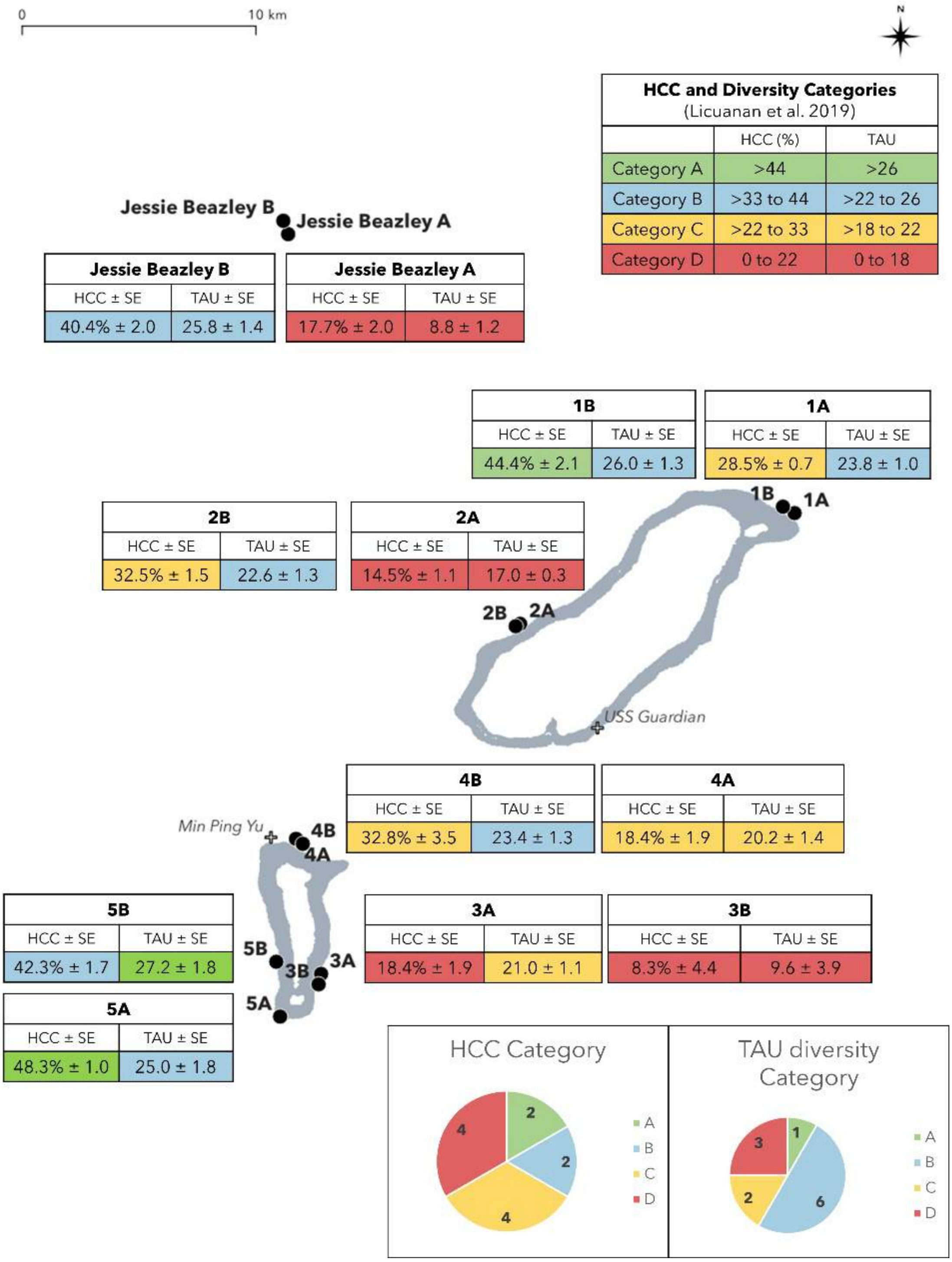

Figure 2. Map of Tubbataha monitoring stations labeled according to hard coral cover (HCC) category and TAU diversity category (Licuanan et al. 2019). 2023 values for average HCC and TAU diversity (± SE) of each station are indicated.

The reefs of Tubbataha had an average algal assemblage (AA) cover of 60.4% in 2023, higher than in 2022 (51.6%). Station level AA cover ranges from as high as 79% in Station 3B to as low as 33% in Station 1B (Table 2). Notably, Station 3A had the highest increase in AA cover, from 49.3% in 2022 to 75.2% in 2023, while Station 5B AA cover decreased from 47.4% in 2022 to 44.8% this year.

Sponges were also observed in all monitoring stations, with an average percent cover of 3.6% (Table 2). At the station level, SP cover ranged from 10.0% in Station 4B to 0.7% in Jessie Beazley A (Table 2). Besides Jessie Beazley A, whose SP cover increased from 2022 to 2023, all monitoring stations experienced a decrease in SP cover over a year, the largest of which was in Station 3B which went from 9.7% in 2022 down to 1.1% in 2023.

Table 2. Summary table for algal assemblage cover (AA), sponge cover (SP), rates of change in AA and SP, and differences in AA and SP among years in the shallow areas. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated. n= not significant (p>0.05)

	AA			SP		
	Average % AA (± SE) 2023	Rate of change in AA (Linear Regression) 2012-2023	Difference among years in AA (ANOVAR; p<0.05 is significant) 2012-2023	Average % SP (± SE) 2023	Rate of change in SP (Linear Regression) 2012-2023	Difference among years in SP (ANOVAR; p<0.05 is significant) 2012-2023
TUBBATAHA (with JB without Site 5)	60.4 ± 2.5	⬆ (+1.5%)		3.6 ± 0.5	⬆ (+0.4%)	
SITE Level						
Site 1	42.4 ± 3.3	⬆ (+0.8%)	p < 0.05	3.7 ± 0.7	⬆ (+0.4%)	p < 0.001
Site 2	62.0 ± 3.7	ns	ns	4.7 ± 0.8	⬆ (+0.6%)	p < 0.001
Site 3	77.1 ± 3.6	⬆ (+2.7%0	p < 0.001	1.4 ± 0.3	⬆ (+0.4%)	p < 0.005
Site 4	64.8 ± 5.0	ns	ns	6.3 ± 1.6	⬆ (+0.7%)	p < 0.001
Jessie Beazley	55.8 ± 6.5	⬆ (+3.2%)	p < 0.001	1.9 ± 0.5	ns	ns
STATION Level						
Station 1A	51.9 ± 0.5	⬆ (+1.3%)	p < 0.05	4.1 ± 1.3	⬆ (+0.5%)	p < 0.001
Station 1B	33.0 ± 19	ns	ns	3.4 ± 0.8	⬆ (+0.4%)	ns
Station 2A	71.3 ± 1.9	⬆ (+1.2%)	ns	3.4 ± 0.8	⬆ (+0.4%)	p < 0.005
Station 2B	52.7 ± 3.2	ns	ns	6.6 ± 1.0	⬆ (+0.8%)	p < 0.001
Station 3A	75.2 ± 2.5	⬆ (+2.0%)	p < 0.001	1.7 ± 0.4	⬆ (+0.4%)	p < 0.005
Station 3B	79.0 ± 7.1	⬆ (+3.5%)	p < 0.001	1.1 ± 0.4	ns	ns
Station 4A	76.8 ± 3.0	⬆ (+1.3%)	p < 0.05	2.5 ± 0.7	⬆ (+0.3%)	p < 0.001
Station 4B	52.9 ± 5.8	ns	ns	10.0 ± 2.0	⬆ (+1.0%)	p < 0.001
Station 5A	40.2 ± 2.7	ns	ns	2.2 ± 0.7	ns	ns
Station 5B	44.8 ± 3.9	ns	ns	3.3 ± 1.2	ns	ns
Jessie Beazley A	74.8 ± 1.8	⬆ (+4.6%)	p < 0.001	0.7 ± 0.4	ns	ns
Jessie Beazley B	36.8 ± 2.4	⬆ (+0.7%)	ns	3.1 ± 0.4	ns	ns

Deep areas

The average HCC in the deep areas of Tubbataha Reefs is 30.1% and the average TAU density is 14 TAUs. HCC in 2023 increased by 7% compared to 2022 (23%), while TAUs density remained relatively the same (14.5 TAUs in 2022). North Atoll had a slightly higher HCC compared to South Atoll, which is consistent with last year's results. Furthermore, HCC in the North Atoll increased by 10% from 2022, which was mainly influenced by the 14.9% increase in Site 2. However, there was no significant change in HCC at the atoll level from 2017 to 2023 (Table 3).

At the site level, Site 1 had the highest HCC in 2023, which is consistent with last year. Site 3 had the lowest HCC value this year (26.1%) but was not far behind the percentage cover of the other four sites (See Table 3). Overall, there was no significant change in HCC in all the sites from 2017 to 2023. TAU density ranged from 10.8 TAUs in Jessie Beazley to 15.8 TAUs in Site 4.

At the station level, the highest HCC was recorded in Station 1A, while the lowest was in Jessie Beazley A. Hard coral cover in Station 1A increased by almost 20% from last year, while an 18.8% increase was recorded in Station 2A. Among the stations, only Station 1B exhibited a significant decline at a rate of -1.5% per year from 2017 to 2023.

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

	Average % HCC (±SE) 2023	Average TAU density (±SE) 2023	Rate of change in HCC (Linear Regression) 2017-2023	Difference Among Years in HCC (ANOVAR; p<0.05 is significant) 2017-2023
TUBBATAHA (without JB)	30.1 (±1.9)	14 (± 0.7)	ns	p<0.001
ATOLL Level				
North Atoll	31.7 (± 2.9)	14.4 (± 0.8)	ns	p<0.001
South Atoll	28.4 (± 2.5)	13.8 (± 1.2)	ns	ns
SITE Level				
Site 1	36.3 (± 4.4)	14.6 (± 1.5)	ns	ns
Site 2	27.2 (± 3.1)	14.3 (± 0.5)	ns	p<0.0001
Site 3	26.1 (± 1.7)	11.8 (± 1.1)	ns	ns
Site 4	30.7 (± 4.8)	15.8 (± 2)	ns	p<0.01
Jessie Beazley	26.6 (± 5.1)	10.8 (± 1.2)	ns	ns
STATION Level				
Station 1A	42.5 (± 6.2)	15.8 (± 3)	ns	p<0.001
Station 1B	30 (± 5.2)	13.5 (± 0.6)	⬇ -1.5%	ns
Station 2A	30.2 (± 4.4)	14.3 (± 1.1)	ns	p<0.001
Station 2B	24.1 (± 4.4)	14.3 (± 0.3)	ns	p<0.05
Station 3A	26.5 (± 3.1)	12.5 (± 1.8)	ns	ns

Station 3B	25.7 (± 1.7)	11 (± 1.4)	ns	ns
Station 4A	24.7 (± 8.6)	12.8 (± 3.6)	ns	ns
Station 4B	36.8 (± 3.2)	18.8 (± 0.9)	ns	p<0.01
Jessie Beazley A	22.5 (± 8.4)	12.5 (± 1.3)	ns	p<0.01
Jessie Beazley B	30.6 (± 6.5)	9 (± 1.9)	ns	p<0.001

The algal cover in the deep areas of Tubbataha Reefs is 9.6% and has shown a significant decline in the South Atoll at -1.5% annually from 2017 to 2023. At the site level, significant changes in algal assemblage cover were recorded in Site 4 and Jessie Beazley, which declined at an annual rate of -2.5% and -1.6%, respectively. These were mainly influenced by the decrease in algal assemblage covers of Station 4B (-3%) and Jessie Beazley B (-2.8%). It should be noted that the AA cover of Station 3B (37.8%) was greater than its HCC (25.7%) this year.

Sponge cover in Tubbataha likewise declined at -0.4% annually. The decline was more apparent in South Atoll, with both Sites 3 and 4 exhibiting annual losses of -0.8% and -1.1%, respectively. At the station level, only Station 3B recorded an annual decline of -0.9%.

Soft corals made up 58.2% of Jessie Beazley A and 36.4% of Jessie Beazley B. Both values were higher than the HCC for both stations. Soft coral cover also increased by 11.4% in Station 4A, almost the same cover as its HCC. An increase was also noted in Station 1B (12.4%) compared to last year.

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

	Average % AA (±SE) 2023	Rate of change in AA (Linear Regression) 2017-2023	Difference Among Years in AA (ANOVAR; p<0.05 is significant) 2017-2023	Average % SP (±SE) 2023	Rate of change in SP (Linear Regression) 2017-2023	Difference Among Years in SP (ANOVAR; p<0.05 is significant) 2017-2023
TUBBATAHA (without JB)	9.6 (± 2.1)	ns	p<0.0001	10.7 (± 1.1)	⬇ -0.4%	p<0.0001
ATOLL Level						
North Atoll	4.4 (± 0.5)	ns	p<0.0001	13.19 (± 1.8)	ns	p<0.0001
South Atoll	14.9 (± 3.7)	⬇ -1.5%	p<0.0001	8.1 (± 1.1)	⬇ -0.9%	p<0.0001
SITE Level						
Site 1	4.6 (± 0.7)	ns	p<0.0001	8 (± 1.5)	ns	p<0.001
Site 2	4.2 (± 0.6)	ns	p<0.0001	18.4 (± 2)	ns	p<0.0001
Site 3	21.5 (± 6.8)	ns	p<0.0001	6.1 (± 1.3)	⬇ -0.8%	p<0.0001
Site 4	8.3 (± 0.9)	⬇ -2.5%	p<0.0001	10.2 (± 1.6)	⬇ -1.1%	p<0.0001

Jessie Beazley	4.8 (± 1.2)	⬇ -1.6%	p<0.0001	5.2 (± 1.6)	ns	p<0.1
STATION Level						
Station 1A	5.6 (± 1)	ns	p<0.0001	6.1 (± 1.8)	ns	p<0.1
Station 1B	3.6 (± 0.9)	ns	p<0.0001	9.9 (± 2.3)	ns	p<0.001
Station 2A	3.8 (± 1)	ns	p<0.0001	15.2 (± 2.7)	ns	p<0.01
Station 2B	4.6 (± 0.9)	ns	p<0.0001	21.6 (± 2)	ns	p<0.0001
Station 3A	5.3 (± 0.8)	ns	p<0.0001	8.6 (± 1.7)	ns	p<0.0001
Station 3B	37.8 (± 6.5)	ns	p<0.0001	3.5 (± 0.7)	⬇ -0.9%	p<0.05
Station 4A	7.8 (± 0.5)	ns	p<0.0001	10.5 (± 3.2)	ns	p<0.0001
Station 4B	8.8 (± 1.8)	⬇ -3%	p<0.0001	9.9 (± 1.4)	ns	p<0.0001
Jessie Beazley A	4.4 (± 1.7)	ns	p<0.0001	2.1 (± 0.6)	ns	ns
Jessie Beazley B	5.1	⬇-2.8%	p<0.0001	8.3 (± 2.4)	ns	p<0.05

Temporal patterns in Benthic Composition

Shallow areas (2012 to 2023)

The average hard coral cover (HCC) of Tubbataha at the location level showed a significant annual decline at an absolute rate of 1.3% from 2012 to 2023 (See Table 1). Among the five monitoring sites, only three demonstrated statistically significant changes in HCC at the site level (Figure 3). Only Site 2 exhibited an increasing trend over time at a rate of approximately 0.6% per year. Site 3 and Jessie Beazley experienced an annual loss of 3.7%, which evidently contributed to the decline across the location level. The overall decline seen in the South Atoll (annual rate of 2.1%) appeared to be influenced by the significant loss in HCC across periods within Site 3.

At the station level, the positive trend in HCC was evident in Stations 1B and 2B from 2012 to 2023 at annual rates of 0.8% and 1.1%, respectively (Table 1). In contrast, a total of five monitoring stations exhibited a significant decline in HCC annually, comprising Stations 1A at 1.1%, 3A at 1.1%, 3B at 4.7%, 4A at 0.8%, and Jessie Beazley A at 5.0% (Figure 4).

Algal assemblage (AA) cover showed a significant increase at the location level with a rate of 1.5 % per year (Table 2). At the site level, HCC dropped in both Site 3 and Jessie Beazley, coinciding with the increase in AA at annual rates of 2.7% and 3.2%, respectively (Figure 3). Site 1 also displayed an annual increase in AA at a rate of 0.8%. Increasing trends in AA cover were also reported at the station level, with annual rates of 1.2% in Station 1A, 2.0% in Station 3A, 3.4% in Station 3B, 1.3% in Station 4A, and 4.6% in Jessie Beazley A.

Results revealed that Sites 1 to 4 demonstrated a slow increasing change in sponge (SP) cover, contributing to the 0.4% annual increase rate (Table 2) within Tubbataha since 2012. Site 2 remained the monitoring site where SP cover has spread the fastest, increasing at a rate of 0.6% per year. Meanwhile, the SP cover in Site 3 was reduced to 1.4% in 2023. The highest levels in SP cover were noticed at Stations 2B and 4B, which are consistent with the findings of the 2022 Benthos Report. In Station 4B, the annual rate of SP cover growth remained at 1.1%, exceeding that of Station 2B, which is currently experiencing a 0.8% annual increase.

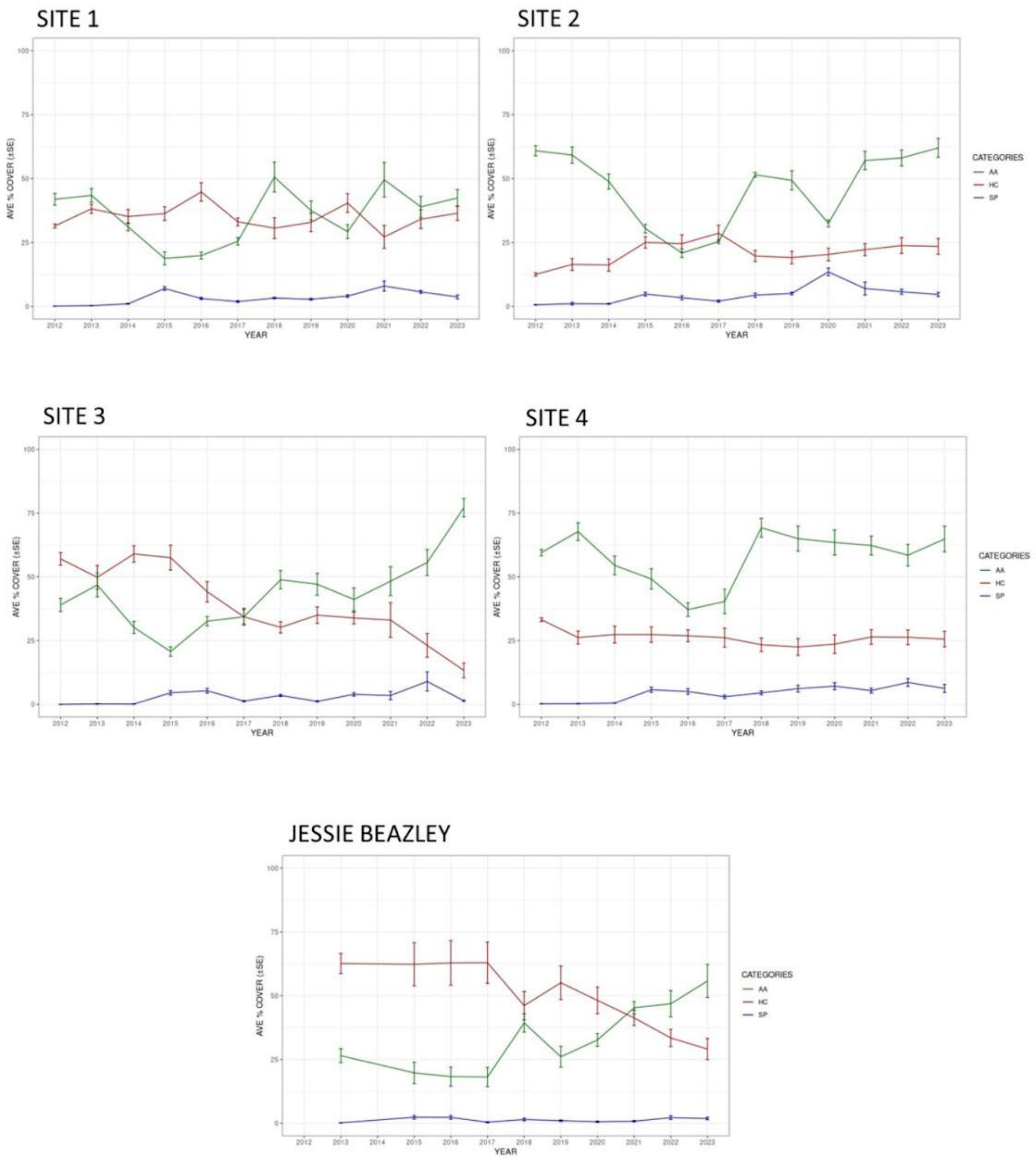

Figure 3. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring sites from 2012 to 2023. Error bars represent +/- one standard error

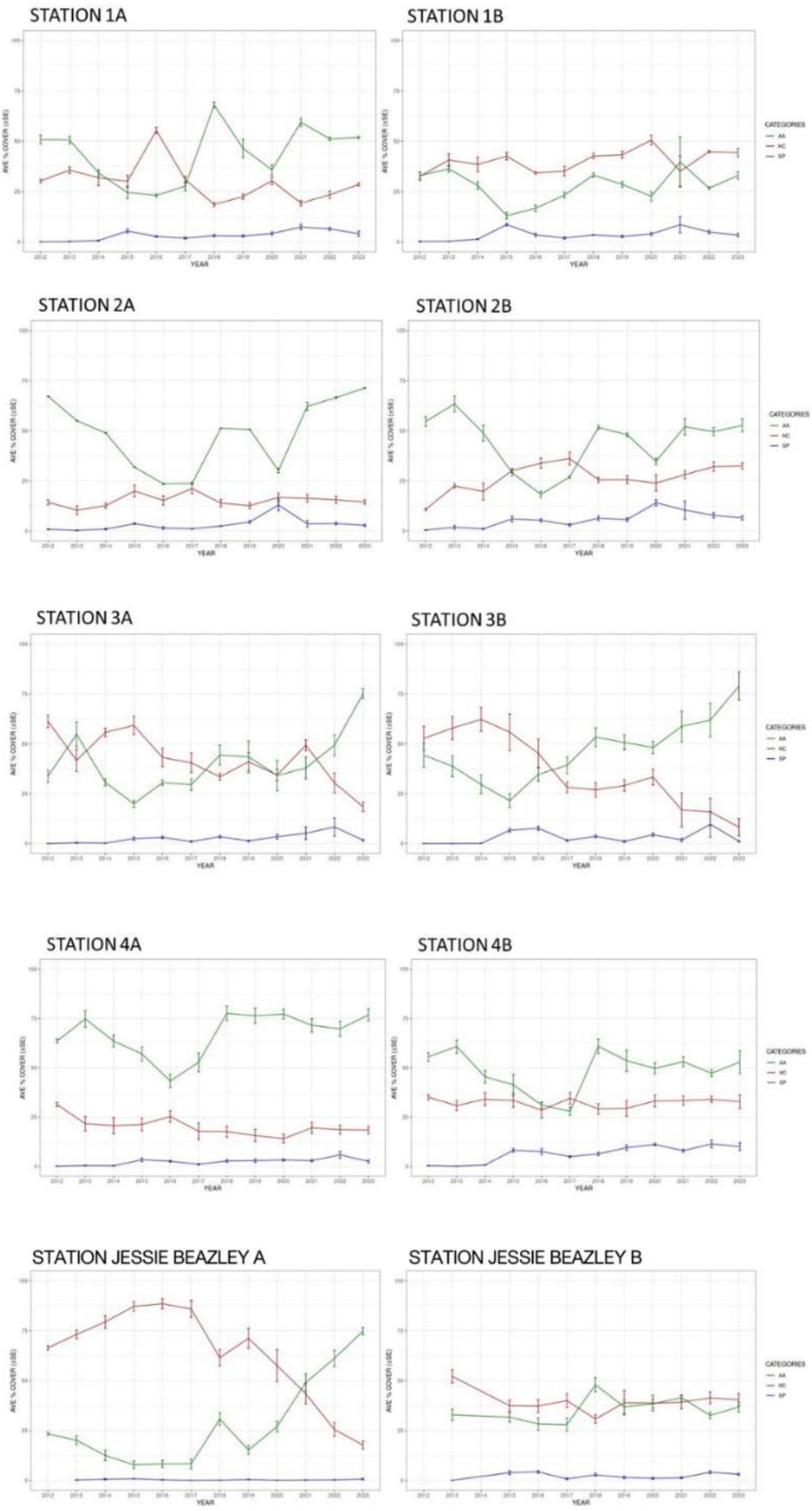

Figure 4. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in Stations 1A, 1B, 2A, 2B, 3A, 3B, 4A, 4B and Jessie Beazley A and B from 2012 to 2023. Error bars represent +/- one standard error

Deep areas (2017 to 2023)

HCC in all sites increased from 2022 to 2023 (Figure 5), but overall, the change in HCC was not significant between 2017 to 2023. At the station level, the annual decline in HCC was only significant in Station 1B at a rate of -1.5%. This year's results showed an improvement in HCC, particularly in Stations 1A, 2A, 4A, and 4B (Figure 6), which previously recorded annual declines from 2017 to 2022 at rates ranging between -1.7% to -2.9%.

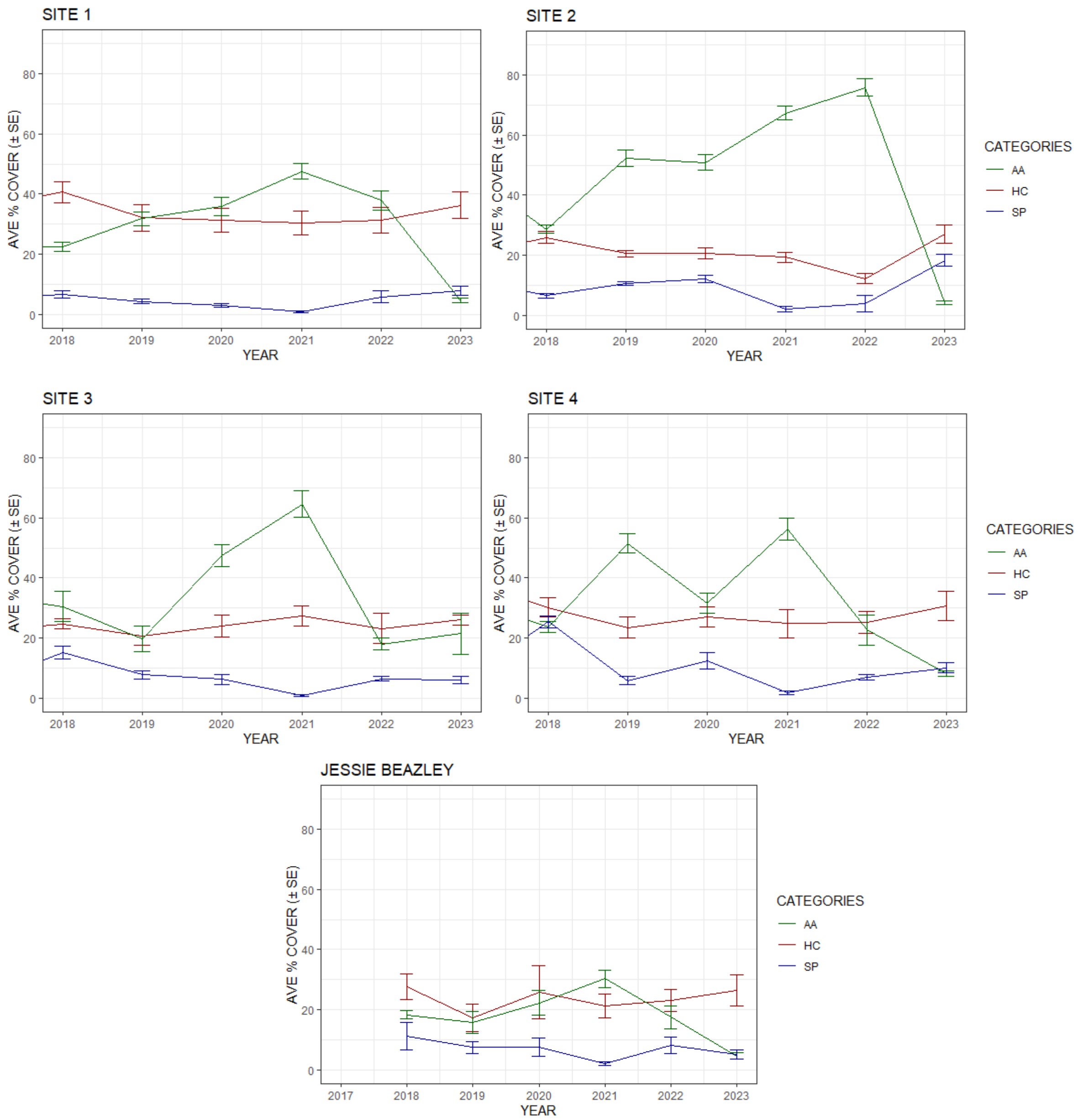

Figure 5. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring sites from 2017 to 2023. Error bars represent +/- one standard error

Algal assemblage cover in Sites 1, 2, 4, and Jessie Beazley declined from last year. This corresponded to the increase in other invertebrates (mainly cyanobacteria), sponges, soft corals, and sand cover from 2022 to 2023. Long-term trends (2017 to 2023) showed that the annual decline in AA cover was most apparent in Site 4 and Jessie Beazley at -2.5% and -1.6%, respectively. At the station level, AA cover declined in Station 4B at a rate of -3% per year and in Jessie Beazley B at -2.8% annually.

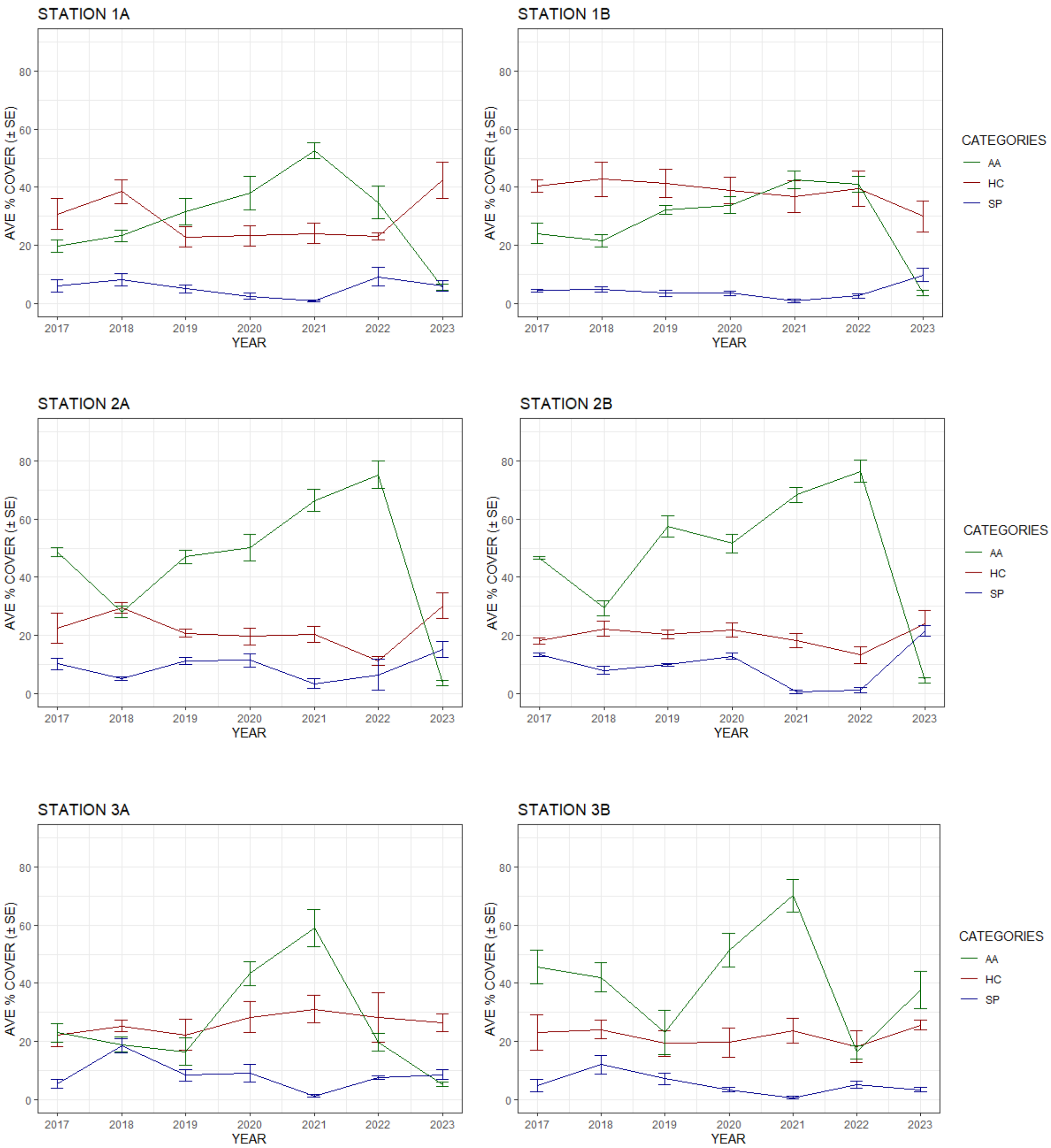

Figure 6. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring stations from 2017 to 2023. Error bars represent +/- one standard error

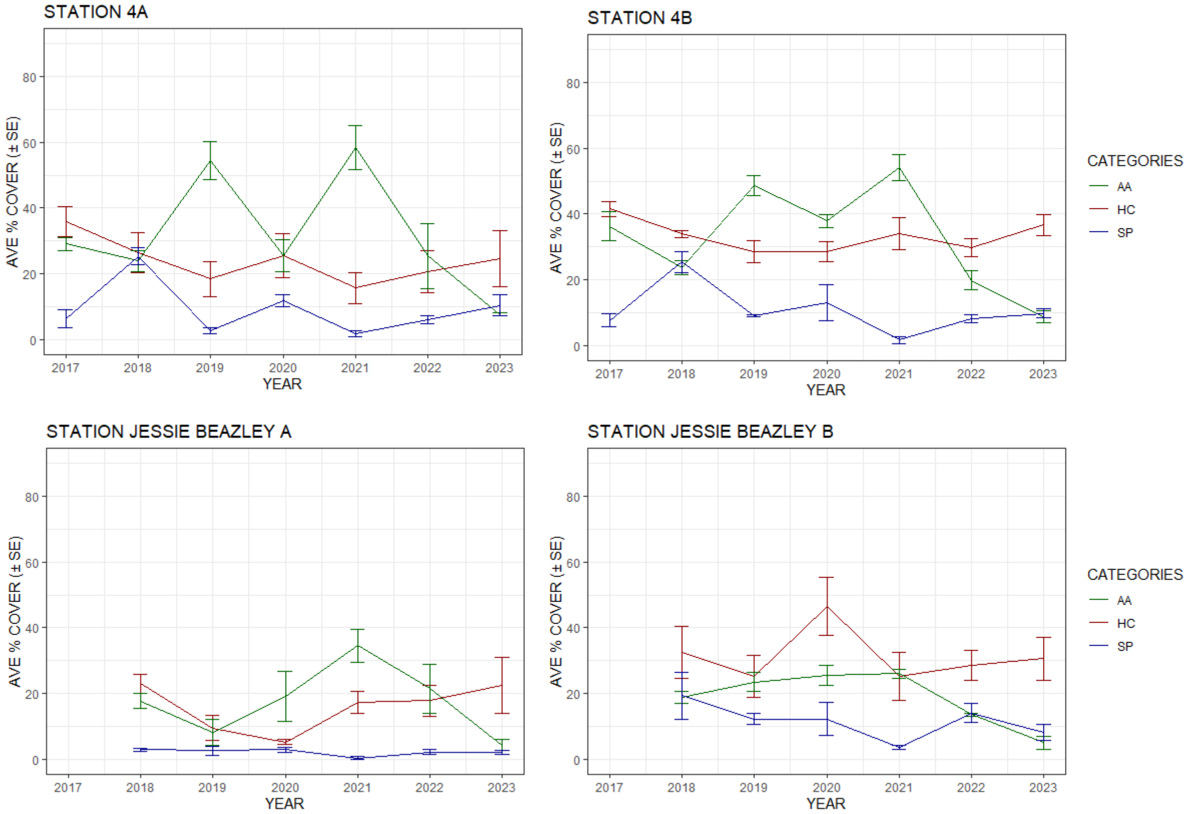

Figure 7. Percent cover of hard coral (HC), algal assemblage (AA), and sponge (SP) in the monitoring stations from 2017 to 2023. Error bars represent +/- one standard error

Sponge cover decreased gradually in Sites 3 and 4 at a rate of -0.8% and -1.1% annually. At the station level, a decrease in SP was only significant in Station 3B at -0.9% annually.

Ship Grounding Sites

Min Ping Yu grounding site

Hard coral cover increased significantly in the Min Ping Yu grounding site quadrats since 2014. The largest rate of increase was observed in the large fragments quadrat, which was repeatedly hit by the rudder of the Min Ping Yu fishing vessel, leaving large carbonate fragments interspersed with sand and rubble in the substrate. HCC in the large fragments quadrat increased at a rate of 1.3% per year (Table 5).

Among the three plots, HCC remains lowest in the small fragments quadrat (3.4%; Figure 8). The small fragments quadrat, which was directly impacted by the ship grounding incident, exhibited a significant trend of increase in HCC from 2014 to 2023 at a rate of 0.3% per year (Table 5). However, in the past five years (2019 to 2023), the rate of HCC increase in the small fragments plot was not significant (LR $p > 0.05$).

Figure 8. Percent hard coral cover (% HCC) in the Ming Pin Yu ship grounding site from 2014 to 2022. % HCC (± SE) is reported for three fixed plots: small fragments, large fragments, and adjacent control.

While HCC in the adjacent control plot was significantly increasing at a rate of 1.1% per year (Table 5), a sharp decline was observed between 2022 and 2023, where a third of the HCC was lost (24.0% in 2022 to 15.3% in 2023; Figure 8). In 2023, HCC in the large fragments plot was comparable to HCC of the adjacent control plot, with HCC in both plots falling under Category D (Licuanan et al. 2019). In contrast, the adjacent control plot belonged to Category C in 2022.

Table 5. Summary of ordinary least squares linear regression results for % HCC changes in Min Ping Yu and USS Guardian grounding sites from 2014 to 2023. Statistically significant ($p < 0.05$) results are highlighted. ns = not significant ($p > 0.05$)

Plot	Annual rate of change in HCC	Permutation p-value	R^2
Min Ping Yu Grounding Site			
Small Fragments	↑ 0.3%	$p < 0.05$	0.59
Large Fragments	↑ 1.3%	$p < 0.005$	0.69
Adjacent Control	↑ 1.1%	$p < 0.05$	0.41
USS Guardian Grounding Site			
Ground Zero	↑ 0.7%	$p < 0.05$	0.59
Impact Border	ns	ns	0.28
Adjacent Control	↓ 1.9%	$p < 0.05$	0.60

USS Guardian grounding site

Different recovery patterns can be observed in the USS Guardian grounding site since the 2013 grounding incident. The ground zero plot, which was directly impacted by the ship grounding, has the lowest HCC among the three permanent quadrats at 7.7% in 2023 (Figure 9). However, the ground zero plot was the only permanent quadrat among the three that showed a significant increase in hard coral cover since 2014 at a rate of 0.7% per year (Table 5; Figure 9). In contrast, the impact border plot's HCC has not significantly changed since 2014 (Table 5; Figure 9).

HCC in the adjacent control plot, located ~50 meters away from the impact area, exhibited a significantly declining trend of 1.9% per year (Table 5). This is attributed to more than half of the HCC here being lost between 2017 and 2018 (24.9% in 2017; 10.4% in 2018). The adjacent control plot has not recovered to the same HCC since then, but an increasing trend in HCC was observed at a rate of 2.0% per year since 2020 (LR uncorrected $p < 0.05$). HCC in the adjacent control plot was also the highest of the three permanent quadrats during the 2023 survey, while it had the lowest HCC among the three quadrats in 2022 (Figure 9).

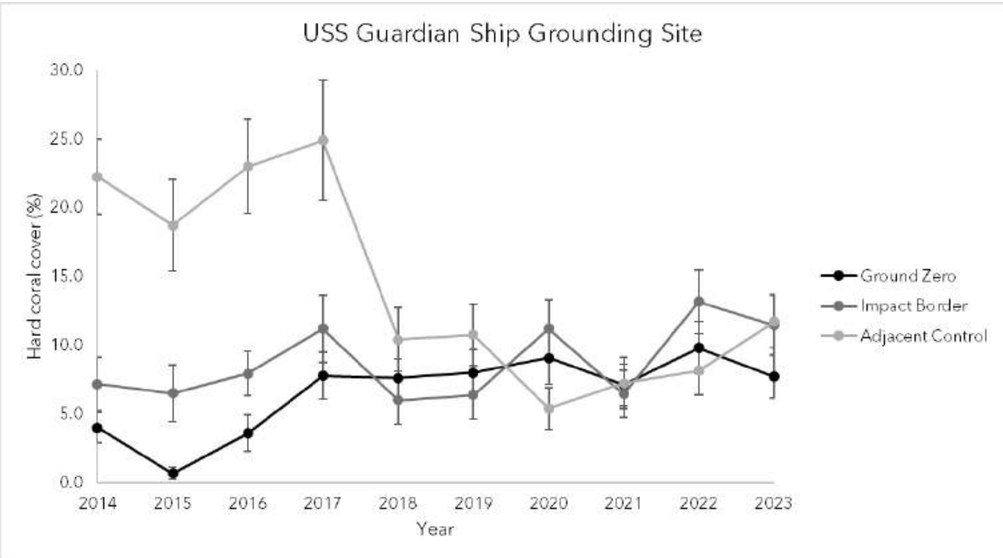

Figure 9. Percent hard coral cover (% HCC) in the USS Guardian ship grounding site. % HCC (± SE) is reported for three fixed plots: ground zero, impact border, and adjacent control.

DISCUSSION

Shallow areas

Present conditions

HCC across the whole of TRNP (excluding Jessie Beazley data) is currently at 24.7%, placing it in Hard Coral Category C using the scale based on the latest national assessment (Licuanan et al. 2019). This is 1.7% higher than in 2022. However, this increase is below the 3% minimum detectable change of the location (Licuanan et al. 2017), which means that the 1.7% increase may only be a result of sampling artifacts such as re-randomization of transects. Increases were also noted at the North Atoll, (8.1% greater than in 2022) driven by increases at both Site 1 and Site 2. Meanwhile, HCC declined at the South Atoll by 4.9%, driven mostly by declines in Site 3. Additionally, Jessie Beazley showed a 5.9% decline in HCC from 2022 to 2023.

Notable declines in HCC were observed in both Stations 3A and 3B. Station 3A lost over 10% HCC in the past year. A similar loss of over 10% was observed in Station 3B, but the loss was more significant at this station because in 2022, Station 3B had 18.3% HCC and now has 8.3% HCC. As in previous years, the low cover in Jessie Beazley was driven by the low cover in Jessie Beazley A, which fell under Category D in 2023. All notable declines in HCC from 2022 to 2023 were accompanied by concurrent increases in AA.

One possible reason for decline in HCC was the typhoon damage caused by Typhoon Paeng, which passed through TRNP in October 2022. The dominant species in both sites – *Isopora brueggemanni* in Station 3A, and foliose and encrusting *Montipora* in Jessie Beazley A – are highly susceptible to mechanical damage (Darling et al. 2012).

Increases in HCC were only seen at the station level, specifically Stations 1B and 2B, in the North Atoll. However, neither were above the minimum detectable change reported by Licuanan et al. (2017) and, therefore, may not be ecologically significant.

Temporal Patterns (2012 to 2023)

Considering the data from the whole location (excluding Jessie Beazley and Site 5), HCC has been declining at an average rate of 0.9% from 2012 to 2023. At the site level, HCC in both Site 3 and Jessie Beazley were declining at an average rate of 3.7%. Meanwhile, only Site 2 showed increasing HCC, specifically at a rate of 0.63% a year. The decline in HCC in Site 3 was reflected at the atoll level, where HCC was declining at a rate of 2.1% per year.

In Station 3A, a more rapid decline in HCC was apparent between 2021 and 2022, and the trend continued in 2023. The decline from 2021 to 2022 was hypothesized to have been caused by Typhoon Odette, and the further decline from 2022 to 2023 may be due to Typhoon Paeng. From the trends in HCC, it appears that there has not been enough time between disturbance events for the reef to recover.

The declines in HCC at various spatial scales are concurrent with increases in AA, especially notable in Site 3 and Jessie Beazley. AA was increasing at an average rate of 2.8% per year in Site 3 and at an average rate of 3.2% in Jessie Beazley. Visually, it appears that the increase in AA at these locations is driven by increases in algal turf, rather than coralline algae or bare carbonate rock. Following a disturbance, dead corals may be overgrown by algal turf, which are short (<2cm) productive networks of filamentous algae and cyanobacteria (Smith et al. 2016). In reef environments that have been recently disturbed, the rapid growth of turf algae may inhibit recovery by slowing the recruitment of new coral (Vermeij et al. 2009). This is likely what is occurring in Station 3A, where the *Isopora bruggemani* rubble fields are increasing each year.

Additionally, the slow decline in HCC across the whole of Tubbataha of over 1% but less than 10% suggests that the reef may be suffering from a chronic stressor (Flower et al. 2017).

Deep areas

Present conditions

Compared to the previous year, hard coral cover in the deep monitoring areas increased in almost all stations, except in Station 1B. The average HCC in the deep monitoring areas increased by 7% from 2022. This was influenced by the increase in HCC in the North Atoll, particularly in Stations 1A and 2A. Hard coral cover in Station 1A increased by almost 20% from last year, mainly due to genus *Echinopora* which constituted 20.4% of the HCC in 2023 compared to 2.7% in 2022. A relatively high increase in HCC (18.8%) was recorded in Station 2A this year compared to 2022 and this was due to the increase in massive *Porites*, *Favites*, and branching *Montipora*.

On the other hand, Station 1 B recorded a decrease in HCC between 2022 and 2023, which was mainly influenced by the drop in encrusting *Montipora*, *Merulina*, and foliose *Pachyseris*.

Temporal Patterns (2017 to 2023)

The non-significant values in the deep monitoring stations suggest that the data is highly variable or that the sample size is low, resulting in the low likelihood of statistical analyses detecting significant ecological changes.

The hard coral cover in Jessie Beazley A slowly improved from 5.3% in 2020 to 22.5% in 2023, unlike its shallow counterpart, which has been declining since 2020. However, the higher cover of soft corals in both stations of Jessie Beazley might be an indication of continued disturbance in the area. The 30% increase in SC cover in Jessie Beazley B in 2023 (36.3%) compared to 2022 (6.2%) should be closely monitored. A proliferation of soft corals in hard-coral dominated reefs may be caused by disturbances such as typhoons and Crown-of-Thorns starfish infestation, poor water quality, and high turbidity (Chadwick-Furman and Spiegel 2000; Baum et al. 2016; Fabricus and Dommisse 2000).

