Barefoot Conservation Science Progress Report

2024-2025

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Arborek Island, Raja Ampat, West Papua

Science Progress Report 2024-2025

For any questions regarding the data, findings or projects mentioned in this report, please contact our Head of Science, Josie Chandler, via barefootscienceteam@gmail.com

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Introduction

Barefoot Conservation is an Indonesian registered NGO (Yayasan Konservasi Jejak Kaki Indonesia: AHU-0004531.AH.01.04. Tahun 2018) working to conserve the unrivalled marine life of Raja Ampat, through monitoring, research and science training of the local community. Barefoot has been running since 2016 and has been collecting data on reef health, manta populations, marine debris and crown of thorns starfish for several years, providing invaluable long-term datasets of the ecosystem over time. Our scientific output is constantly evolving and expanding and we now have 11 science projects running in parallel. This report provides an update on the progress of 7 of our major science projects in 2025.

Our Science team at Barefoot currently consists of Project Scientist Reyhan Arifin (Jenderal Soedirman University), Project Scientist Mathilda Bates (James Cook University), Project Scientist Nikolai Madland Shorter (University of Cambridge), Science Officer Septya Putri (Jenderal Soedirman University) and the Head of Science Josie Chandler (James Cook University) who is working remotely from Australia. Our Head of Operations (Iris Uijttewaal), Dive Manager (Matt Perrodou), and Divemasters (Reven and Markus) are also heavily involved in the science projects. Other scientists who have been involved with the science at Barefoot during 2024 but are no longer working us are: Lena Pollett (Plymouth University), Max Kimble (Plymouth University), Corey Cathcart (Bournemouth University), Issy Inman (Swansea University). We also thank Erika Gress (James Cook University) for her involvement with Barefoot Science and dedication to the reefs of Raja Ampat during 2024.

Last year in 2023 we commenced new projects, most notably setting up a Coral Ecology and Bleaching Project and extensive cyanobacteria monitoring. This year in 2024 we have built upon these projects with the addition of installing temperature loggers and setting up new monitoring techniques such as large-scale photogrammetry, we have also started employing AI technologies into some of our data analysis (ReefCloud). In addition to Coral Bleaching Project expansion this year we have also included two new monitoring projects – monitoring prevalence of coral-killing sponge (Terpios hoshinota) and monitoring coral spawning. This year has also seen new collaborations commence which we hope to build on further in 2025. All of these projects will be outlined in more detail within this report, including background, progress and goals for 2025.

We have continued to progress with the long-term data collection of Reef Check, hitting our monitoring targets each quarter and adding bonus sites to our data bank. We have also contributed to ongoing data collection within a wide variety of projects including marine debris, manta rays, black corals, crown-of-thorns starfish and more. However, with the emerging threats of marine heatwaves and deteriorating water quality becoming more and more problematic for this region, we have put the majority of our efforts into two focal projects this year: 1) Coral Ecology and Bleaching Project and the 2) Water Quality and Cyanobacteria Monitoring project.

One of the key projects we have been working towards this year has been monitoring the presence of cyanobacteria & macroalgae in the Dampier Strait, which we have recognised to be increasing dramatically in recent years. Rapid growth of cyanobacteria and macroalgae is an issue linked to nutrient pollution which is known to have caused significant irreversible damage to coral ecosystems in the Caribbean and other parts of the Indo-Pacific. This year we contracted water testing of key water quality parameters and have highlighted our concerns of poor water quality to BLUD UPTD during meetings and a separate water quality report.

Unfortunately, in recent months we have witnessed a severe bleaching event unfold in the western side of the Dampier Strait, starting in November 2024. It was heartbreaking to observe mass bleaching at such magnificent reefs and unfortunately we have already witnessed some mortality of corals as a result of this event. In 2023 we had established a comprehensive coral bleaching monitoring programme for Raja Ampat, coordinated with NOAA Coral Reef Watch collaborators, and so we have been able to capture the event unfold and we continue to collect unprecedented data on this event into 2025. We continue to work with provincial government and other stakeholders on the status of Raja Ampat reefs and strive to inform management decisions in the region.

All of the projects currently running at Barefoot Conservation collect observational data only. Correct permissions were sought from both Chief of Arborek Village, Bapa Juan, and Head of BLUD, Pak Syafri, before commencing any of the projects mentioned in this report.

Where is the data going?

Reef Check

Data from our Reef Check project is shared with Reef Check Indonesia and Reef Check Worldwide. This data contributes to a national and global reef health monitoring initiative using standardized monitoring methodologies to gain insight into changing reef health at multiple locations globally. We contribute critical long-term data on Raja Ampat reefs.