Sand cover, previously unrecorded, constituted 7.9% of Station 3A, 12.5% in 4A, 8.5% in 4B, and 18.4% in Jessie Beazley B. This year's increase in soft coral cover and sand in Jessie Beazley B is concerning albeit the gradual improvement in HCC.

Station 3A is now mostly composed of coral rubble of the beds of *Isopora brueggemanni,* which previously dominated the area. No signs of recovery were observed in the station. In Station 3B, rubble cover declined from 50.2% in 2022 to 23.2% in 2023, while the cover of crustose coralline algae increased from 7.9% in 2022 to 22.3%. Crustose coralline algae play an important role in reef-building by providing space for coral recruits to settle.

Ship Grounding Sites

The 10-year time series of HCC in the Min Ping Yu quadrats indicates recovery, though at a rate of less than 2% HCC per year (Table 5). The highest rate of recovery was observed in the large fragments plot, which remained the only quadrat in Min Ping Yu that maintained an upward trend in HCC. Recovery in the large fragments quadrat is favorable, given that unstable surfaces combined with strong wave movement limit coral recruitment and growth (Kenyon et al. 2023). Since recovery from acute disturbances such as ship groundings may occur at decadal timescales (Precht et al. 2001), it is crucial to continue monitoring these plots to track the trajectory of HCC recovery, especially in the small fragments plot, where recovery may have plateaued.

The USS Guardian grounding site showed declines in both ground zero and impact border plots between 2022 and 2023 (Figure 9). The adjacent control plot continued to decline in terms of HCC; however, it showed an increasing HCC trend for the past four years (2020 to 2023; Figure 9). Despite the USS Guardian grounding site conditions, e.g., low turbidity, sufficient water movement, and hard, contiguous substrate free of spatial competitors such as thick algal turf, cyanobacterial mats, and sponges (Vermeij 2005; Arnold et al. 2010), recovery is limited in both the ground zero and impact border plots. Indeed, since 2018, HCC among the three plots has been comparable (Figure 9). Given the low HCC in the surrounding reef area, it is possible that a lack of a source of coral larvae may be limiting recruitment, as higher density of coral recruits was reported in reefs with higher HCC (e.g., Thomson et al. 2021, Dampier Archipelago, Australia). Alternatively, a chronic stressor such as increased nutrient level may be affecting coral settlement and growth (see below).

The adjacent control plots were established within the same reef area, about 150m from the impact zone. Acute disturbance may be a factor in the sharp HCC decline in the USS Guardian adjacent control plot between 2017 and 2018 (Figure 9). The same is true in the Min Ping Yu adjacent control plot between 2022 and 2023 (>10% decline in HCC over consecutive sampling points; Flower et al. 2017). However, the slow recovery at the site level for both Min Ping Yu and USS Guardian grounding sites may indicate that wider-scale disturbances are affecting both sites. This is also considering the HCC declines observed in the regular monitoring stations (Table 1). Additionally, common genera of corals observed in the plots have weedy and competitive life-history strategies, such as *Pocillopora* and *Acropora*, which are fast-growing but vulnerable to disturbance (Darling et al. 2012).

CONCLUSIONS

Overall, hard coral cover at the shallow monitoring stations of TRNP continues to decline. Meanwhile, there is a notable increase in algal assemblages and sponge cover across the locations where hard coral cover is declining. Major declines at Station 3A and Jessie Beazley A may be attributed to storm damage, but the slow (greater than 1% but less than 10% per year) decline in hard coral across the location may be indicative of a chronic stressor.

The insignificant values in the deep monitoring stations may be due to data fluctuation or low sample size, resulting in a low likelihood of detecting ecological changes through statistical analyses. The increase in soft corals in both stations of Jessie Beazley may suggest a possible disturbance in the area.

For the ship grounding sites, the Min Ping Yu site shows signs of recovery, although the USS Guardian site continues to decline. The contrasting trends may be attributed to factors outside the grounding incidents.

RECOMMENDATIONS

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

2. Establish monitoring stations within the lagoons, aligning them with regular monitoring stations located at the reef crest to determine whether observed changes in the reef slope correspond with those in the lagoons.

3. Record juvenile coral density and coral growth rate and establish additional plots in the ship grounding sites. Consider using auxiliary datasets, e.g., water movement and water quality parameters, to diagnose the drivers of the trends observed in the grounding sites.

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

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

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2. Coral Recruits

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OVERVIEW

Coral recruitment studies provide crucial information on the capacity of the reefs to recover. Stronger typhoons and longer thermal anomalies in the ocean have negative effects on the reefs. Tubbataha Reefs, one of the largest marine protected areas in the Philippines (Veron et al. 2009), is not safe from these disturbances. Typhoons passed Tubbataha in 2021, 2022, and 2023, damaging some portions of the reef and leading to the decline in hard coral cover in most of the monitoring sites (TMO 2022). These disturbances present an opportunity to assess the potential for reef recovery following such events.

Understanding the patterns of coral recruitment is crucial for conserving and managing coral reefs. This is because the abundance and coverage of adult corals, even when consistent or predictable, do not automatically ensure the predictability of fundamental processes like coral recruitment that maintain these ecosystems (Hughes et al. 1999). Consequently, predicting the future condition of a reef might be more accurately done by considering current processes, like recruitment rates, in addition to the present status of its coral population (Soong et al. 2003).

The purpose of the study is to quantify juvenile coral abundance, recruitment density, and distribution in TRNP. Furthermore, it aims to understand factors that may affect its population, such as the variability of juvenile corals among site and depth.

METHODS

Data collection

The sites monitored for fish and benthos were the same sites monitored for coral recruitment (Figure 1). In each depth of five and 10 meters, one 50-meter transect was assessed for coral recruits. A set of pre-determined random numbers generated in Excel was used as a guide to determine the placement of the quadrats in the transect. Next to each transect, a diver randomly placed a 34 x 34 cm (0.12 m^2) quadrat on the substrate to obtain representative samples of each station. The quadrat was marked with 2 and 5-cm scale bars on both sides for size reference (Figure 10b).

Five photos were taken: four close-up shots at each corner and one full quadrat shot to capture detailed images of juvenile corals (Figure 10c). Images were taken using a 20-megapixel camera with an underwater casing. A total of 40 quadrats per station were processed – 20 in the shallow and 20 in the deep areas.

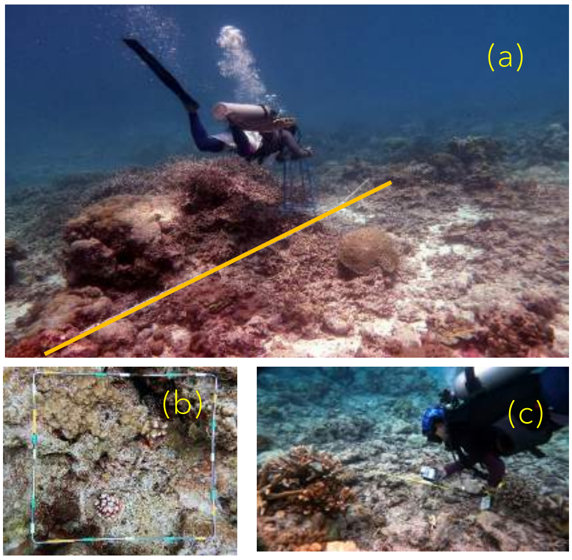

Figure 10. Coral recruitment sampling: (a) quadrat placed alongside the transect; (b) close-up shot of the quadrat with scale bars, and (c) multiple photos taken using underwater camera.

For the grounding sites of the Min Ping Yu and USS Guardian, permanent monitoring plots measuring 4 x 4 meters (Figure 11) were laid following the method described by Licuanan et al. (2014). They were strategically positioned to capture the impacts of the ship groundings on the reefs.

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

At the Min Ping Yu grounding site, three plots were established on the fragments of corals left behind by the vessel. Quadrat 1 was established on the piles of small fragments measuring between 20-50 cm in diameter. Quadrat 2 was placed on the large fragments of corals, which were approximately 1m in diameter and shattered by the rudder. Quadrat 3 was positioned adjacent to the impact zone. A total of 10 quadrats were sampled in each plot. The quadrat was placed in the middle, at the four corners, and haphazardly (five spots) on each plot. For the USS Guardian grounding site, one quadrat was positioned in the impact zone (Quadrat 1), one in the buffer zone (Quadrat 2), and another in the control zone (Quadrat 3).

Data processing

All photos were downloaded, grouped, and labeled according to year, site, station, and quadrat. Coral Point Count with Excel Extension® (CPCe) software was used for post-processing and scoring. Only coral colonies measuring <5cm were considered recruits (Burgess et al. 2010). In the CPCe software, each photo was calibrated using the 5cm scale bar located on each side of the quadrat. This scale bar provided an adequate size estimate of the coral recruits. The recruits were classified to the closest possible taxonomic level, usually the genus level. The Indo-Pacific Coral Finder version 3.0 and the Corals of the World were used as references for coral identification. Small coral fragments that were deemed remnants of adult corals were excluded.

Data analysis

The percentage of each hard coral (TAUs) was computed for every station and was plotted using Microsoft Excel. Estimates of coral recruit density were calculated for each quadrat as the number of recruits per $0.12 m^2$. Differences in the densities of recruits across sites, depths, grounding plots, and years were tested using Analysis of Variance (ANOVA: Two-factor without replication, $p<0.05$). In addition, a paired *t-test* (two samples of the mean, $p<0.05$) was performed to compare the differences in the recruit density across depths and its corresponding value from the previous year. The size frequency distribution of recruits was plotted for each site. A chi-square contingency table analysis was used to test whether the size-frequency distribution of recruits differed among sites.

RESULTS

Shallow Areas

Family and Percentage Cover

From 2018 to 2023, 26 genera belonging to 17 coral families were recorded in the shallow area. A consistent pattern was observed over the 5-year monitoring period, with coral brooder types dominating shallow areas: Agariciidae (22.44%), Poritidae (19.8%), and Pocilloporidae (18.7%). Next in dominance were broadcast spawning corals from the families Acroporidae and Faviidae, at 14.12% and 12.15% (Figure 12).

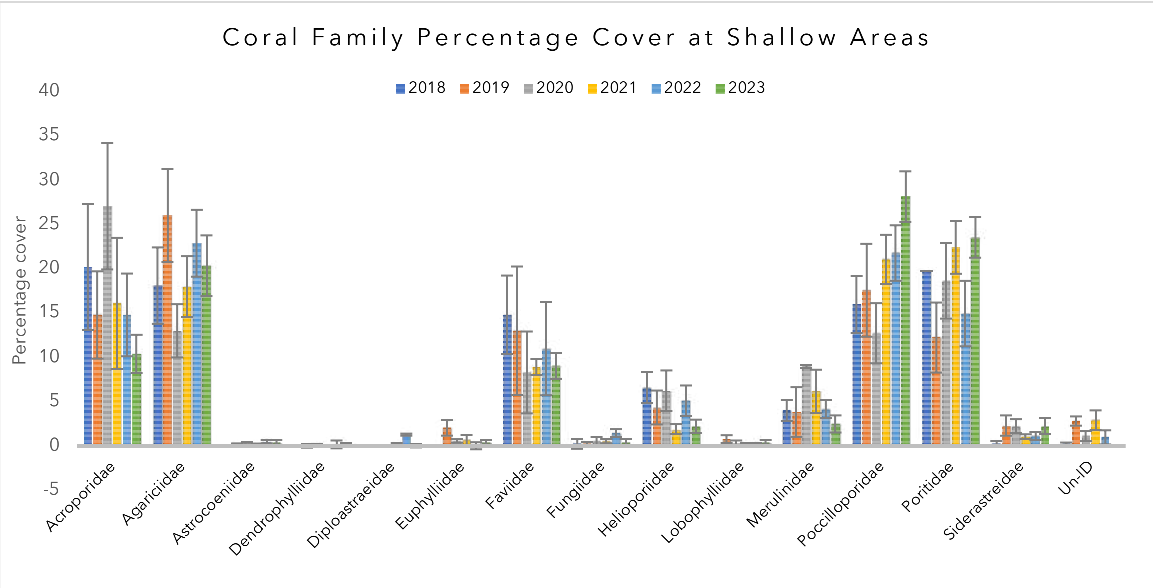

Figure 12. Annual mean percentage cover per family of all coral recruits at shallow areas. Error bars represent standard error of mean. Unidentified corals were group under the category Un-ID.

Density

The average mean density of recruits was 56.3 ind/m^2 (±3.7 SE), lower than 59.9 ind/m^2 (±3.6 SE) in 2022. Site JB had the highest recruit density of 67.8 ind/m^2 (±6.6 SE), and Site 4 had the lowest density of 48.7 ind/m^2 (±8.4 SE) (Table 6). Overall, in the five years, the shallow areas recorded an average of 55 ind/m^2 (±3.7 SE) and have increased in density at the rate of 1.76 ind/m^2 per year (Table 6).

Table 6. Coral recruit density of all stations at shallow areas from 2018 to 2023. SE represents the standard error of the mean. ns = no significant difference

Site	2022	2023	Average (2018-2023)	Rate of change Linear regression (individuals/m^2 2018-2023)
S1	42.3 (±6.9 SE)	60.1 (±7.2 SE)	61.1 (±8.1 SE)	ns
S2	65.4 (±9.1 SE)	55.5 (±10.3 SE)	56.9 (±8.2 SE)	ns
S3	81.5 (±15.7 SE)	49 (±7.4 SE)	53.8 (±7.5 SE)	5.42
S4	63.1 (±10.8 SE)	48.7 (±8.4 SE)	49.8 (±7.4 SE)	ns
JB	46.9 (±3.9 SE)	67.8 (±6.6 SE)	50.2 (±7 SE)	3.94
Average	**59.9 (±4.7 SE)**	**56.3 (±3.6 SE)**	**55 (±3.7 SE)**	↑ **1.76**

Only two sites showed a significant increase in recruit density from 2018 to 2023. Site 3 recorded an annual increase of 5.42 ind/m^2, and Site JB increased by 3.94 ind/m^2 per year (Table 6). In Site JB, the increase coincided with the increase in the density of the genus *Montipora* similar to the 2022 results. In Jessie Beazley Station A, a large portion of the reef was damaged, providing a substrate for coral recruits to thrive in the area from 2020 onwards. These sites experienced disturbances in the latter part of 2020, i.e., suspected blast fishing, bleaching in July 2020, and Typhoon Vicky in December 2020, leaving portions of the reef open for recolonization. The Genus *Pocillopora, Porites, and Pavona*, dominated the shallow areas. These were followed by broadcast spawning corals, e.g., *Isopora, Goniastrea, Acropora* branching, *Echinopora*, and *Montipora*.

Size-frequency distribution

From 2018 to 2023, coral recruit size frequency distribution showed a consistent pattern. Juvenile coral recruits were the most abundant (68.4%), followed by mature corals (24.9%), while newly settled corals were the least frequently observed among the three groups (6.7%). The highest number of juveniles was observed in Site 1 and JB. These sites had the greatest number of individuals of the fast-growing types of corals from genus *Pocillopora*, *Porites, and Montipora.* As recruits reach maturity (≥4cm), their number decreases, possibly due to the lower survival rate of coral recruits as they pass through the juvenile stage.

The transition from the juvenile stage to survival is a critical yet perilous stage in the life cycle of a coral. Several factors affect the survival rate of coral recruits, including predation, diseases, and competition. Coral recruits are particularly vulnerable to predators, which can lead to a decimation of juvenile populations, with losses sometimes exceeding 80% (Hariott and Fisk 1988). Warmer oceans and pollution can also trigger coral diseases that increase the susceptibility of young polyps to bacterial and fungal infections (Bruno et al. 2007). These diseases weaken and ultimately kill the polyps, contributing to the decline in survival rate (Bruno et al. 2007). Competition for space and resources on the crowded reef floor leads to low survival rates of juvenile corals. Juvenile corals must compete with algae, sponges, and even adult corals for scarce niches. These harsh environmental factors often leave many juveniles outmaneuvered and ultimately lost in the cycle of life (Connell et al. 1994).

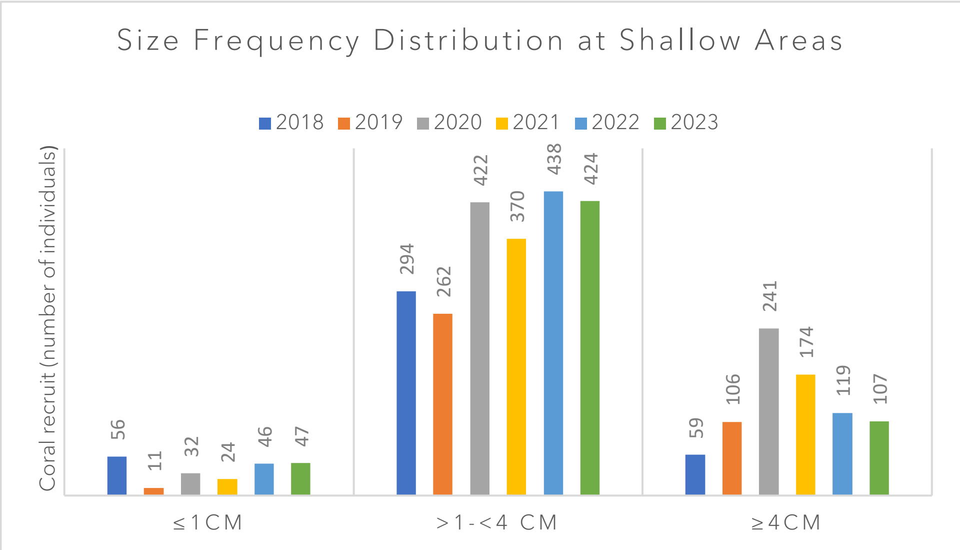

Figure 13. Five-year data on size frequency distribution of coral recruits at shallow areas.

Overall, a similar pattern in the frequency distribution of individual recruits according to size class has been observed since 2018 (Figure 13).

Deep Areas

Family and Percentage Cover

In the deep area, 32 genera belonging to 16 families were recorded. Over the span of five years, three coral families – Agariciidae (25.8%), Poritidae (19.2%), and Poccilloporidae (16%), were the most dominant. This year, the family Pocilloporidae had the highest percentage cover at 25.3%, followed by Agariciidae, Poritidae, and Pocilloporidae at 23.6% and 19.7%, respectively (Figure 14). This was followed by the family Faviidae at 9.1% and Acroporidae at 6.7%. There has been an increase in the density of coral recruits belonging to the family Faviidae and Acroporidae since 2022. Throughout the years, the proportions of different coral families showed no significant change.

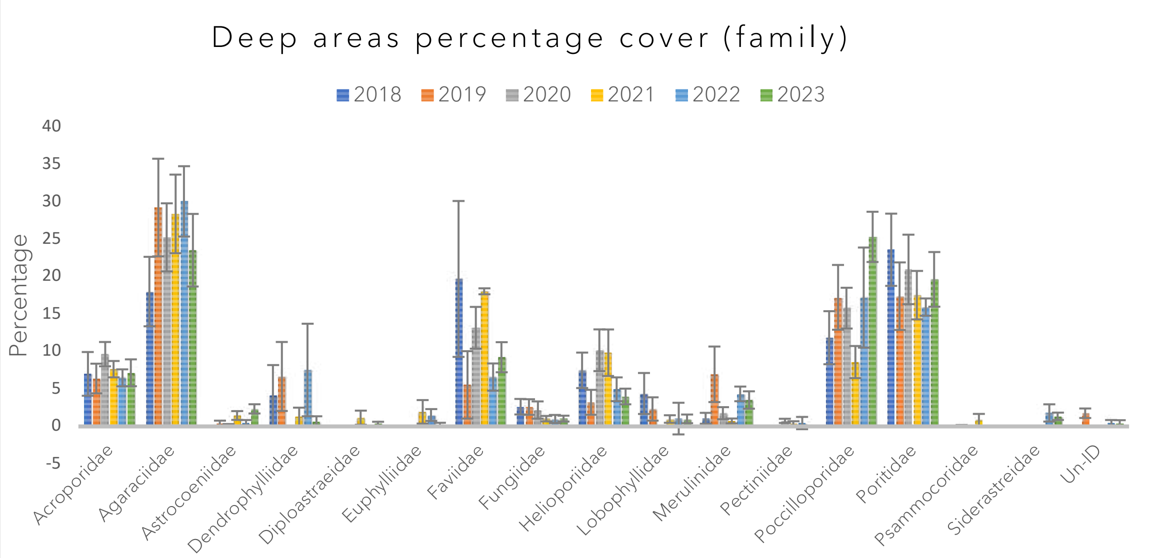

Figure 14. Annual mean percentage cover per family of all coral recruits at deep areas. Error bars represent standard error of mean. Unidentified corals were group under the category Un-ID.

Density

The encrusting type of corals from genus *Pocillopora, Pavona*, and *Porites* dominated all the sites. The mean recruitment density was recorded at 56.2 ind/m^2 (±3.4 SE), which is almost similar to the values in the shallow. Site 4 had the highest density at 42.8 ind/m^2 (±6.5 SE), while Site 2 had the lowest density at 42.8 ind/m^2 (±6.5 SE). From 2018 to 2023, Site 3 was declining at the rate of 5.06 ind/m^2 per year. Overall, two sites namely Site 3 and Site JB experienced a gradual decline as opposed to the increasing trend in the shallow areas. Coral recruits over the years and across sites significantly declined at the rate of 5.3 ind/m^2 annually.

Table 7. Coral recruit density of all sites at deep areas from 2018 to 2023. SE represents the standard error of the mean, ns = no significant difference.

Site	2022	2023	Average (2018-2023)	Rate of change Linear regression *(individuals/m^2* 2018-2023)
S1	52.4 (±5.5 SE)	58.8 (±8 SE)	52.9 (±6.7 SE)	1.3
S2	31.1(±4.6 SE)	42.8 (±6.5 SE)	43.9 (±7.3 SE)	ns
S3	89.5 (±8.1 SE)	59.3 (±6.7 SE)	89.1 (±9.3 SE)	-5.06
S4	47.1 (±6.1 SE)	65.3 (±7.4 SE)	63.1(±8.1 SE)	ns
JB	59.5 (±13.6 SE)	54.6 (±8.6 SE)	53.6 (±8.9 SE)	ns
AVERAGE	**55.9 (±4 SE)**	**56.2 (±3.4 SE)**	**60.5 (±8.1 SE)**	**-5.3**

A total of 706 individual coral recruits were encountered. Newly settled coral recruits measuring ≤1cm comprised 7.5%, while juvenile corals between >1 to <4 cm had the highest frequency at 66.3%. In all the stations, only 27.8% of the population measured ≥4cm, or close to the total population of coral recruits over the span of five years at 30.7%. The Chi-square test for size-frequency distribution showed a significant difference only at Site JB (p=0.05). In Site JB, fewer coral recruits were

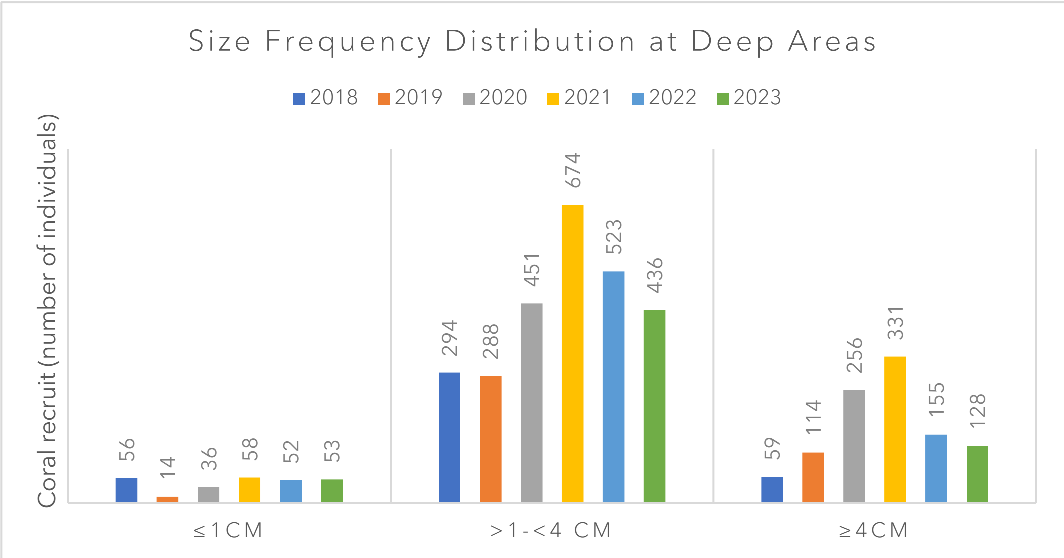

Figure 15. Five-year data on size frequency distribution of coral recruits at deep areas.

recorded compared to previous years. The continuous proliferation of corallimorphs and soft corals in both Stations may affect the deeper areas.

Ship Grounding Sites

Density in MPY

The average density in the MPY grounding site (5.3 ind/m^2 ± 2.0 SE) was higher than in 2022 (5.5 ind/ m^2 ±1.9 SE) (Figure 16). Coral recruit densities were recorded at 6.5 ind/m^2 in the adjacent plot and 6.0 ind/m^2 (±5.3 SE) in the small fragments plot. The large fragments plot had 3.5 ind/m^2 (±0.9 SE), the lowest record for this year's survey (Figure 16). In MPY, the comparison between 2022 and 2023 data showed that both large fragments and adjacent plots decreased by 22% and 13%, respectively. The small fragment plot showed an 85% increase in recruit density.

From 2018 to 2023, the average coral recruit density in all three plots was 5.1 ind/m^2 (±1.9 SE). The variations of coral recruit densities in the MPY grounding site (across plots and years) did not show significant differences. The genus *Porites, Pocillopora*, *Merulina, Isopora, and Acropora* were the most common genus recorded in the plots which mirrored the adjacent healthy reef in this area.

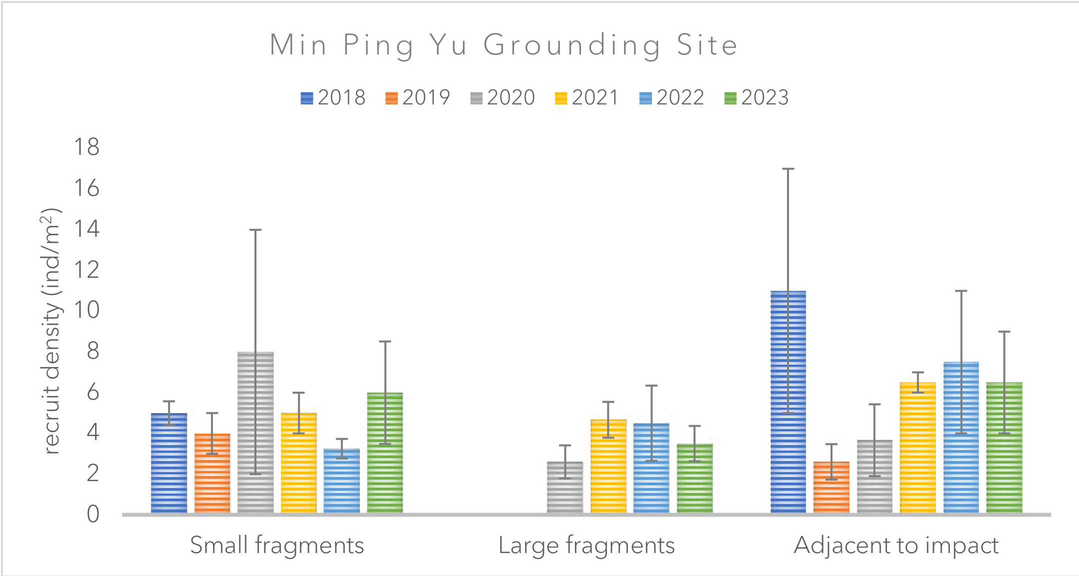

Figure 16. Coral recruit density of the three plots at MPY grounding site from 2018 to 2023. The error bars represent standard error of the mean.

Density in USSG

In this year's survey, the overall mean density recorded at the USS Guardian grounding site was 6.1 ind/m^2 (±1.4 SE), higher than 4.6 ind/m^2 (±1.7 SE) recorded in 2022. The highest density was recorded at the adjacent control plot with 9.5 ind/m^2, 6.5 ind/m^2 in the impact border, and 2.4 ind/m^2 in ground zero. From 2018 to 2023, the average coral recruit density at USSG grounding site was 5.9 ind/m^2 (±1.5 SE). The adjacent control plot increased by 73%, and the impact border plot by 39%. The adjacent control and impact border plots were mostly dominated by genus *Pocillopora, Porites, and Pavona,* while the ground zero plot was dominated by genus *Montastrea*, branching *Acropora,* and genus *Favites*.

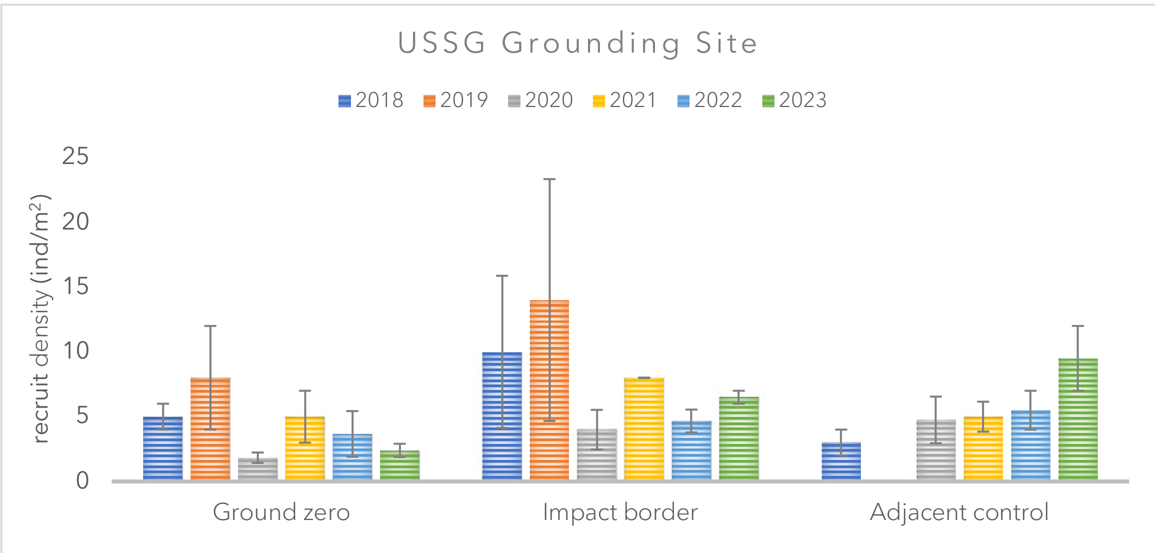

Figure 17. Coral recruit density of the three plots at USSG grounding site from 2018 to 2023. The error bars represent standard error of the mean.

DISCUSSION

In this year's survey, 1848 individual coral recruits from 32 genera under 17 coral families were recorded at both depths. The density of coral recruits in Tubbataha remains higher compared to other tropical sites, e.g., Bolinao, Pangasinan at 23.5 ind/m^2 (Cruz and Harrison 2017) and Panjang Island, Central Java at 22.1 ind/m^2 (Munasik et al. 2021).

The shallow areas recorded an overall mean density of 56.3 ind/m^2, lower than the coral recruit densities recorded in 2022 at 59.9 ind/m^2. From 2018 to 2023, the average density significantly increases by about 1.75 ind/m^2 annually. Meanwhile, the deep area had a mean density of 56.2 ind/m^2, lower than 2022 at 59.9 ind/m^2. In the span of five years (2018 to 2023), the average densities recorded at the deep area showed a gradual decline at the rate of 5.3 ind/m^2 per year.

Shallow Areas

In the shallow areas, the brooder coral families of Pocilloporidae Agariciidae, and Poritidae were the most dominant, in contrast to the previous years when the broadcast spawning corals from the family Acroporidae consistently dominated the monitoring sites. The five-year data showed a significant increase in coral recruit density at Site 3 and Site JB. These two sites face the Northeast monsoon. Monospecific stands of *Isopora bruggemannii* flourished at Site 3, while foliose *Montipora* thrived in Site JB. These coral forms are susceptible to breakage (Obura 2001).

Natural stressors such as the typhoons (Odette in 2021 and Paeng in 2022), which affected most of the sites in Tubbataha, might have caused significant impacts on the reef (Gardner et al. 2005). Sites 3 and JB experienced continuously declining trends in hard coral cover since 2021. The loss of live corals creates an available area for other biota to thrive. These open spaces, combined with compacted rubbles, are favorable conditions for the early colonizer and brooder corals to increase in density, as was reflected in this year's survey.

From 2018 to 2023, the increasing trend in coral recruitment densities may be attributed to the consistently high coral recruits observed at Sites 1, 3, and JB. In addition, some brooder types of corals, e.g., *Pocillopora,* known as an early colonizer, can reproduce asexually via fragmentation as well as sexually through spawning to produce fully formed larvae ready to settle in the substrate (Grimsditch et al. 2016). The brooder type of corals has a higher rate of survival and subsequent recruitment success in a disturbed reef than broadcast spawning corals (Glynn and Colley 2008). This may be related to the increasing dominance of coral recruits in the shallow areas, particularly in Sites 3 and JB.

Deep Areas

In the deep areas, the coral recruits were likewise dominated by brooder corals, *e.g.,* genus *Pavona* and *Porites*. This condition reflects the abundance of parent colonies within the area. They reproduce multiple times a year, unlike broadcast spawning corals, which usually spawn only once a year (Harrison and Wallace 1990). As opposed to the increasing trend observed in the shallow areas, a decline in coral recruit densities was recorded in the deep areas over the last five years. Between 2018 and 2023, there has been a decline in the density of coral recruits in deep areas. This decline could be due to a lack of suitable substrate available for coral recruits, as the area has already been occupied by larger corals or other biota, such as soft corals, sponges, corallimorphs, and loose rubble. These have been observed in deep areas in Tubbataha since 2021. Furthermore, the presence of predators and the strong currents passing through the deep areas may have eradicated smaller coral colonies. This declining trend of coral recruit densities at Sites 2, 3, and 4 coincided with the general increase of hard coral cover at 7% across all sites in this year's survey.

Size Distribution Pattern

A similar size-frequency distribution pattern was observed at both depths and within years. A high number of juvenile coral recruits were constantly recorded throughout the years, which may be influenced by the dominant adult coral population and observer bias. In an actual survey, a newly settled coral, measuring less than 1 cm, is difficult to see with the naked eye. Thus, the role of the researcher who will process the photos is very crucial. The photos taken during the fieldwork were analyzed using the CPCe software. CPCe software was utilized to identify and measure coral recruits. However, the reduced resolution of the photograph in the software made it more difficult to identify the newly settled coral smaller than 0.8 cm in size. This may be related to the small number of detections of recruits less than 1 cm in size. The researcher's proficiency in identifying the morphological features of smaller coral organisms, combined with ultra-violent light integrated into the camera, could enhance the ability to detect coral colonies smaller than 1cm in size (Martinez et al. 2021).

The greatest frequency among size classes of coral recruits was juvenile corals. This may be related to the dominance of brooder coral, such as genus *Pocillopora*. This coral genus reproduces by releasing planulae (free-swimming, fully formed coral larvae), which tend to grow in diameter within a short period of time exponentially and have an extended reproductive stage as opposed to broadcast spawner (Dai et al. 1992). The short pre-competent phase of brooding corals could contribute substantially to coral recruits at the local coral communities (Tioho et al. 2001). Based on our data, only less than 20% of all coral recruits yielded annually would survive and be able to integrate themselves as an adult colony. Since the monitoring stations are located on the reef crest, the coral recruits are subjected to various factors such as the presence of predators, stress, and monsoons.

Density in the Grounding Sites

The average density in the MPY grounding site (5.3 ind/m^2) was lower than in the USSG grounding site (6.1 ind/m^2). Coral recruitment density in the MPY grounding site was low but fell within the range of coral recruitment density in a vessel grounding in Florida, which was between 0.2 ind/m^2 (±0.1 SE) to 7.1 ind/m^2 (±1.0 SE) (Moulding et al. 2012). This highlights that the recovery of a grounding site is possible albeit at a slow rate. The lower coral recruit density in MPY is due to the composition of the substrate in the area. Sand and loose rubble in the small and large fragment plots do not provide a suitable habitat for coral recruits to settle. The adjacent control plot located at the shallower portion of the grounding site, exposed to strong waves and composed of stable substrate provides shelter for coral recruits to thrive.

In the USSG grounding site, the adjacent control and the impact border plots increased by 73% and 39%. This was influenced by the increase in the number of massive forming coral such as genus *Favites*, *Goniastrea,* and *Merrulina*. These coral genera can endure strong waves and stress compared to short-lived corals such as the genus *Poccillopora*. Despite the improvement observed at each plot, a high amount of loose rubble in the impact border and adjacent control plots was observed every year. This may be related to a low coral recruit density recorded at the grounding sites. The presence of dislodged coral rubble that fall over the coral recruits threatens the ongoing recovery of this grounding site.

CONCLUSIONS

Over the years, coral recruitment densities in Tubbataha have remained consistently high, coupled with the year-to-year increase in coral genera. This combination indicates the reef's capacity to replenish itself after disturbances. The continuous improvement observed in the grounding sites provides insights into the reef's ability to produce coral recruits in its natural environment. Over the years, in the shallow areas, the increasing trend in recruit population, particularly in South Atoll, is influenced by the available space. In contrast, the deeper areas have experienced a decline in coral recruit density, potentially attributed to physical characteristics and competition with other larger coral and non-coral species. The study shows that in the event of disturbances such as typhoons and coral bleaching, a healthy reef like Tubbataha has a potential for natural recovery and replenishment.

RECOMMENDATIONS

1. Improve coral recruitment monitoring to include colonization of coral recruits, track growth rates, and assess the temporal and seasonal variation in the influx of recruitment in Tubbataha.
2. In-depth research on the adult-juvenile relationship with depth and the mechanisms involved to generate better understanding of the size class distribution of coral recruits in Tubbataha.

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3. Reef Fish

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OVERVIEW

Climate change has become one of the most pressing global issues of our time (IPCC 2021). Its impact extends beyond rising temperatures and sea levels, affecting some of our planet's most delicate and vital ecosystems, including coral reefs (Coffroth et al. 2010).

Elevated water temperatures can lead to coral bleaching (Glenn 1996), disrupting the intricate, interdependent relationship between reefs and fish that rely on them for shelter and sustenance (Jones et al. 2004). It can also cause stress in fish, often resulting in their migration to cooler waters (Kassahn et al. 2007; Morales-Marin et al. 2019) and leaving behind their traditional habitats. The changes in ocean currents and temperature patterns can affect the distribution and abundance of fish species (Auth et al. 2018; Wang et al. 2020). As a result, climate change can alter environmental conditions, which may have cascading effects throughout the entire food web in the coral reefs.

In this dire scenario, continuously monitoring fish populations in marine protected areas, such as Tubbataha, is essential to identify ways to mitigate these impacts. Marine protected areas (MPAs) are crucial in conserving fish populations. Well-managed MPAs can boost fish populations and enhance their resilience to environmental stressors, such as those caused by climate change (Bonaldo et al. 2017; Chiriko et al. 2017; Osuka et al. 2021; Rojo et al. 2019).

The TRNP has a well-established ecosystem research and monitoring program and has one of the most comprehensive data sets in the country. The data collected is used to assess the effectiveness of the park's management and to formulate policy. This chapter presents the findings of the fish survey in TRNP across years and sites.

METHODS

Data collection

Reef fish population were monitored in the same stations as the benthos. Three 50-meter replicate transects were established at each station in shallow (~5m) and deep (~10m) areas, separated by a 10-meter buffer. Each transect formed an imaginary corridor of 10 x 50 meters with a 5-meter width on each side. The transect was divided into 5-meter segments along its length. Modified daytime Fish Visual Census (FVC), described by English et al. (1997), was used to assess the fish community's biomass, density, and species richness.

Data processing

Species richness was calculated as the average number of species recorded per $500m^2$ while fish density is the number of individuals per $500m^2$. Fish biomass (g/m^2)

was calculated using the length and weight model (Kulbicki et al. 1993), with the formula:

$$W = axL^b,$$

where W is the weight (g), L is the total length in cm, and *a* and *b* are length-weight relationship estimates from Fishbase (Froese and Pauly 2023; www.fishbase.org).

Data analysis

The RStudio (RStudio Team 2020) was used for data summarization and analysis. For statistical analysis, only the data from 2013 to 2023 were considered due to the change in methodology and the number of sites in the previous years. To determine significant changes in biomass over the study period, simple linear regression (LR) and one-factor analysis of variance (ANOVAR) were utilized. Linear regression was used to identify the direction and rate of biomass change from 2013 to 2023, while ANOVAR was used to validate whether there were significant alterations in density and biomass between years, keeping the significant threshold at $p<0.05$.

Site 5 was not included in the statistical analysis since monitoring commenced only in 2020 and covered only the shallow area. Graphical visualizations were produced using RStudio. Additionally, species richness, biomass, and density values were compared against Philippine reef fish standards (Hilomen et al. 2000; Nañola et al. 2004) (Appendix *2*).

RESULTS

Present conditions

Three hundred three (303) species across 34 families and subfamilies were identified. In shallow stations, 209 species were recorded, with a species richness of 50 species/500m^2. In contrast, 245 species were identified with a species richness of 66.3 sp/500m^2 recorded in the deep stations. The species richness at both depths fell under the very high category in the context of the Philippine reef fish standard (Hilomen et al. 2000).

Mean density

The mean density in the shallow station was 1,243 ind/500m^2 and 1,308 ind/500m^2 in the deep (Figure 18). The shallow stations were dominated by damselfish (Pomacentridae; 784 ind/500m^2), surgeonfish (Acanthuridae; 100 ind/500m^2), and fairy basslets (Anthiinae; 95 ind/500m^2). The same species predominate the deep stations albeit with varying densities: damselfish (Pomacentridae; 605 ind/500m^2), fairy basslets (Anthiinae; 286 ind/500m²), and surgeonfish (Acanthuridae; 64 ind/500m²).

Demersal species or those closely associated with the reefs, e.g., Acanthuridae (surgeonfish), Balistidae (triggerfish), and Chaetodontidae (butterflyfish), made up 98% and 96% of the mean density in shallow and deep stations, respectively.

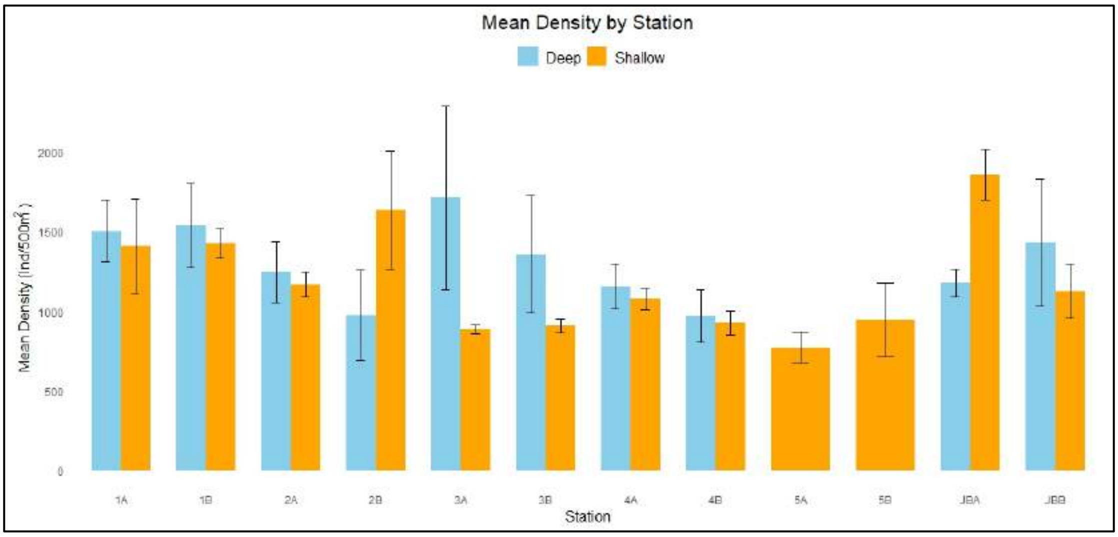

Figure 18. Average density in shallow and deep of each station in Tubbataha. Vertical bars denote the standard error of the mean.

Mean Biomass

In shallow stations (75.92 g/m²) (Figure 19), jacks (Carangidae; 13.22 g/m²), triggerfish (Balistidae; 13.74 g/m²), and parrotfish (Scaridae; 12.45 g/m²) were more prevalent. Meanwhile, deep stations contributed the most to the mean biomass with 100.31 g/m² (Figure 19), primarily dominated by unicornfish (Nasinae; 24.08g/m²), triggerfish (Balistidae; 15 g/m²), and parrotfish (Scaridae; 11 g/m²).

In shallow stations, the highest estimate was observed in Site 1, which was also due to the presence of unicornfish (Nasinae) and jacks and trevallies (Carangidae). At Site JB's deep station, the highest estimated fish biomass was due to the presence of triggerfish (Balistidae; 62 g/m²) and unicornfish (Nasinae; 25 g/m²). The deep station of Site 1 showed the next highest estimate, primarily influenced by unicornfish (Nasinae; 49 g/m²) and jacks and trevallies (Carangidae; 19 g/m²).

Demersal fish comprise 73% and 66% of total biomass in shallow and deep stations, respectively, with triggerfish and parrotfish as top contributors in both depths.

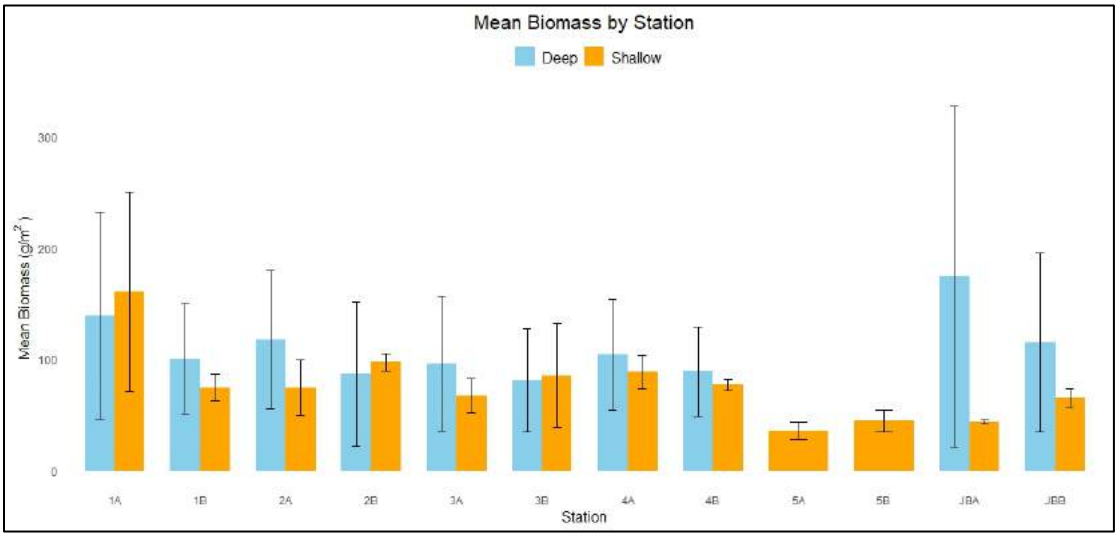

Figure 19. Average biomass in shallow and deep of each station in Tubbataha. Only the shallow station is monitored in Site 5. Vertical bars denote the standard error of the mean.

Temporal Patterns in Density and Biomass in Tubbataha

Temporal Mean Density and Biomass in Shallow and Deep

The mean density and biomass in shallow and deep stations over the years are presented in Figures 5 and 6. The outputs from deep transects were relatively higher than those from shallow ones.

The mean fish density exhibited notable variability and fluctuations over the years (Figure 20). The highest densities were observed in 2007 and 2015, with especially lower values in 2005, 2006, 2008, and 2011 - 2014. An increasing trend in fish density was observed from 2015 to the present. The prevalent families in Tubbataha comprised small-bodied fish, primarily damselfish (Pomacentridae) and fairy basslets (Anthiinae), often forming aggregations in the hundreds or thousands.

For the mean biomass, the lowest was noted in 2006 in the shallow, while the highest was recorded in 2009 in the deep stations (Figure 21). Biomass peaked in 1999, 2008-2009, and 2015-2016, while the lowest values were recorded in 2003-2006 and 2018-2023. Between 2017-2022, fish density was high, but the biomass decreased in both shallow and deep stations (Figure 21). This decline significantly contributed to the overall reduction in fish biomass between 2013 to 2023.

The fluctuating trend observed in the overall mean biomass was more prominent in the deep stations than in the shallow ones. Biomass estimates in the deep were significantly different (t-test; $p<0.05$) from the shallow stations.

In the last 11 years (2013 – 2023), deep stations showed a significant declining rate of -25.75 g/m^2 per year (LR and ANOVA, $p<0.05$) (Table 8), whereas no significant decline was observed in shallow stations.

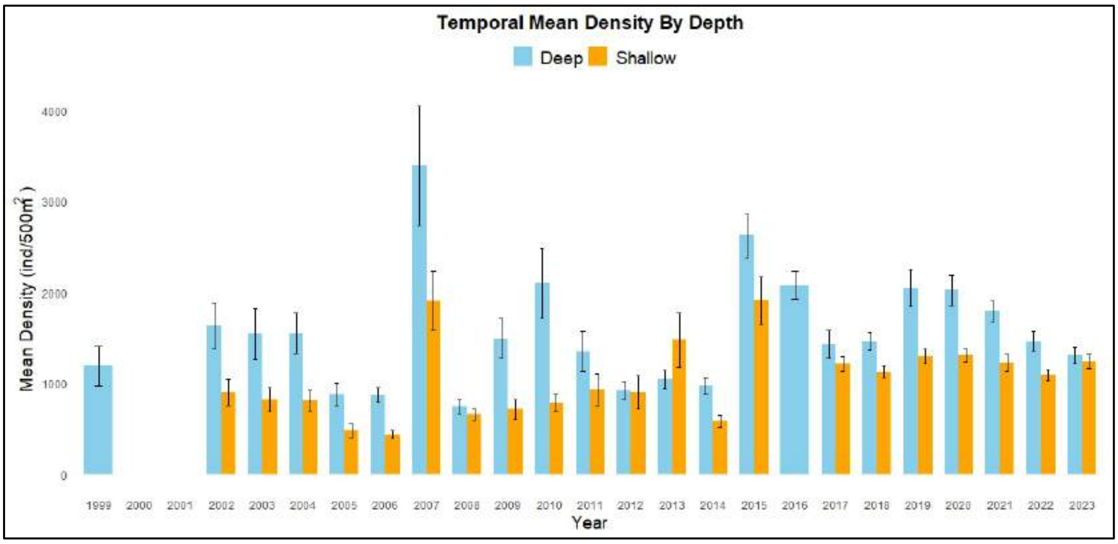

Figure 20. Mean density in shallow and deep stations in Tubbataha. Some years have no shallow stations (i.e., 1999 and 2016), while no survey was conducted in 2000-2001. Vertical bars denote standard error of the mean.

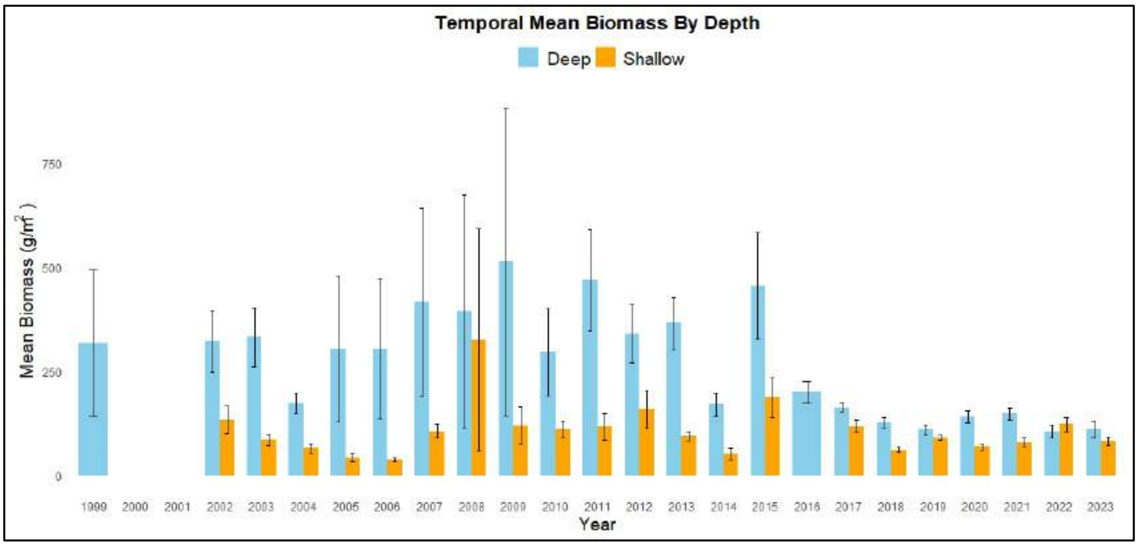

Figure 21. Mean biomass in shallow and deep stations in Tubbataha. Some years has no shallow stations (i.e., 1999 and 2016), while no survey was conducted in 2000-2001. Vertical bars denote standard error of the mean.

Temporal Mean Biomass Across Sites

Across all sites, mean biomass underscores a consistent downward trend for the last 11 years, especially in the deep stations (Figure 22). At Site 1, the mean biomass levels varied between 46 g/m^2 and 396.24 g/m^2. In Site 2, they fluctuated between 27.43 g/m^2 and 511g/m^2. Site 3 has a range between 40.84 g/m^2 shallow and 404.88 g/m^2, while Site 4 displays values ranging from 66.28 g/m^2 to 928 g/m^2, and Site JB shows the mean biomass between 24.26 g/m^2 to 248 g/m^2.

Between 2013 and 2016, biomass increased initially, followed by a subsequent decline. In 2015, most sites showed exceptionally high fish biomass and density. However, the data's high variability, as indicated by elevated standard error values, suggests that there may have been site-specific differences or observer biases.

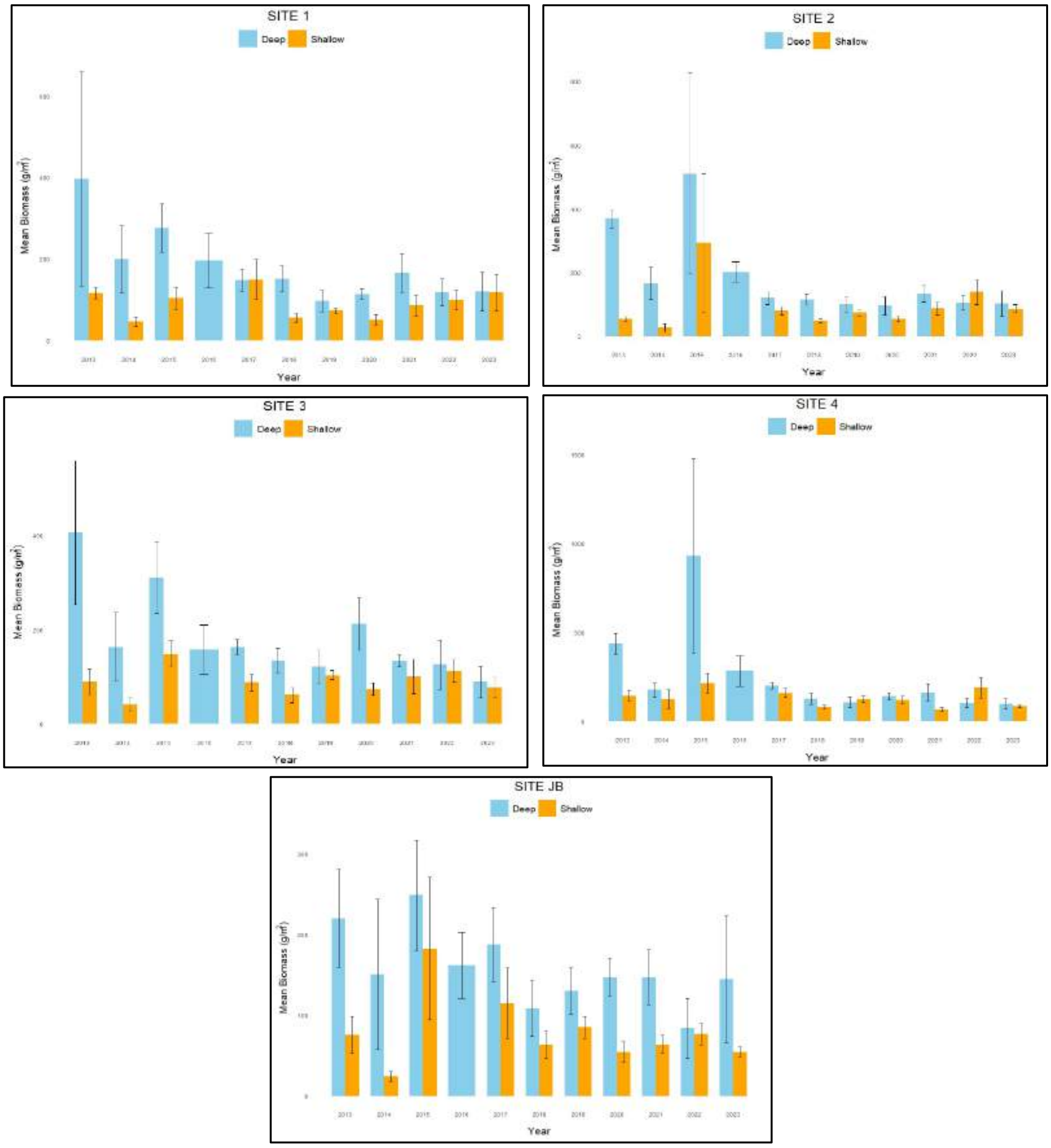

Figure 22. Mean biomass in the five (5) regular monitoring sites for both depths from 2013-2023. Vertical bar denotes the standard error of the mean.

For the last 11 years, each site's fish biomass has shown an evident decrease (Figure 22). Site 4, which has the highest annual average biomass among sites, experienced the highest decline at a rate of -27.11 g/m^2 (Table 8), followed by Site 2 (-16.24 g/m^2), Site 1 (-10.52 g/m^2), Site 3 (-10.51 g/m^2), and Site JB (-7.79 g/m^2).

Temporal Mean Biomass of Target Fish Groups in Both Depths

The term "target species" refers to the fish that fishermen harvest, whether for human consumption or recreational fishing purposes (FAO 1997). Figure 8 presents the temporal mean biomass of target species in shallow and deep stations.

The biomass in shallow stations appears stable, with peaks in 2008. From 2018 to 2023, the fish biomass in the shallow stations fluctuated. Meanwhile, in the deep station, there was a fluctuating trend with peaks in 2007-2009 (Figure 23) due to the high abundance of Carangidae (jacks and trevallies) not seen in later years. A noticeable decline in subsequent years was observed, with minimum estimates in 2010, 2014, 2018, and 2017-2023.

Overall biomass exhibited a decreasing trend in both depths, but only the deep stations showed a significant decline at a rate of -19.85 g/m^2 annually (LR & ANOVA, $p<0.05$) (Table 8) for the last 11 years (2013-2023).

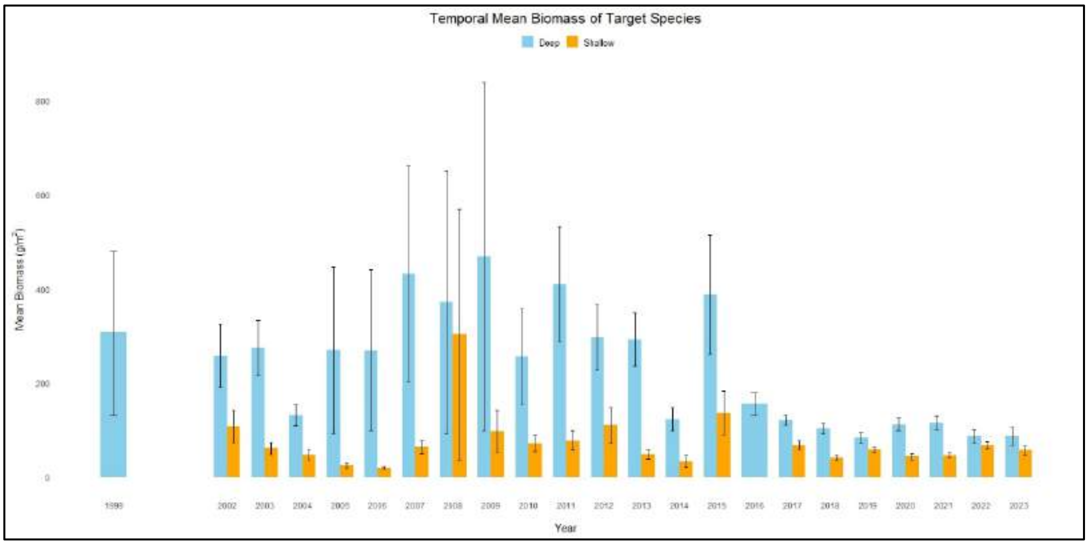

Figure 23. Mean biomass of commercially important species in shallow and deep. Vertical bar denotes standard error of the mean.

Temporal Mean Biomass of Demersal Fish Groups in Both Depths

Figure 24 displays the average biomass of demersal species over time. These fish are closely linked to coral reefs for food and shelter, making them better indicators of reef health than pelagic species. In terms of biomass, demersal fish in Tubbataha were mainly comprised of parrotfish (Scaridae), damselfish (Pomacentridae), triggerfish (Balistidae), snappers (Lutjanidae), and surgeonfish (Acanthuridae), among others.

The general trend for the shallow areas was increasing (Figure 24). However, in deep stations, a downward trend was observed due to the relatively lower biomass estimates from 2016 to 2023. Demersal fishes were observed more frequently at deeper stations, except for 2022. In 2015, a significant peak in both depths was due to the encounter with several schools of Bumphead parrotfish (*Bolbometopon muricatum*). Over the last 11 years (2013-2023), deep stations recorded an annual decline of -13.89 g/m^2 for demersal fishes (LR & ANOVA;p<0.05) (Table 8).

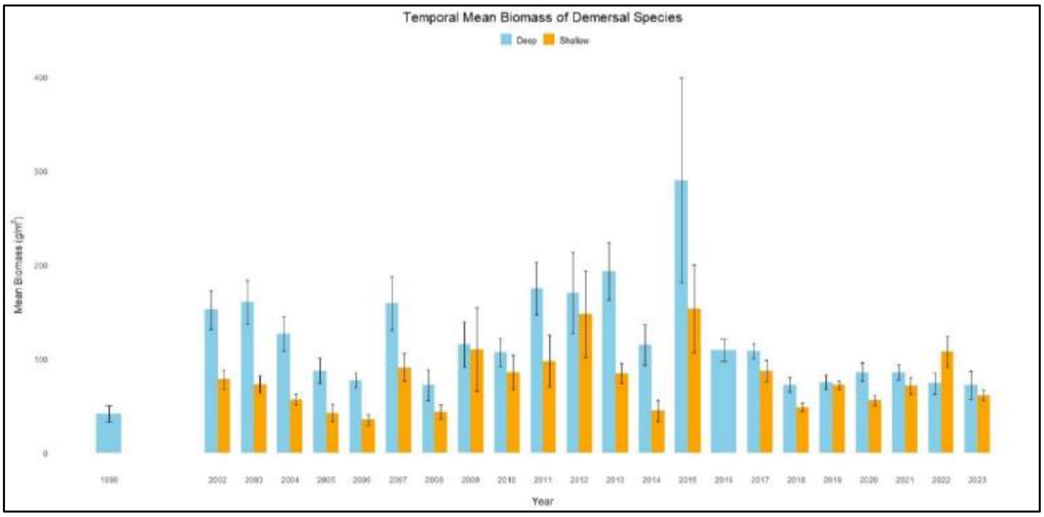

Figure 24. Mean biomass of demersal fish groups in shallow (~5m) and deep (~10m) stations. Vertical bar denotes standard error of the mean.

Table 8. Summary table for 11-year (2013-2023) mean biomass, rates of change, and differences in mean biomass among years in Tubbataha. Statistically significant (p<0.05) results from linear regression and ANOVAR are indicated. ns = not significant

	Depths	2023 Mean biomass (g/m^2)	Average Biomass (g/m^2; 2013-2023)	Rate of change (g/m^2) 2013-2023	Difference Among Years in Biomass (ANOVAR; 2013 -2023)
OVERALL DEPTH					
Overall	hallow	83.51	100.3	ns	ns
	Deep	110.34	191.24	-24.31	p<0.05
GROUPS					
Target	Shallow	56.5	61.32	ns	p<0.05
	Deep	87.67	147.78	-19.85	p<0.05
NATURE					
Demersal	Shallow	61.07	80.28	ns	p<0.05
	Deep	72.37	131.97	-13.89	ns
Pelagic	Shallow	22.43	21.09	ns	ns
	Deep	37.96	55.26	-4.66	p<0.05
SITES					
Site 1	Shallow	117.73	90.12	ns	ns
	Deep	119.73	172.3	-19.34	ns
Site 2	Shallow	85.96	97.84	ns	ns
	Deep	102.32	178.03	-27.67	ns

Site 3	Shallow	76.33	90.76	ns	ns
	Deep	88.21	176.36	-19.22	p<0.05
Site 4	Shallow	82.87	129.82	ns	p<0.05
	Deep	96.71	244.05	-47.26	ns
Site JB	Shallow	54.67	81.69	ns	ns
	Deep	144.75	155.6	-9.77	p<0.05

Ship Grounding Sites

Min Ping Yu

This year, 67 species were identified in the shallow station of Min Ping Yu grounding site, corresponding to a species richness of 38.67 per 500m^2. Meanwhile, 122 species were identified at the deep station, with a species richness of 68 per 500m^2. In total, 153 species were identified in the vicinity of the Min Ping Yu grounding site.

The mean density in the deep station (1,524 ind/500m^2) was relatively higher than in the shallow (602 g/m^2) (Figure 25). The most abundant fish family in terms of population for both depths was damselfish (Pomacentridae). Fairy basslet (Anthiinae) was only present in the deep station, while Surgeonfish (Acanthuridae) was abundant at both depths.

In terms of biomass, the deep stations (50.68 g/m^2) had higher biomass than shallow stations (38.80 g/m^2), but the difference was not significant (t-test; $p>0.05$). The deep station had a higher abundance of squirrelfish (Holocentridae; 11.44 g/m^2) and damselfish (Pomacentridae; 10 g/m^2), while jacks and trevallies (Carangidae; 11.71

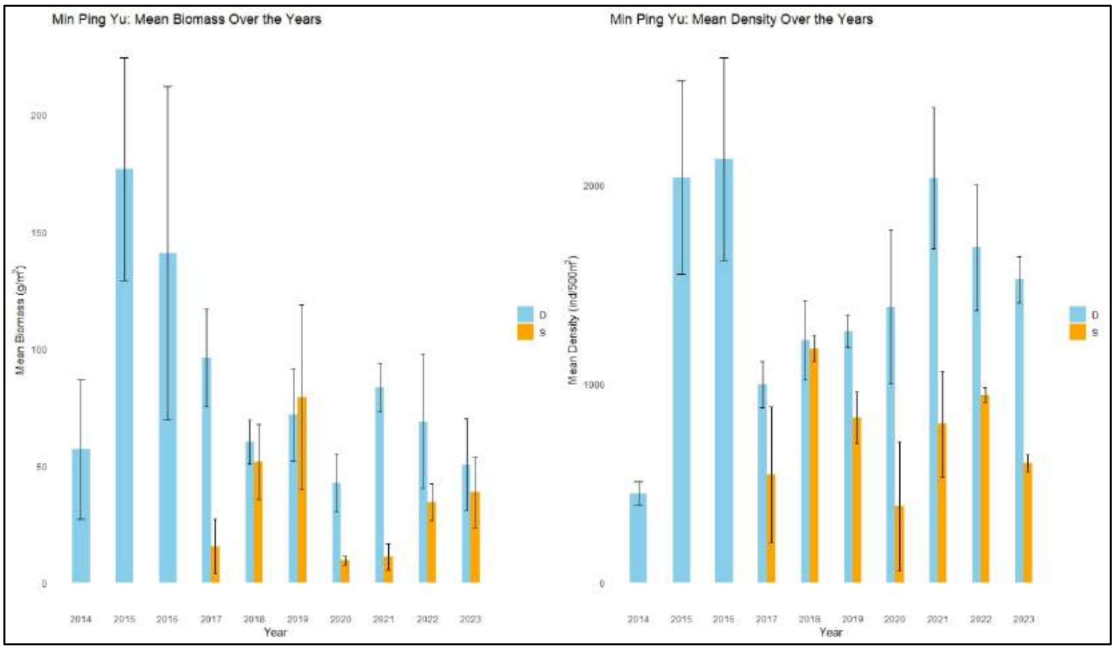

Figure 25. Mean biomass (g/m^2) and mean density (ind/500m^2) in the Min Ping Yu grounding site over the years. Vertical bar denotes standard error of the mean.

g/m²) and surgeonfish (Acanthuridae; 9.26 g/m²) were more common in the shallow area.

The MPY grounding site features gently sloping terrain leading to a drop-off, with the ~10m adjacent site located >50 meters from the impact site (shallow). There were years when only the adjacent ~10m station was surveyed and not the shallow one (see Figure 10) due to lack of observers and safety concerns.

The average density in both depths has increased over the years (Figure 25). However, in terms of mean biomass, while the shallow station showed a slightly increasing trend, the deep station has exhibited a decreasing trend, translated to an annual declining rate of -8.67 g/m² (LR $p<0.05$).

USS Guardian

A total of 140 species were identified in the area around the USS Guardian grounding site. The shallow station recorded 78 species with a species richness of 46.66 per 500m², while the deep station recorded 103 species with a species richness of 55.33 per 500m².

The abundance in the shallow station was 944 ind/500m², slightly lower than the deep station (1,053 ind/500m²) (Figure 26), but not significantly different (t-test; $p>0.05$). The shallow stations were predominantly inhabited by damselfish (Pomacentridae; 398.33 ind/500m²) and wrasses (Labridae; 266.33 ind/500m²). Meanwhile, the deep station was dominated by fairy basslets (Serranidae; 452 ind/500m²) and damselfish (Pomacentridae; 329.67 ind/500m²).

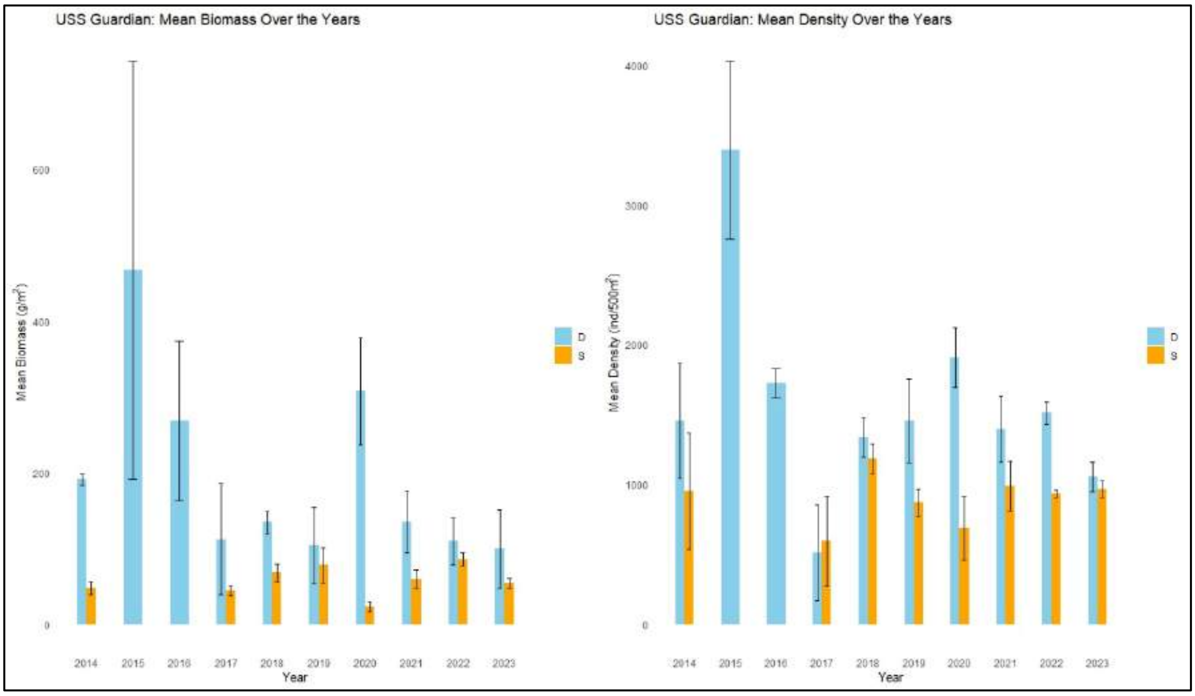

Figure 26. Mean biomass (g/m²) and mean density (ind/500m²) in the USS Guardian grounding site over the years. Vertical bar denotes standard error of the mean.

For the mean biomass, the shallow stations (55 g/m^2) were lower than their deep counterpart (99.76 g/m^2) (Figure 26), but the two depths were not significantly different (t-test; p>0.05). Parrotfish (Scaridae; 15 g/m^2) and surgeonfish (Acanthuridae; 11.28 g/m^2) mainly contributed to the mean biomass in the shallow station. Triggerfish (Balistidae; 23.43 g/m^2) and unicornfish (Nasinae; 15.38 g/m^2) were the most dominant fish families in deep stations.

Similar to the MPY grounding site, the only consistent available data in the USS Guardian grounding site was in the adjacent deeper station. This adjacent site refers explicitly to the immediate drop-off zone at a depth of approximately 10 meters. The mean density and biomass showed a slight decreasing trend in the deep areas, while increasing in shallow areas over the years (Figure 26). However, these trends were not significant.

DISCUSSION

Present conditions

Density slightly increased in the shallow station from 1,097 ind/500m2 (2022) to 1,242.67 and/500m2 this year, while it slightly decreased in the deep station from 1,464.53 ind/500m2 (2022) to 1,308.07 in/500m. However, the difference for both years in two depths was not significant (t-test; p>0.05).

The increase in shallow stations from 2022 was due to relatively higher numbers of damsels (Pomacentridae) and wrasses (Labridae). Meanwhile, the decrease in the deep station was mainly due to fewer encounters with fairy basslets (Anthiinae). From 2022, the presence of surgeonfish (Acanthuridae), wrasses (Labridae), and damselfish (Pomacentridae) increased.

A decrease in mean biomass was recorded in shallow stations from 123.30 g/m^2 in 2022 to 79.82 g/m^2 this year. The decrease, however, was not significant (t-test; p>0.05). The decrease in shallow stations was primarily attributed to fewer encounters with Bumphead parrotfish (*Bolbometopon muricatum)*. Two schools comprising 40 individuals (size >70cm) were encountered in the previous year but not this year. Meanwhile, for the deep stations, the mean biomass is the same this year and last year at 100 g/m^2.

Among all sites, Site 1 and Site JB increased in mean biomass from 2022. The increase in Site 1 was mainly due to the presence of jacks and trevallies (Carangidae). This year, the number of triggerfish (Balistidae) and jacks and trevallies in Site JB also increased.

Sites 2, 3, and 4 experienced a decrease in biomass from the previous year's estimate. In Site 2, a school of Bumphead parrotfish (*Bolbometopon muricatum)* encountered in 2022 was not encountered this year. More groups of Redfin emperor *Monotaxis* *heterodon* were encountered last year than this year, contributing to the decrease in the Site.

At Site 3, reduced encounters with sweetlips (Haemulidae), emperorfish (Lethrinidae), and fusiliers (Caesionidae) resulted in a decline in mean biomass. Large-sized (90cm) Giant sweetlips (*Plectorhinchus albovittatus*) were observed at Site 3 last year but were absent this year. Despite more encounters with individuals of *Plectorhinchus sp*. (size >35 cm) this year, it could not compensate for the biomass contribution of *P. albovittatus* in 2022. A school of Midnight snapper (*Macolor macularis*) with a size of 45 cm was also present last year but not this year. Meanwhile, Site 4 experienced the most significant decline, mainly due to the absence of a school of Bumphead parrotfish (*Bolbometopon muricatum)* encountered in 2022.

Despite the recorded declines, this year's reef fish density and biomass still fall between the "high" and "very high" categories according to benchmarks set by Hilomen et al. (2000) and Nanola et al. (2004) (see Appendix 2).

Temporal Trends in Biomass in Tubbataha

For the last 11 years (2013-2023), the decline in fish biomass in the deep stations was largely due to the significant drop in biomass of fusiliers, jacks, and trevallies. The biomass of fusiliers (Caesionidae) decreased at a rate of -7.41 g/m^2 per year (LR $p<0.0001$, ANOVAR $p<0.001$), and jacks and trevallies at 2.45 g/m^2 (LR $p<0.001$, ANOVAR $p<0.05$).

Biomass in the deep stations significantly declined in all sites from 2013-2023 (Table 1). The decline in the biomass of fish groups mentioned above, and top contributors in each respective site, generally caused the decrease. Specifically, in Site 1, the decline was influenced by fewer encounters with triggerfish (-1.80 g/m^2; LR & ANOVAR, $p<0.05$), parrotfish (-1.62 g/m^2; LR & ANOVAR, $p<0.05$), and damselfish (-1.53 g/m^2; LR & ANOVAR, $p<0.05$). In Site 2, there was an annual decline of jacks and trevallies (-4.65 g/m^2; LR & ANOVAR, $p<0.05$) and damselfish (-2.32 g/m^2; LR & ANOVAR, $p<0.05$). For Site 3, an annual decline was also observed for parrotfish (-4.97 g/m^2; LR & ANOVAR, $p<0.05$) and damselfish (-2.06 g/m^2; LR & ANOVAR, $p<0.05$). Site 4 saw a declining biomass of unicornfish (-3.22 g/m^2; LR & ANOVAR, $p<0.05$), jacks and trevallies (-3.39 g/m^2; LR & ANOVAR, $p<0.05$), and sweetlips (-2.24 g/m^2; LR & ANOVAR, $p<0.05$). Site JB, meanwhile, showed a declining population of damselfish (-1.23 g/m^2; LR & ANOVAR, $p<0.05$). A school of *Scolopsis* sp. recorded in 2015 and 2016, and not in succeeding years, mainly drove the decline in the deep station of Site JB.

The presence of certain fish species, often targeted for fishing or occupying the highest trophic level in a specific area, can indicate a positive impact of reef protection. Marine protected areas are established, in part, to enhance and restore the population of these fishes, given sufficient time of protection (Russ and Alcala 1996; Helfman et al. 2009). In Tubbataha, the top fish families considered commercially important that were influencing the mean biomass are the jacks and trevallies, barracuda, unicornfish, fusiliers, parrotfish, and mackerels. Except for parrotfish, these fish families are considered pelagics. Pelagic fish frequent the deeper parts of the reef and rarely visit the shallower areas. They are also relatively large-sized and often form groups for efficient hunting and protection against predators (Ritz et al. 2011; Kaundra-Arara and Rose 2004), which leads to variability in transect data when encountered.

For instance, over the course of monitoring, barracudas and mackerels were only observed in certain years. However, their substantial size significantly influenced the trend in average biomass. Jacks, trevallies, and fusiliers were observed every year, but their numbers varied when encountered. In some years, they appeared in relatively large groups, while in others, they were present in fewer numbers. These uncertainties in the presence of pelagic species influenced the overall decline in the mean biomass of deep stations. For the last 11 years, an annual decline of -10.53 g/m^2 in pelagics, which corresponded with the decline in encounters with jacks and fusiliers.

Over the past decade, demersal fish significantly contributed to the overall biomass in Tubbataha. Demersal fishes are highly associated with coral reefs, making them better indicators of reef health than the pelagics, which inhabit and feed in the open water column (Lal and Fortune 2000). While the general trend for demersal fish since 1999 showed a slight decline, the data from 11 years (2013-2022) exhibited a significant annual decline of -13.89 g/m^2 (LR & ANOVA; $p<0.05$). This was mainly influenced by the significant annual decline in the mean biomass of snappers (-1.43 g/m^2; LR & ANOVAR, $p<0.05$), sweetlips (-1.31 g/m^2; LR & ANOVAR, $p<0.05$), and groupers (-1.43 g/m^2; LR & ANOVAR, $p<0.05$). The high number of Bumphead parrotfish encountered in 2015 but not in the succeeding years also contributed to the decline. Despite the encounters in subsequent years, their numbers were lower compared to 2015.

Multifaceted factors can contribute to the decline in fish population, including environmental and ecological factors and anthropogenic stressors. The presence or absence of fish in a given area is significantly influenced by various factors, including but not limited to food availability, spawning seasons, and predator avoidance (Helfman et al. 2009; Bone and Moore 2008). These factors affect fish distribution and abundance and influence much larger synchronized migrations of populations.

Other factors include migrations due to tidal and lunar cycles. Many fish species exhibit tidal movements, venturing into shallow reef areas during high tides to feed and subsequently retreating to deeper water during low tides, which enables them to evade predators and optimize their foraging efforts (Gibson 1992; Gibson, 2003; Choat & Robertson 1975). Some fish species exhibit lunar-synchronized spawning, with peak activity occurring around new and full moons. These factors influence fish behavior, movement patterns, spawning activity, and overall population dynamics (Hsiao et al. 1994; Ikegami et al. 2014; Takamura et al. 2010) and can influence their presence in the reef, thereby affecting fish biomass and abundance.

Climate change poses a significant threat to tropical fisheries. Elevated sea surface temperatures, one effect of climate change, could drive the fish to migrate to deeper and colder waters (Currey et al. 2015; Thompson et al. 2022). Anecdotal evidence suggests that schooling fishes, e.g., jacks and trevallies, are still observed in Tubbataha. However, they were commonly found beyond depths (>10 m) monitored by TMO.

Protected areas, such as Tubbataha, are used as a tool to promote the recovery of reef fish biomass overtime and provide 'spillover' to nearby local fishing grounds (Graham et al. 2011; Baskett and Barnett 2015; Muallil et al. 2015). A recent study by Frid et al., (2023) found that the rate of decrease in fish biomass due to high sea temperatures was similar between protected and fished sites. This suggests that marine protected areas (MPAs) may not buffer the impacts of warming waters as much as anticipated. Global ecosystem models predict a decline in zooplankton and marine fish biomass due to climate change, even without fishing (Tittensor et al. 2021).

While this might be true, protection from fishing will remain an important management tool, even with future high water temperatures (Frid et al. 2023). Therefore, MPAs, especially large no-take ones such as Tubbataha, are expected to sustain benefits to conservation and local fisheries amidst climate change-related challenges.

Moreover, while Tubbataha is a no-take MPA with stringent enforcement measures in place, illegal fishing activity remains an ever-present threat, although few apprehensions were recorded in the last decade (i.e., 2014, 2017, 2021, and 2023). Undetected illegal fishing activity is also a possibility, considering the large area of Tubbataha. Reports were also received from dive operators during tourism seasons on sightings of fishing vessels near the boundaries of Tubbataha.

High variability in the data collected is evident through high standard errors and must also be considered. This variability may have been influenced by observer biases caused by overestimating or underestimating fish counts and sizes. Therefore, it could also be considered one of the factors that affect the mean biomass and density outputs of Tubbataha.

The aforementioned factors could have played a role in the decrease of fish biomass in Tubbataha, underscoring the complex interconnection of environmental, ecological, anthropogenic, and management-related factors in shaping the dynamics of the fish population in the area. Nevertheless, additional research is required to pinpoint the primary contributors to the variations in fish biomass.

According to Hilomen et al. (2000) and Nañola et al. (2004), in the context of a healthy reef fish community in the Philippines, Tubbataha's fish population still exceeds the minimum standards for marine protected areas and has remained consistently healthy over time.

Ship Grounding Sites

Min Ping Yu

Mean densities in shallow and deep stations this year (shallow – 602.33 ind/500m^2; deep – 1524 ind/500m^2) were slightly lower than in 2022 (shallow – 944.33 ind/500m^2; deep – 1685 ind/500m^2), although the differences were not significant. The decrease in both depths was primarily driven by fewer encounters with damselfish (Pomacentridae).

An increase in the mean biomass in the shallow station was recorded this year (38.79 g/m^2) compared to last year (34.50 g/m^2). Meanwhile, the estimate in the deep station this year (50.68 g/m^2) was slightly lower than in 2022 (69.02 g/m^2). The differences for both depths between years were not significant. The increase in shallow stations was influenced by jacks and trevallies (Carangidae) that were not recorded in 2022. The decrease in biomass from 2022 in the deep station was due to fewer encounters with fusiliers (Caesionidae), parrotfish (Scaridae), and unicornfish (Nasinae).

In general, the mean density in the shallow and deep stations of the MPY grounding site was stable despite the fluctuations in the data. These fluctuations were mainly influenced by the number of the damselfish and fairy basslets in each encounter. Several species of these two fish families tend to aggregate in large numbers, ranging from hundreds to thousands, which impacts the overall mean density in the MPY grounding site and other monitoring sites.

The average biomass at deep stations has been decreasing, consistent with the trend observed in regular monitoring sites. The decline was mainly caused by the absence of large-sized pelagic groups, such as unicornfish, fusiliers, and jacks and trevallies. These groups have been recorded in some years causing fluctuations in the data at this depth.

USS Guardian

The average density at the shallow (944 ind/500m^2) and deep (1,053 ind/500m^2) stations this year did not significantly differ from the values recorded in 2022 (shallow – 935 ind/500m^2; deep – 1512 ind/500m^2). The biomass in the shallow station this year (55 g/m^2) was lower than last year (85.87 g/m^2) at the same depth, attributed to fewer sightings of triggerfish. Similarly, the average biomass in the deep station this year (99.76 g/m^2) was slightly lower than in 2022 (109 g/m^2) due to fewer sightings of triggerfish (Balistidae), squirrelfish (Holocentridae), and sweetlips (Haemulidae).

The mean density remained stable in both depths of the USS Guardian grounding site over the years. The density of fish was primarily influenced by damselfish and fairy basslets in both depths.

At the shallow station, triggerfish, parrotfish, and surgeonfish were the most dominant at the shallow site. On the other hand, in the deep station, triggerfish (Balistidae), unicornfish (Nasinae), and parrotfish (Scaridae) were the dominant fish groups in terms. While the biomass remained stable at both depths over the years, fluctuations in the year-to-year outputs were influenced by the aforementioned fish groups in the USS Guardian grounding sites.

Other Observations

During the survey, some species of interest, not within the transects, were also noted. Humphead wrasses (*Cheilinus undulatus*) were spotted in almost all the sites except Site 2. Schools of big-eye trevallies (*Caranx sexfasciatus*) was also observed in Site 1. Additionally, a school of Humpback red snapper (*Lutjanus gibbus*) with over 800 individuals and Bumphead wrasses (*Bolbometon muricatum*) with over 10 individuals were present in Site 4. Four individuals (size >100m) of milkfish (*Chanos chanos*) were also noted in the Min Ping Yu grounding site. Whitetip reef sharks (*Trianodon obesus)* were seen in Sites 1, 2, and JB. Hawksbill turtles (*Eretmochelys imbricata*) were noted in Site JB and the USS Guardian grounding site.

CONCLUSIONS

Fish populations in the monitoring sites exhibited annual variations. Specifically, the deep station experienced a significant decline in the last 11 years, influenced by a decrease in schooling large-sized fish groups such as fusiliers and trevallies. Various factors, including ecological (e.g., migrations, natural movements), environmental (e.g., climate change, tidal/lunar cycles), and anthropogenic factors (e.g., illegal fishing, observer biases), among others, are interconnected and are believed to contribute to fluctuations in biomass and density in Tubbataha.

Despite challenges, Tubbataha Reefs Natural Park remains relatively healthy and surpasses the country's established yields for reef fish populations. However, it is crucial to understand the reasons behind the decline in some fish groups in recent years. This understanding will enable park authorities to address the challenges effectively. By doing so, the park can ensure its continued health and support the country’s fishery sector by providing fish and coral larvae to its surrounding fishing grounds.

RECOMMENDATIONS

1. Conduct further data analysis to explore the possibility of seasonality and the effects of declining coral cover and increasing sea surface temperature on fish populations, especially those species with certain temperature thresholds.
2. Sustain vigilant enforcement mechanisms against anthropogenic activities, especially during the diving season, to mitigate possible undetected illegal fishing activities.
3. Standardize estimates among the observers to mitigate biases in size and count measurements.

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4. Seabirds

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OVERVIEW

Fieldwork

The fieldwork was divided into two periods as avifauna inventory was part of other biodiversity surveys. The team arrived at the Ranger Station on 8 May 2023 and inventories were conducted from 9 to 11 May 2023 at Bird Islet and 12 – 13 May 2023 at South Islet.

An orientation was conducted at the Ranger Station, where the Tubbataha Management Office's (TMO) seabird consultant, ornithologist Arne Jensen, explained the monitoring protocols and highlights of previous years' results. Each participant was assigned tasks to carry out over the succeeding days.

Seabird Inventory Team

The 2023 survey constituted 23 participants headed by the Protected Area Superintendent (PASu) of Tubbataha Reefs Natural Park (TRNP), including 13 TMO staff and Marine Park Rangers (MPRs), one crew from M/Y Navorca, and seven volunteers (Appendix 1). The team of MPRs consisted of three from the Philippine Coast Guard, one from the Philippine Navy, two from the Municipal Government of Cagayancillo, and four from TMO. Headed by Captain Darius Cayanan, M/Y Navorca of WWF-Philippines transported the team to Tubbataha Reefs and back to mainland Palawan.

METHODS

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

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

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

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

Calculation of land area and vegetative cover

Photos of permanent photo documentation sites in Bird Islet and South Islet were taken (Appendix 13). These sites were established in 2004 to measure changes in land area and in vegetation. GPS readings were taken measuring the land area of Bird Islet at high tide.

Vegetative cover was monitored by conducting a census of the condition of trees and other vegetation on the islets. Trees, all planted saplings mostly of *Pisonia grandis* (*Anuling*, Bird-catcher or Lettuce Tree) were all eradicated due to the impacts of the spike in the population of Red-footed Booby *Sula sula* and years of drought. The condition of trees is classified as either in optimal (good), moderately deteriorating (fair) or severely deteriorating (bad) condition, and lastly, as dead. For photos of beach forest species, see Jensen et al. (2019). The vegetation inventory of 2023 was carried out using the same methodology as all other years, and the trend over time is therefore comparable.

Figure 27. From left to right: Scaevola taccada (beach cabbage/sea lettuce/beach naupaka), Heliotropium foertherianum (tree heliotrope), and Pisonia grandis (Anuling, bird-catcher tree/lettuce tree). Photos: Teri Aquino

Calculation of breeding populations

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

- Daytime direct counts of birds, nests, and eggs;
- Dawn count estimations (5 am) of the Brown Booby and Red-footed Booby populations at the 'Plaza' and the adjacent area;
- In-flight data of Red-footed Booby and, Brown Booby *Sula leucogaster*;
- Count of Great Crested Tern *Thalasseus bergii* and Brown Noddy *Anous stolidus* along the shoreline at high tide.
- Assessment of the MPRs quarterly inventory results enabling calculations and estimations of the annual breeding populations of the seabirds.

The result of the fieldwork was compared with several data sets: the WWF Philippines data from 1998 to 2004; the annual inventory results from 2004 to 2022; and data gathered by MPRs from June 2022 to May 2023. The data from 1981 to 2013 were analyzed in detail by Jensen and Songco (2016) and published in the Journal of Asian Ornithology (FORKTAIL 32 (2016): 72–85). Other analyses are found in the 28-year seabird population development data published in 2004 to 2006, and in the 2009 to 2022 seabird monitoring reports (see Jensen 2004 to 2006 and 2009 to 2016, and Jensen et al. 2017-2022).

RESULTS AND DISCUSSION

Monitoring of Changes in Land Area and Habitats

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

Bird Islet

The land area has increased by almost 5% from 13,334 m^2 in 2022 to 13,993 m^2 in 2023. The circumference of the islet measured along the high tide line was 540 meters compared to 494 meters in 2022, or an increase by nearly 9%. As in 2022, erosion was observed particularly at the northeast part of the islet. The 'Plaza', defined as the central area of the islet dominated by compacted barren soil with very limited vegetation (Figure 28), was measured to be 5,435 m^2 representing a 23% decrease compared to 2022 (7,014 m^2). The circumference of the 'Plaza', however, is not demarcated and there are uncertainties in the measurement data. The decrease may represent a combination of loss of land area at the coastal section of the "Plaza" and an expansion of grass vegetation.

Figure 28. Landscape of 'Plaza', Bird Islet, May 2023. Photo: Gerlie Gedoria/TMO

When the vegetation in Bird Islet was first assessed in 2006, 229 beach forest trees were recorded. The vegetation began to deteriorate due to impacts of bird droppings coupled with several years of drought; by 2016 all trees had died. As part of reforestation efforts, beach forest saplings were planted in small numbers from

2017 to 2019 on Bird Islet. In June 2020, 329 saplings of Anuling were planted. In May 2023 only eight saplings, encased in protective bamboo guards, remained.

Table 9. Approximate changes in the land area of Bird Islet from 1911 to 2023. Source: Worcester 1911, Kennedy 1982, Heegaard and Jensen 1992, Manamtam 1996, WWF Philippines 2004 and Tubbataha Management Office 2004 to 2023.