Coral Bleaching data

Our coral bleaching survey data is shared with University of Queensland, CoralWatch (ALA's Biocollect CoralWatch Data Portal) and NOAA Coral Reef Watch, it contributes to projects improving our understanding of global bleaching patterns and taxa-specific bleaching response

Photogrammetry Project

Our photogrammetry and temperature monitoring project is a collaborative research project with researchers from NOAA Coral Reef Watch and AOML. Data arising from this project is shared with these teams and aids in informing their bleaching prediction satellite models as well as furthering coral bleaching research

Water Quality & Cyanobacteria Project

Data from our water quality & cyanobacteria project has been presented to BLUD UPTD (local government) in a formal report and shared with local stakeholders as we urgently seek a solution to the wastewater issue in Raja Ampat

Marine Debris Project

Our marine debris data is shared with BLUD UPTD (local government) to mobilise local action. We are also communicating our data to other environmental organisations in Indonesia in the hope of creating collaborative solutions to the waste issue we are facing

Manta Project

Data from our long-term manta project contributes to our building database and is also shared with international manta scientist Edy Setyawan who maintains the Bird's Head Seascape Manta ID Database and works for Manta Trust. Our data complements the ongoing research he is conducting in Raja Ampat.

Antipatharia (Black Coral) Project

Data collected from our Antipatharia Project is provided to Erika Gress, a leading Antipatharia researcher at James Cook University, working on the ecology, phylogeny and population dynamics of Antipatharia corals. Our data contributes to furthering an understanding of the distribution and ecology of Antipatharians in Raja Ampat

BLUD UPTD Pengelolaan Kawasan Konservasi di Perairan Kepulauan Raja Ampat

Coral Ecology Project Report

Introduction

2024 saw the confirmation of a fourth global mass bleaching event, documented in the northern and southern hemispheres across all major ocean basins (Image 1; NOAA, 2024). Areas such as the Caribbean observed heat waves that lasted longer and were more severe than previously experienced. The Great Barrier Reef also experienced unprecedented degree heating weeks (DHWs) leading to half of all reefs exhibiting high to extreme bleaching levels (Cantin et al., 2024). In light of this, NOAA's Coral Reef Watch issued Raja Ampat a bleaching warning, predicting a 80-90% chance of a large-scale bleaching event to occur during early 2024. This was the first time such a severe bleaching warning had been issued for the region, greater than the previous 2023 bleaching season.