Year	Land area (length x width)/ circumference (m)	Land area (high tide) (m^2)	Open area ("Plaza") (m^2)	Major sandbars position and condition	Erosion area
1911	400 x 150	60,000	No data	>40,000 m^2 (?)	No data
1981	268 x 70	18,760	18,000	NW, SE	South coast
1991	>220 x 60	13,200	>8,000 (est.)	NW, SE	South coast
1995	265 x 82	21,730	8,000 (est.)	NW, SE	South coast
2004	219 x 73	17,000	>1,100 (est.)	NW: Stable SE : Decrease	South coast
2005	No data	15,987	>4,000 (est.)	NW, SE: Stable	South coast
2006	No data	14,694	7,900 (est.)	NW, SE: Stable	South coast
2007	No data	13,341	8,000 (est.)	NW, SE: Stable	South coast
2008	No data	12,211	< 8,000	NW: Decreasing SE : Stable	South coast
2009	No data	10,557	< 7,000	NW: Eroded SE : Decreasing	West coast
2010	No data	11,038	4,367	NW: Eroded SE : Stable	South coast
2011	No data	12,968	4,000 (est.)	NW: Stable SE : Stable	Northeast coast
2012	590	12,494	3,892	NW: Stable SE : Stable	Northeast coast
2013	548	10,955	4,840	NW: Decreasing SE : Stable	Northeast coast
2014	503	>10,220	4,124	NW: Decreasing SE : Stable	Northeast coast
2015 [1]	<561	<13,408	3,279	NW: Stable SE : Stable	Northeast coast
2016 [2]	590	15,649	4,513	NW: Disappeared SE : Decreasing	Northeast coast
2017 [3]	588	15,307	6,704	NW: Disappeared SE : Decreasing	Northeast coast
2018 [4]	568	15,373	2,572	NW: Two small sandbars off the coast SE : As above	Northeast Coast
2019 [5]	574	17,987	6,202	NW: Two small sandbars off the coast SE: Three sandbars off the coast	None compared to 2018
2020	610	19,297	5,826	NW: Two stable sandbars	No erosion

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

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.

South Islet

South Islet was originally part of a large sandbar until a circumferential concrete seawall was constructed in the 1980s (Kennedy 1982) to accommodate a lighthouse. In 2019 an embankment and construction of a new seawall and lighthouse changed the size of the islet. The circumference of the islet since the completion of the new seawall in 2020 has been 307 meters from 230 meters in 2018 and the land area has increased to 5,222 $m^2$from 2,884 m^2 in 2018.
Until 2009, the beach forest comprising about 125 trees was in optimal condition, with several trees as high as about 30 feet. By 2014, trees in bad condition dominated the islet. In 2019, the remaining five dying trees were covered in sand during the reconstruction of the islet. In June 2020, 101 Anuling saplings were planted. By April 2022 all were dead due to sea spray during rough sea conditions. Nineteen samplings were sent to TRNP and planted on South Islet after the inventory ended in April 2022. However, by May 2023, no saplings had survived.

Avifauna Inventory Results

Thirty 30 bird species including two species new to TRNP, the Oriental Pratincole *Glareola maldivarum* and Dusky Warbler *Phylloscopus fuscatus*, were identified (Appendix 12). The total number of all avifauna species, mostly migratory, recorded in TRNP over time is 124. Among these are seven seabird species that breed in TRNP: Brown Noddy *Anous stolidus,* Black Noddy *Anous minutus,* Great Crested Tern *Thalasseus bergii*, Sooty Tern *Onychoprion fuscata*, Masked Booby *Sula dactylatra,* Red-footed Booby *Sula sula*, and Brown Booby *Sula leucogaster.* There are three other species that breed in addition to the ones previously mentioned. The Pacific Reef-egret *Egretta sacra* breeds every year, while the Barred Rail *Gallirallus torquatus* breeds on an irregular basis. The Eurasian Tree Sparrow *Passer montanus* are now only occasionally observed.

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

Overall, the booby species of TRNP breed throughout the year and the tern species around nine months annually (Heegaard and Jensen 1992, Manamtam 1996, Kennedy et al. 2000, Jensen 2009, Jensen and Songco 2016). The April/May inventory results, therefore, represent only the breeding population present during the time of the inventory.

Table 10. Total count numbers of adult resident seabirds present on Bird Islet and South Islet in May 2023 compared to the inventory result of end of April 2022.

Species / Numbers	2022			2023			% Change 2022 - 2023
	Bird Islet	South Islet	Total	Bird Islet	South Islet	Total	
Brown Noddy	638	1,446	**2,084**	541	621	**1,162**	- 44%
Black Noddy	976	1,238	**2,214**	1,590	1,252	**2,842**	+28%
Great Crested Tern	11,536	6,018	**17,554**	3,438	12,718	**16,156**	- 8%
Sooty Tern	8,790	2,658	**11,448**	3,900	715	**4,615**	- 60%
Masked Booby	2	0	**2**	2	0	**2**	0
Red-footed Booby	410	326	**736**	258	231	**489**	- 34%
Brown Booby	4,732	174	**4,906**	4,728	126	**4,854**	-1%
Total	27,084	11,860	38,944	14,457	15,663	30,120	-23%

In May 2023, 30,120 adult individuals of seven breeding seabird species were recorded; 14,457 on Bird Islet and 15,663 on South Islet (Table 10). Bird Islet hosted 48% of the breeding population (70% in 2022) and South Islet 52% of the population (30% in 2022). Compared to the inventory in 2022, the population on Bird Islet decreased by 47%, while the number of seabirds on South Islet increased by 32%.

Compared to the 2022 inventory, the May 2023 count result is lower by more than 8,824 birds or by -23% (Table 10). The total of adult seabirds in May 2023 was almost at the same level as the population in 2020 (32,633 individuals) but 122% higher than in the baseline year of 1981 (Kennedy 1982). The difference in result for May 2023 compared to May 2022 is mainly due to the variation in the breeding period of Sooty Tern and Brown Noddy but not in the annual population numbers.

The result for the Brown Noddy suggests that there have been changes in phenology, such as migration or breeding patterns. Meanwhile, the result for the Sooty Tern indicates that the population was going through a normal seasonal variation in breeding cycle during the 2023 inventory period. This means that the Sooty Tern population was at an early stage of breeding where they were not fully present during the day, did not have established territories, and laid fewer eggs than usual. Specifically, only 576 birds laid eggs during this period. The population trend for Black Noddy does not express the total annual breeding population. The high population total for Brown Booby reflects the later years' continued increase in the breeding population. Brown Booby population in May 2023 is almost the same as last year's and is 29% higher than the baseline year 1981. The continued decline in the Red-footed Booby population is a result of absence of breeding trees with the note that a small number (five pairs) now is breeding on the ground at South Islet, a phenomenon first observed in 2022.

Review of Marine Park Rangers Data

Since the inventory in May 2022, MPRs made three (3) inventories in Bird Islet and 14 in South Islet until December 2023. In-flight counts were not conducted in Bird Islet due to bad weather conditions during the last quarter inventory.

Until April 2023, MPRs also conducted 12 distance counts in Bird Islet and nine (9) in South Islet. They also noted the number of seabirds roosting at the Ranger Station in July 2022. The data gathered revealed several important observations (see Table 11).

Table 11. Highlights of MPR distance and direct counts from May 2022 to April 2023

Species	Bird Islet	South Islet
Brown Noddy	Since 2017, a change in phenology has been evident with overwintering Brown Noddies. In November 2022, Brown Noddy was recorded breeding in Bird Islet with 1,158 adults, 87 juveniles, 51 pullus, and 131 eggs.	Breeding every month from May to December 2022, and in March 2023.
Black Noddy	Distance counts revealed Black Noddy's presence throughout the year, with breeding recorded in August, November 2022, and February 2023.	Used to be absent from November to February. Continuously breeding every month from May 2022 to April 2023.
Great Crested Tern	Absent from August 2022 to January 2023. 1,040 adults recorded in February 2023, but not yet breeding.	Laid eggs until July 2022 and did not breed after. Eggs were recorded in May 2023. Present until September 2022, and returned in March 2023. No counts were conducted in October – November 2022 and January to February 2023 due to bad weather conditions.
Sooty Tern	Absent in August 2022, but overwintered. Breeding in	Breeding every month with peak in September 2022 with 6,913 eggs. 4,200

	November 2022 with 243 juveniles, 27 pullus, and 132 eggs. Absent in December 2022 and January 2023.	adults recorded in December 2022 (distance counts), with 8,045 pullus/juveniles.
Masked Booby	Two (2) adults and one (1) juvenile reported from August 2022 to February 2023.	No breeding population
Red-footed Booby	Low number of adults, less than 200 individuals since May 2022, except in August when 350 individuals were recorded. Numbers of nests also remained low, <100, and in general with very few off-springs. A total of 45 empty nests were removed between November 2022 to February 2023.	Less than 200 individuals, except in August 2022 when there were 237 adults recorded. Nesting rate low as empty active nests are removed, 198 nests since May 2022. A total of 148 active nests, with just six (6) juveniles and nine (9) pulli were reported over the 12-month period.
Brown Booby	Low number of active nests from August and November 2022. In August 2022, only 612 nests compared to 1,642 in 2021. There were only 96 active nests in November compared to 228 nests in 2021. However, in February 2023, there were 88% more active nests compared to 2022.	Lower number of active nests compared to Bird Islet, with an average of 12 nests per month from May 2022 to March 2023. In April 2023, 49 active nests were recorded.
Pacific Reef-egret	Three individuals observed in November 2022.	10 adults reported in August 2022, four (4) in July 2022 and March 2023, and five (5) in September 2022.
Barred Rail	Not observed	Not observed
Eurasian Tree Sparrow	Not observed	One found dead on 31 March 2023.

Species Account of Breeding Birds

Brown Noddy (Conservation Status - Philippine Red List: Vulnerable): Fluctuating population. Total estimated annual population: 2,646 individuals (including inventory counts in March and August 2023). The population is gradually declining after it peaked in 2017 (see Figure 29).

The breeding population in May 2023 is 1,162 individuals, 44% lower than in April 2022 (2,084 individuals). In Bird Islet, the breeding population declined by 15%, while a 57% decline was observed in South Islet.

The species is normally absent in the TRNP from November to February. However, similar to 2022, a portion of the population overwintered at Bird Islet and is present and breeding at South Islet for the whole year. In March 2023, 96 juveniles, 152 pullus, and 196 eggs were recorded by the MPRs, suggesting an early breeding start.

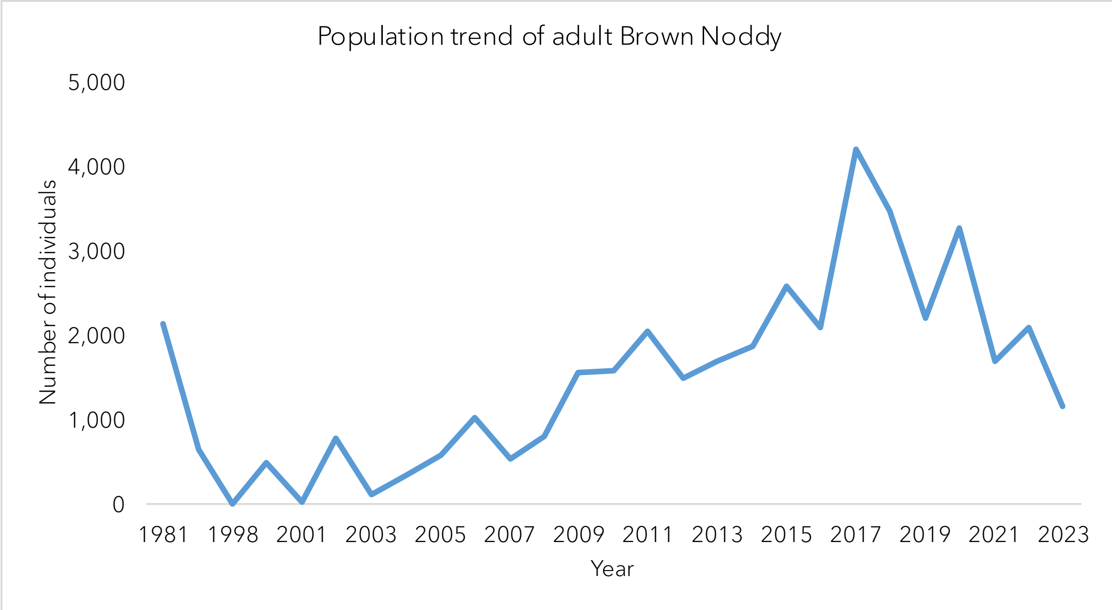

Figure 29. Population trend of adult Brown Noddy from 1981 to 2023

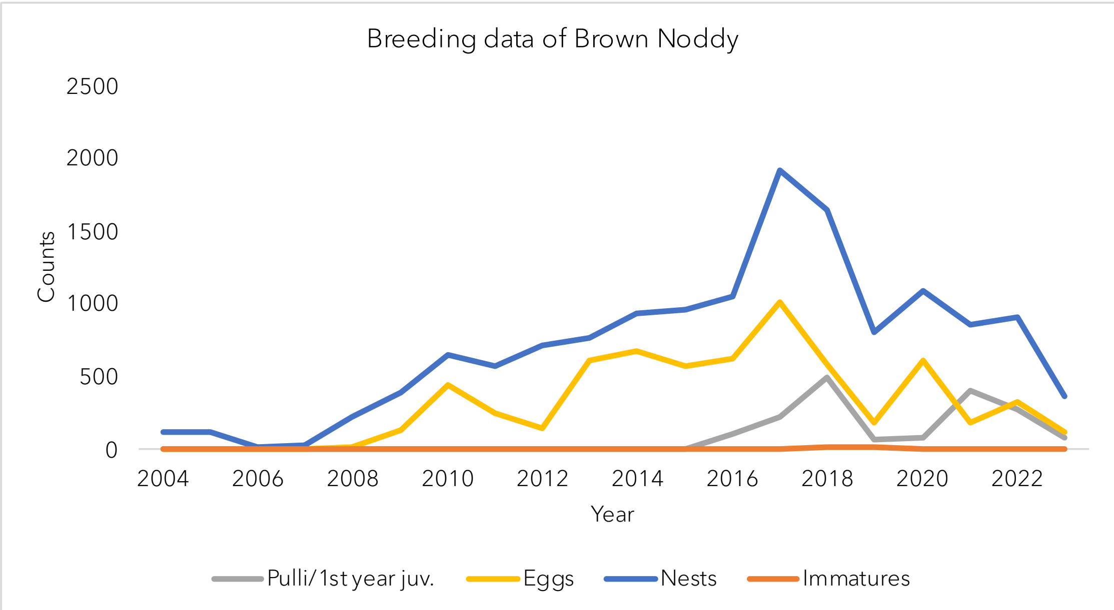

Figure 30. Breeding data of Brown Noddy from 2004 to 2023

Black Noddy (Conservation Status – Philippine Red List: Endangered): Declining population. Total estimated annual population: 3,802 adult individuals.

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

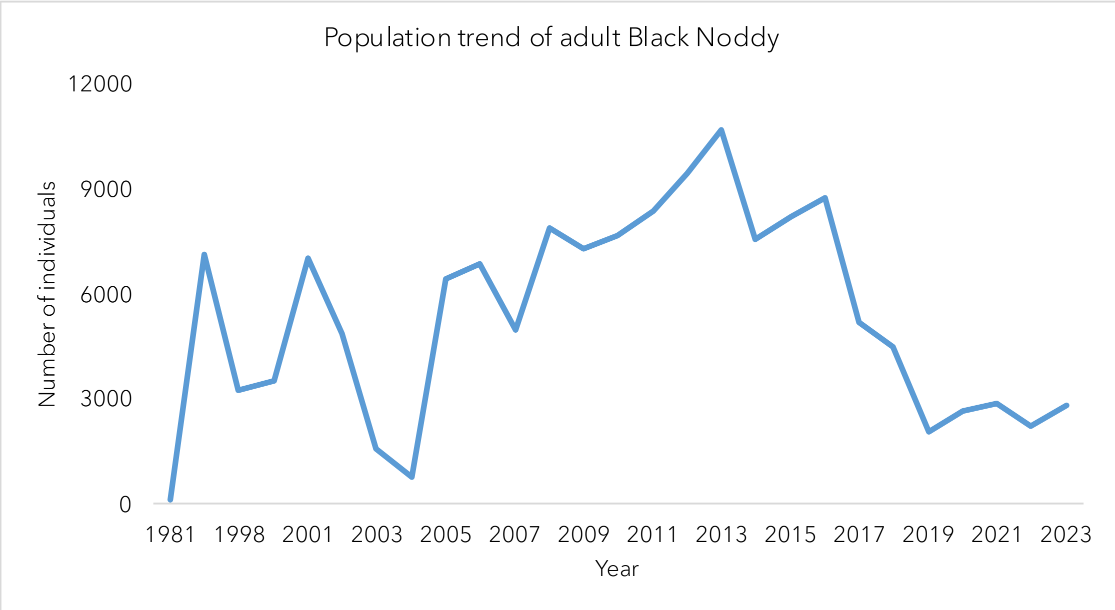

Figure 31. Population trend of adult Black Noddy from 1981 to 2023

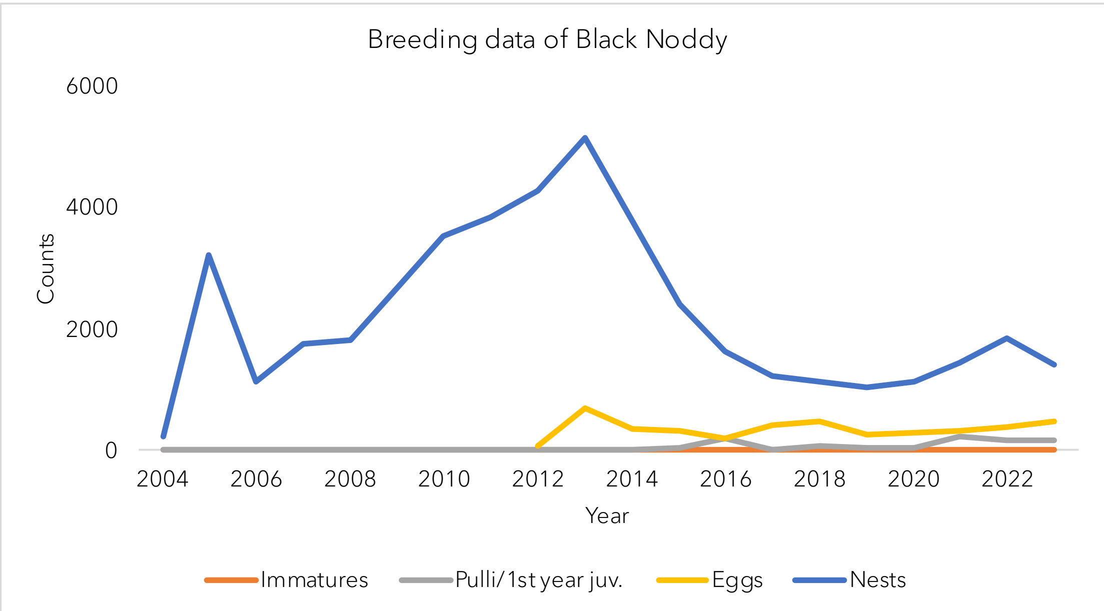

Figure 32. Breeding data of Black Noddy from 2004 to 2023

To date, only 35% of the original population of 10,656 adult birds (2013) remain. The continued population decline is correlated to the loss of its natural breeding habitat over time. Consequently, artificial nesting structures were built by the MPRs in both islets, which now serve as an alternative breeding habitat for the Black Noddy.

A total of 2,842 adults were recorded (based on number of nests, eggs, pulli, and juveniles) in May 2023, compared to 2,214 adults in 2022 or a substantial decline of 22%. Similar to 2022, the Black Noddy began breeding early in the calendar year. The MPRs have recorded 28 juveniles, 47 pulli, and 335 eggs in Bird Islet (February) and South Islet (March). The species, which was historically generally absent from November to February, overwintered and bred in December 2022, with 166 eggs and 39 pulli recorded in Bird Islet and 226 eggs and 32 pulli in South Islet.

The Black Noddy utilized the artificial nesting structures built in both islets. Cut grasses were also provided to remedy the absence of natural nesting materials. Additional structures need to be built to replace the deteriorating ones. Despite the success of the artificial nesting structures in increasing the reproduction rate, the rate is still too low to maintain the breeding population as it needs to produce enough offspring to replenish the population over time.

A detailed investigation of the breeding structures at South Islet revealed high mortalities: a total of 51 adult birds were found dead. Forty-three (43) of these were found on the ground and eight birds with legs or heads entangled either in cavities in the bamboo structures or were strangulated in nylon fishing lines included in nesting materials. Further, 21 dead pulli were also noted.

Great Crested Tern (Conservation Status - Philippine Red List: Vulnerable): Stable annual population of 16,156 adult individuals.

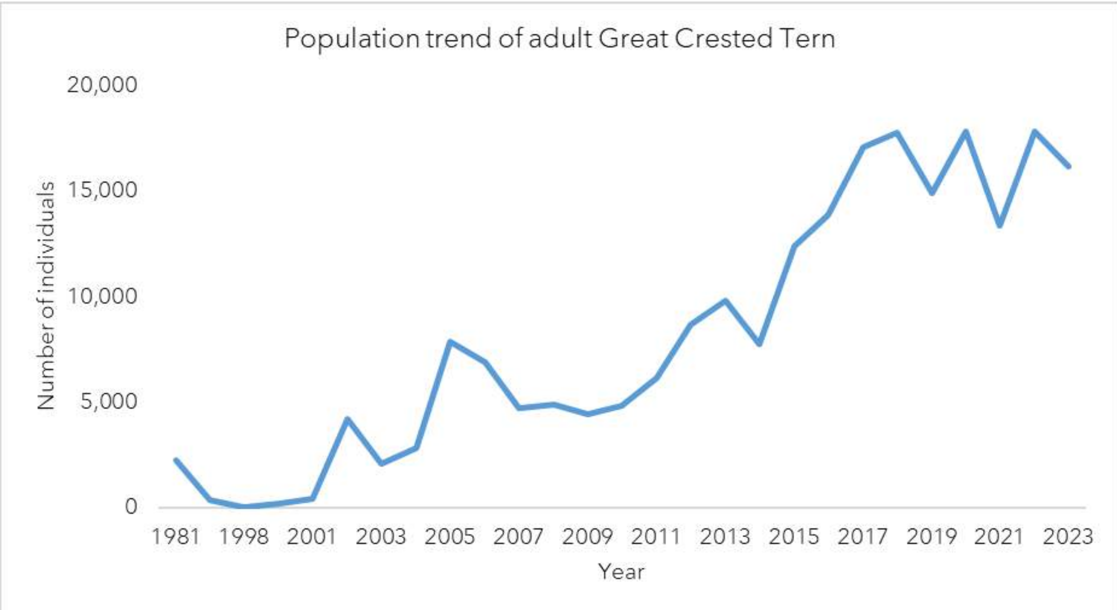

Figure 33. Population trend of adult Great Crested Tern from 1981 to 2023

Compared to April 2022, the population in May 2023 (16,156 adults) decreased by 8%. In Bird Islet, the population declined by 70%, while in South Islet a 111% increase was recorded. In 2023, 78% of the population bred in South Islet.

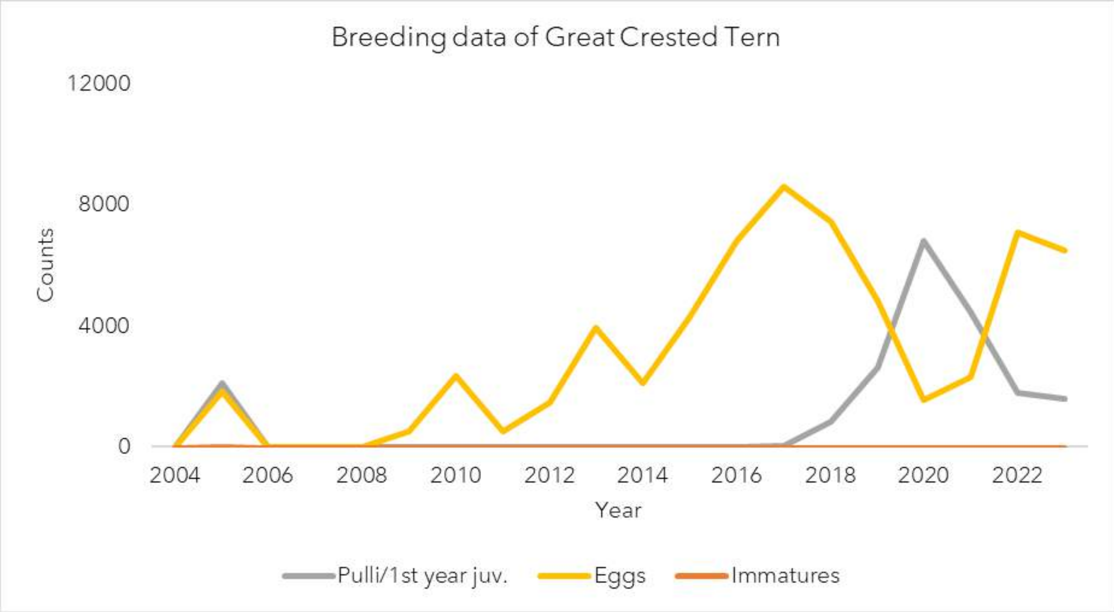

Figure 34. Breeding data of Great Crested Tern from 2004 to 2023

The Marine Park Rangers recorded an early start of breeding in South Islet with 265 eggs laid by the end of March and 3,130 eggs by mid-April. Breeding in Bird Islet begun a little later as indicated by 203 juveniles and 1516 eggs counted in May.

Sooty Tern (Conservation Status – Philippine Red List: Vulnerable): Stable population. Total estimated annual population: 12,210 adults.

The inventory counts were made early in their breeding season, thus, during the daytime counts, only 3,900 adults and 77 eggs were recorded in Bird Islet and 715 adults and 211 eggs in South Islet. The total population was calculated based on the number of juveniles (6,105 individuals) in December 2023.

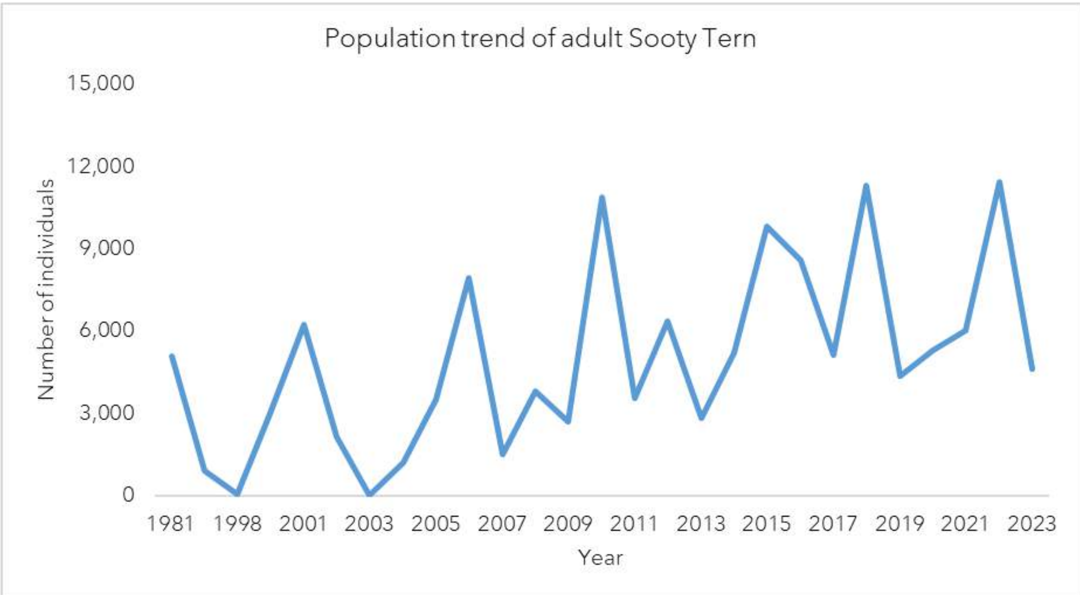

Figure 35. Population trend of adult Sooty Tern from 1981 to 2023

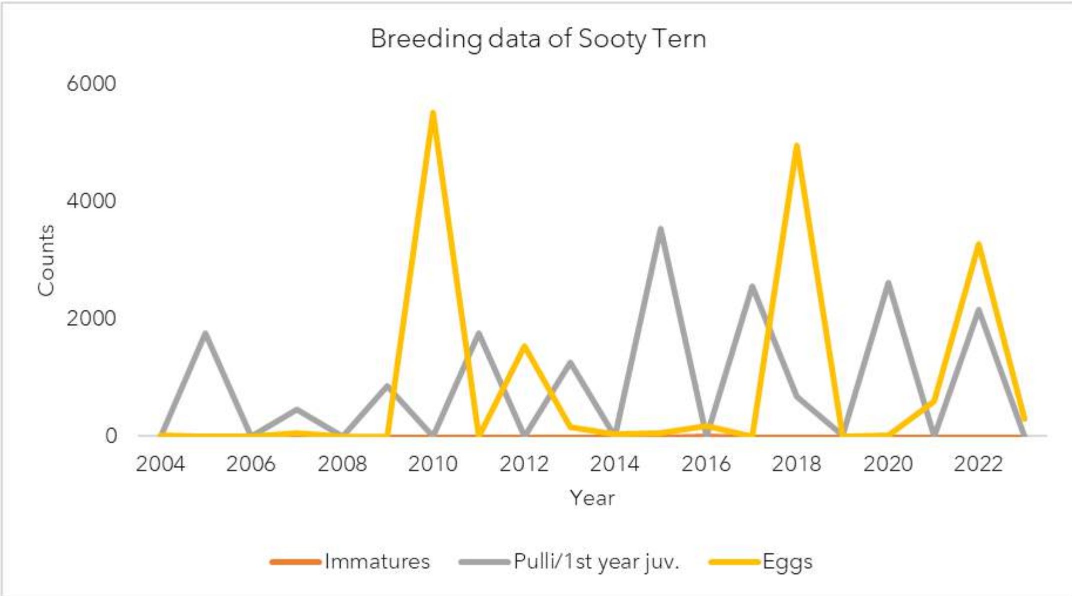

Figure 36. Breeding data of Sooty Tern from 2004 to 2023

Masked Booby (Conservation Status - Philippine Red List: Critically Endangered): In June 2022, a nest monitoring camera was installed, revealing that an egg hatched on 23 June 2022. The juvenile was not present in Bird Islet during the MPR's visit on 16 October 2022, and was seen flying out from the islet at 6am on the camera. On 24 March 2023, the MPRs reported two eggs in the Masked Booby nest, but they were no longer present during the May 2023 count. On 29 July 2023, however, the Rangers reported one pullus.

Figure 37. Masked Booby pair with pullus taken in October 2023. Photo by Jeffrey David

Red-footed Booby (Conservation Status - Philippine Red List: Least Concern): Declining population. Total estimated annual population: 489 adult individuals.

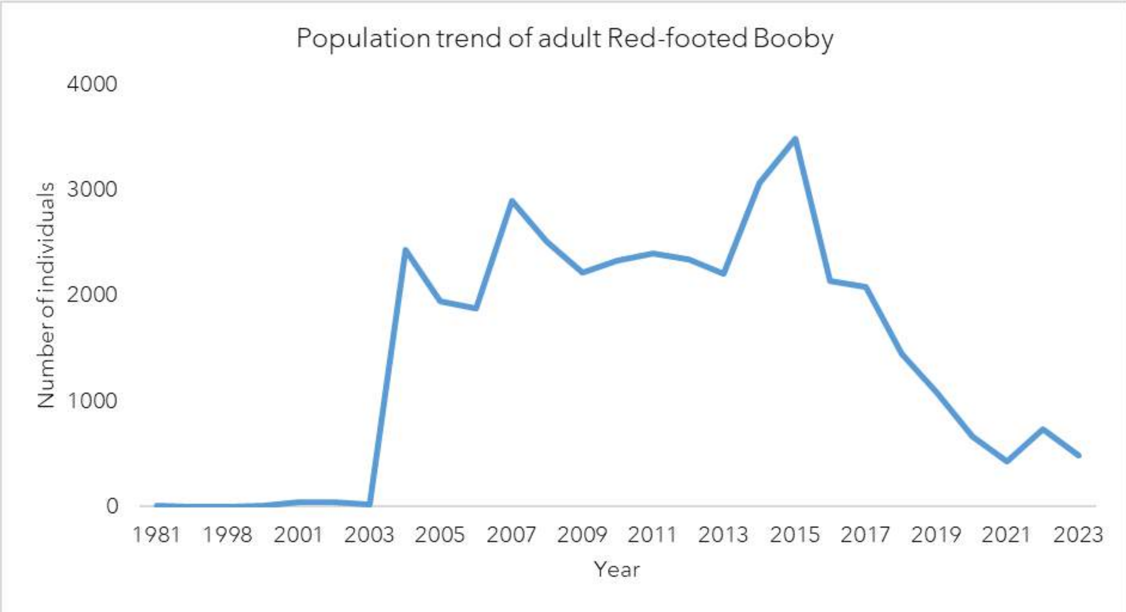

Figure 38. Population trend of adult Red-footed Booby from 1981 to 2023

The adult population in May 2023 was 489 individuals, 37% less compared to April 2022. Compared to the baseline year 2004, the current population is lower by 80%. The number of nests in May 2023 was very low, with only 26 active nests. The declining population is a result of population management through the removal of empty nests by the MPRs. In May 2023, similar to 2022, five (5) nests were observed on the ground at the South Islet. This adaptive strategy may allow the species to increase its population size in the future.

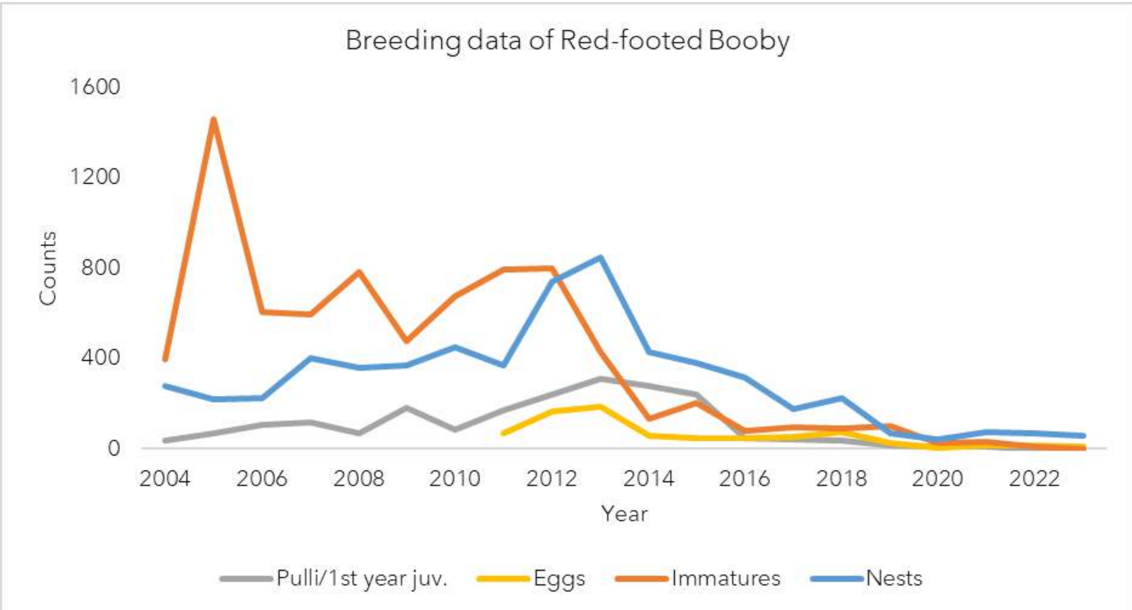

Figure 39. Breeding data of Red-footed Booby from 2004 to 2023

Brown Booby (Conservation Status - Philippine Red List: Endangered): Increasing population. Total estimated annual population: 5,998 adult individuals.

A total of 4,854 adults (based on the number of active nests) were recorded in May 2023. This is 29% more than the baseline population in 1981 (3,768 individuals) but almost similar to the April 2022 counts (4,906 individuals). The May 2023 inventory recorded an extraordinarily high number of pulli compared to the previous years.

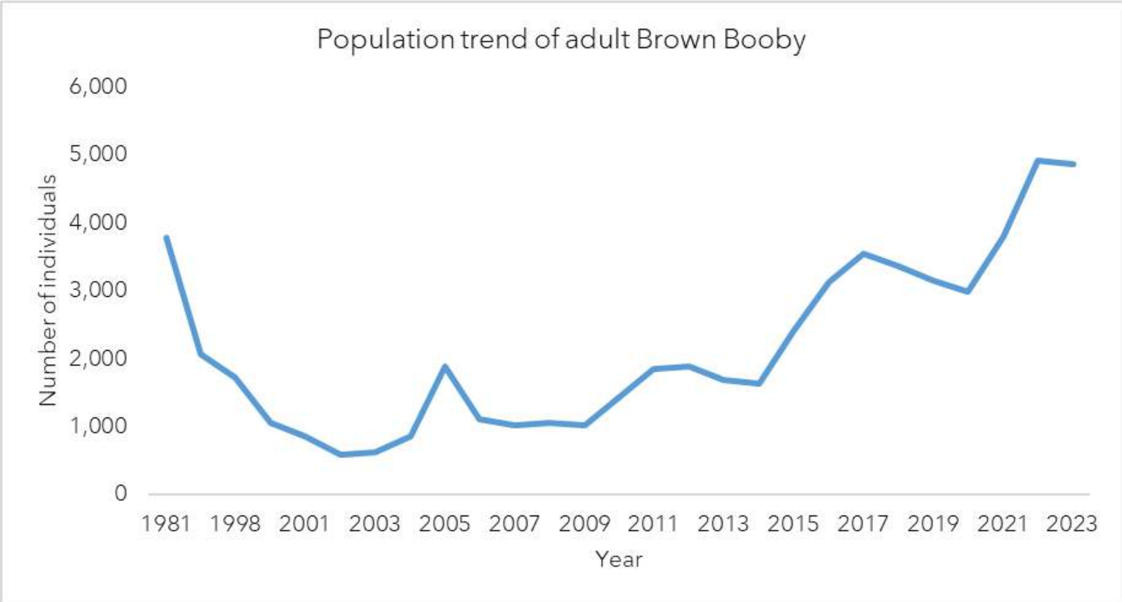

Figure 40. Population trend of adult Brown Booby from 1981 to 2023

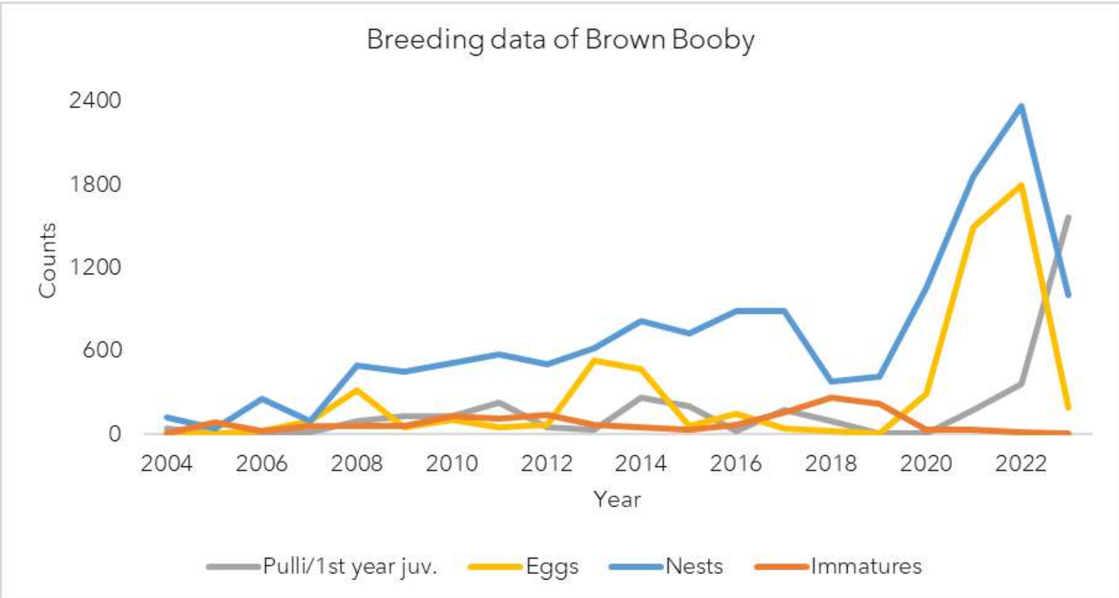

Figure 41. Breeding data of Brown Booby from 2004 to 2023

RECOMMENDATIONS

Habitats

1. Restoration of Beach Forest: During periods with drought-like weather patterns it is recommended not to attempt planting of saplings because of the very low survival rate. Further, do not attempt more planting unless advice from experienced forest experts is taken into consideration. See Annex of the 2021 report.

2. Habitat restoration of South Islet: Ensure a wide enough sandy beach habitat free of vegetation enabling Great Crested Tern, Sooty Tern, and Brown Booby to breed on the islet. This may entail removing or cutting of expanding grass areas, preferably during non-breeding season for Great Crested Tern, Sooty Tern, and Black Noddy.

Land area at Bird Islet and South Islet

3. Produce an erosion map with coordinates highlighting erosion-prone areas and areas under direct erosion at Bird Islet. Based on the erosion study results in 2024 and the advice of experts, start securing eroding areas using best-practice nature-based solutions, including beach sand nourishment. Sand deposits may have to be pumped in from sandbars elsewhere along the coral crest.

4. At South Islet, fill in 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.

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

Species

6. Black Noddy:

a) When constructing or repairing bamboo-made breeding structures, ensure that split bamboo designs have as few openings as possible to reduce the risk of birds becoming entangled in their heads, feet, or wings.

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

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

d). Marine plastic debris is increasingly used as nesting materials particularly by the Black Noddy and Brown Booby populations (Jensen and Songco 2016).

Each year, Black Noddies are found strangled at their nests due to entanglement in discarded or lost fishing lines that the birds have used as nesting material. However, the impact of plastic debris used in the nests is often overlooked, posing a significant threat to the survival of the species. It is recommended to:

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

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

7. Satellite tracking devices is in the TMO pipeline for 2025. It is recommended to also use color-coded leg flags on all tern and noddy species, and their off-springs caught. Other than tracking of Black Noddy, also gather information on Brown Noddy, Sooty Tern, and Great Crested Tern. Include a budget for the cost of capacity-building of TMO, data analysis, and results dissemination.

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

9. Red-footed Booby: Nests in the artificial breeding structures or on plant protection device, or directly on the ground should be regularly removed.

Methodology

10. Recommended improvements on data collection and reporting includes:

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

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

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5. Water Quality

OVERVIEW

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

Twenty (20) monitoring stations were established in TRNP based on the location, anthropogenic activities, and other regular monitoring stations of ecosystem conditions. These water quality monitoring stations are located in the core zone (17) and buffer zone (3) of the park. The annual monitoring of water quality started in April 2014 to 2017. It resumed from 2020 during the nationwide lockdown due to COVID-19 pandemic. Parameters such as temperature, dissolved oxygen, pH, total dissolved solids, salinity and turbidity are measured on-site using a multiprobe/parameter water quality meter. Water samples were then collected and brought to the environmental laboratory for analysis of solids, nutrients, oil and grease and coliform.

This report presents the latest water quality in TRNP and the trends of physico-chemical and microbiological parameters measured during pre-pandemic period (2014 to 2017), during pandemic (2020-2021) when there were no tourism activities in the park, and during the resumption of tourism activities from 2022 to 2023.

METHODOLOGY

Water Quality Monitoring Stations

There are twenty (20) established water quality monitoring stations strategically located in North Atoll, South Atoll, and Jessie Beazley Reef (Figure 42). The geographical location and description of the water quality monitoring stations in TRNP are shown in Appendix *15*.

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

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

The monitoring station in Jessie Beazley Reef (WQ19) is located at a dive site on the top of the reef and is also a monitoring station for fish and benthos.

Three (3) water quality monitoring stations are located in the buffer zone of TRNP, each of which is located adjacent to three reef formations: WQ08 in South Atoll, WQ18 in North Atoll, and WQ20 in Jessie Beazley Reef.

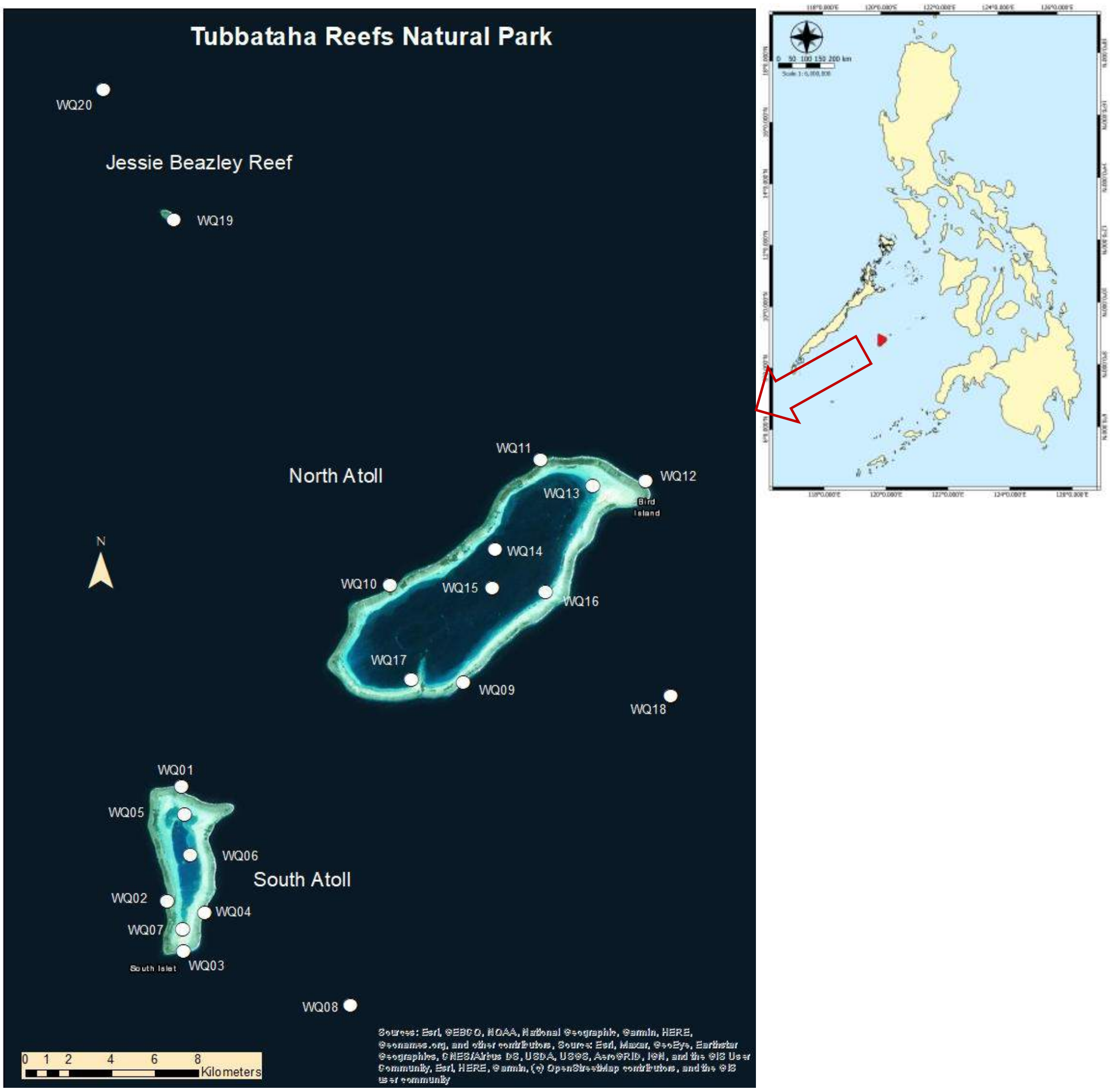


Figure 42. Water quality monitoring stations in Tubbataha Reefs Natural Park, May 2023.

Collection of Water Samples

The water quality monitoring was conducted on 12-13 May 2023 by the staff of Tubbataha Management Office and the park rangers in Tubbataha Reefs Natural Park.

On-site measurement of sea surface temperature, dissolved oxygen, pH, turbidity, salinity, conductivity, and total dissolved solids were conducted using HORIBA multiprobe meter. Grab water samples were then collected in three separate containers: wide-mouth glass with 1-liter capacity for oil and grease, 2.5-liter capacity-HDPE for physicochemical parameters such as color, total suspended solids, nitrates and phosphates, and 150 ml sterilized glass bottle for total and fecal coliform analysis. Table 12 shows the collection, preservation, and handling of collected water samples. All water samples were taken to the PCSD Environmental Laboratory for analysis.

Table 12. Sample container, preservation, and handling of water samples per parameter analyzed in Tubbataha Reefs Natural Park.

Parameters	Sample volume/container	Preservation technique	Holding time
Color	500 mL-Plastic container*	Refrigerate	48h
Solids	300 mL-Plastic container*	Refrigerate	7d
Nitrate and Phosphate	200 mL-Plastic container*	Analyze as soon as possible or refrigerate	48h
Oil and Grease	1-Liter wide-mouthed glass with screw cap containers	Add 1:1 HCl to pH <2; refrigerate	28d
Total and Fecal Coliform	150 mL-sterilized glass bottles	Analyze as soon as possible or refrigerate	24h

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

Water Quality Parameters and Guidelines

Physico-chemical and microbiological parameters were analyzed to determine the trends and prevailing water quality in TRNP. The complete list and general description of parameters analyzed in TRNP since 2014 is shown in Appendix 14. The water quality data taken from *in situ* measurement and laboratory analysis were compared to the Water Quality Guidelines (WQG) issued through the DENR Administrative Order (DAO) 2016-08 and DAO 2021-19 (Table 13).

In the absence of water classification, which is under the mandate of DENR, Class SA of DAO 2016-08 was used as a basis to assess the quality of parameters analyzed in TRNP. Class SA pertains to the protected waters or waters designated as national or local marine parks, reserves, sanctuaries, and other areas established by law (Presidential Proclamation 1801 and other existing laws), and/or declared as such by an appropriate government agency, LGUs, etc.

Table 13. Water quality guidelines for primary parameters for marine and coastal waters under Class SA.

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

*DAO 2016-08 **DAO 2021-19.

RESULTS

2023 Water Quality in Tubbataha Reefs Natural Park

The elevated sea surface temperature during the 2023 water quality monitoring was observed in all stations. The temperature ranged from 32.87 °C (WQ10, North Atoll) to 35.56 °C (WQ13, North Atoll), all above 30 °C, the maximum temperature for Class SA (DAO 2016-08). Aesthetic and visual quality of water appeared to be very clear with a color of <5 PCU in all stations. Similarly, the total suspended solids ranged from <1 mg/L to 11 mg/L, below the 25 mg/L WQ guideline for Class SA (DAO 2016-08).

Nitrates ranged from <0.001 mg/L to 1.73 mg/L (WQ20), and all recorded concentrations are way below the 10 mg/L WQ guideline for Class SA (DAO 2016-08). These have been consistent with recorded concentration since 2014. On the other hand, phosphate levels ranged from 0.02 mg/L to 0.92 mg/L, with concentrations exceeding the WQ standard from class SA recorded from WQ01 and WQ05 in South Atoll; WQ12 and WQ17 in North Atoll and WQ08 in Buffer Zone close to South Atoll.

The oil and grease in all WQ stations were below the minimum detection limit of <1 mg/L and the WQ guideline of 1 mg/L (DAO 2016-08). The fecal coliform concentration ranged from <1.8 MPN/100 mL to 17 MPN/100 mL, all within the WQ guidelines of 20 MPN/100 mL (DAO 2021-19).

Table 14. Results of water quality monitoring conducted in Tubbataha Reefs Natural Park (May 2023).

Parameters		pH	DO	Color	TSS	Phosphates	Nitrates	Oil & Grease	Temperature	Total Coliform	Fecal Coliform
Unit			mg/L	PCU	mg/L	mg/L	mg/L	mg/L	°C	MPN/100 mL	MPN/100 mL
South Atoll	WQ01	8.37	6	<5	<1	0.44	<0.001	<1	33.4	49	4
	WQ02	8.38	7	<5	7	0.03	<0.001	<1	33.7	25	8.3
	WQ03	8.34	6	<5	6	0.02	<0.001	<1	33.8	4.5	2
	WQ04	8.37	6	<5	<1	0.03	<0.001	<1	33.8	<1.8	<1.8
	WQ05	8.39	5	<5	<1	0.21	<0.001	<1	35.0	47	17
	WQ06	8.48	7	<5	1	0.04	0.1	<1	34.9	130	14
	WQ07	8.61	7	<5	7	0.1	0.23	<1	35.4	920	17
North Atoll	WQ09	8.33	5	<5	7	0.07	0.41	<1	33.7	2	<1.8
	WQ10	8.32	6	<5	7	0.05	0.49	<1	32.9	79	17
	WQ11	8.34	6	<5	2	0.14	0.39	<1	33.3	<1.8	<1.8
	WQ12	8.36	6	<5	<1	0.41	0.72	<1	33.3	350	9.3
	WQ13	8.55	7	<5	11	0.07	0.73	<1	35.6	<1.8	<1.8
	WQ14	8.46	6	<5	6	0.06	0.78	<1	34.2	<1.8	<1.8
	WQ15	8.36	6	<5	7	0.06	1.05	<1	34.2	<1.8	<1.8
	WQ16	8.57	6	<5	5	0.05	1.15	<1	34.4	<1.8	<1.8
	WQ17	8.27	7	<5	4	0.18	1.02	<1	34.4	<1.8	<1.8
JB Reef	WQ19	8.17	6	<5	2	0.06	1.71	<1	33.6	<1.8	<1.8
Buffer Zone	WQ08	8.35	6	<5	7	0.92	0.16	<1	33.6	2	<1.8
	WQ18	8.32	6	<5	<1	0.05	1.61	<1	33.3	240	14
	WQ20	8.24	6	<5	6	0.11	1.73	<1	33.7	23	<1.8
WQG Class SA		7.0-8.5	6	5	25	0.1	10	1	26-30	-	20
WQG Class SB		7.0-8.5	6	50	50	0.2	10	2	26-30	-	100

*Based on DAO 2018-06 and DAO 2021-19 (for Fecal Coliform and Phosphates). Abbreviations: DO – Dissolved Oxygen; TSS – Total Suspended Solids; MPN - Most Probable Number; WQG – Water Quality Guidelines; JB Reef - Jessie Beazley Reef

Trends in Water Quality from 2014 - 2023

In situ Parameters

Parameters such as dissolved oxygen and temperature were measured using a multiprobe meter (HORIBA multiprobe meter) and shown in Figure 43. The concentration of all parameters measured *in situ* per water quality station from 2014 to 2023 is presented in Appendix 16.

The highest temperature in TRNP monitored from 2014 - 2023 was recorded at 38.40°C in 2014 (WQ17, North Atoll) while the lowest was recorded also in the same year at 25.4°C (WQ02, South Atoll). The average temperature from 2014 to 2023 in South Atoll was 30.10 °C, 30.83 °C (North Atoll), 30.51 °C in Jessie Beazley Reef (WQ19), and 30.4 °C in the Buffer Zone.

Dissolved oxygen showed a varying concentration across all WQ stations in TRNP, from 5.3 mg/L to 9.92 mg/L. DAO 2018-06 stipulates that the water quality standard for dissolved oxygen for water classification SA (Protected Areas) should be above 6 mg/L.

While previous years showed DO levels above 6 mg/L, 2023 data in Jessie Beazley Reef (WQ19) and the buffer zone (WQ08, WQ18, and WQ20) were below 6 mg/L. Similarly, some stations in South and North Atolls have levels of DO slightly lower than 6 mg/L.

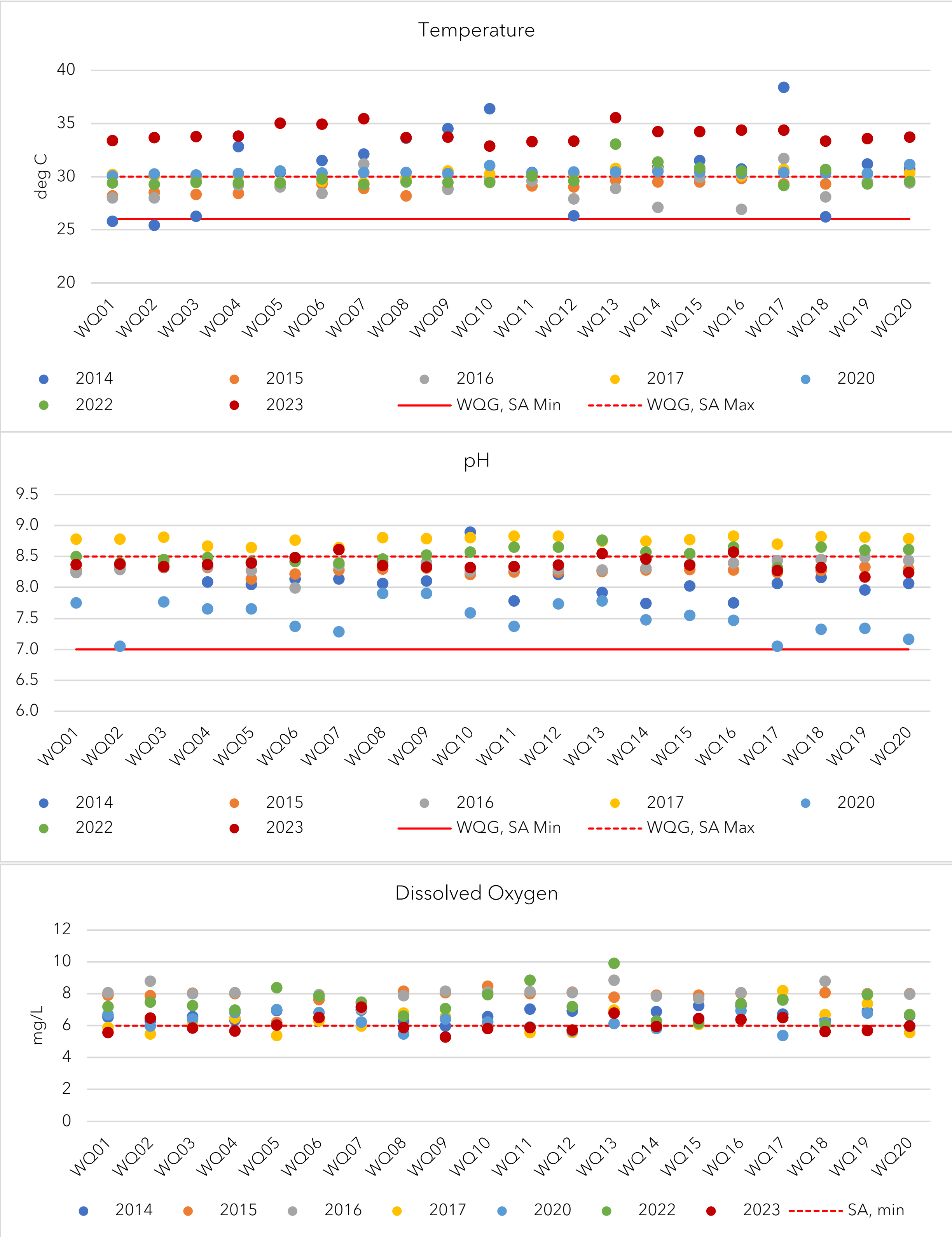
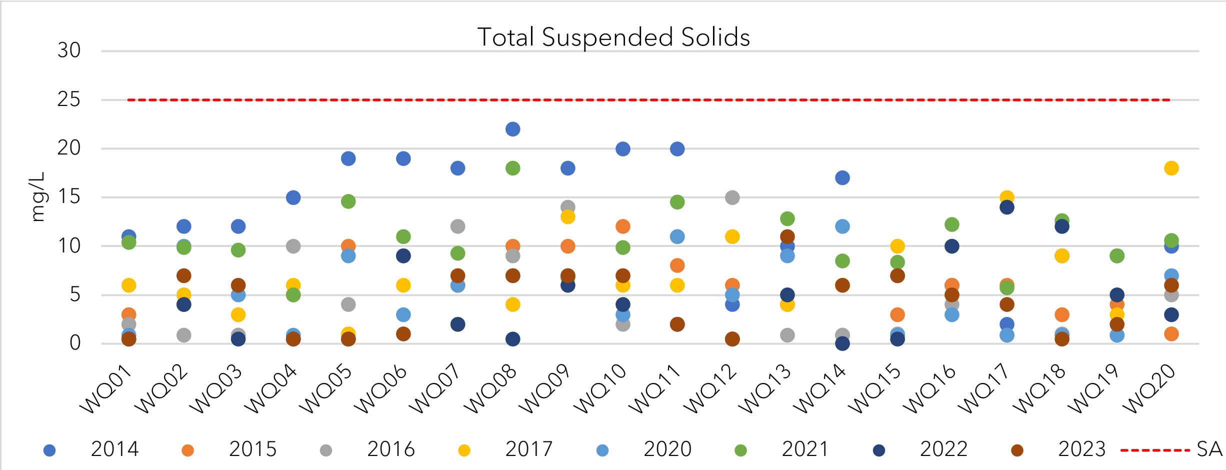


Figure 43. Trends of water quality parameters measured on-site in Tubbataha Reefs Natural Park from 2014 to 2023 vis-à-vis the water quality guidelines (DAO 2016-08).

The pH around North Atoll was recorded from 7.05 (WQ17, 2021) to 8.89 (WQ14, 2014). Recent monitoring recorded pH in North Atoll slightly higher than 8.5 except in WQ17. While recorded to exceed the WQ guidelines in the previous years, 2023 data of pH in Jessie Beazley Reef and the buffer zone were within the range of 7 to 8.5, respectively. The pH level ranged from 7.16 (WQ20, 2020) to 8.82 (WQ18, 2017), while the pH level ranged from 26.19°C (WQ08, 2014) to 33.60°C (WQ08).

Aesthetic/Visual Water Quality

Recent results of color and total suspended solids, parameters that refer to the physical appearance or aesthetic quality of seawater in TRNP showed levels below the WQ guidelines as shown in Figure 44.



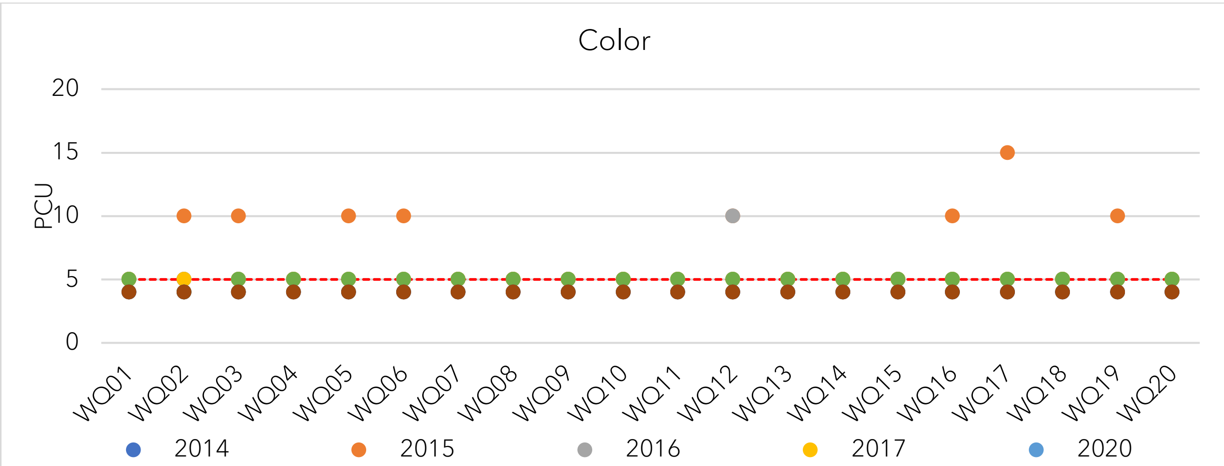


Figure 44. Trends of water quality parameters monitored in Tubbataha Reefs Natural Park from 2014 to 2023.

In South Atoll, the color ranged from <5 PCU to 15 PCU, with recent results (2020-2023) showing levels within the WQ guideline of 5 PCU (Class SA). Similarly, the total suspended solids (TSS) ranged from <1 mg/L to 22 mg/L, all below the water quality guidelines (25 mg/L, Class SA).

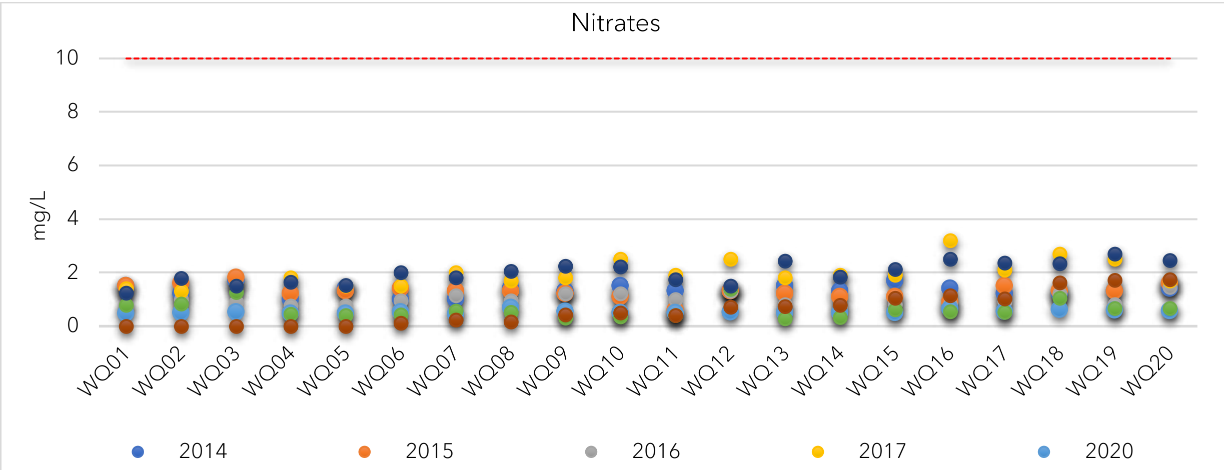
While exceedance in color was also recorded in 2015 (WQ12, WQ16, and WQ17) in North Atoll, recent results showed clear waters with color below 5 PCU. The concentration of TSS monitored in North Atoll from 2014 to 2023 ranged from <1 mg/L to 20 mg/L (WQ10, WQ11) which were all below the water quality guidelines (25 mg/L, Class SA).

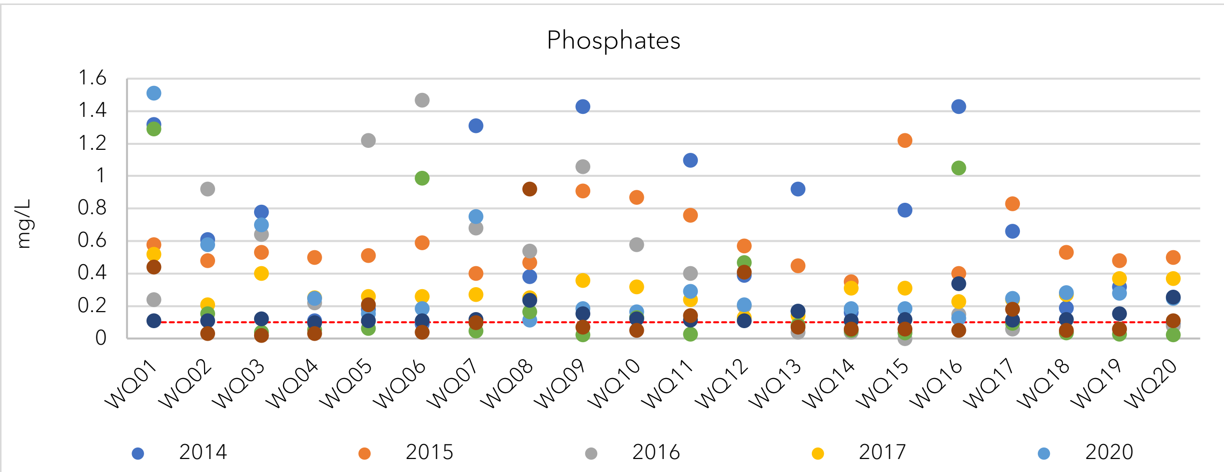
The waters surrounding Jessie Beazley Reef and the monitoring areas located in the Buffer Zone remained clear as shown by the trends in TSS and color. The concentration of TSS ranged from 1 mg/L to 9 mg/L, way below the guideline (25 mg/L, Class SA). The color remained at <5 to 5 PCU from 2016 to 2023.

Oil & Grease & Nutrients

Trends in oil and grease showed a concentration of <1 mg/L in all WQ stations from 2021 to 2023 as shown in Figure 45. This indicated improvements from high concentration recorded in some stations during the active operation of tourism activities from 2014 until 2020, the highest concentration of oil and grease measured in North Atoll being 5.83 mg/L (WQ17, 2014).

The highest oil and grease concentration was measured in WQ08 (8.8 mg/L) in 2016. In South Atoll, the highest concentration was 7.9 mg/L (WQ03) in 2016. The recorded excess in the oil and grease concentration in almost all stations recorded from 2014 to 2017 was attributed to tourism activities. Oil and grease in WQ07 exceeded 1 mg/L until 2020. From 2021 to 2023, the concentration of oil and grease from all WQ stations in South Islet was below 1 mg/L.





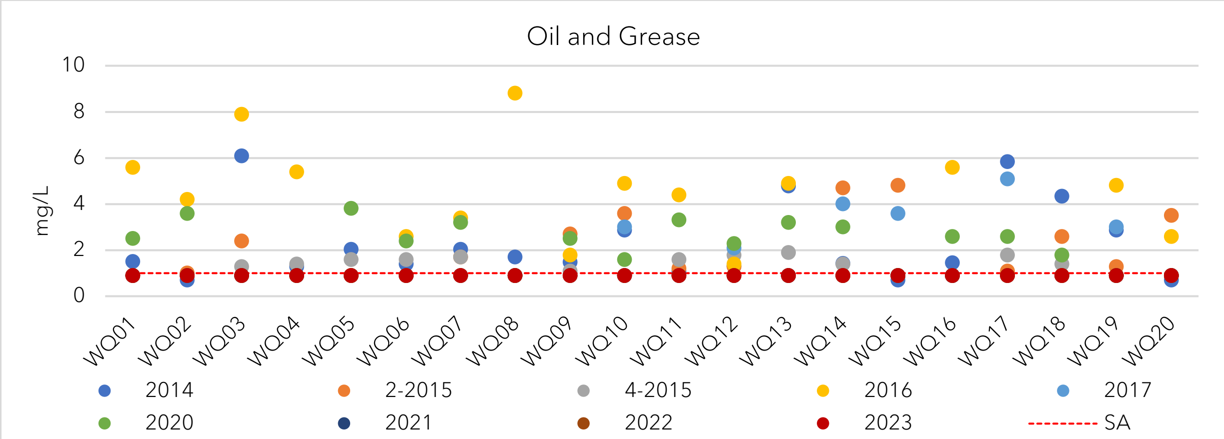


Figure 45. Concentration of nitrates, phosphates, and oil and grease in Tubbataha Reefs Natural Park from 2014 to 2023.

Nitrates concentration in TRNP from 2014 to 2023 ranged from <0.001 mg/L (WQ01 – WQ05, 2023) to 3.20 mg/L (WQ16, 2017), all consistently within the WQ guideline of 10 mg/L (Class SA).

Phosphate levels exceeded the WQ guideline of 0.1 mg/L from 2014 to 2022. The concentration of phosphate recorded from 2014 to 2022 in South Atoll exceeded the WQ guidelines for protected areas (Class SA, 0.1 mg/L). The highest concentration was measured in WQ01 (1.51 mg/L) in 2020 while the lowest (0.02 mg/L) was recorded from WQ03 in 2023. In North Atoll, the highest concentration of phosphate was recorded in WQ09 and WQ16 at 1.43 mg/L (2014) and the lowest concentration was 0.02 mg/L in WQ09 in 2021. The phosphate levels in all WQ monitoring stations in the buffer zone ranged from 0.024 mg/L (WQ20, 2021) to 0.54 mg/L (WQ08, 2016), exceeding the WQ guideline of 0.1 mg/L for Class SA (DAO 2016-08) in 2022.

Fecal Coliform

Fecal coliform primarily determines the suitability of the body of water for direct contact recreation such as bathing and swimming. Figure 46 shows different levels of fecal coliform measured in TRNP from 2014 to 2023. High levels of fecal coliform were observed in all stations from 2014 to 2017, and gradually declined during the lockdown in 2020 and 2021. Recent results showed low levels of fecal coliform in some WQ monitoring stations but were still within the water quality guideline for Class SA.

The trend shows that the concentration of fecal coliform in South Atoll was above 20 MPN/100 mL from 2016 to 2017, with the highest concentration (140 MPN/100 mL) corded in 2016. Improvements were observed in all stations during the closed season and lockdown from 2020 to 2021. This level was maintained even after the reopening of tourism activities in 2022, while low levels of fecal coliform were recorded in 2023, but these were within 20 MPN/100 mL as per Class SA (DAO 2021-19).

A similar trend was observed for fecal coliform in North Atoll, the highest concentration was recorded at 140 MPN/100 mL at WQ16 (2016). While in exceedance in previous years (2014 – 2017), low levels of fecal coliform in North Atoll were recorded from 2020 to 2023, all within the WQ guideline of 20 MPN/100 mL (Class SA, DAO 2021-19). The highest concentration of fecal coliform recorded in the Buffer Zone was 170 MPN/100 mL (WQ08, 2016), while 94 MPN/100 mL was observed in Jessie Beazley Reef in 2016.

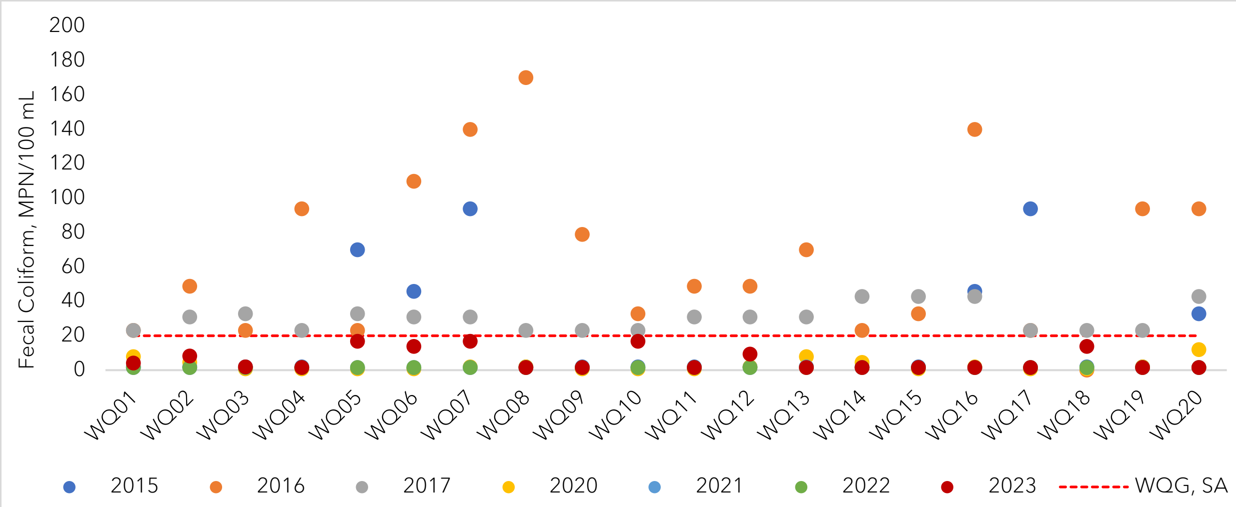


Figure 46. Concentration of fecal coliform in water quality monitoring stations in Tubbataha Reefs Natural Park from 2015 to 2023. Water quality guideline for fecal coliform: 20 MPN/100 mL (DAO 2021-19).

DISCUSSION

Water quality is a crucial factor in the beneficial usage of water bodies. In coastal and marine areas, it highly affects the survival of resources such as seagrass, reef fishes, and coral reefs. Parameters such as temperature, salinity, nutrients, light, and carbonate ion concentration are among the most important factors in the survival of shallow-water coral reefs (Couce et al. 2012; Kleypas et al. 1999; Freeman et al. 2013).

Table 15 represents the phase-wise mean and standard deviation of nine (9) parameters monitored in TRNP during the pre-lockdown, lockdown, and reopening phase. The results showed that the lockdown allowed the water to assimilate the pollution load thereby cleansing the water naturally. The aggregated data shows that the water quality in TRNP complies with the most stringent water quality guideline as per DAO 2016-08 and DAO 2019-21 for marine parks, reserves, and sanctuaries (Class SA).

Table 15. Descriptive statistics of variables of physiochemical, and microbiological parameters monitored in three periods in Tubbataha Reefs Natural Park (+SD).

Parameters	Pre-Lockdown (2014-2017)	Lockdown (2020-2021)	Reopening Phase (2022-2023)	Water Quality Guidelines
Temperature, °C	29.77 ± 1.29	30.41 ± 0.25	31.96 ± 2.21	26-30
pH	8.37 ± 0.28	7.51 ± 0.26	8.45 ± 0.13	7.0-8.5
Dissolved Oxygen, mg/L	7.63 ± 0.90	6.28 ± 0.47	6.76 ± 0.99	6.0
Color, PCU	5.63 ± 1.83	<5	<5	5
Total Suspended Solids, mg/L	7.69 ± 5.60	6.00 ± 3.82	4.32 ± 3.51	25
Oil & Grease, mg/L	2.33 ± 1.76	2.19 ± 0.99	<1	1
Phosphates, mg/L	0.49 ± 0.36	0.31 ± 0.24	0.15 ± 0.16	0.1*
Nitrates, mg/L	1.38 ± 0.47	0.57 ± 0.22	1.49 ±0.74	10
Fecal Coliform, MPN/100 mL	39.57 ± 37.95	2.74 ± 2.93	3.88 ±4.80	20*

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

In general, parameters that were observed to have high concentrations during the beginning of water quality monitoring in TRNP declined, thus showing improvements during the COVID-19 lockdown from 2020 to 2021 to a level within the water quality guidelines under the Class SA of DAO 2016-08. These parameters are oil and grease, phosphates, and fecal coliform. The water quality continued to improve even after the reopening of tourism activities in 2022. In 2023, a low concentration of fecal coliform was recorded in stations WQ05 and WQ07in South Atoll, and WQ10 in North Atoll but still within the water quality guideline of 20 MPN/100 mL.

Water quality guidelines stipulate that the pH values for Class SA (marine waters within protected areas) should be within the range of 7 – 8.5. pH and values lower than 7 indicate the onset of ocean acidification. Albeit slow, its impact on the coastal marine resources can be profound. The surface ocean pH was estimated to drop from 8.25 to approximately 8.14 between 1751 and 2004 and is projected to decrease further to 7.85 in 2100 attributed to the increased carbon dioxide absorption (Jacobson, 2005). In TRNP, the recorded pH from 2014 to 2023 ranged from 7.05 (WQ02, 2020) to 8.89 (WQ10, 2014). The latest monitoring (2023) showed a pH range of 8.17 to 8.61, indicating that it is still within the lower range of pH values which is safe for marine life, and that ocean acidification has not manifested in TRNP.

Among the monitored parameters, the average concentration of phosphates in TRNP is 0.38 mg/L, where all monitoring stations remained in exceedance of the

Class SA WQ guideline of 0.1 mg/L. High levels of phosphates in stations surrounding and near the rookery and breeding grounds of seabirds in WQ05 (Lighthouse) and WQ13 (Bird islet) could be attributed to the droppings of the seabirds.

Data from post-lockdown (2022 – 2023) was used for simple correlation analysis of pH, dissolved oxygen, and temperature. It showed the correlation between pH and temperature was -0.5328, which means that temperature has a moderate inverse influence on pH levels in TRNP. Similarly, temperature and dissolved oxygen have a moderate inverse influence on each other at -0.3189. The varying wave action and increased surface temperature have directly affected the short-term concentration of DO in the water. DO is also vital in the decomposition of organic matter in water. A high concentration of dissolved oxygen indicates better water quality conducive to the growth, breeding, and metabolic processes of all aquatic living organisms. The temperature affects the solubility of oxygen in water, with cold water holding more dissolved oxygen than warm water.

The average sea surface temperature measured in 2023 (34.01 °C) in TRNP increased by 4.1°C, from an average of 29.91 °C in 2022 (Figure 47).

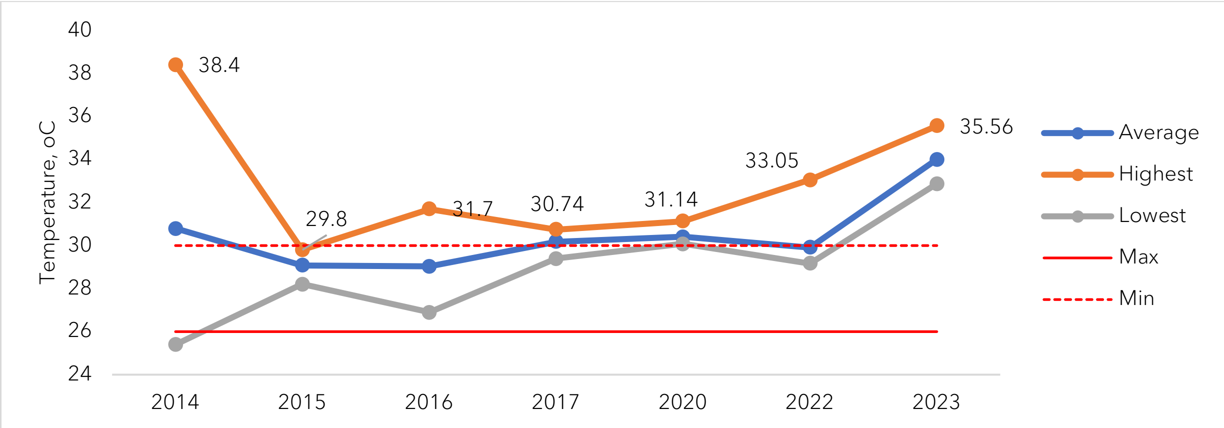


Figure 47. Trends of average temperature observed in Tubbataha Reefs Natural Park from 2014 to 2023.

The average temperature recorded in TRNP has been increasing in the past three (3) years. The months of April and May 2023 were particularly hot in the Philippines where the highest temperature reported by PAGASA reached 37 °C, and a heat index of 50°C. Such a trend was also observed in neighboring countries in Asia and was attributed to the 2023 Asian Heat Wave from April to May.

A sea surface temperature from 30°C and above was also observed across the coral triangle as shown in Figure 48, where the transition towards the rightmost end of the color spectrum indicates a higher temperature (approximately 30°C and above) on 12 May 2023.

A study conducted by Szekielda and Guzman (2021) observed that the sea surface temperature of the Philippines has increased by 0.5°C in the last two decades and is projected to increase by 1.8°C from 2020 to 2050. While corals can survive at a temperature between 18°C and 36°C (Khalil 2019), the optimal sea surface temperature for coral reefs to grow is between 22°C and 28°C (Hubbard 1997). A recent study by Guan et al. (2015) showed that the average tolerance limits for coral reefs are 21.7°C to 29.6°C. The temperatures in the water monitoring stations in TRNP are above the optimal, but are still within the maximum temperature critical for the survival of coral reefs.

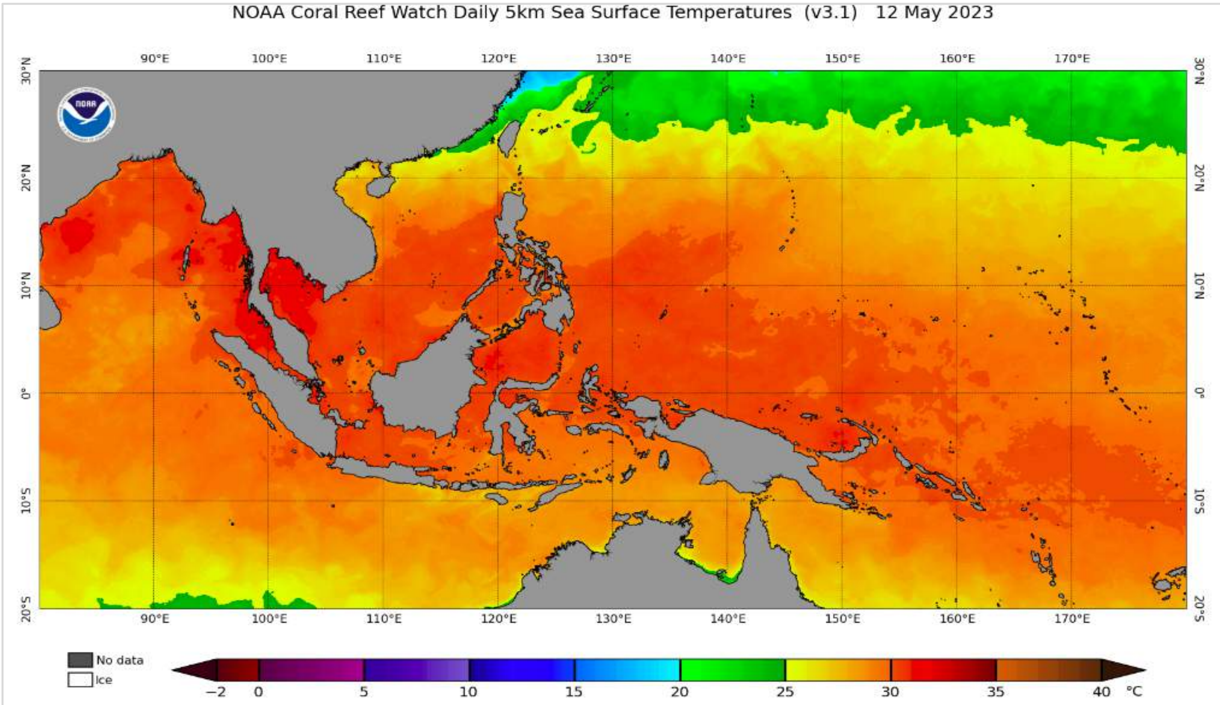


Figure 48. Sea surface temperature in Coral Triangle and the surroundings of TRNP on 12 May 2023. Source: NOAA Satellite and Information Service https://coralreefwatch.noaa.gov/product/5km/index.php

Increased sea surface temperature has a profound effect on the coral reefs where the prolonged event can lead to coral bleaching (Hughes et al. 2017; Claar et al. 2018) and has caused the decline of warm-water coral reefs in tropical regions by at least 50% over the past 30-50 years (Gardner et al. 2003; Bruno and Selig 2007).

Aesthetically, the surrounding water of Tubbataha Reefs Natural Park is very clear and allows the penetration of sunlight to sustain the survival, growth, and reproduction of marine organisms. However, the water quality has been threatened both by natural and anthropogenic factors. The increasing sea surface temperature due to global climate change affects other water quality parameters such as dissolved oxygen, which is also vital to the survival of marine organisms. The anthropogenic factors affecting water quality were mitigated with the implementation of Park Policies against the discharge of untreated wastewater from dive boats in the core zone and the designation of TRNP in 2017 as a Particularly Sensitive Sea Area by the International Maritime Organization. It also reduced the risk of ship groundings and marine pollution. These measures were reinforced by the closure of tourism activities in TRNP for two (2) years due to the COVID-19 pandemic. This allowed the natural assimilation of pollutants by the marine water of TRNP.

CONCLUSION AND RECOMMENDATIONS

Recent results of water quality monitoring in Tubbataha Reefs Natural Park showed that the surface temperature has increased from an average of 29.91 °C in 2022 to 34.01°C in 2023, still within the maximum temperature critical for the survival of coral reefs (18°C and 36°C). The pH range of 8.17 to 8.61, indicated that it is still within the lower range of pH values that are safe for marine life, and ocean acidification has not manifested in TRNP. Results of nitrates, color, total suspended solids, fecal coliform, and oil and grease from recent water quality monitoring were all within the water quality standards for Class SA of DAO 2016-08 and DAO 2021-19. Low levels of fecal coliform were recorded in some stations but were all within water quality guidelines of 20 MPN/100 mL (Class SA). Phosphates remained to be in exceedance of the water quality guideline for Class SA (0.1 mg/L).

Based on the recent water quality monitoring results , it is recommended that the following be conducted:

1. Measurement of on-site parameters such as temperature, dissolved oxygen, pH, and turbidity with the use of a multiprobe water quality checker should be done at regular and more frequent intervals.
2. Monitor changes and trends in the quality of coral reefs or benthic cover to establish the relationship or effects of increased nutrients from seabird guano.
3. Classification of waters surrounding the Tubbataha Reefs Natural Park should be conducted by DENR. Data collected and accumulated through the years of water quality monitoring may be used as baseline data for assessment and identification of water classification.

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6. Marine Turtles

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OVERVIEW

Marine turtles are important components of the Sulu-Sulawesi Marine Ecoregion (SSME), and a priority conservation species. Green turtles are important for maintaining healthy seagrass beds and coral reefs. Seagrass beds may become overgrown without constant grazing, obstructing currents, shading the bottom, or decomposing. Seagrass beds, in turn, are nurseries for a number of species of commercial fish and crustaceans, including shrimp. Hawksbill turtles control the population of sponges in coral reefs, which can easily out-compete corals for the same space. Through selective foraging, hawksbill turtles are able to impact the overall reef diversity.

The Tubbataha Reefs Natural Park (Cagayancillo, Palawan, Philippines) covers 97,030 has and is a World Heritage Site. Tubbataha is included in the Sea Turtle Marine Protected Area Network, which includes the Turtle Islands Heritage Protected Area (TIHPA) and El Nido. It is also part of the Network of Protected Areas to Safeguard Marine Turtles in the Sulu Sulawesi Seascape adopted by the Tri-National Committee (Malaysia, Philippines, and Indonesia) of the Sulu Sulawesi Seascape (SSS).

The seagrass beds on the reef flats at Tubbataha have been previously described as a developmental habitat for green turtles (*Chelonia mydas*), and the reefs (to a lesser extent) are a habitat for hawksbill turtles (*Eretmochelys imbricata*). Green turtles used to nest on the two islands (South Islet and Bird Island), but this is no longer possible with the new seawall at South Island. Hawksbills have not been recorded as nesters on the Tubbataha beaches (Cruz & Torres 2005, Pilcher 2010). These turtle species are recognized at various national and regional levels: turtles are the focus of the Indian Ocean and Southeast Asia Memorandum of Understanding on the Conservation of Sea Turtles and their Habitats (IOSEA MoU), and the Association of Southeast Asian Nations (ASEAN) Sea Turtle MoU, and priority species under Theme 5 of the Coral Reef Triangle (CTI) Regional Action Plan.

At the National level, sea turtles are completely protected in all three countries bordering the SSS. The Convention on International Trade in Endangered Species of Flora and Fauna (CITES) lists marine turtles occurring in the TIHPA on Appendix I, while the World Conservation Union (IUCN) lists the green turtle as Endangered and the hawksbill as Critically Endangered.

The Tubbataha Reefs National Park is an important foraging ground for green turtles (*Chelonia mydas*). Since 2010 the population has been periodically assessed via in-water sampling that includes tagging, measuring, genetic sampling, and laparoscopy, with sampling of an average of 200 turtles of all age classes during each of the six seasons in which the study has been conducted. The data from the laparoscopy procedures is of critical importance to this study.

The 2023 sampling season marked the beginning of an even greater collaboration between the TRNP and MRF, including scientists from NOAA, who joined the expedition to test a new diagnostic technique in sea turtle research. Dr. Jeff Seminoff and Mr. Garret Lemons from the Marine Turtle Ecology and Assessment Program at NOAA's Southwest Fisheries Science Center in La Jolla, California, collected blood and tissue samples to test whether stable isotopes of hydrogen could be used to assess reproductive status in sea turtles. For this, they needed access to a large sample size of sea turtles and to determine the gender and sex of the turtles, which was provided via laparoscopic inspections.

Absolute determination of a sea turtle's reproductive status typically comes from gonadal examination (via laparoscopy) and, in some cases, ultrasound or hormonal analysis, invasive and highly technical methods that are difficult to execute in field-based studies. Establishing a less invasive blood-based technique would be invaluable for sea turtle demographic studies, particularly in areas where laparoscopy was not an option or was unavailable. If such a test is established, this would revolutionize our ability to study the reproductive biology of sea turtles assembled in foraging areas across the world.

In short, the essence of the study was that Dr. Seminoff and his team in the US detected a possible way to tell a mature female turtle from an immature female turtle by the specific ratio of hydrogen isotopes. That is, one takes a blood sample, checks the stable isotope ratios, and says 'mature' or 'not mature.' But to do this, one would need to know for sure the process worked, and for that, they needed access to turtles of known age-class, which the TRNP program provides through laparoscopy. If this all works, it means people who are not allowed to use laparoscopy (e.g., because of permits under the US Endangered Species Act) might be able to use blood instead to produce demographic pictures like we do for Tubbataha.

The objectives of the 2023 field season were to contribute to the ongoing assessment of the population structure analysis of marine turtles in Tubbataha, which

Figure 49. Patrol boat full of marine turtles caught by rangers and volunteers. These turtles will be hauled onboard M/Y Navorca and undergo carapace measurement, tagging, blood/skin sampling, and laparoscopy. Photo: Nick Pilcher

includes information on age class structure, sex ratios within age classes, growth rates, and estimated residence periods, while also contributing to the NOAA study and the functionality of the diagnostic tool. These data are important for understanding habitat use by turtles at Tubbataha and the role Tubbataha plays in the generalized life cycles of sea turtles in the Sulu Sulawesi Seascape. In addition, a training component was also provided to build capacity amongst staff from the Tubbataha Marine Park and the Philippines Department of Environment and Natural Resources.

With the addition of the NOAA team, the sampling season aimed to validate the tool of stable hydrogen isotope (2H, [H]) analyses for determining the maturity status of green turtles assembled in waters of the Tubbataha Reefs Natural Park and surrounding areas. To address the need for these demographic parameters to answer meaningful conservation questions, we propose a suite of studies that ideally will refine and improve our ability to accurately determine maturity state and reproductive dynamics in sea turtle populations.

METHODS

In-Water Captures

Search techniques followed closely the methodology used by researchers in Queensland (Limpus & Reed 1985; Limpus et al. 1994) and in Malaysia (Pilcher 2010a), with novel modifications by TMO Rangers and M/Y Navorca crew. Two teams of catchers would comb the reef flats in search of turtles and bring these back for processing on the M/V Navorca.

Laparoscopy

Laparoscopy uses a miniature telescope to view the inside of the peritoneal cavity directly. The surgical procedure results in important population structure data that can be used for effective marine turtle conservation. In this study, laparoscopy provided information on gender, age class, and reproductive status.

Turtles were checked for general appearance and obvious signs of damage or sickness, and photographs were taken of obvious defects. The turtles were examined internally using a BAK (Germany) 30◦, 5mm diameter × 30 cm long laparoscope. Turtles were scored for gender and appearance of gonads (oviduct size and shape, the color of ovaries in females; testes size, shape and color, and shape of the epididymis in males) sensu Miller & Limpus (2003). Following laparoscopic examination, two sutures using self-dissolving catgut were used to seal the 0.8-1 cm incision. The turtles were tagged with Inconel tags as they were returned to the water for identification in future recaptures and marked with a patch of bright rapid-drying orange spray paint to enable within-season observations and to avoid repeat captures of turtles. They were then carefully returned to the sea, and their behavior was observed as they swam away from the base station/vessel.

Morphometric Measurements

Turtles were carefully measured for curved carapace length (CCL) using a fiberglass tape measure (+/- 1mm) – measured over the curve of the carapace along the midline from the anterior point at the midline of the nuchal scute to the posterior tip of the supra caudal scutes.

Blood sampling

Building upon long-term in-water monitoring of Hawaiian green turtles, the NOAA team collected blood (up to 10 cc from dorsal cervical sinus, 7) and skin (0.5cm x 0.5cm, shoulder region) tissue samples. Blood plasma was then separated from red blood cells via centrifugation onboard the M/V Navorca and stored in liquid nitrogen for transport to the U.S. where laboratory analyses for $\delta^{2}H$, [H], $\delta^{13}C$, $\delta^{15}N$ will be conducted.

Figure 50. Each turtle undergoes skin and blood sampling (left) and laparoscopy (middle). Collected blood is processed via centrifugation to separate blood plasma from red blood cells (right photo) before being stored in liquid nitrogen storage (foreground). Photos: Nick Pilcher

RESULTS AND DISCUSSION

Laparoscopy investigations provided a wealth of information on population structure, sex ratios, nesting activity, spatial distribution, residence times, growth rates, and size structure. Data from past surveys allowed calculations of growth rates, and based on these, an inference of residence periods. A total of 200 green turtles (*Chelonia mydas*) were captured via rodeo jumps. Of these, 40 turtles (20.0%) were recaptured from past seasons (identified via tags applied previously).

Population Structure and Age Class Distribution

In the first three seasons of sampling at Tubbataha (2010, 2014, and 2015), the population was primarily comprised of juvenile sea turtles (~79 to 90% juvenile), but by 2016 and 2019, notable changes were apparent: Juvenile turtles comprised only slightly more than 50% of all turtles, and by 2023 juveniles comprised only 25% of all turtles, and less than both sub-adults and adults (Figure 51).

Tubbataha was considered a juvenile development ground up until recently, and the smallest turtles on record were ~35cm which we classified as new recruits to the foraging area. No turtles smaller than this size have ever been recorded despite substantial diver and ranger activity, so while there is a degree of nesting on the small islets in the TRNP, it is not believed these turtles remain resident from hatchling stages. It is presently unknown if turtles that hatch at Tubbataha return to Tubbataha in subsequent years as foraging animals. Laparoscopy data indicates that turtles previously classified as juveniles have progressed to sub-adults, and sub-adults have progressed to adults. We believe that Tubbataha continues to function adequately as a development feeding area.

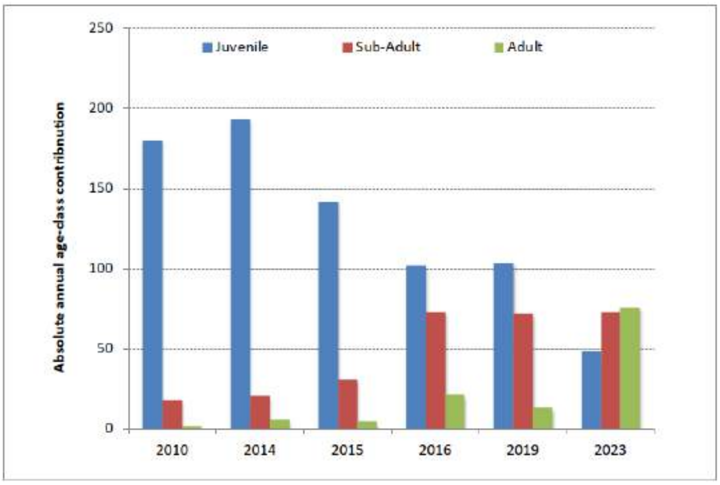

Figure 51. Age class structure of rodeo captures at Tubbataha since 2010.

The gradual shift in proportions of juveniles versus sub-adults and adults is of grave concern, as this signifies that somewhere along the 'production line,' juvenile turtles are being removed from the population or are not being produced. The Turtle Islands Park and the Turtle Islands Wildlife Sanctuary, the largest combined green turtle rookery in SE Asia, and also in the Sulu Sea where Tubbataha lies, continue to increase the number of nesters and production of hatchlings. Similarly, we are unaware of any 'new' foraging area where turtles may have shifted. We believe that hatchling production is not the culprit, and this points to either bycatch or intentional poaching in other breeding areas as potential reasons behind the gradual loss of juveniles at this site.

Population Structure and Male: Female Ratio

Whereas in the past, the smaller turtles made up the bulk of all captures, in 2023, only 49 of the green turtles caught during the rodeo exercises were juveniles (24.7%). Five of these 49 juveniles (12.5%) were identified as new recruits based on a white scratch-less plastron and small size. Any viable population of sea turtles needs to have eggs that develop into hatchlings, hatchlings into juveniles, juveniles into sub-adults, and sub-adults that develop into egg-laying adults. The proportion of new entrants to the juvenile age class (the new recruits) was encouragingly greater than findings in the past, but there are overlying concerns about the absolute number of juveniles remaining on Tubbataha. It is possible that the 5%-10% annual recruitment is insufficient to maintain this population.

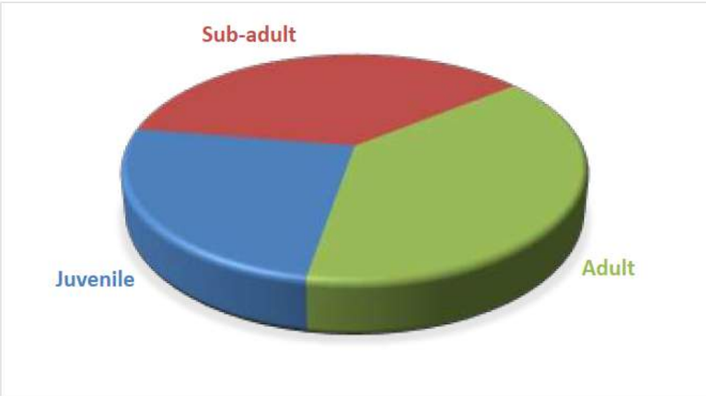

Figure 52. Age class structure of rodeo captures at Tubbataha, June/July 2023.

A total of 73 sub-adult turtles >65cm CCL comprised 36.9% of the captures, and a record-high of 76 adults comprised 38.4% of all turtles captured during the 2023 survey (Figure 52). These findings are at great odds with the population structure detected in 2010, 2014, 2015, and 2019, with a notably higher proportion of sub-adults and adults (Figure 53). Substantially more females (64.1%) were captured than males (35.9%). A breakdown by age class and sex ratio is provided in Figure 54.

Size Distribution

Unlike in past seasons, and given the age-class structure, most turtles were in the mid- to larger size ranges. Given these are all presumed to represent the same genetic stock, turtles from all three locations were treated as one group. As expected, given the variation in growth rates, there was overlap in sizes amongst the differing age-classes, particularly between the 55cm and 80cm carapace sizes, which comprised juveniles and subadults (Figure 54). Although there was some variation in sizes amongst males and females in the different size classes, none of these were significant.

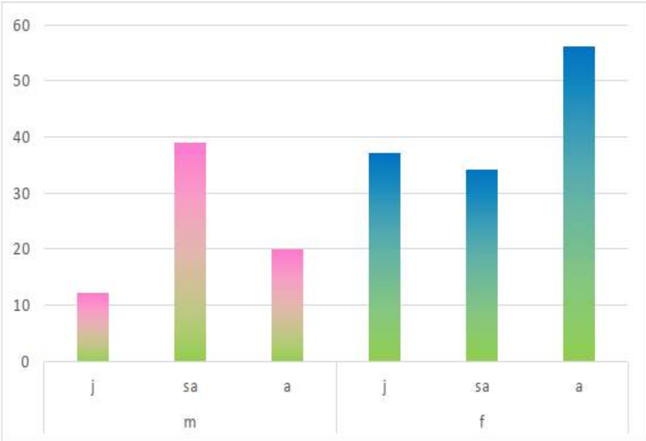

Figure 53. Sex and age class structure of rodeo captures at Tubbataha, June/July 2023.

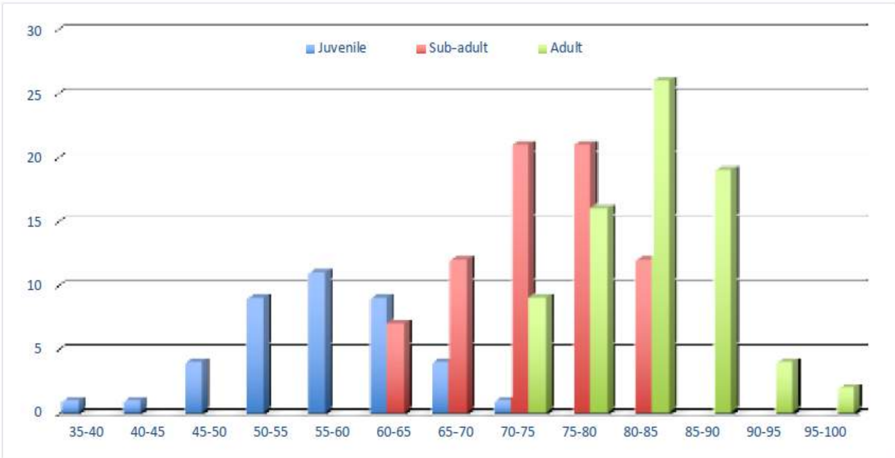

Figure 54. Size distribution broken down by age class for turtles captured at Tubbataha, 2010-2016.

Mark-Recapture, Intervals, and Growth

Capture-mark-recapture studies allow assessments of growth rates, residence periods, migrations, and age-specific mortality. This survey benefited from past efforts at the site by the Tubbataha Management Office personnel (unpublished data), by DENR (Cruz & Torres 2005), and TMO mark-recapture research since 2010 (Pilcher 2010, 2014, 2015, 2019). To standardize tagging records, a master tag field was added to the database so that turtles can be tracked through time even if a tag is lost or replaced. In several instances where tags had been replaced, the tracing back to a master tag number was done manually. The master tag field was then used to search among turtles for recapture records. All growth data is derived from green turtles, as the low number of hawksbill turtle captures precludes any further analysis.

In 2023, the 36 recaptures for which previous data was available accounted for 90% of all recaptures, indicating the database is becoming more and more robust with accurate records over the years. Two of these turtles had been recaptured previously, also providing two additional growth records. In total, there were 38 growth records available for recaptures in 2023. The continued (and apparently rising) number of recaptures is suggestive of a stable resident population, with steady growth rates.

Figure 55. Comparison photo of small (~35cm) vs large (>75cm) turtles caught during this survey.

The average recapture interval among female turtles was 1,873.9 days (5.13 years), ranging from 1.77 to 8.07 years. The average recapture interval among male turtles was 1,664.3 days (4.56 years), ranging from 4.07 to 10.09 years. Fourteen turtles recaptured in the past had advanced from juvenile to sub-adult age classes, and four of the recaptures had grown from juvenile to adult. These data indicate successful progression from age class to age class at Tubbataha.

Eleven of these (32%) were recaptured at North Islet, while only five recaptures (15%) came from the Ranger Station. Eighteen previously marked turtles were caught at South Atoll (53%). In earlier years, we have had no recaptures from this site, possibly as a result of fewer catches and the lower tagging effort at this site in previous years, but this number has increased over the years as tagging efforts continue. These data can be added to more than 100 recapture records from all previous data provided by TMO and DENR and, over time, will contribute to understanding growth as a function of climate and ambient conditions.

CONCLUSION

The ongoing work at Tubbataha continues to provide robust data on population structure and size. Of concern is the substantially lower number of juveniles found in the population during the 2023 season, and it is unknown precisely what the cause of this change has been. In the first three seasons of sampling (2010, 2014, and 2015), the population was primarily comprised of juvenile sea turtles (~79 to 90%

juvenile), but by 2016 and 2019, notable changes were apparent: Juvenile turtles comprised only slightly more than 50% of all turtles, and by 2023 juveniles comprised only 25% of all turtles, and less than both sub-adults and adults.

Tubbataha was considered a juvenile development ground until recently, and the smallest turtles on record were ~35cm which we classified as new recruits to the foraging area. No turtles smaller than this size have ever been recorded despite substantial diver and ranger activity, so while there is a degree of nesting on the small islets in the TRNP, it is not believed these turtles remain resident from hatchling stages. It is presently unknown if turtles that hatch at Tubbataha return to Tubbataha in subsequent years as foraging animals. Laparoscopy data indicates that turtles previously classified as juveniles have progressed to sub-adults, and sub-adults have progressed to adults. We believe that Tubbataha continues to function adequately as a development feeding area.

The gradual shift in proportions of juveniles versus sub-adults and adults is of grave concern, as this signifies that somewhere along the 'production line', juvenile turtles are being removed from the population or are not being produced.

The Turtle Islands Park and the Turtle Islands Wildlife Sanctuary, the largest combined green turtle rookery in SE Asia, and located in the Sulu Sea where Tubbataha lies, continue to increase in the number of nesters and production of hatchlings. Given this continued increase in nesting and the adequacy of conservation efforts at these locations, we believe that hatchling production is not the culprit, and this points to either bycatch or intentional poaching before turtles arrive at Tubbataha as potential reasons behind the gradual loss of juveniles at this site.

Protection efforts at Tubbataha itself are extremely robust and we are certain that there is no poaching of turtles once they arrive. At present, we are unaware of any 'new' or 'alternate' foraging area where turtles may have shifted. The small number of new recruits in 2023 suggests the arrival has not ceased completely, but the lack of small (<~10-year-old turtles) also suggests the pressures on this stock are not new to 2023, and point to an upsurge in turtle losses (either to bycatch or poaching) in the Sulu-Sulawesi region in the last decade. MRF and TRNP will continue to monitor the situation through ongoing sampling. We will also liaise with other researchers in the region to determine if any large influx of juvenile green turtles has been recorded elsewhere.

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7. Fish Inventory: Year 3

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OVERVIEW

Since 2018, an extensive inventory of fish species in Tubbataha has been conducted. The main goal is to improve the existing fish species listed during the annual monitoring of the Tubbataha management office (TMO) and WWF- Philippines since 1999. From 2018 to 2019, 61 new species were added to the growing record. Now in its third year, Dr. Klaus Stiefel from Neurolinx Research Institute joined the team. The roving diver method was used to identify species encountered. For the first time, the lagoon of North Atoll was surveyed.

METHODS

Data Collection

The team was onboard M/Y Infiniti, and survey sites were determined according to the schedule of the dive boat. A total of nine (9) sampling sites were visited this year, where seven (7) were dive sites and two (2) were in the lagoon in the North Atoll (see Table 16). Sites previously visited are in Appendix *17*. Overall, 27 sites have been surveyed since this study began.

Table 16. Sites surveyed

Dive No.	Description of dive sites
T1	Lagoon Station, North Atoll about 1 km north of Ranger Station,
T2	North Atoll, South Park Dive Station 72' to 10'
T3	North Atoll, Northern area, Shark Airport
T4	North Atoll, Lagoon, about 1 km South of Bird Islet
T5	South Atoll, Delsan Wreck
T6	South Atoll, Ko-Ok Dive site
T7	South Atoll, Southwest Wall Dive Site
T8	Jessie Beazley, northeast side
T9	Jessie Beazley, northeast side, but a different part than the first dive

This study utilized the roving diver survey (RDS) method to quickly assess species diversity, as in previous surveys conducted in 2018 and 2019. Divers began at a depth of approximately 65 ft (20 meters) and worked their way toward the reef's shallowest area, carefully noting every species observed during their one-hour dive. The objective was to document as many species as possible. Divers also searched for fish in various locations, such as under ledges (e.g., corals, rocks), caverns, and crevices. The RDS method provided valuable information, including a species list, frequency of sightings, and relative abundance data.

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 Analysis

Microsoft© Excel was used in collating the data. The descriptive analysis for this report was patterned after Schmitt *et al.* (2002) and Schmitt and Sullivan (1996).

Percent Sighting Frequency (%SF) indicates the percentage of all dives in which the species was recorded or observed. Observed values ranged from 0-100% and were calculated as:

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

Species were classified into three frequency categories based on the percentage of dives where each species was observed: frequent (≥70%), common (>20% x >70%), and uncommon (≤ 20%).

The **Abundance Index** is a weighted average index calculated to measure each species' abundance using the abundance categories. This was calculated as follows:

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

S, F, M, and **A** are the frequency categories of single, few, many, and abundant observations for each species, and ***n*** is the total number of dives. This produced an abundance index per species, then scaled from 0 to 4, where Single = 1, Few = 2, Many = 3, Abundant = 4, and Not Observed = 0.

The abundance index provided for each species indicates their level of prevalence. For example, an index of 2.2 means that the species was frequently observed in "few" numbers (between 2 to 10 individuals) during most dives but occasionally appeared in "many" or "abundant" numbers in other dives.

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

0.1 to 2.0 – species observed in smaller numbers
2.0 to 3.0 – species typically seen in few numbers but could be abundant in other locations
3.0 to 4.0 – species were abundant in most if not all, sites

To evaluate the overall biodiversity of Tubbataha Reefs, Estimate S (Colwell 2013) was utilized. This free software application utilizes accumulation curves for rarefaction and extrapolation (nonparametric) reference samples to calculate biodiversity.

RESULTS

This year, 337 fish species (excluding sharks and rays) were encountered, which was relatively higher than in 2018 (329 species) and 2019 (331 species). The family Labridae (wrasses) had the highest number of species, with 55 recorded, followed by Pomacentridae (damselfish) with 46, and Chaetodontidae (butterflyfish) with 29. The number of species varied from 68 to 139 per sampling site (see Figure 56), with Site T5 (Delsan Wreck) having the highest count, followed by T3 (Shark Airport) and T8 (northeast side of Jessie Beazley). The two sites with the lowest species abundance were T1 and T4, both in the lagoon of North Atoll.

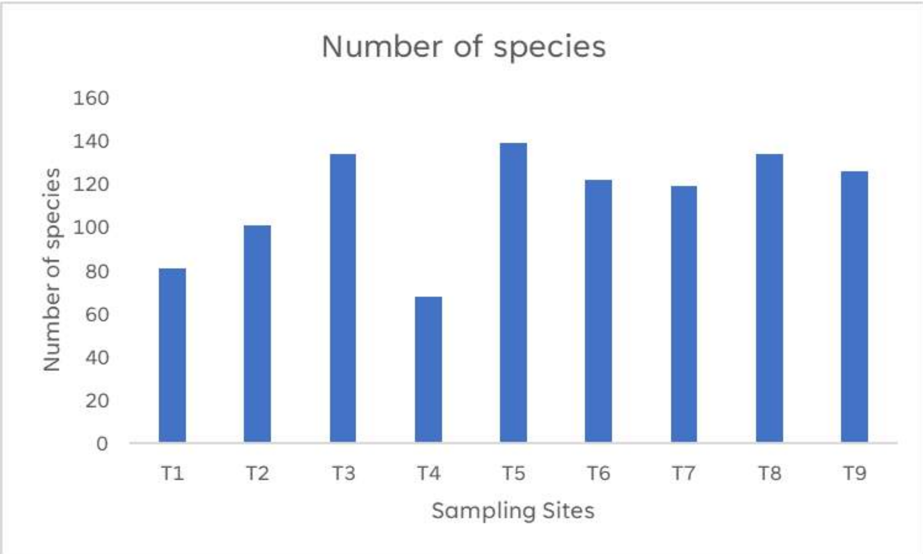

Figure 56. Number of species encountered in each sampling site this year.

Sighting Frequency and Abundance Index

Table 17 displays the fish species count in Tubbataha Reefs, based on sighting frequency categories (frequent, common, and uncommon) and abundance index ranges (0.1-1.0, 1.1-2.0, 2.1-3.0, and 3.1-4.0). The sighting frequency reflects how often a species is seen, while the abundance index represents the average number of individuals observed per species.

Table 17. The number of species on each sighting frequency and their abundance index ranges.

Abundance Index	Sighting Frequency			
	Frequent (≥70%)	Common (>20% x <70%)	Uncommon (≤20%)	Total
(0.1-1.0)	0	139	106	**245**
(1.1-2.0)	12	44	0	**56**
(2.1-3.0)	15	17	0	**32**
(3.1-4.0)	4	0	0	**4**
Total	**31**	**200**	**106**	**337**

Of the 337 recorded species, 107 were considered 'uncommon' because they were only seen in 1/9 of the survey sites, indicating that these species were rarely observed. Two hundred (200) species were classified as 'common' because they were recorded in at least two to six sampling sites. Thirty-one species were classified as 'frequent' because they were encountered in at least seven sampling sites. The Oval butterflyfish *Chaetodon lunulatus* was observed in all sites, consistent with previous surveys in 2018 and 2019.

Approximately 73% of the species recorded fell under the 0.1-1.0 range of the abundance index, meaning they were solitary or in small groups of less than ten individuals. Some species tend to be solitary, in pairs, or in relatively small groups, while some occur in large concentrations. For example, some species of cardinalfish (Apogonidae) are solitary or occur in small groups, while others, such as damselfish (Pomacentridae) and fairy basslets (Anthiinae), tend to occur in large concentrations.

A wide range of sighting frequencies and abundance levels characterize the fish species richness in the Tubbataha Reefs. No species in the "frequent" sighting frequency category had an abundance index of 0.1-1.0, suggesting that all commonly observed species in Tubbataha Reefs are at least moderately abundant. For example, species such as golden damselfish *Amblyglyphidodon aureus*, bicolor chromis *Chromis margaritifer*, Weber's chromis *Chromis weberi*, and goldbelly damsel *Pomacentrus auriventris* fell under 3.1-4.0 of the abundance index, occurring in hundreds to thousands of individuals and with high sighting frequency. This is consistent with the findings of previous studies on fish species richness in other coral reef ecosystems (Schmitt & Sullivan 1996; Carpenter et al. 2002).

Although there is a correlation between the number of sightings and the relative abundance of a species, it is not guaranteed that a high frequency of sightings equates to high numbers of species (Schmitt & Sullivan 1996). This is because some species may have different ecological niches than others, resulting in varying abundance levels despite being commonly observed. For instance, the cleaner wrasse *Labroides bicolor* was present in 21 of 27 sampling sites but had a relatively low abundance. On the other hand, the lunar fusilier (*Caesio lunaris*) and yellowbelly damselfish *Amblyglyphidodon leucogaster* were recorded in only 10/27 sites, yet they were categorized as "Many" or "Abundant" when encountered. This highlights that relying on sighting frequency alone can be misleading, as some commonly observed species may be relatively abundant. In contrast, some species may be less abundant but still play an essential role in the reef ecosystem.

Species accumulation and extrapolation curve

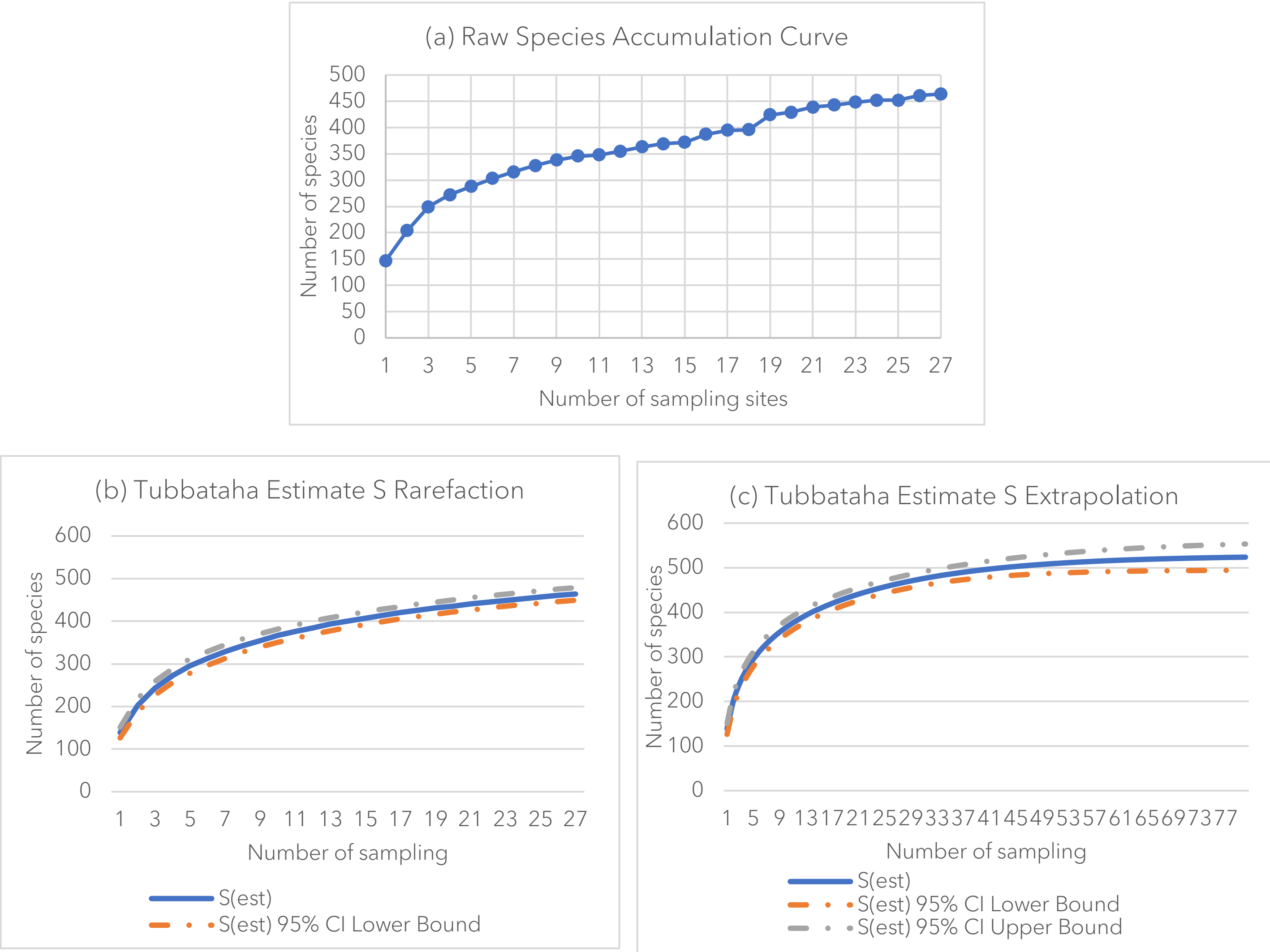

Figure 57. Results of the species abundance analysis for Tubbataha Reefs (2018-2023) using EstimateS software: (a) species accumulation curve collected from 27 sites; (b) sample-based rarefaction using data collected from 27 sites with 95%Confidence Intervals (Upper and Lower Bound); and (c) species accumulation in 27 sites with extrapolation up to 80 sites with 95% confidence intervals (Upper and Lower Bound).

Since 2018, the researchers covered 27 sampling locations within Tubbataha and identified 475 species of fish (Figure 57a). By utilizing rarefaction and extrapolation techniques on reference samples, we could project the number of species in the Tubbataha Reefs (refer to Figure 57bc). Based on the species accumulation curve generated from 27 collections over the past three years (a and b), we have identified almost 500 species. Extrapolating this data, we estimate that the number of species could increase from 494 (95% CI Lower Bound) to over 550 (95% CI Upper Bound) with the addition of up to 80 collection sites (c). These findings indicate that new species will likely be identified through the systematic investigation of 80 collection sites. However, once this threshold is reached, the rate of discovering new species is expected to decrease significantly, and it will become increasingly unlikely to find additional species beyond that point. It is likely that more species would be identified by surveying sites with different habitat types, e.g., lagoons of North and South Atolls.

DISCUSSION

Thirty eight (38) species not previously listed in Tubbataha were recorded this year. Out of 38 species, 25 were only recorded in the lagoon of North Atoll. This study highlights the potential species richness inside the lagoons of Tubbataha. The number of newly recorded species was higher than in 2018 (36 species) and 2019 (29 species). Overall, a total of 103 species not previously recorded in Tubbataha were identified throughout the years. This brings the fish species list to 798 species identified through regular monitoring and this study.

Since the 2018 survey, some notable species have been observed to have a high prevalence in both presence and abundance. Oval butterflyfish *Chaetodon lunulatus* were present in all the survey sites. At least two (2) individuals per site were noted. Meanwhile, sunburst butterflyfish *Chaetodon kleinii* were recorded in 26/27 sampling sites. Notably, at least ten individuals were encountered in 22/27 sites, indicating their abundance in the area. Other species of butterfly that were frequently sighted were the *Chaetodon baronnesa, Chaetodon ocellicaudus, Chaetodon ornatissimus*, and *Chaetodon vagabundus*. Butterflyfish are strongly dependent and closely associated with coral reefs for food and habitat; hence, their presence and abundance in the reef indicate reef health (Pratchett et al. 2014; Bellwood et al. 2006). Royal angelfish *Pygoplites diacanthus* was also recorded in 26/27 sites and often occurred alone or in pairs. Aside from the butterflyfish and angelfishes, herbivorous fishes such as nine (9) species of damselfish (Pomacentridae), four (4) species of surgeon (Acanthuridae), and unicornfish (Nasinae), and one (1) species of triggerfish (Balistidae) were also recorded in at least 21/27 sampling sites. These families, among others, play a crucial role in maintaining coral reef health and function through various ecological roles, such as herbivory and coral cleaning (Mumby et al. 2006; Williams and Polunin 2001).

It is also worth noting the presence and abundance of large-sized species, including the bluefin trevally *Caranx melampygus*, two-spot red snapper *Lutjanus bohar*, bignose unicornfish *Naso vlamingii*, and the peacock Hind *Cephalopholis argus* and darkfin hind *Cephalopholis urodeta*, in at least 23/27 sampling sites. These species are commercially important fishes highly targeted for food. Their occurrence and abundance (and varying sizes) in Tubbataha could indicate low to almost absent fishing pressure in the park.

Various factors can influence the occurrence and abundance of fish species on coral reefs. Some species, such as damselfish and butterflyfish, live in specific habitats, like shallow reefs or coral-rich areas (Harborne 2013). Some fish species are more active and observable than others, while others tend to stay close to the benthos (Allen and Robertson 1998; Depczynski and Bellwood 2003). Another factor is the ecological niche that the species occupy in the coral reefs. Some are predators, herbivores, or scavengers, while others are generalists or specialists. This niche can affect their behavior, habitat preferences, and abundance levels.

CONCLUSION

Since 2018, the comprehensive inventory of fish species in the Tubbataha Reefs yielded 103 species. The sighting of 25 species exclusively in the lagoon of North Atoll underscores the species richness of the lagoons and highlights the need for continued protection and research in this part of the park. The total count of 798 fish species, including 103 previously unrecorded in Tubbataha, is a testament to the biological wealth of this World Heritage Site.

This study has also identified interesting trends in the population and occurrence of fish species in the park. The oval butterflyfish *Chaetodon lunulatus*, sunburst butterflyfish *Chaetodon kleinii*, and royal angelfish *Pygoplites diacanthus* have been consistently observed across survey sites, signifying their ecological significance and contribution to the overall health of the coral reef ecosystem. Herbivorous fishes, such as various damselfish (Pomacentridae) and surgeonfish (Acanthuridae), also found in abundance, play pivotal roles in maintaining coral reef health, underlining the ecological importance of these species. Furthermore, the presence and abundance of commercially valuable species, including the bluefin trevally *Caranx melampygus* and two-spot red snapper *Lutjanus bohar*, suggest low to nearly absent fishing pressure within the park, a positive indicator of effective conservation efforts.

Continuing the survey is expected to increase the number of species identified in the park. While this study has yielded valuable insights into fish biodiversity, further sampling should include the lagoons of both atolls. Adding sites, especially in less studied reef areas (i.e., lagoons), is expected to increase the current fish species list of Tubbataha. Furthermore, the Roving Diver Survey provides an overview of the fish biodiversity in sites that are not part of the monitoring sites of the management. This monitoring could also provide temporal data on the sightings and abundance of fish species, hence, it is a valuable complement to the annual fish visual census.

RECOMMENDATIONS

Based on this study, we recommend the following activities for conservation and future studies in the Tubbataha Reefs:

1. **Conduct more surveys in the lagoons:** Due to the many previously unlisted species found in the North Atoll lagoon, we advise further investigation in both

lagoons of Tubbataha. These places possess diverse fauna and flora, and therefore, need more attention for protection and research.

2. Continuous monitoring: Sustained monitoring efforts are crucial to track changes in fish populations and ecosystem health over time. This survey complements other reef surveys conducted in Tubbataha and detects signs of ecological shifts in fish biodiversity. TMO should also maintain a comprehensive fish database to include species recorded by other researchers.

3. Conservation measures: This study further underscores the fragility of the lagoons of Tubbataha, not only for unique fish species but also for vulnerable coral species. The ban on tourism activities in the lagoons should be maintained to safeguard the habitat integrity of the area. Enforcement of protected area regulations is vital to preserve the marine ecosystem's health.

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8. Cetaceans

Ma. Theresea R. Aquino, DVM

Marine Wildlife Watch of the Philippines

OVERVIEW

Figure 58. Map of the Coral Triangle. Red square indicates Sulu Sea.

The Coral Triangle accounts for 76% of the world's coral species (Veron et al. 2009). It spans six countries in the Southwestern Pacific and is touted to harbor the highest marine diversity in the world. The Sulu Sea, one of the smallest basins in the Western Pacific, lies near the apex of the Coral Triangle (Figure 58). As such, Sulu Sea harbors one of the world's most productive and diverse marine ecosystems. Its central area has been shown to have a significantly higher level of chlorophyll than South China Sea (Jones 2002). Ventilation by the Panay and Sibutu Straits allows for a unique deep stratification (Gordon, Tessler, and Villanoy 2011), creating upwellings that contribute to its productivity.

The Tubbataha Reefs Natural Park (TRNP) is a marine protected area located at the center of the Sulu Sea (Figure 59). Its core zone covers about 97,030 hectares that is surrounded by a 10- nautical mile-wide buffer zone (Secs. 4 and 5, RA 10067). The TRNP serves as a strategic feeding area for highly migratory marine organisms such as cetaceans (Aquino and Calderon, 2004) crossing the Sulu Sea. Its rich marine biodiversity has earned the park international recognition as UNESCO World Heritage Site (1993), Ramsar Site (1999), ASEAN Heritage Site (2014), and East Asian-Australasian Flyway Partnership, Flyway Network Site in the Philippines (2015). The International Maritime Organization (IMO) acknowledged its significance to marine conservation when it declared TRNP as a Particularly Sensitive Sea Area (PSSA) in 2017. In the 2020 Conservation Assessment of TRNP, IUCN has reported that the conservation outlook of the park was "Good with some Concerns".

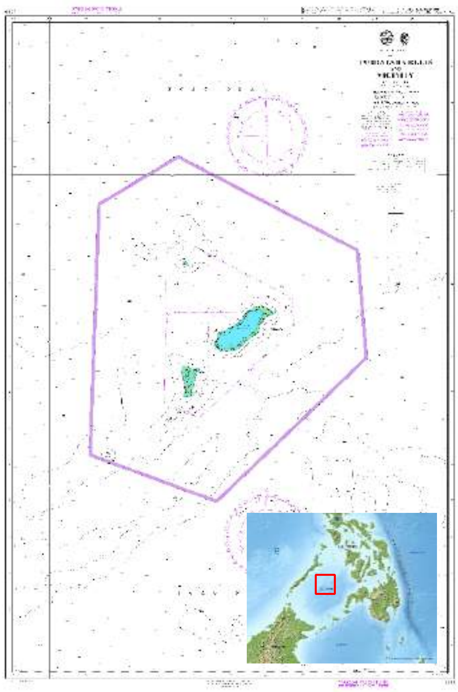

Figure 59. Map of the TRNP

The Tubbataha Management Office (TMO) which manages the daily operations of TRNP uses, among others, bioindicators to monitor its management effectiveness. These bioindicators include large marine vertebrates, one of which is the cetacean group. Cetaceans are good indicators of the health condition of its marine environment since all aspects of its life are wholly spent in the sea. Problems that may affect the Sulu would likely reflect its cetacean population even before it may be felt by the human population.

Since the first cetacean survey conducted in Tubbataha in 1993 (Dolar & Alcala 1993), TMO has established a cetacean species inventory list built upon succeeding cetacean surveys as well as corroborated and verified reports, i.e., supported by photos or video footage, from marine park rangers, other researchers, dive crew, and tourists. A total of 14 species belonging to five families have been identified. The species recorded in TRNP to date are presented in the table below. Families, taxonomic authorities, and conservation status are lifted from Alava et al. (2012).

Table 18. Cetacean species inventory list for Tubbataha. The Philippine conservation status is used in this table.

	Scientific Name	Common Name	Conservation Status	
Family Balaenopteridae				
1.	*Balaenoptera omurai*	Omura's whale (Wada, Oishi & Yamada, 2003)	DD	
Family Delphinidae				
2.	*Globicephala macrorhynchus*	short-finned pilot whale (Gray, 1846)	DD	
3.	*Grampus griseus*	Risso's dolphin (Cuvier, 1812)	DD	
4.	*Lagenodelphis hosei*	Fraser's dolphin (Fraser, 1956)	VU	A2d
5.	*Orcinus orca*	killer whale (Linnaeus, 1758)	DD	
6.	*Peponocephala electra*	melon-headed whale (Gray, 1846)	DD	
7.	*Pseudorca crassidens*	false killer whale (Owen, 1846)	DD	
8.	*Stenella attenuata*	pantropical spotted dolphin (Gray, 1846)	DD	
9.	*Stenella longirostris longirostris*	long-snouted spinner dolphin (Gray, 1828)	VU	A2d
10.	*Tursiops truncatus*	bottlenose dolphin (Cuvier, 1828)	DD	
Family Kogiidae				
11.	*Kogia sima*	dwarf sperm whale (Owen, 1866)	DD	
Family Physeteridae				
12.	*Physeter macrocephalus*	sperm whale (Linnaeus, 1758)	VU	A1d
Family Ziphiidae				
13.	*Indopacetus pacificus*	Longman's beaked whale (Longman, 1926)	DD	
14.	*Mesoplodon densirostris*	Blainville's beaked whale (de Blainville, 1817)	DD	

Since the last cetacean survey in 2010, the TMO has had a hard time continuing their efforts due to logistical constraints. Increasing fuel prices and the remoteness of the park have made boat transect surveys challenging to accomplish every three years as initially indicated in their Research and Monitoring Plan. Thus, this WWF cetacean project was a welcome development for TMO. This 2023 survey aimed to update information on cetacean populations as one of the top predators that reflected the state or condition of its marine environment.

METHODS

The boat transect survey was conducted from 6 to 18 June 2023, following the tracklines used in the 2010 cetacean survey (Figure 60). All tracklines were covered twice except for trackline D (TD) which was passed only once due to weather and time constraints. Only the long legs of the tracklines were covered on-effort in consideration of time and budget constraints. During on-effort, three observers (center, left, and right) actively scanned the water using 7x50 military marine waterproof binoculars with an internal compass. A fourth observer, using the naked eye, monitored the bow of the boat to call out sightings close to the trackline and the boat that could be easily missed when using binoculars. The center observer covered about 20° to the left and right of the trackline while the left and right observers scanned their respective sides of the boat to cover the rest of the 180° of the boat

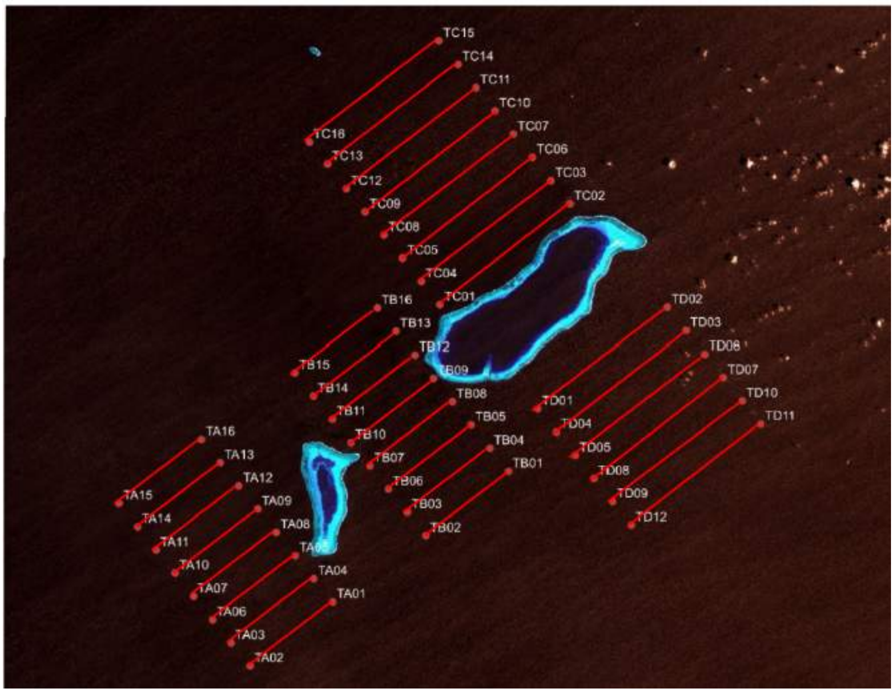

Figure 60. Satellite map of Tubbataha showing tracklines followed during the 2023 survey

Figure 61. Observers were positioned at the front of the boat at an elevation of about six meters above sea level. (1) center, (2) left observer, (3) right observer, (4) naked eye, and (R) recorder. (Photo credit: D Cayanan)

altogether. The team perched at an elevation of about six meters above sea level. They were distributed as shown below:

All encounters made within 180° of the front and the sides of the boat while actively following these trackline were considered on-effort sightings while those that did not follow these conditions were categorized as off-effort sightings. All sightings were first confirmed by other observers and boat position on the trackline was marked by a recorder using a Garmin GPSMap 78S before leaving the trackline. Once the trackline position was marked, the boat would start its pursuit of the sighted pod or individual to document the sighting as best as possible with the least stress to the animal or animals. Speed was increased if the sighting was farther away or maintained when individuals were near.

Sea conditions were noted all throughout the survey and categorized using the Beaufort scale as follows:

Scale	Description
0	Smooth & mirror-like
1	Scale-like ripple without foam crests
2	Small short wavelets; crests have glassy appearance & don't break
3	Large wavelets; some crests begin to break; foam of glassy appearance; occasional white
4	Small waves, becoming longer; fairly frequent white foam crests
5	Moderate waves, taking more pronounced long form; many white foam crests; may have
6	Large waves begin to form; white foam crests more extensive everywhere; may have some

Normally, effort was ended if sea conditions were at Beaufort 4 or higher as excessive boat movement hampered observation in the higher categories, rendering the effort counterproductive. It was also deemed unsafe to proceed with the survey in these higher categories.

Attention was closely paid to boat position in relation to the pod or individuals to avoid cutting through their path or disrupting its current activity. The boat captain was also instructed to position the boat between the sun and the pod whenever possible to avoid the glare when taking photographs. Behavior, activity, group size, species, and presence of calves were noted, and photographs were taken to aid in recording and identification of the species. When sufficient data had been collected, interaction was ended, the boat returned to the position previously marked on the trackline, and the on-effort survey resumed. Survey effort was recorded using a log sheet (Appendix 19) while details of sightings were recorded on sighting sheets (Appendix 20).

At the end of the survey, the trackline covered and survey time were totaled separately. Encounter rate was calculated per species using the formula:

$$\frac{\text{\# of sightings}}{\text{total distance covered}} \quad X1000$$

In addition, the team monitored the radio on channel 16 for any reports of marine mammal encounters from other dive boats and the marine park rangers. Any relevant report received was further investigated when necessary and noted. Lastly, satellite data on chlorophyll concentration in the Sulu Sea during the survey dates of 2004 (24 March to 3 April and 12-25 April), 2010 (8 April to 1 May), and 2023 (6-18 June) were collected to further understand the results of the cetacean survey. Collecting data from a single dataset was intentional to reduce bias in processing. However, the June data in the chosen dataset was not yet available and, thus, the May 2023 data had to be used as proxy.

RESULTS AND DISCUSSION

Cetacean Encounters

The 2023 cetacean survey coincided with the start of the rainy season as officially declared by PAGASA for the year. Prior to this, super typhoon Betty (international name: Mawar) hit the country with heavy rains and floods on 27 May 2023 which pushed the original survey schedule back a whole week. The weather conditions alone created a vastly different situation for the 2023 survey compared to that experienced in 2004 and 2010 which were conducted well within the summer season.

The 2023 cetacean survey recorded a total of 11 on-effort and seven off-effort sightings. Five species were encountered, namely: (1) long-snouted spinner dolphin *Stenella longirostris*, (2) short-finned pilot whale *Globicephala macrorhynchus*, (3) Fraser's dolphin *Lagenodelphis hosei*, (4) Blainville's beaked whale *Mesoplodon densirostris*, and (5) false killer whale *Pseudorca crassidens*. All five species had been previously documented in the park. Three on-effort encounters were cut short while still too far away to allow for identification of the species. Encounter rates were calculated similar to previous surveys and presented below:

Table 19. Table of encounter rates for 2004, 2010, and 2023 cetacean surveys. Highlighted rows indicate species that were seen in 2023. The total trackline distance covered for each survey are indicated at the bottom of their respective columns.

	2004		2010		2023	
	Sightings	Encounter Rate	Sightings	Encounter Rate	Sightings	Encounter Rate
B. omurai			4	4.995		
G. macrorhynchus	3	4.086	10	12.487	2	4.344
G. griseus	5	6.809	3	3.746		
I. pacificus			2	2.497		
K. sima	1	1.362				

L. hosei			5	6.244	1	2.172
M. densirostris	1	1.362			2	4.344
P. crassidens	1	1.362	1	1.249	1	2.172
S. attenuata			1	1.249		
S. longirostris	16	21.790	7	8.741	3	6.516
T. truncatus			3	3.746		
Unidentified	11	14.981	3	3.746	3	6.516
species encountered	**6**		**9**		**5**	
total distance covered (km)	734.28		800.82		460.43	

Due to unfavorable weather and sea conditions as well as time constraints, only replicates per trackline could be done, with trackline D being done only once. A total transect distance of 460.43 kms was covered in 50 hours and 25 minutes. The first week of the survey was conducted in predominantly unfavorable sea conditions at Beaufort 3 and 4. The team initially attempted to continue survey efforts despite some rain to make up for lost time but eventually had to discontinue efforts when visibility and team members' health were compromised. Thus, the effort taken in 2023 was only a little over half that expended in the 2004 and 2010 surveys.

Similar to the 2004 cetacean survey results, spinner dolphins were the most commonly encountered during the 2023 survey. However, the encounter rate was much lower compared to the 2004 results and interaction did not yield much information beyond the basics, i.e., species identification, group size estimate, activity. In all three encounters with the species during the 2023 survey, the pods were mostly traveling, and during the encounter with sighting #3, several spinner dolphins slapped their tails in immediate succession, which prompted the team to move away and eventually discontinue interaction.

Of all species encountered, the spinner dolphin appeared to consistently decrease in encounter rates from 2004 to 2023. Given the difference in effort and seasons upon which the surveys occurred, it might be presumptuous to conclude that the decrease is significant, but it is nevertheless unsettling. Factors beyond the scope of the TRNP management were likely at play. The spinner dolphin has been listed as Vulnerable (VU) in the Philippines due to a substantial number of by-catch incidents over the past years which has led local experts to suspect a decline of 30% or more over three generations in the country (Dolar et al. 2012). The 2023 survey results in TRNP appeared to reflect the experts' suspicions. All 11 on-effort encounters exhibited cryptic surface and/or avoidance behavior, seemingly reluctant to interact. Only sighting #5, spotted within the buffer border of the TRNP, was highly interactive. During this sighting, the Fraser's dolphins were porpoising, spyhopping, and bowriding while the pilot whales were logging from a distance. Furthermore, cetaceans encountered by the survey team off-effort and those reported by dive boat captains near the reefs seemed more active and interactive. The generally cryptic behavior was a bit unexpected, especially for most of the species except probably the beaked whales. Interaction was often short and not fully documented.

The distribution of on-effort sightings in the 2023 survey is illustrated in Figure 62. Cetacean sightings during the 2023 survey were mostly concentrated south of the South Atoll with three more encountered between the North Atoll and Jessie Beazley Reef. Only one cetacean encounter occurred in the channel between the North and South Atolls.

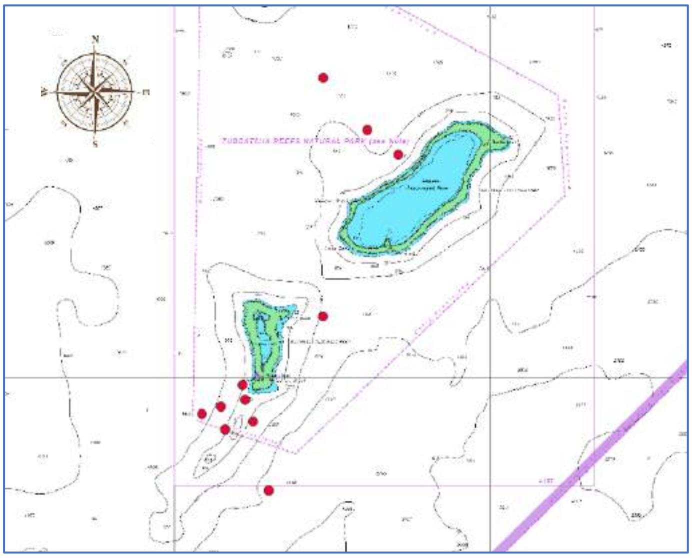

Figure 62. Map showing the positions of on-effort cetacean sightings.

This was unusual and in direct contrast to previous surveys of 2004 (Aquino and Calderon 2004) and 2010 (Aquino and Alarcon 2010) which reported a significant number of sightings within the channel, often encountered while the animals were feeding (Figure 63).

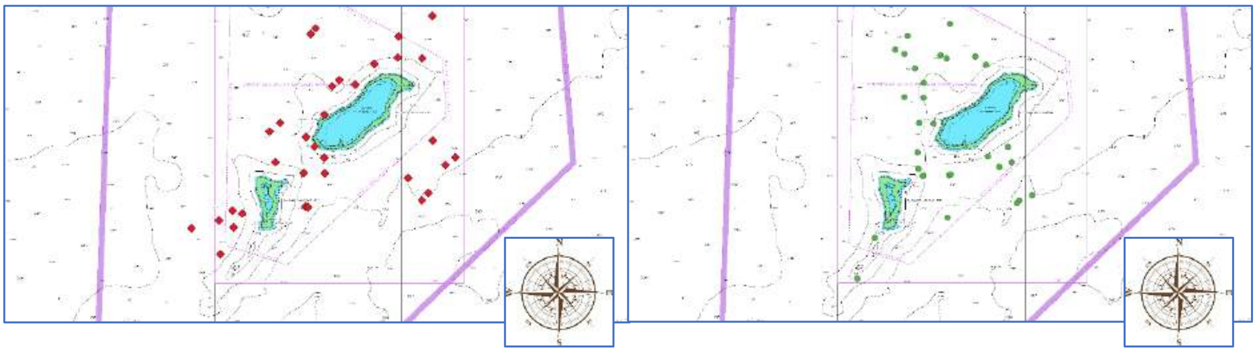

Figure 63. Map showing the distribution of sightings encountered in 2004 (left, red diamonds) and 2010 (right, green circles).

Furthermore, the encounters during the previous surveys were more spread out over the park. Quantifying the difference in distribution, however, might be tricky since there could be several factors at play. Possibly one of the biggest differences between the 2023 survey and the previous ones is the season in which the surveys were conducted. The latest survey occurred during the rainy season while the previous ones were wholly done during the summer season. This may have affected circulation, salinity, and other environmental conditions which, in turn, could have influenced the use of the habitat by the animals as illustrated by their current distribution in the park.

Given the apparent difference in behavior and distribution of cetaceans in the 2023 survey results and those of previous surveys, we decided to investigate possibly similar differences in sea conditions during the same time frame. One of the deciding factors for migration and orientation would be prey distribution (Tyack

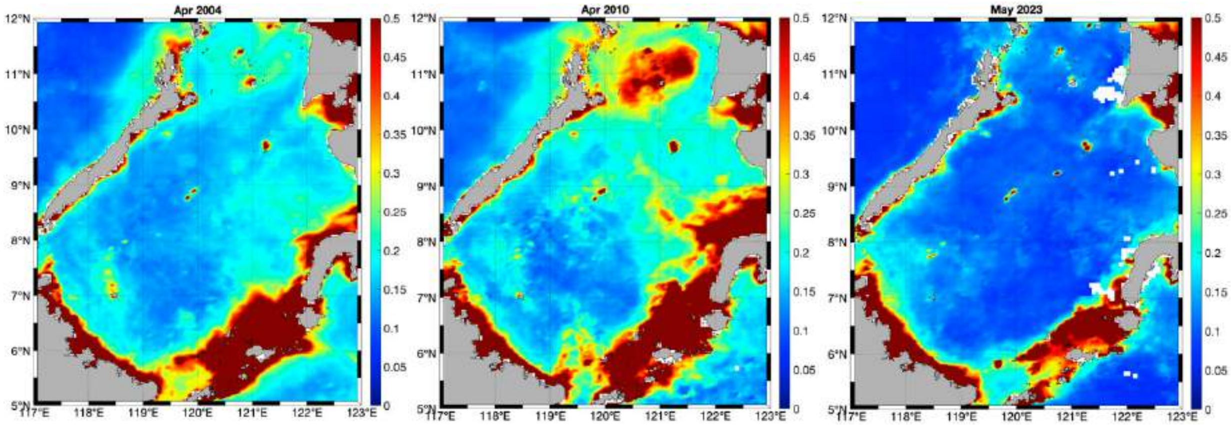

Figure 64. Map of mean chlorophyll concentrations during the 2004, 2010, and 2023 surveys. Note the distinctly low chlorophyll concentration in the general area of Sulu Sea in 2023. Map prepared by Dr. Villanoy and his interns.

2008). Satellite data accessed with the help of Dr. Cesar Villanoy and his team showed a distinct difference in chlorophyll (a) concentration between the three survey time frames (Figure 64). The mean chlorophyll concentration in the general Sulu Sea area during the 2023 survey was distinctly lower than either of the two previous surveys despite high levels close to the two atolls in the TRNP. Chlorophyll concentration has been used as proxy indicator for phytoplankton biomass which, in turn, pointed to productivity levels in oceans (Dvoretsky et al. 2023). With a very low productivity in the general Sulu Sea area at the time of the 2023 survey, it might potentially explain the lower encounter rates during this survey. With productivity low away from the coasts, it would be likely that most pods would travel closer to the coastlines where food would be more abundant. It might also partially explain the propensity of frequent sightings of pods closer to the atolls where productivity appeared to be high in TRNP. The question remains, though, whether the difference in behavior and distribution was a result of the rainy season with its frequent heavy rainfall or something else entirely.

Group sizes were smaller compared to previous surveys. Except for the Fraser's dolphins which the team estimated to number 65 individuals at best and the spinner dolphins at 28, all other species barely made a total of 10 per group. Nevertheless, it was heartening to observe several pods with calves. Only encounters with the Blainville's beaked whales seemed to be made up of adults but still appeared to be either of mixed sexes or age group. In one such encounter, one individual was undoubtedly male, exhibiting a pronounced set of tusks while another did not, prompting the team to suspect it as being a female, a juvenile, or both (Figure 65).

Sighting #3 was suspected to be a long-snouted spinner *Stenella longirostris*

Figure 65. Male Blainville's beaked whale (left) with prominent tusks and its companion (right) showing none. (Photo credits: Kymry Delijero)

longirostris group mixed with dwarf spinners *S. longirostris roseiventris*. Due to the evasive behavior of the pod, however, no photographs taken during the survey yielded proper biometrics. Suspicions were nevertheless strong because some individuals exhibited physical attributes different from the rest, e.g., small head paired with a robust upper body and a rose-colored belly (Figure 66). Unfortunately, without supporting biometrics, its identification as the subspecies could not be ascertained. As of writing, the dwarf spinner, initially documented in Balabac (Dolar et al. 2007; Perrin et al. 2007), has since been documented in Tañon Strait (Aquino and Aca 2019) as well as in Bohol Sea and Puerto Princesa Bay (Aquino et al. 2021).

Figure 66. Suspected dwarf spinner dolphin (A) porpoising next to a long-snouted spinner dolphin (B). The team noted a difference in the size of the head in relation to its upper body (left photo: Kymry Delijero*). These individuals exhibited pink bellies and were often observed jumping out of the water (right photo: Teri Aquino).*

Citizen Science

In addition to the boat transect method, the team employed citizen science by soliciting information from boat captains of dive boats and the marine park rangers regarding their own cetacean encounters during the same time frame. As a result, boat captains and dive masters radioed in their cetaceans encounters often while it happened.

During the survey, dive boat crew and dive masters reported cetacean encounters almost daily while tied to a mooring buoy or idling close to the reefs. They reported that spinners were frisky – jumping and spinning in the air while pilot whales were seen either sedately travelling and/or logging. These encounters near the reefs were likewise experienced by the survey team. At least one off-effort encounter per day was recorded when the team was forced by bad weather and sea conditions to stay tied to the mooring buoy on Black Rock for three consecutive days. It appeared that pods were more visibly active while close to the atolls during the whole of the survey period.

Figure 67. Dugong encountered by dive tourists off the Wall Street dive site. Video was taken by Kevin Rice.

In one surprising incident, a guest on the dive boat Atlantis Azores, Kevin Rice, reported an underwater encounter with a dugong *Dugong dugon* off the Wall Street dive site on 11 June 2023 (Figure 67). Gracian dela Rosa, his divemaster, was the one who spotted and pointed the animal out to him and he was able to get a short footage of it. The video showed the animal swimming quickly away from the reef. Dugongs have not been previously encountered nor even suspected to be in TRNP despite the presence of its preferred seagrass in the area. The dugong is classified in the Philippines as Critically Endangered (CR) due to a suspected severe reduction in the extent of occupancy and the extensive loss of seagrass habitat over the years (Aquino et al. 2012).

Citizen science helped in putting the survey results in perspective. The supplemental information garnered from dive boats proved to be very helpful since it expanded the observation coverage to more than was physically possible for the team to achieve. They confirmed the team’s observation that pods were staying close to the reefs. It also augmented the results of survey, especially in the case of the dugong presence that would have likely passed unnoticed if not for the dive master and tourists being underwater in the right place and at the right time. This first record of the dugong in TRNP brought the marine mammal species count of the park to 15: 14 cetaceans and one dugong.

CONCLUSION

Five species were encountered during the 2023 survey, namely: (1) spinner dolphins, (2) short-finned pilot whales, (3) Blainville's beaked whales, (4) Fraser's dolphins, and (5) false killer whale. These had already been identified in the species inventory of TRNP. A total of 11 on-effort and seven off-effort sightings were recorded during the 13-day survey that was hampered by unfavorable weather and sea conditions. Comparison of results to previous surveys in 2004 and 2010 proved tricky due to the difference in effort and season in which all three surveys were done. Satellite data on the mean values of chlorophyll density for the survey time frames in 2004, 2010, and 2023 indicated a distinct difference in the Sulu Sea conditions between the 2023 survey and that of the previous surveys. This difference was speculated to have possibly affected the encounter rates and distribution of sightings. The lower chlorophyll concentration covered the larger part of the Sulu Sea way beyond the boundaries and purview of TRNP and could be potentially problematic if the condition continues over time.

Survey results were complemented by citizen science through which the presence of the dugong in TRNP was first documented by a dive tourist. This brought the marine mammal species count to 15 (14 cetaceans and one sirenian), belonging to six taxonomic families. It also increased the number of threatened marine mammal species to four with the addition of the Critically Endangered dugong.

Lastly, suspicions about the presence of the dwarf spinner dolphins in the park could not be confirmed because of the lack of proper biometrics. It, nevertheless, deserves further investigation, given the limited information on the subspecies and its habitat range.

RECOMMENDATIONS

The survey undoubtedly raised more questions than it answered. One of the difficulties encountered in this project was our inability to confidently compare the results of the 2023 survey with those of the previous ones. There were differences, but we were uncertain whether it was an issue of seasonality or some other factor/s, e.g., the decline in population density due to anthropogenic factors outside of the Sulu Sea. In order to investigate the impact of seasons on sightings, we suggest that the next two surveys be stratified: the first half done during the summer and the next half during the rainy season of the same year, to be replicated the following year. Results may then be compared to see whether the impact of seasons is significant or not.

A follow-up survey also needs to verify the presence of dwarf spinner dolphins as much as possible. The need for perfect pictures is crucial in definitively diagnosing the subspecies. Biometrics can only be done properly if anatomical features are not warped by the position of perspective. To achieve this, the animal needs to be perfectly perpendicular to the photographer with at least the upper half of its body out of the water. Very little information has been collected on the presence of the subspecies in the country, and every new information helps to further our understanding of animals.

Lastly, the low productivity levels in the Sulu Sea this season should warrant further investigation. Although this may be beyond the purview of the TRNP, it has a strong potential to affect the integrity of the park. Thus, a better understanding of the problem is required.

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9. Marine Park Ranger Report

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Marine park rangers collect the following research and monitoring data during their tour of duty:

- Seabirds – monthly distance and quarterly direct counts (analysis included in the seabird report)
- Marine turtles – biannual islets and atoll counts
- Beach profiling – biannual in Bird Islet
- Coral bleaching

Marine turtles

Boat surveys for marine turtles are conducted twice a year, in June and November. Straight line transects are conducted in Bird Islet, South Islet, and ranger station. Boat surveys following a zigzag pattern are conducted over the shallow areas of the reef flats of the north and south atolls (Figure 68). Both surveys follow a pre-determined set of coordinates to allow replication of the method. All turtles sighted within 10 meters on either side of the boat are recorded and the position of the boat is marked with GPS equipment.

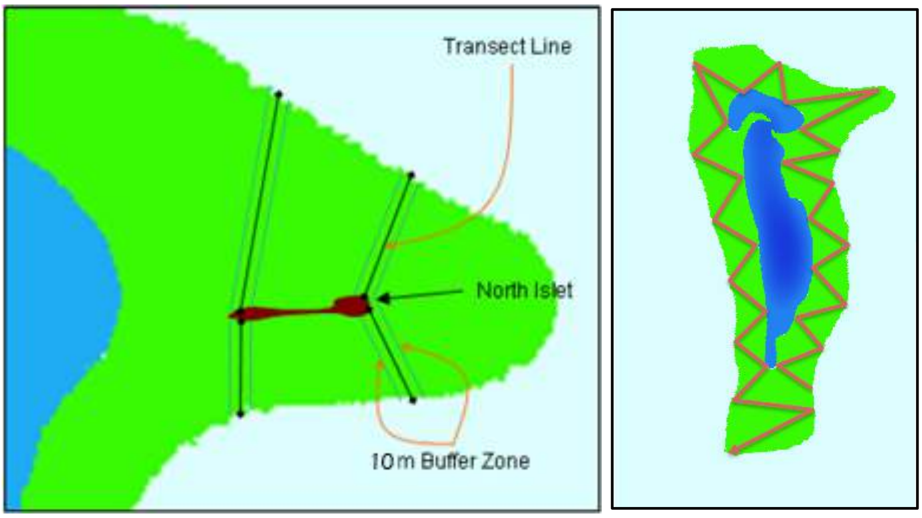

Figure 68. Illustration of transects surveyed by marine park rangers on the islets (left) and over the reef flats (right).

In 2023, straight line transects on the islets and survey over reef flats were only conducted once, in June. It was not possible to conduct one in November due to the extreme low tide during the day. There were 27 sightings in the straight line transects, 19 in Bird Islet and eight (8) in South Islet. Of the 27 sightings, 21 had one

(1) individual, five (5) sightings with two (2) individuals, and one (1) with three (3) individuals (Figure 69).

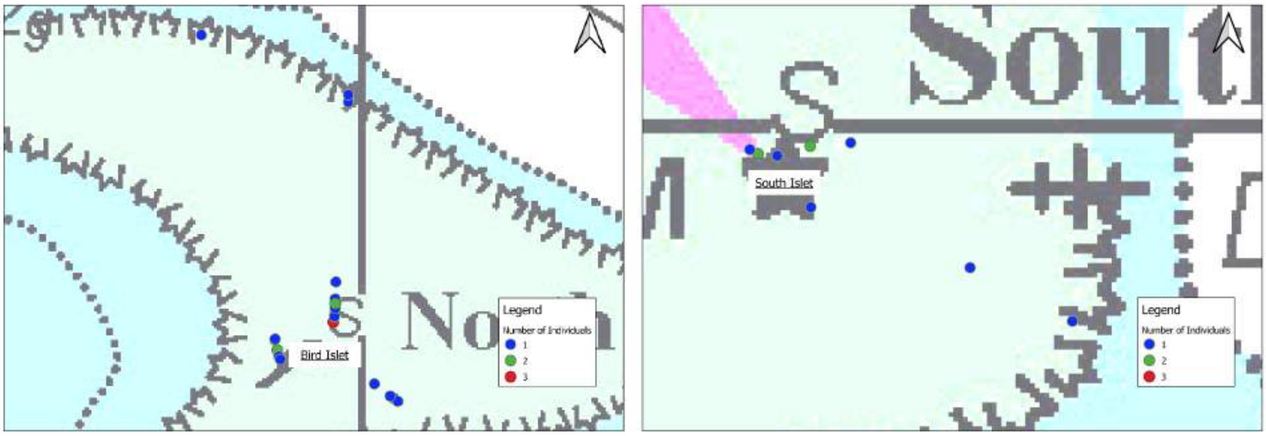

Figure 69. Sightings recorded in the straight line transects in Bird and South Islets.

A total of 78 sightings were recorded during the survey over reef flats, 52 in north atoll and 26 in south atoll. Of these, 67 had one individual, six (6) with two (2) individuals, three (3) with three (3) individuals and two (2) with four (4) individuals (Figure 70). Most of the sigthings during the survey over reef flats were recorded around the islets - 58% (30 of 52 sightings) in Bird Islet and 77% (20 of 26 sightings) in South Islet.

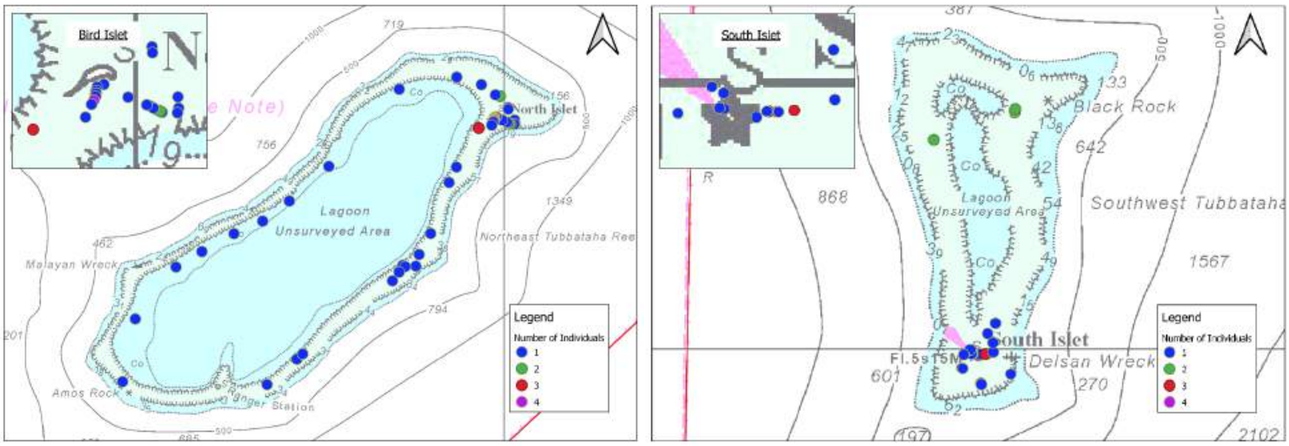

Figure 70. Sightings recorded in the boat survey over reef flats of the north and south atolls.

Beach profiling

Beach profiling is conducted twice a year to document the erosion or deposition of sand in Bird Islet during the Northeast and Southwest Monsoons. This year, beach profiling was conducted in July and November, during low tide. The four (4) permanent monitoring points were revisited, and distance and elevation of the contours from the monitoring points to the water line were measured (Figure 71).

Figure 71. Marine Park rangers conduct beach profiling in Bird Islet.

There was a significant deposit of sand in the North and Southwest side of Bird Islet in November (Figure 72). A minimal sand deposition was recorded in the South of the islet while a slight decrease was observed in the Northeast.

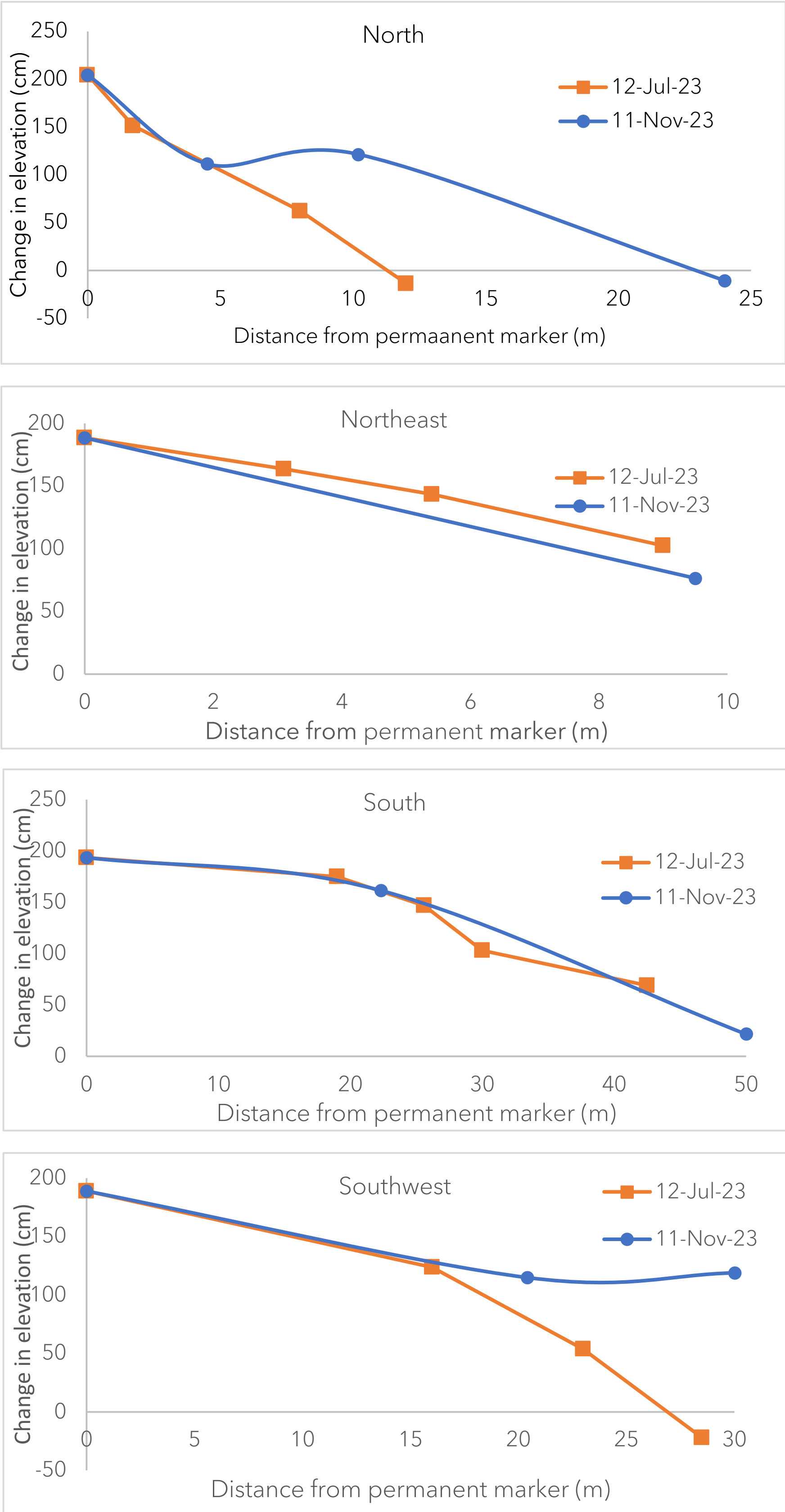

Figure 72. Beach profiling measurements taken in July and November 2023.

Coral bleaching

In October to November 2023, the rangers observed that some corals bleached due to long exposure to extreme low tide during the day. As seen in Figure 73, most of the corals that bleached were branching corals, e.g., *Acropora* and *Pocillopora*. Western Philippines, including Tubbataha, was in the 'bleaching watch' status from April to December 2023 (Figure 74). In the months of May, June, and November 2023 it elevated to 'bleaching warning' status, which coincided with the report of the rangers. However, they did not observe bleaching elsewhere in the park.

Figure 73. Bleached corals near the ranger station in November 2023.

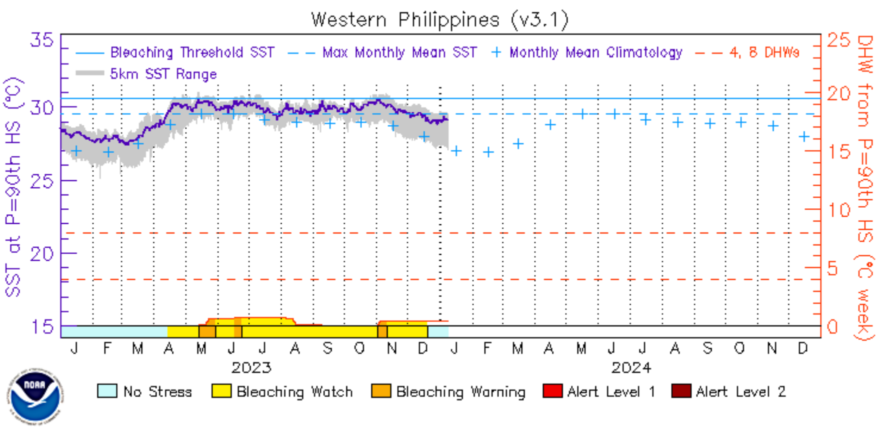

Figure 74. Sea surface temperature in 2023. Source: NOAA Coral Bleaching Watch

APPENDICES

Appendix 1. 2023 Survey Teams.

Fish and Benthos

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Appendix 2. Categories used to evaluate the ecological health of coral reef fish communities according to Hilomen et al. (2000) and Nañola et al. (2004). Note: (*) Modified categories from Hilomen et al. (2000).

Parameter	Measure	Category
Species richness*	Number of species per $500m^2$	
	<13	Very poor
	13.5 – 23.5	Poor
	24 -37	Moderate
	37.5 -50	High
	>50	Very high
Density*	Number of fish per $500m^2$	
	<100.5	Very poor
	101 – 338	Low
	338.5 – 1,133.5	Moderate
	1,134 – 3,796	High
	>3,796	Very high
Biomass	mt/km^2	
	0-10	Very low to low
	11-20	Moderate
	21-40	High
	>40	Very High

Appendix 3. The mean density (ind/500m²) of fish families in deep (~10m) and shallow (~5m) stations in the regular monitoring sites in the Tubbataha Reefs Natural Park this year.

Families	Common Names	Deep (ind/500m²)	Shallow (ind/500m²)	Average (ind/500m²)
Acanthuridae	surgeonfish	70.2	95.73	82.96
Acanthuridae/Nasinae	unicornfish	19.43	14.77	17.10
Aulostomidae	trumpetfish	0.03	0.00	0.02
Balistidae	triggerfish	23.87	52.80	38.33
Blenniidae	blenny	1.00	0.33	0.67
Caesionidae	fusiliers	23.43	0.27	11.85
Carangidae	jacks and trevallies	3.77	5.03	4.40
Chaetodontidae	butterflyfish	22.17	13.93	18.05
Cirrhitidae	hawkfish	1.90	6.23	4.07
Diodontidae	porcupinefish	0.03	0.03	0.03
Ephippidae	batfish	0.30	0.00	0.15
Epinephelidae	groupers	0.30	0.00	0.15
Fistulariidae	cornetfish	0.07	0.00	0.03
Haemulidae	sweetlips	0.90	1.03	0.97
Holocentridae	squirrelfish	35.67	0.07	17.87
Kyphosidae	sea chub	0.60	0.20	0.40
Labridae	wrasses	61.07	148.27	104.67
Lethrinidae	emperor fish	12.30	0.30	6.30
Lutjanidae	snappers	9.13	10.07	9.60
Malacanthidae	tilefish	0.00	0.03	0.02
Monacanthidae	filefish	0.20	0.20	0.20
Mullidae	goatfish	1.53	1.27	1.40
Nemipteridae	breams	0.00	0.13	0.07
Ostraciidae	boxfish	0.27	0.10	0.18
Pinguipedidae	sandperch	0.17	0.00	0.08
Pomacanthidae	angelfish	10.53	14.17	12.35
Pomacentridae	damselfish	665.17	740.27	702.72
Ptereleotridae	dartfish	2.67	5.27	3.97
Scaridae	parrotfish	11.40	11.83	11.62
Serranidae	groupers	10.33	16.83	13.58
Serranidae/Anthiinae	fairy basslets	314.67	98.43	206.55
Siganidae	rabbitfish	0.47	0.33	0.40
Synodontidae	lizardfish	0.00	0.07	0.03
Tetraodontidae	pufferfish	0.33	0.37	0.35
Zanclidae	moorish idol	4.17	4.30	4.23
Total		**1308.07**	**1242.67**	**1275.37**

Appendix 4. The mean biomass (g/m²) of fish families in deep (~10m) and shallow (~5m) stations in the regular monitoring sites in the Tubbataha Reefs Natural Park this year.

Families	Common Names	Deep (g/m²)	Shallow (g/m²)	Average (g/m²)
Acanthuridae	surgeonfish	7.744	9.724	8.734187
Acanthuridae/Nasinae	unicornfish	24.078	6.894	17.03438
Aulostomidae	trumpetfish	0.004	0.000	0.002171
Balistidae	triggerfish	15.069	12.207	15.00195
Blenniidae	blenny	0.004	0.002	0.003538
Caesionidae	fusiliers	3.327	0.105	1.887766
Carangidae	jacks and trevallies	7.116	13.396	11.28146
Chaetodontidae	butterflyfish	2.477	1.670	2.281072
Cirrhitidae	hawkfish	0.029	0.069	0.05416
Diodontidae	porcupinefish	0.102	0.102	0.112175
Ephippidae	batfish	0.419	0.000	0.23044
Epinephelidae	groupers	0.268	0.000	0.147463
Fistulariidae	cornetfish	0.018	0.000	0.00964
Haemulidae	sweetlips	1.827	1.526	1.844243
Holocentridae	squirrelfish	7.191	0.043	3.978464
Kyphosidae	sea chub	0.272	0.091	0.199507
Labridae	wrasses	0.925	1.297	1.222503
Lethrinidae	emperor fish	3.038	0.154	1.755677
Lutjanidae	snappers	4.968	6.532	6.324967
Malacanthidae	tilefish	0.000	0.005	0.002722
Monacanthidae	filefish	0.065	0.018	0.045357
Mullidae	goatfish	0.366	0.179	0.299392
Nemipteridae	breams	0.000	0.014	0.007654
Ostraciidae	boxfish	0.026	0.017	0.02348
Pinguipedidae	sandperch	0.011	0.000	0.006125
Pomacanthidae	angelfish	0.810	0.522	0.732902
Pomacentridae	damselfish	4.356	5.338	5.331782
Ptereleotridae	dartfish	0.005	0.019	0.013023
Scaridae	parrotfish	10.997	11.138	12.17427
Serranidae	groupers	3.229	4.506	4.254255
Serranidae/Anthiinae	fairy basslets	0.932	0.275	0.663959
Siganidae	rabbitfish	0.295	0.099	0.216904
Synodontidae	lizardfish	0.000	0.002	0.000881
Tetraodontidae	pufferfish	0.167	0.069	0.130047
Zanclidae	moorish idol	0.882	0.789	0.918809
Total		100.313	75.918	96.92732

Appendix 5. The mean density (ind/500m^2) of fish families in deep (~10m) and shallow (~5m) stations in the Min Ping Yu and USS Guardian grounding sites in the Tubbataha Reefs Natural Park this year.

Families	Common names	Min Ping Yu		MPY (Average)	USS Guardian		USSG (Average)
		Deep	Shallow		Deep	Shallow	
Acanthuridae	surgeonfish	66	99	83	22	104	63
Acanthuridae/ Nasinae	unicornfish	3	1	2	13	4	9
Balistidae	triggerfish	6	11	9	94	36	65
Blenniidae	blenny	0	0	0	1	0	0
Caesionidae	fusiliers	28	0	14	9	0	4
Carangidae	jacks and trevallies	1	3	2	6	1	4
Chaetodontidae	butterflyfish	31	22	26	13	16	15
Cirrhitidae	hawkfish	1	1	1	1	3	2
Epinephelidae	groupers	0	0	0	0	0	0
Gobiidae	gobbies	0	0	0	0	2	1
Haemulidae	sweetlips	0	0	0	3	1	2
Holocentridae	squirrelfish	62	0	31	36	0	18
Labridae	wrasses	53	23	38	27	266	147
Lethrinidae	emperorfish	1	0	1	7	0	4
Lutjanidae	snappers	3	1	2	5	1	3
Monacanthidae	filefish	0	0	0	0	0	0
Mullidae	goatfish	1	2	2	0	0	0
Ostraciidae	boxfish	1	0	1	0	0	0
Pomacanthidae	angelfish	7	7	7	12	11	11
Pomacentridae	damselfish	1040	412	726	330	398	364
Priacanthidae	bigeye	0	0	0	0	0	0
Ptereleotridae	dartfish	0	1	0	2	0	1
Scaridae	parrotfish	13	10	12	5	18	12
Serranidae	groupers	7	8	8	13	11	12
Serranidae/ Anthiinae	fairy basslets	194	0	97	452	66	259
Siganidae	goatfish	3	2	2	0	1	0
Tetraodontidae	pufferfish	0	0	0	1	0	0
Zanclidae	moorish idol	3	0	1	2	6	4
Grand Total		**1525**	**602**	**1064**	**1053**	**944**	**999**

Appendix 6. The mean biomass (g/m²) of fish families in deep (~10m) and shallow (~5m) stations in Min Ping Yu and USS Guardian grounding sites in the Tubbataha Reefs Natural Park this year.

Families	Common names	Min Ping Yu		MPY (Average)	USS Guardian		USSG (Average)
		Deep	Shallow		Deep	Shallow	
Acanthuridae	surgeonfish	4.07	9.26	6.67	3.64	11.28	7.46
Acanthuridae/ Nasinae	unicornfish	2.48	2.29	2.39	15.39	2.89	9.14
Balistidae	triggerfish	1.45	2.31	1.88	23.43	9.31	16.37
Blenniidae	blenny	0.00	0.00	0.00	0.00	0.00	0.00
Caesionidae	fusiliers	3.54	0.00	1.77	6.36	0.00	3.18
Carangidae	jacks and trevallies	1.78	11.71	6.75	6.78	2.94	4.86
Chaetodontidae	butterflyfish	2.12	2.52	2.32	1.53	2.05	1.79
Cirrhitidae	hawkfish	0.02	0.03	0.02	0.01	0.03	0.02
Epinephelidae	groupers	0.00	0.00	0.00	0.43	0.00	0.21
Gobiidae	gobbies	0.00	0.00	0.00	0.00	0.02	0.01
Haemulidae	sweetlips	0.00	0.00	0.00	5.74	1.86	3.80
Holocentridae	squirrelfish	11.45	0.00	5.72	8.55	0.00	4.28
Labridae	wrasses	0.93	1.17	1.05	0.94	2.06	1.50
Lethrinidae	emperorfish	0.24	0.00	0.12	2.91	0.37	1.64
Lutjanidae	snappers	2.37	0.27	1.32	5.47	0.28	2.88
Monacanthidae	filefish	0.06	0.02	0.04	0.00	0.00	0.00
Mullidae	goatfish	0.14	0.17	0.15	0.00	0.00	0.00
Ostraciidae	boxfish	0.52	0.00	0.26	0.00	0.00	0.00
Pomacanthidae	angelfish	0.19	0.16	0.18	3.98	0.95	2.47
Pomacentridae	damselfish	10.07	2.15	6.11	3.42	1.03	2.22
Priacanthidae	bigeye	0.06	0.00	0.03	0.00	0.00	0.00
Ptereleotridae	dartfish	0.00	0.01	0.00	0.00	0.00	0.00
Scaridae	parrotfish	3.22	2.82	3.02	5.11	15.91	10.51
Serranidae	groupers	3.64	2.60	3.12	3.59	1.99	2.79
Serranidae/ Anthiinae	fairy basslets	0.56	0.00	0.28	1.85	0.12	0.99
Siganidae	goatfish	1.35	1.26	1.31	0.00	0.35	0.18
Tetraodontidae	pufferfish	0.05	0.03	0.04	0.13	0.00	0.07
Zanclidae	moorish idol	0.38	0.00	0.19	0.50	1.55	1.03
Grand Total		50.69	38.79	44.74	99.77	55.02	77.39

Appendix 7. Condition of vegetation on Bird Islet and South Islet.

Condition of vegetation on Bird Islet, May 2006 (baseline year), and 2021 to 2023

Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead trees			
	2006	2021	2022	2023	2006	2021	2022	2023	2006	2021	2022	2023	2006	2021	2022	2023	2006	2021	2022	2023
Dead trees																	82	ND	ND	**ND**
Mature, live trees (> 3 feet)	10	0	**0**	**0**	49	0	**5**	**5**	11	0	**0**	**0**	70	0	**5**	**5**				
Small, live trees (2- 3 feet)	109	13	**0**	**0**	0	0	**2**	**0**	0	10	**1**	**0**	109	23	**3**	**0**				
Seedlings (< 1 feet)	50	0	**0**	**0**	0	0	**0**	**2**	0	0	**0**	**0**	50	0	**0**	**2**				
Total	**169**	**13**	**0**	**0**	**49**	**0**	**7**	**7**	**11**	**0**	**1**	**0**	**229**	**332**	**8***	**7***	**82**	**ND**	ND	**ND**

Notes

Seedlings/small trees 2019 were planted saplings > 1 foot tall, taken from Cagayancillo Municipality. In June 2020, 329 Anuling saplings planted.
In 2021 planting took place only after the May inventory, e.g., 16 mostly Anuling as of August 2021 and in June 2022, 20 saplings
***All plants placed in protective bamboo boxes**
Coco Palms: 2018: 3, 2019: 2, 2020: 0, 2021: 0, 2022: 3, 2023: 0

Condition of vegetation on South Islet May 2011 (baseline year), and 2021 to 2023

Trees/ Condition	Good (optimal)				Fair (moderately deteriorating)				Bad (severely deteriorating)				Total (live trees)				Dead			
	2011	2021	2022	2023	2011	2021	2022	2023	2011	2021	2022	2023	2011	2021	2022	2023	2016	2021	2022	2023
Dead trees																	16	ND	ND	**ND**
Mature, live trees (> 3 feet)	70	0	**0**	**0**	28	0	0	**0**	5	0	0	**0**	103	0	0	0				
Small, live trees (2- 3 feet)	2	51	**19**	**0**	0	0	0	**0**	0	0	0	**0**	2	35	19	0				
Seedlings (< 1 feet)	19	0	**0**	**0**	0	0	0	**0**	0	0	0	**0**	19	0	0	0				
Total	**91**	**0**	**19**	**0**	**28**	**0**	**0**	**0**	**x**	**0**	**0**	**0**	**124**	**35**	**19**	**0**	**16**			
Notes:	**In June 2020, 101 Anuling saplings > 1 feet tall were planted. In 2021 planting took place only after the May inventory, e.g. 35 mostly Anuling as of August and again in August 2022. <u>Coco Palms</u> 2011: 13, 2016: 6, 2017:6, 2018:10, 2019:6, 2020:7, 2021: 3, 2022: 5, 2023: 4**																			

Appendix 8. Population results and population trend of breeding seabirds in TRNP April to June 1981 – 2023.

Inventory baseline years are underlined. Source: Kennedy 1982, Manamtam 1996, WWF Philippines 1998-2004 and TMO 2004-2023

Species/ Numbers	1981	1995	1998	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Ground-breeders Sub-total	13,388	3,949	1,744	4,695	7,529	7,635	2,804	5,200	13,825	16,957	7,746	10,534	9,721	18,669
Masked Booby	150	1	0	0	0	0	0	0	0	0	0	0	0	**0**
Brown Booby	3,768	1) 2,060	1,716	1,045	850	577	623	856	1,877	1,108	1,016	1,059	1,018	**1,438**
Brown Noddy	2,136	643	0	500	37	775	115	336	590	1,035	530	800	1,570	**1,575**
Great Crested Tern	2,264	335	0	150	414	4,160	2,064	2,808	7,858	6,894	4,700	4,875	4,433	**4,790**
Sooty Tern	5,070	1) 910	28	3,000	6,228	2,123	2	1,200	3,500	7,920	>1,500	3,800	2,700	**10,866**
Tree-breeders Sub-total	156	7,128	3,250	3,502	7,042	5,003	1,630	3,240	8,353	8,727	7,902	10,403	9,525	9,975
Red-Footed Booby	9	0	0	2	44	43	20	2,435	1,947	1,877	2,902	2,513	2,220	**2,331**
Black Noddy	147	7,128	3,250	3,500	6,998	4,860	1,610	805	6,406	6,850	> 5,000	7,890	> 7,305	**7,644**
TOTAL	13,544	11,077	4,994	8,197	14,571	12,638	4,434	8,440	22,178	25,684	15,648	20,937	19,246	28,644

Notes:

1) End of March data.

2) Based on Park Rangers distance count 1 June 2014.

3) Based on Park Rangers count 9 August 2014.

4) Based on Park Rangers egg count 14 Feb 2015.

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

Species/ Numbers	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Trend (%)
Ground-breeders Sub-total	13,592	18,383	15,988	16,448	27,193	27,654	29,940	35,878	24,569	29,323	24,880	35,994	26,789	
Masked Booby	0	0	0	0	0	1	1	1	1	2	2	2	2	-99%
Brown Booby	1,846	1,879	1,690	1,632	2,403	3,122	3,535	3,367	3,138	>2,977	3,800	10) 4,906	4,854	+29%
Brown Noddy	2,042	1,492	1,688	1,862	2,583	2,096	4,209	3,470	2,208	3,262	6) 1,702	11) 2,084	1,162	-46%
Great Crested Tern	6,160	8,653	9,794	2) 7,730	<12,387	13,880	17,097	17,752	14,880	17,810	13,376	17, 812	16,156	+614%
Sooty Tern	3,544	6,359	2,816	3) 5,224	4) 9,820	8,555	>5,098	11,288	4,342	5) >5,272	7) 6,000	12) 11,448	4,615	-9%
Tree-breeders Sub-total	10,746	11,776	12,858	10,630	11,718	11,101	7,278	5,916	3,152	3,310	3,298	2,950	3,331	
Red-Footed Booby	2,395	2,340	2,202	3,074	3,492	2,141	2,087	1,443	1,080	660	422	736	489	-80%
Black Noddy	8,351	9,436	10,656	7,556	8,226	8,716	5,191	4,473	2,072	8) 2,650	9) 2,876	13) 2 ,214	2,842	-60%
TOTAL	24,338	30,159	28,846	27,078	38,911	38,549	37,218	41,794	27,721	32,633	28,178	39,202	30,120	-17

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

Appendix 9. Seabird breeding data from Bird Islet and from South Islet, 2nd Quarter (mainly May) 2004-2023

Species/Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Red-footed Booby										
Immatures	398	1,455	606	597	780	477	677	795	799	**426**
Pulli/1st year juv.	> 35	71	105	116	69	180	88	171	243	**312**
Eggs	+	+	+	+	+	+	+	68	>166	**>185**
Nests	279	217	225	404	361	367	451	369	739	**848**
Brown Booby										
Immatures	0	81	26	55	55	61	126	110	140	**62**
Pulli/1st year juv.	43	2	7	12	91	126	125	225	46	**28**
Eggs	1	0	18	95	317	48	106	52	69	**532**
Nests	117	43	250	89	497	453	513	575	507	**618**
Brown Noddy										
Immatures	0	2	0	0	0	4	1	1	2	**3**
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	**0**
Eggs	0	0	0	3	17	126	438	253	>147	**>607**
Nests	115	124	20+	25+	218	384	653	571	709	**771**
Black Noddy										
Immatures	0	0	0	0	0	0	0	0	0	**0**
Pulli/1st year juv.	0	0	0	0	0	0	0	0	0	**0**
Eggs	ND	+	0	+	+	430	+	+	>80	**>700**
Nests	208	3,203	1,131	1,734	1,824	2,680	3,525	3,827	4,282	**5,156**
Great Crested Tern										
Immatures	0	1	0	0	0	0	0	0	0	**0**
Pulli/1st year juv.	0	2,100	0	0	0	0	0	0	0	**0**
Eggs	0	1,829	0	0	0	515	2,341	498	1,456	**3,939**
Sooty Tern										
Immatures	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**
Eggs	9	0	0	63	2	3	5,515	2	1,534	**146**

Species/Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Red-footed Booby										
Immatures	134	206	80	97	89	104	24	30	12	**0**
Pulli/1st year juv.	277	240	49	43	39	14	8	8	0	**13**
Eggs	>57	>46	> 49	55	74	26	>7	14	18	**11**
Nests	431	379	315	177	223	72	43	73	68	**57**
							Note 1		Note 8	
Brown Booby										
Immatures	51	28	66	157	264	218	35	27	13	**2**
Pulli/1st year juv.	266	200	22	175	95	8	8	172	360	**1562**
Eggs	466	55	144	43	25	6	286	1,496	1,792	**187**
Nests	816	726	887	886	376	412	1,054	1,861	2,369	**1002**
							Note 2	Note 6	Note 9	
Brown Noddy										
Immatures	5	2	0	2	14	9	0	0	0	**0**
Pulli/1st year juv.	0	6	109	223	493	68	79	406	279	**77**
Eggs	679	571	620	1,005	581	183	615	177	326	**124**
Nests	931	960	1,048	1,917	1,644	805	1092	851	907	**363**
							Note 3	Note 7	Note 10	
Black Noddy										
Immatures	0	0	0	0	0	0	o	0	0	**0**
Pulli/1st year juv.	0	30	193	8	74	39	40	207	161	**149**
Eggs	>351	>299	>191	406	468	254	269	323	380	**463**
Nests	3,778	2,397	1,634	1,205	1131	1036	1,135	1,438	1,852	**1,421**
							Note 4		Note 11	
Great Crested Tern										
Immatures	0	0	0	0	0	0	0	0	0	**0**
Pulli/1st year juv.	0	0	0	29	832	2610	6,813	4,447	1,807	**1,572**
Eggs	2,120	4,280	6,800	8,620	7,461	4830	1,568	2,292	7,099	**6,506**
							Note 5			
Sooty Tern										
Immatures	0	0	1	0	0	0	0	0	0	**0**
Pulli/1st year juv.	0	3,538	0	2,549	680	11	2,622	1	2,150	**3**
Eggs	37	52	166	0	4,964	3	14	593	3,284	**287**
									Note 12	

Source: WWF Philippines 2004 and TMO 2004 to 2023

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 10. In-flight to roost statistics of boobies and noddies on Bird Islet May 2005 to May 2023.

Species/ Numbers	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	May 10: 17.00-18.15	Apr 28: 16.30-18.25	May 8: 16.30-18.20	May 7: 16.00-18.00	May 7: 16.30-18.30	May 13: 16.30-18.30	May 9: 16.30-18.30	May 10: 16.30-18.30	May 10: 16.30-18.30	**May 9: 16.30-18.30**
	Red-footed Booby									
Adult: Daytime	823	655	631	1,241	686	982	1,011	382	830	**950**
In-flight	960	1,171	2,082	1,272	1,534	1,259	1,259	1,680	779	**813**
Adjusted to 2-hour period	1,012	1,222	2,271	-	-	-	-	-	-	**-**
Total	1,835	1,877	2,902	2,513	2,220	2,241	2,270	2,062	1,609	**1,763**
%-in-flight population	55	65	78	51	69	56	55	81	48	**46**
Average In-flight (%)	60.4									
Immature: Daytime	514	>205	275	239	179	194	106	174	125	**61**
In-flight	588	401	295	541	298	483	483	249	149	**5**
Adjusted to 2-hour period	941	419	322	-	-	-	-	-	-	**-**
Total	1,455	>606	597	780	477	677	589	423	274	**66**
%-in-flight population	65	69	54	69	63	71	82	59	54	**8**
Average In-flight (%)	59.4									
	Brown Booby									
Adult: Daytime	629	405	660	691	650	930	1,338	1,060	968	**834**
In-flight	360	225	326	368	368	508	508	819	722	**798**
Adjusted to 2-hour period	576	235	356	-	-	-	-	-	-	**-**
Total	1,205	640	1,016	1,059	1,018	1,438	1,846	1,879	1,690	**1,632**
%-in-flight population	48	37	35	35	36	35	28	44	43	**49**
Average In-flight (%)	39									
Immature: Daytime	22	20	21	20+?	22	30+	96	81	30	**13**
In-flight	37	6	31	34	39	96	14	59	32	**39**
Adjusted to 2-hour period	59	6	34	-	-	-	-	-	-	**-**
Total	81	26	55	54	61	126	110	140	64	**51**
%-in-flight population	73	23	62	63	64	76	13	42	50	**76**

Average In-flight (%)	54.2									
	Brown Noddy									
Adult: Daytime							618	607	1,004	1,045
In-flight							1,124	525	142	239
Total							1,742	1,132	1,146	1,284
%-in-flight population							65	46	12	19
Average In-flight (%)	35.5									
	Black Noddy									
Adult: Daytime							421	1,098	2,243	1,506
In-flight							1,334	1,124	272	318
Total							1,755	2,222	2,515	1,824
%-in-flight population							76	51	11	17
Average In-flight (%)	38.8									

Species/ Numbers	2015	2016	2017	2018	2019	2020	2021	2022	2023
	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
	Red-footed Booby								
Adult: Daytime	1,499	248	343	470	362	131	97	279	63
In-flight	602	367	527	356	282	309	224	131	195
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	
Total	2,101	615	870	826	644	430	321	410	285
%-in-flight population	29	25	25	43	44	72	70	32	76
Average In-flight (%)	46.2								
Immature: Daytime	111	8	29	24	27	5	5	3	3
In-flight	37	17	40	20	34	16	20	0	2
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	
Total	148	25	69	44	61	21	25	3	5
%-in-flight population	25	25	25	45	56	76	80	0	40
Average In-flight (%)	41.3								
	Brown Booby								
Adult: Daytime	1,505	1,920	2,257	1,295	2,212	888	1,556	3,560	1,274
In-flight	848	1,202	1,278	2,072	727	1,640	1,352	1,172	1,790
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	
Total	2,353	3,122	3,535	3,367	2,939	2,528	2,908	4,732	3,064
%-in-flight population	36	25	25	62	25	65	47	25	58
Average In-flight (%)	40.1								
Immature: Daytime	1	25	74	127	187	16	3	0	0
In-flight	25	41	78	105	30	19	18	3	2
Adjusted to 2-hour period	-	-	-	-	-	-	-	-	
Total	26	66	152	232	217	35	21	3	2
%-in-flight population	96	62	51	45	14	26	86	0	100
Average In-flight (%)	53.3								
	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 11. In-flight to roost statistics of boobies and noddies on South Islet May 2014 to 2023.

Species/ Numbers	2014	2015	2016	2017	2018	2019	2020	2022	2023
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
Adult: Daytime	401	366	508	584	262	154	32	41	84
In-flight	910	1,020	1,018	633	355	282	198	285	147
Adjusted to 2-hour period	1,820	-	-	-	-	-	-	-	
Total	2,221	1,386	1,526	1,217	617	436	230	326	231
% in-flight population	82.0	73.6	66.7	52.0	57.5	64.7	86.1	12.6	64
Average	62.13								
Immature: Daytime	68	58	32	27	22	43	5	6	7
In-flight	1	No count	21	1	23	27	4	2	0
Adjusted to 2-hour period	2	-	-	-	-	-	-	-	
Total	70	> 58	63	28	45	70	9	8	7
% in-flight population	2.9	-	33.3	3.6	51.1	38.6	44.4	25.0	0
Average	24.86								

Species/ Numbers	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Brown Booby										
	May 8: 16.30 - 17.30	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12: 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	May 31: 16.30 - 18.30	April 29: 16.30 - 18.30	May 12: 16.30 - 18.30
Adult: Daytime	7	22	40	31	160	41	73	81	174	219
In-flight	2	28	24	11	144	158	376	20	109	130
Adjusted to 2-hour period	4	-	-	-	-	-	-	-	-	
Total	11	50	64	42	304	199	449	101	174	349
% in-flight population	18.2	56.0	37.5	26.2	47.4	79.4	83.7	19.8	62.6	37.2
Average	46.8									
Immature: Daytime	0	2	0	4	32	1	16	3	0	18
In-flight	0	No count	No count	1	0	4	16	2	1	0
Adjusted to 2-hour period	0	-	-	-	-	-	-	-	-	
Total	0	>2	0	5	32	5	32	5	1	18
% in-flight population	0	-	-	20.0	0	80.0	50.0	40.0	50.0	0
Average	30									

Species	Black and Brown Noddy							
	Year	2015	2016	2017	2018	2019	2022	2023
	(Note 1)	(Note2)	(Note 3)		(Note 4)	(Note 5)		
	May 8: 16.30 - 18.30	May 13: 16.30 - 18.30	May 9: 16.30 - 18.30	May 12 16.30 - 18.30	May 15: 16.30 - 18.30	May 21: 16.30 - 18.30	30 April: 16.30 - 18.30	12 May: 16.30 - 18.30
Adult: Daytime	6,856	> 4,421	4,126	2,179	0	-	-	-
In-flight	4,678	> 3,500	< 2,066	1,335	0	-	-	-
Adjusted to 2-hour period	4,678	-	-	-	-	-	-	-
Total	11,534	7,921	6,192	3,514	0	-	-	-
% in-flight population	40.6	44.2	33.4	38.0	-	-	-	-
Average	39.0							
	Brown Noddy							
Adult: Daytime			2,921	1,347	0	427	1,270	1,162
In-flight			1,461	681	0	249	176	104
Adjusted to 2-hour period			-	-	-	-	-	-
Total			4,382	2,028	0	676	1,446	1,266
% in-flight population			33.3	33.6	0	36.8	12.2	8
Average	20.65							
	Black Noddy							
Adult: Daytime			1,205	832	60	948	1,125	2,842
In-flight			605	654	19	171	113	168
Adjusted 2-hour period			-	-	-	-	-	-
Total			1,810	1,486	79	1,119	1,238	3,010
% in-flight population			33.4	44.0	24.0	15.3	9.1	5.6
Average	21.9							

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

Appendix 12. Systematic list of other avifauna than resident seabirds observed at South Islet, Bird Islet, and Ranger Station, Tubbataha Reefs Natural Park from May 8 to May 13, 2023, and random observation by Marine Park Rangers from June 2022 to April 2023.

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

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

Status and Abundance (within Sulu Sea) Threat Status (IUCN and National Red List)	Species name	Number of individuals	Locality	Notes
Resident Common LC	Barred Rail *Hypotaenidia torquata*	3	Bird Islet	9 May 2023
Migratory, Resident (?) Common LC	Black-wing Stilt *Himantopus himantopus*	1	South Islet	June 2023
Migrant Uncommon LC	Ruddy Turnstone *Arenaria interpres*	2	Bird Islet	9 May2023
Migrant Uncommon	Sanderling *Calidris alba*	1	Ranger Station	8 May 2023
Migrant Uncommon NT	Grey-tailed Tattler *Tringa brevipes*	2	Bird Islet	9 May 2023
Migrant Common LC	Wood Sandpiper *Tringa glareola*	1	Bird Islet	9 May 2023. One heard migrating
Migrant/ Resident Common LC	Oriental Pratincole *Glareola maldivarum*	1	Bird Islet	9 May 2023 1st Tubbataha record
Migrant Uncommon LC	Little Tern *Sternula albifrons*	11	Bird Islet	9 May 2023
Resident Uncommon LC	Black-naped Tern *Sterna sumatrana*	1	Ranger Station	8 May 2033
		2	Ranger Station	12 May 2033
Migrant Common LC	Whiskered Tern *Chlidonias hybrida*	1	Bird Islet	9 May 2023. 2nd calendar year bird
		1	South Islet	12 May 2023. 2nd calendar year bird
Migrant Common LC	White-winged Tern *Chlidonias leucopterus*	2	Ranger Station	8 May 2023. Migrating north
		23		13 May 2023. Migrating north
		2	Bird Islet	9 May 2023. Migrating north

Accidental Rare LC	White-tailed Tropicbird *Phaethon lepturus*	1	Bird Islet	9 – 11 May 2023. Adult
Accidental Rare LC	Short-tailed Shearwater *Ardenna tenuirostris*	1	Ranger Station	13 May 2023. 2nd Tubbataha record. Observed by rangers at some distance from the station. Bird drifted to the station where it disappeared
Migrant Uncommon LC	Great Frigatebird *Fregata minor*	Male 4 Female > 1	Bird Islet	9 May 2023
		Male 4 Female 3 Juvenile 1	South Islet	
Migrant Uncommon LC	Lesser Frigatebird *Fregata ariel*	1 Juvenile	Bird Islet	9 May 2023
	Unidentified Frigatebird *Fregata sp*	1 juv	Bird Islet	9 May 2023
		19	South Islet	12 May 2023
Migrant, Resident Common LC	Eastern Cattle Egret *Bubulcus coromandus*	2	South Islet	13 May 2023
Migrant, Resident Common LC	Little Egret *Egretta garzetta*	1	South Islet	13 may 2023
Resident Uncommon LC	Pacific Reef-egret *Egretta sacra*	5	Bird Islet	9 May 2023. Black Phase. 1 nest with 1 egg and 1 pullus
		10	South Islet	12 -13 May 2023. 5 White phase + 4 dark phase + 1 dead (df) in lighthouse. 2 nests
Accidental Rare LC	Dusky Warbler *Phylloscopus fuscatus*	1	Ranger Station	8 May2023: 1st record for Tubbataha
Migrant Common LC	Middendorff's Grasshopper Warbler *Helopsaltes ochotensis*	1	South Islet	12 May 2023. Observed at the research vessel
Migrant Common LC	Lanceolated Warbler *Locustella lanceolata*	1	Bird Islet	9 May 2023
Resident Very Common LC	Asian Glossy Starling *Aplonis panayensis*	1	South Islet	13 May 2023
Resident Very Common LC	Eurasian Tree Sparrow *Passer montanus*	1	South Islet	31 March 2023. One found dead. The species may be considered locally extinct as it is not recorded annually since 2020
Migrant Fairly Common LC	Eastern Yellow Wagtail *Motacilla tschutschensis*	1	Ranger Station	8 May 2023
		3	Bird Islet	9 May 2023
		2	South Islet	12 May 2023

Appendix 13. Comparison of the landscape and habitats seen from the Permanent Photo Documentation Sites on Bird Islet and South Islet, May 2004 and May 2023

Bird Islet:

Viewing angle for photo: facing NW 180°
Date: May 7, 2004

Comments: panoramic view
Photo no (camera): 4 shots

Photo Doc Site NI No. 01 - 2004

Photo name code: B1 01
Photo nos.: DSC_0507-0512

Comments: 6 shots (Stitched by Microsoft ICE)
Photo credit: Teri Aquino

Date: 11 May 2023
Coordinates: N8.92961° E119.99879°

Viewing angle for photo: facing NE 038º

Film no: 27, 28

Photo name code: BI 02

Comments: 2 shots good angle

Photo no (camera):

Photo no (negative):

Date: May 7, 2004

Photo name code: BI 02
Comments: 4 shots
Photo nos.: DSC_0462-0465
Date: 11 May 2023
Photo credit: Teri Aquino
Coordinates: N8.92972° E119.99637°

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

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

Photo name code: BI 03 | Comments: 9 shots stitched (Microsoft ICE) | Photo credit: Teri Aquino

Date: 11 May 2023 | Photo no (camera): DSC_0481-0489 | Coordinates: N8.93130° E119.99701°

Photo Doc Site NI No. 04 - 2004

Viewing angle for photo: facing E 067°

Film no: 14 Photo no (negative):

Photo name code: BI 04 Photo no (camera):

Comments: 1 shot Plaza Date: May 7, 2004

Photo name code: BI 04 Comments: 4 shots Date: 11 May 2023
Photo nos.: DSC_0472-0475 Photo credit: Teri Aquino Coordinates: N8.93005° E119.99656°

South Islet:

Viewing angle for photo: facing S 060º

Comments: shot includes view of the old lighthouse at the background;
Photo taken behind the old nipa hut

Photo name code: SI 01

Photo name code: SI 01

Date: 10 May 2023

Comments: single shot including new lighthouse at the background;
Coordinates for new photocdoc site was taken in 2019

Photo no (camera): P5100554

Photo credit: Gerlie Gedoria

Coordinates: N8.74901° E119.81967°

Appendix 14. Water Quality parameters monitored in Tubbataha Reefs Natural Park.

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

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

*Measurement done on site; ** Measured on-site and/or analyzed in the laboratory

Appendix 15. Coordinates and site description of water quality monitoring stations in Tubbataha Reefs Natural Park, May 2023.

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

Appendix 16. Water Quality Parameters Per WQ Monitoring Stations in Tubbataha Reefs Natural Park from 2014-2023.

WQ01	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	11	25.8	5	8.24	6.57	1.5	1.32	1.5	33	no data	25,060	-0.0022	2	35.8
2015	3	28.2	5	8.28	7.92	1.5	0.58	<1	23	1.8	25,078	0.0001	0.5	35.5
2016	2	28	5	8.24	8.09	0.75	0.24	5.6	94	23	18,768	0.0001	0.5	34.8
2017	6	30.19	5	8.78	5.9	1.4	0.52	no data	49	23	20,184	<0.003	<1	29.1
2020	<1	30.07	<5	7.75	6.73	0.46	1.51	2.5	23	7.8	30,240	no data	no data	30.07
2021	10	no data	5	no data	no data	0.7908	1.2901	<1	79	<1.8	no data	no data	no data	no data
2022	<1	29.4	<5	8.5	7.23	1.2429	0.1097	<1	<1.8	<1.8	29,600	no data	no data	31.6
2023	<1	33.38	<5	8.37	5.58	<0.001	0.44	<1	49	4	22,200	no data	no data	22.95

WQ02	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	12	25.40	5	8.36	6.32	1.20	0.61	0.69	49	no data	27,640	-0.0028	2.6	35.8
2015	4	28.5	10	8.31	7.89	1.60	0.48	<1	33	1.8	24,720	0.0001	0.5	35.5
2016	<1	28	5	8.29	8.8	1.00	0.92	4.2	49	49	21,200	0.0001	1	34.8
2017	5	30.07	5	8.78	5.5	1.30	0.21	no data	58	31	23,506	<0.003	<1	29
2020	10	30.26	<5	7.05	5.99	0.49	0.58	3.6	23	4.5	30,080	no data	no data	29.88
2021	10	no data	<5	no data	no data	0.8218	0.1534	<1	<1.8	<1.8	no data	no data	no data	no data
2022	4	29.25	<5	8.39	7.51	1.7791	0.1082	<1	4.5	<1.8	27700	no data	no data	
2023	7	33.65	<5	8.38	6.5	<0.001	0.03	<1	25	8.3	22,900	no data	no data	23.73

WQ03	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	12	26.27	5	8.32	6.58	1.7	0.78	6.08	23	no data	25778	-0.0034	0.9	34.9
2015	<1	28.3	10	8.33	8.05	1.8	0.53	1.85	46	1.8	24875	0.0001	0.5	35.5
2016	<1	29.6	5	8.4	8.02	0.9	0.64	7.9	33	23	19099	0.0001	0.5	34.5
2017	3	29.91	5	8.81	6.1	1.5	0.4	no data	49	33	22084	<0.003	<1	28.4
2020	5	30.15	<5	7.77	6.44	0.53	0.70	<1	4.5	<1.8	29900	no data	no data	29.67
2021	10	no data	5	no data	no data	1.2502	0.0379	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.44	<5	8.45	7.29	1.4926	0.1219	<1	<1.8	<1.8	29700	no data	no data	31.8
2023	6	33.75	<5	8.34	5.88	<0.001	0.02	<1	4.5	2	22,600	no data	no data	23.38

WQ04	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	15	32.8	5	8.09	6.38	1.00	0.11	1.29	23	no data	27,186	0.0008	2.9	35.9
2015	5	28.4	5	8.32	8.04	1.20	0.50	1.15	33	1.8	25,943	0.0001	0.5	35.2
2016	10	29.2	5	8.34	8.09	0.75	0.22	5.4	120	94	19,325	0.0001	0.5	33.4
2017	6	30.1	5	8.67	6.5	1.80	0.25	no data	23	23	23,352	<0.003	<1	29.1
2020	<1	30.29	<5	7.65	6.84	0.48	0.25	<1	7.8	<1.8	30,490	no data	no data	30.33
2021	10	no data	5	no data	no data	0.4504	0.0558	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.39	<5	8.48	7.01	1.642	0.0983	<1	<1.8	<1.8	30200	no data	no data	32.4
2023	<1	33.8	<5	8.37	5.68	<0.001	0.03	<1	<1.8	<1.8	22,900	no data	no data	23.78

WQ05	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	19	30.4	5	8.05	6.95	1.4	0.18	2.03	79	no data	29,788	0.0005	0.9	36.1
2015	10	29.1	10	8.14	6.2	1.3	0.51	1.25	170	70	25,280	0.0001	0.5	35.6
2016	4	29	5	8.27	6.09	0.75	1.22	<1	33	23	19,215	0.0001	0.5	34.9
2017	1	29.46	5	8.64	5.4	1.5	0.26	no data	49	33	24,045	<0.003	<1	29
2020	9	30.52	<5	7.65	7.04	0.47	0.15	3.8	4.5	<1.8	30,390	no data	no data	30.22
2021	15	no data	5	no data	no data	0.3933	0.0614	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.38	<5	8.41	8.4	1.5155	0.1091	<1	<1.8	<1.8	29100	no data	no data	31
2023	<1	35	<5	8.39	6.05	<0.001	0.21	<1	47	17	22,800	no data	no data	23.59

WQ06	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	19	31.5	5	8.14	6.47	1	0.09	1.41	23	no data	29436	-0.0046	3.8	36.1
2015	9	29.3	10	8.22	7.65	1.4	0.59	1.25	140	46	26000	0.0001	0.5	35.6
2016	9	28.4	5	7.99	7.95	0.95	1.47	2.6	140	110	20080	0.005	1	34.8
2017	6	29.53	5	8.76	6.3	1.5	0.26	no data	43	31	22552	<0.003	<1	29.2
2020	3	30.34	<5	7.37	6.85	0.53	0.18	2.4	4.5	<1.8	30310	no data	no data	30.25
2021	11	no data	5	no data	no data	0.4186	0.9893	<1	2	<1.8	no data	no data	no data	no data
2022	9	29.76	<5	8.42	7.88	2.003	0.1082	<1	2	<1.8	28900	no data	no data	30.7
2023	1	34.93	<5	8.48	6.53	0.1	0.04	<1	130	14	23,200	no data	no data	24

WQ07	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	18	32.1	5	8.14	7.01	1	1.31	2.04	44	no data	26096	-0.0034	1.1	35.5
2015	6	28.9	5	8.28	7.48	1.3	0.4	1.7	350	94	26225	0.0001	0.5	35.6
2016	12	31.2	5	8.35	7.07	1.15	0.68	3.4	210	140	24010	0.0001	0.5	34.4
2017	2	29.39	5	8.64	6	2	0.27	no data	43	31	23982	<0.003	<1	29
2020	6	30.36	<5	7.28	6.26	0.44	0.75	3.2	7.8	2	30340	no data	no data	30.17
2021	9	no data	5	no data	no data	0.5631	0.0469	<1	7.8	<1.8	no data	no data	no data	no data
2022	2	29.25	<5	8.39	7.51	1.8011	0.1183	<1	4.5	<1.8	27700	no data	no data	29.6
2023	7	35.42	<5	8.61	7.17	0.23	0.1	<1	920	17	22800	no data	no data	23.6

WQ08	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	11	33.6	5	8.06	6.3	1.40	0.38	1.69	130	no data	26,533	-0.0022	2.5	34.9
2015	3	28.2	5	8.30	8.18	1.30	0.47	0.9	23	1.8	27,728	0.0001	0.5	35.4
2016	2	29.6	5	8.40	7.91	0.95	0.54	8.8	280	170	21,158	0.0001	0.5	34.3
2017	6	29.91	5	8.80	6.8	1.70	0.25	no data	49	23	18,340	<0.003	5	28.9
2020	1	30.36	<5	7.90	5.5	0.69	0.12	<1	7.8	2	28,310	no data	no data	27.9
2021	18	no data	5	no data	no data	0.51	0.1649	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.48	<5	8.46	6.62	2.037	0.2369	<1	6.8	<1.8	29000	no data	no data	30.9
2023	7	33.64	<5	8.35	5.91	0.16	0.92	<1	2	<1.8	22400	no data	no data	23.13

WQ09	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	18	34.5	5	8.1	6	1.3	1.43	1.49	94		33265	-0.0037	1.4	35.1
2015	10	28.9	5	8.31	8.09	1.2	0.91	1.19	23	1.8	28270	0.0001	0.5	35.4
2016	14	28.8	5	8.4	8.18	1.2	1.06	1.8	140	79	22580	0.0001	2	35
2017	13	30.52	5	8.79	6.6	1.8	0.36	no data	23	23	22746	<0.003	5	28.8
2020	7	30.29	<5	7.9	6.42	0.55	0.18	2.5	<1.8	<1.8	30510	no data	no data	30.35
2021	7	no data	5	no data	no data	0.3084	0.0237	<1	<1.8	<1.8	no data	no data	no data	no data
2022	6	29.43	<5	8.52	7.1	2.2451	0.154	<1	<1.8	<1.8	28700	no data	no data	30.8
2023	7	33.69	<5	8.33	5.3	0.41	0.07	<1	2	<1.8	22400	no data	no data	23.14

WQ10	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	20	36.4	5	8.89	6.58	1.5	0.13	2.86	23	no data	34643	-0.0028	0.9	36.4
2015	12	29.6	5	8.21	8.51	1.1	0.87	2.25	23	1.8	26100	0.0001	0.5	35.6
2016	2	29.9	5	8.26	8.13	1.2	0.58	4.9	33	33	23232	0.0001	2	35.2
2017	6	30.25	5	8.8	6.1	2.5	0.32	3	23	23	21688	<0.003	<1	29
2020	3	31.04	<5	7.59	6.25	0.49	0.17	1.6	2	1.1	30760	no data	no data	30.6
2021	10	no data	5	no data	no data	0.3607	0.1315	<1	<1.8	<1.8	no data	no data	no data	no data
2022	4	29.46	<5	8.57	7.97	2.2206	0.1206	<1	<1.8	<1.8	29700	no data	no data	31.8
2023	7	32.87	<5	8.32	5.85	0.49	0.05	<1	79	17	21600	no data	no data	22.27

WQ11	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	20	30.4	5	7.78	7.05	1.3	1.1	1.1	70	no data	29535	-0.0028	1.3	36.6
2015	8	29.1	5	8.25	8.02	0.6	0.76	1.4	23	1.8	27270	0.003	0.5	35.5
2016	11	29.6	5	8.31	8.15	1	0.4	4.4	70	49	20520	0.0001	0.5	35.1
2017	6	30.24	5	8.83	5.6	1.9	0.24	no data	43	31	22091	<0.003	<1	29
2020	11	30.33	<5	7.37	5.92	0.50	0.29	3.3	4.5	<1.8	30640	no data	no data	30.51
2021	15	no data	5	no data	no data	0.3998	0.0267	<1	<1.8	<1.8	no data	no data	no data	no data
2022	2	30.05	<5	8.65	8.87	1.7309	0.1153	<1	<1.8	<1.8	29000	no data	no data	31
2023	2	33.31	<5	8.34	5.9	0.39	0.14	<1	<1.8	<1.8	22600	no data	no data	23.43

WQ12	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	4	26.28	5	8.21	6.93	1.3	0.39	1.3	94	no data	36579	-0.001	0.9	32.1
2015	6	29	10	8.25	8.13	1.3	0.57	1.55	23	1.8	27151	0.0001	0.5	35.5
2016	15	27.9	10	8.29	8.1	1.3	0.2	1.4	70	49	23546	0.009	1	34.7
2017	11	30.23	5	8.83	5.6	2.5	0.13	2.1	23	31	23839	<0.003	<1	29
2020	5	30.44	<5	7.73	5.69	0.52	0.21	2.3	4.5	2	30750	no data	no data	30.62
2021	<3.7	no data	5	no data	no data	1.3694	0.4688	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	29.57	<5	8.65	7.2	1.4885	0.1083	<1	2	<1.8	29600	no data	no data	31.7
2023	<1	33.34	<5	8.36	5.74	0.72	0.41	<1	350	9.3	22100	no data	no data	22.79

WQ13	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	10	30.7	5	7.92	6.9	1.5	0.92	4.8	23	no data	23910	-0.0025	1.48	36.4
2015	4	29.7	5	8.26	7.8	1.2	0.45	1.4	46	1.8	25366	0.0001	0.5	35.5
2016	0.9	28.9	5	8.28	8.87	0.8	0.04	4.9	120	70	23050	0.0001	2	35.1
2017	4	30.74	5	8.75	7	1.8	0.14	<1	31	31	23091	<0.003	7	29.2
2020	9	30.45	<5	7.78	6.15	0.51	0.17	3.2	17	7.8	30700	no data	no data	30.56
2021	13	no data	5	no data	no data	0.2791	0.082	<1	13	2	no data	no data	no data	no data
2022	5	33.05	<5	8.76	9.92	2.4312	0.1638	<1	<1.8	<1.8	21500	no data	no data	23.7
2023	11	35.56	<5	8.55	6.82	0.73	0.07	<1	<1.8	<1.8	22800	no data	no data	23.61

WQ14	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	17	30.9	5	7.74	6.91	1.3	0.16	1.43	79	no data	35706	-0.0043	<1	30.9
2015	0.9	29.5	5	8.28	7.94	1.1	0.35	3.05	33	1.8	22051	0.0001	0.5	35.6
2016	0.9	27.1	5	8.31	7.87	0.7	0.04	<1	23	23	22428	0.0001	0.5	35.3
2017	6	30.67	5	8.75	6.1	1.9	0.31	4	63	43	23095	<0.003	5	28.7
2020	12	30.48	<5	7.48	5.83	0.48	0.18	3	79	4.5	30610	no data	no data	30.64
2021	13	no data	5	no data	no data	0.2791	0.082	<1	13	2	no data	no data	no data	no data
2022	<1	31.37	<5	8.57	6.31	1.8338	0.1108	<1	<1.8	<1.8	30100	no data	no data	32.2
2023	6	34.21	<5	8.46	5.95	0.78	0.06	<1	<1.8	<1.8	22300	no data	no data	23.02

WQ15	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	7	31.5	5	8.02	7.29	1.7	0.79	0.7	23	no data	35846	-0.0028	0.9	36.5
2015	3	29.5	5	8.29	7.92	1.1	1.22	2.85	49	1.8	22880	0.0001	0.5	35.6
2016	1	29.9	5	8.37	7.73	0.8	0.02	<1	49	33	21128	0.0001	3	35.5
2017	10	30.61	5	8.77	6.1	1.9	0.31	3.6	43	43	18861	<0.003	<1	29
2020	<1	30.42	<5	7.55	6.28	0.49	0.18	<1	2	<1.8	30610	no data	no data	30.46
2021	8	no data	5	no data	no data	0.6161	0.0369	<1	<1.8	<1.8	no data	no data	no data	no data
2022	<1	30.81	<5	8.55	6.19	2.1178	0.1186	<1	<1.8	<1.8	28800	no data	no data	30.7
2023	7	34.24	<5	8.36	6.46	1.05	0.06	<1	<1.8	<1.8	22700	no data	no data	23.55

WQ16	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	6	30.7	5	7.75	7.28	1.40	1.43	1.45	23	no data	22,228	-0.0037	1.18	36.8
2015	6	29.8	10	8.28	8.05	0.90	0.4	0.90	84	46	23,000	0.0001	0.5	35.6
2016	4	26.9	5	8.39	8.09	0.80	0.15	5.6	170	140	21,906	0.0001	0.5	35.3
2017	5	30.07	5	8.83	7.4	3.20	0.23	0.9	43	43	22,181	<0.003	<1	28.8
2020	3	30.28	<5	7.47	6.97	0.64	0.13	2.6	7.8	2	30,520	no data	no data	30.37
2021	12	no data	5	no data	no data	0.5312	1.0515	<1	<1.8	<1.8	no data	no data	no data	no data
2022	10	30.54	<5	8.65	7.39	2.4997	0.3401	<1	<1.8	<1.8	28900	no data	no data	31
2023	5	34.36	<5	8.57	6.41	1.15	0.05	<1	<1.8	<1.8	22,800	no data	no data	23.59

WQ17	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	2	38.4	5	8.06	6.76	1.20	0.66	5.83	110	no data	25,408	-0.0028	1.38	35.9
2015	6	29.3	15	8.24	7.67	1.50	0.83	1.45	170	94	23,611	0.0001	0.5	35.7
2016	1	31.7	5	8.43	7.62	0.90	0.06	<1	23	23	20864	0.0001	0.5	35.1
2017	15	30.65	5	8.70	8.2	2.10	0.24	5.1	23	23	22,818	<0.003	<1	28.9
2020	1	30.36	<5	7.05	5.41	0.54	0.248	2.6	<1.8	<1.8	30340	no data	no data	30.17
2021	6	no data	5	no data	no data	0.5182	0.0963	<1	<1.8	<1.8	no data	no data	no data	no data
2022	14	29.17	<5	8.32	7.65	2.3561	0.1227	<1	<1.8	<1.8	29700	no data	no data	31.8
2023	4	34.36	<5	8.27	6.52	1.02	0.18	<1	<1.8	<1.8	22600	no data	no data	23.38

WQ18	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	9	26.19	5	8.16	6.37	1.2	0.19	4.35	46	no data	22133	-0.0043	0.9	35.7
2015	3	29.3	5	8.27	8.08	1.3	0.53	2	94	1.8	24970	0.003	0.5	35.6
2016	1	28.1	5	8.45	8.8	1.2	0.04	<1	23	no data	21728	0.0001	0.5	34.9
2017	9	30.48	5	8.82	6.7	2.7	0.27	no data	31	23	19595	<0.003	<1	28.8
2020	<1	30.35	<5	7.32	6.22	0.62	0.28	1.8	<1.8	<1.8	30680	no data	no data	30.4
2021	13	no data	5	no data	no data	1.0503	0.0371	<1	<1.8	<1.8	no data	no data	no data	no data
2022	12	30.65	<5	8.65	6.07	2.3332	0.1189	<1	<1.8	<1.8	29600	no data	no data	31.6
2023	<1	33.34	<5	8.32	5.66	1.61	0.05	<1	240	14	23200	no data	no data	24.12

WQ19	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	9	31.2	5	7.96	6.93	1.3	0.32	2.88	33	no data	23470	-0.0016	0.9	36.6
2015	4	29.4	10	8.33	8.03	1.3	0.48	1.1	46	1.8	23081	0.005	0.5	35.6
2016	0.9	29.5	5	8.49	7.99	0.8	0.06	4.8	140	94	23229	0.0001	0.5	35.4
2017	3	30.28	5	8.81	7.4	2.5	0.37	3	23	23	19630	<0.003	<1	28.1
2020	<1	30.3	<5	7.34	6.81	0.58	0.28	<1	14	2	30990	no data	no data	30.89
2021	9	no data	5	no data	no data	0.6675	0.0267	no data	<1.8	<1.8	no data	no data	no data	no data
2022	5	29.3	<5	8.6	7.98	2.6882	0.152	<1	<1.8	<1.8	29500	no data	no data	31.5
2023	2	33.56	<5	8.17	5.71	1.71	0.06	<1	<1.8	<1.8	22400	no data	no data	23.14

WQ20	TSS, mg/L	Temp, °C	Color, PCU	pH	Dissolved Oxygen, mg/L	Nitrates, mg/L	Phosphates, mg/L	Oil and Grease, mg/L	Total Coliform, MPN/100 mL	Fecal Coliform, MPN/100 mL	TDS, mg/L	Chromium hexavalent, mg/L	BOD, mg/L	Salinity, ppt
2014	10	30.7	5	8.06	6.65	1.4	0.09	0.69	no data	no data	21901	-0.0004	2.67	36.6
2015	1	29.6	5	8.3	8.03	1.6	0.5	2.2	79	33	23701	0.003	0.5	35.6
2016	5	29.4	5	8.43	7.99	1.45	0.08	2.6	140	94	24952	0.0001	3	35.4
2017	18	30.32	5	8.79	5.6	1.7	0.37	no data	43	43	20532	<0.003	<1	29
2020	7	31.14	<5	7.16	5.95	0.56	0.25	<1	41	12	30930	no data	no data	30.81
2021	11	no data	5	no data	no data	0.6488	0.024	<1	<1.8	<1.8	no data	no data	no data	no data
2022	3	29.53	<5	8.61	6.71	2.4581	0.254	<1	<1.8	<1.8	29800	no data	no data	31.9
2023	6	33.72	<5	8.24	6	1.73	0.11	<1	23	<1.8	22600	no data	no data	23.39

Appendix 17. Sampling sites, description, and the number of species identified.

Year	Sampling sites	No. of species identified	Description
2018	T1	147	Site 4 Station A. Malayan wreck; southern tip of North Atoll; SW North Atoll; 08.89236oN; 119.90627oE
2018	T2	147	Site 1 Station A. South of Ranger station. S tip of North Atoll
2018	T3	176	Site 3 Station A. Shark airport; Northern part of North Atoll
2018	T4	156	Site 2 Station A. Seafan alley, northern North Atoll
2018	T5	159	Site 5, Station A southern South Atoll
2018	T6	149	Site 6 Station A. Near Delsan wreck. South Atoll
2018	T7	154	Site 7, Station A. T-Wreck
2018	T8	157	Site Jessie Beasley Reef, Station A.
2019	T9	160	Dive site 'Staghorn Point' south of lighthouse island; drop off high coral cover
2019	T10	146	Dive Site 'Delson Wreck
2019	T11	130	Dive Site Ko-ok, northern part of S Atoll
2019	T12	131	Dive Site T-Wreck, northern part of S Atoll
2019	T13	169	Dive Site Black Rock, northern part of S Atoll
2019	T14	161	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	153	Dive Site Seafan Alley (at first buoy), northern part of N. Atoll.
2019	T16	166	Dive Site Shark Airport, over long sand flat and drop off, northern part of N. Atoll
2019	T17	146	Dive Site Jessie Beazley, directly in front of Island
2019	T18	122	Dive Site Jessie Beazley, opposite side of the reef from the coral cay
2023	T19	80	Lagoon Station, North Atoll about 1 km N of Ranger Station
2023	T20	101	North Atoll, South Park Dive Station 72' to 10'
2023	T21	134	North Atoll, Northern area, Shark Airport
2023	T22	68	North Atoll, Lagoon, about 1 km south of Bird Islet
2023	T23	139	South Atoll, Delsan Wreck
2023	T24	122	South Atoll, Ko-Ok Dive site
2023	T25	119	South Atoll, Southwest Wall Dive Site
2023	T26	134	Jessie Beazley, NE Side
2023	T27	126	Jessie Beazley, NE Side, but a different part than the first dive

Appendix 18. List of species previously unrecorded in Tubbataha.

Year	Scientific Name	Family		Year	Scientific Name	Family
2018	*Cheilodipterus isostigmus*	Apogonidae		2018	*Trimma emeryi*	Gobiidae
2018	*Chlorurus capistratoides*	Scaridae		2018	*Trimma erdmanni*	Gobiidae
2018	*Chromis alpha*	Pomacentridae		2018	*Trimma naudei*	Gobiidae
2018	*Chrysiptera springeri*	Pomacentridae		2018	*Trimma yanoi*	Gobiidae
2018	*Ctenogobiops feroculus*	Gobiidae		2019	*Amblyeleotris steinitzi*	Gobiidae
2018	*Ecsenius dilemma*	Blennidae		2019	*Caranx papuensis*	Carangidae
2018	*Escenius tricolor*	Blennidae		2019	*Centropyge multifasciatus*	Pomacanthidae
2018	*Eviota ancora*	Gobiidae		2019	*Diodon holocanthus*	Diodontidae
2018	*Eviota fallax*	Gobiidae		2019	*Enneapterygius nanus*	Tripterygiidae
2018	*Eviota guttata*	Gobiidae		2019	*Epinephalus maculatus*	Serranidae
2018	*Eviota latifasciata*	Gobiidae		2019	*Eviota atriventris*	Gobiidae
2018	*Eviota minuta*	Gobiidae		2019	*Genicanthus melanospilos*	Pomacanthidae
2018	*Eviota nebulosa*	Gobiidae		2019	*Genicanthus watanabei*	Pomacanthidae
2018	*Eviota sebreei*	Gobiidae		2019	*Halichoeres podostigma*	Labridae
2018	*Eviota shimadai*	Gobiidae		2019	*Halichoeres solorensis*	Labridae
2018	*Gnatholepis cauerensis*	Gobiidae		2019	*Mulloidichthys flavolineatus*	Mullidae
2018	*Hoplolatilis starcki*	Malacanthidae		2019	*Naso caesius*	Acanthuridae
2018	*Labropsis alleni*	Labridae		2019	*Ostorhinchus chrysopomus*	Apogonidae
2018	*Lutjanus bengalensis*	Lutjanidae		2019	*Ostorhinchus dispar*	Apogonidae
2018	*Ostorhinchus nanus*	Apogonidae		2019	*Pseudodax mollucanus*	Labridae
2018	*Ostorhinchus neotes*	Apogonidae		2019	*Ptereleotris randalli*	Microdesmidae
2018	*Ostorhinchus nigrofasciatus*	Apogonidae		2019	*Remora sp.*	Echeneidae
2018	*Ostorhinchus novemfasciatus*	Apogonidae		2019	*Scolopsis ciliatus*	Nemipteridae
2018	*Ostracion nasus*	Diodontidae		2019	*Spratelloides delicatulus*	Clupeidae
2018	*Oxycirrhites typus*	Cirrhitidae		2019	*Synodus jaculum*	Synodontidae
2018	*Pleurosicya micheli*	Gobiidae		2019	*Synodus varieagatus*	Synodontidae
2018	*Pseudochromis bitaeniata*	Pseudochromidae		2019	*Trimma cheni*	Gobiidae
2018	*Pseudochorus yamashiroi*	Labridae		2019	*Trimma preclarum*	Gobiidae
2018	*Pseudochromis marshallensis*	Pseudochromidae		2019	*Valenciennea puellaris*	Gobiidae
2018	*Scolopsis affinis*	Nemipteridae		2023	*Aioliops novaeguineae*	Microdesmidae
2018	*Trimma anaima*	Gobiidae		2023	*Amphiprion sandaracinos*	Pomacentridae
2018	*Trimma benjamini*	Gobiidae		2023	*Aspidontus dussumieri*	Blennidae

Year	Scientific Name	Family		Year	Scientific Name	Family
2023 2023	*Amblyglyphidodon sp. cf1 Kuiter* *Corythoichthys intestinalis*	Pomacentridae Syngnathidae		2023 2023	*Pleurosicya elongata* *Pomacentrus armillatus*	Gobiidae Pomacentridae
2023	*Cryptocentrus strigilliceps*	Gobiidae		2023	*Pristiapogon fraenatus*	Apogonidae
2023	*Decapterus russelli*	Carangidae		2023	*Rhabdamia gracilis*	Apogonidae
2023	*Diademichthys lineatus*	Gobiesocidae		2023	*Siphamia elongata*	Apogonidae
2023	*Dischistodus perspicullatus*	Pomacentridae		2023	*Taeniamia fucata*	Apogonidae
2023	*Dischistodus prosopotaenia*	Pomacentridae		2023	*Taeniamia zosterophora*	Apogonidae
2023	*Epinephelus miliaris*	Serranidae		2023	*Tomiyamichthys oni*	Gobiidae
2023	*Epinephelus quoyanus*	Serranidae		2023	*Trimma okinawae*	Gobiidae
2023	*Escenius bimaculatus*	Blennidae		2023	*Trimma taylori?*	Gobiidae
2023	*Eviota prasites*	Gobiidae		2023	*Trimma stobbsi*	Gobiidae
2023	*Exyrias bellisimus*	Gobiidae		2023	*Vanderhorstia nannai*	Gobiidae
2023	*Fusigobius melacron*	Gobiidae		2023	*Zoramia viridiventer*	Apogonidae
2023	*Fusigobius signipinnis*	Gobiidae				
2023	*Gobiodon okinawae*	Gobiidae				
2023	*Gymnothorax zonipectus*	Muraenidae				
2023	*Hemiglyphidodon plagiometopon*	Pomacentridae				
2023	*Istigobius regilis*	Gobiidae				
2023	*Myriptistis pralinia*	Holocentridae				
2023	*Ostorhinchus apogonoides*	Apogonidae				
2023	*Ostorhinchus compressus*	Apogonidae				
2023	*Ostorhinchus monospilus*	Apogonidae				
2023	*Parapercis multipunctata*	Pinguipedidae				
2023	*Parapercis xanthozona*	Pinguipedidae				

Appendix 19. Effort log used in the 2023 cetacean survey.

2023 TRNP CETACEAN SURVEY: EFFORT LOGFORM

Date___________ Begin Location _____________ End Location _____________ Page#_________ Total Pages________

Series	Leg	Time	Wpt	Position	Course	Speed	Odom	Trip Time	F/R	BFRT	Observers			End leg Time	End Code	Sight#
											L	Rec / 👁 / C	R			
												/				
												/				
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Ending Codes: 1 = course change, 2 = speed change, 3 = effort stop, 4 = record position, 5= environmental conditions, 6 = observer position change
Fog/Rain Codes: 1 no fog or rain, 2 = fog, 3 = rain, 4 = fog and rain, 5 = hazy but no fog or rain

Appendix 20. Sighting form used in the 2023 survey.

2023 TRNP CETACEAN SURVEY: Sighting Sheet

Date_________ Time __________Sighting# ______ Position ________________________ Way Pt. _______

Distance __________ Compass Bearing ________ Vessel Bearing_______ Sighting Angle___________

Effort	Observer	Beaufort	Group Size	Species ID
Off/On				

Drawing and notes on diagnostic features, behavior, popn structure, habitat, and human activities

Date_________ Time ___________Sighting# _____ Position ________________________ Way Pt. _______

Distance __________ Compass Bearing ________ Vessel Bearing________ Sighting Angle___________

Effort	Observer	Beaufort	Group Size	Species ID
Off/On				

Drawing and notes on diagnostic features, behavior, popn structure, habitat and human activities