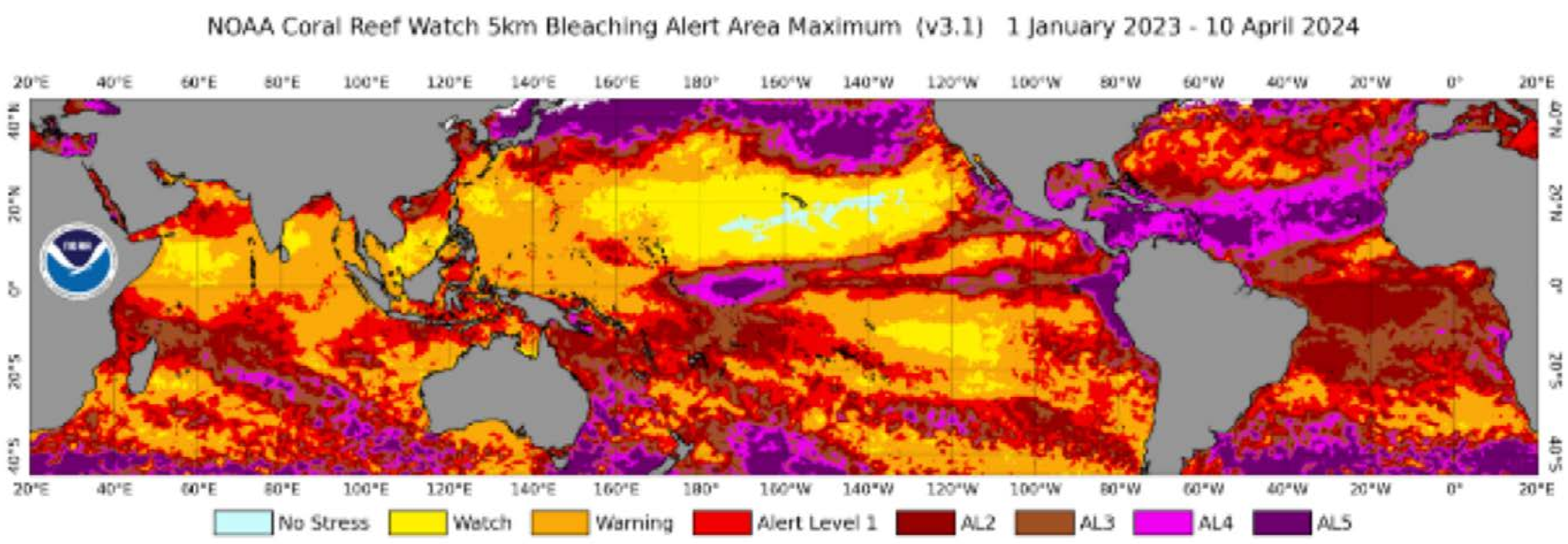

Figure 1.1. *NOAA Coral Reef Watch's global 5km-resolution satellite Coral Bleaching Alert Area Maximum map, for January 1, 2023 to April 10, 2024. This figure shows the regions, around the globe, that experienced high levels of marine heat stress (Bleaching Alert Levels 2-5) that can cause reef-wide coral bleaching and mortality. (Image credit: NOAA)*

Nestled within the biodiverse coral triangle, Raja Ampat is believed to be one of the world's few thermal refugia, receiving cool water through upwelling and strong currents which has been alleviating potential heat induced stress on corals (De Clippele et al., 2023). As a refuge from climate change stresses, Raja Ampat is predicted to play a crucial role in maintaining biodiversity on coral reefs as well as supporting the large proportion of Indonesian and Papuan communities that rely on the reefs as their food-source, income, and way of life. As the effects of climate change intensify, specifically the frequency and magnitude of thermal stresses, monitoring the health and condition of coral reefs within Raja Ampat is imperative to both inform and manage adequate monitoring and restoration techniques.

In response to NOAA's initial warning of a potential bleaching season, Barefoot Conservation established the Coral Ecology Project at the end of 2023. This project mainly consisted of the Bleaching sub-project, which focused on recording and monitoring the health of coral colonies on one of our local reefs in order to capture high resolution bleaching data if such a phenomenon were to happen (Barefoot Conservation, 2023). Deciding to further expand the Coral Ecology Project, the Barefoot science team established the Temperature Monitoring sub-project in June 2024, in order to gain an accurate and holistic understanding of temperature fluctuations at varying depths off our jetty on the eastern tip of Arborek Island. This sub-project was established to verify the hypothesis that the cool water flushing driven by upwelling and strong currents across the region may mitigate rising sea surface temperatures, thereby preventing bleaching as well as promoting recovery of affected reefs (De Clippele et al., 2023). set

up our Photogrammetry sub-project, with the aim to establish an overarching monitoring methodology that would enable the surveying of a variety of different impacts on our local reefs over a wider area, including stresses that are known (ie. bleaching) as well as ones that are unforeseen.
The following sections delve into the specifics of each of these sub-projects, including our overarching aims, current results and their significance, as well as future plans for the continuation and growth of the larger Coral Ecology project.

Bleaching

INTRODUCTION

As aforementioned, the Bleaching sub-project was established in November 2023 in response to a warning of a potential bleaching season in early 2024 from NOAA. The Barefoot science team designed the project to be an ongoing bleaching monitoring programme. We aimed to record accurate and high-resolution bleaching data for coral colonies across a range of different morphologies as well as across a depth gradient.

METHODS

Bleaching Surveys occur weekly at JPP dive site, a seamount located just south of Arborek Island (0°34'02.6"S, 130°31'18.6"E). Each survey is conducted along a 20-metre belt transect defined by permanent stakes at three different depths (5m crest, 8m slope, 16m slope) around the seamount. Bleaching surveys occur in two stages, firstly by taking photo-quadrats with a rig and secondly by imaging and recording bleaching levels of 20 tagged coral colonies per depth.

A 20m transect is laid between two permanent stakes, ensuring the same section of reef is monitored every survey. Date, time, weather (ie. sun, rain, cloud), and temperature (°C) are recorded. Two divers position the photo-rig above the reef with the transect running straight through the middle of the quadrat. The project scientist will take a photo quadrat of the reef every metre along the belt transect using an Olympus TG-7 (in RAW mode with white balance manually adjusted with every change in depth). A CoralWatch card is captured in every photo-quadrat image, as a standardised bleaching severity scale for objective comparison. The CoralWatch card was created by the Atlas of Living Australia (ALA) as part of their CoralWatch program that allows surveyors to monitor coral colour as an indicator of coral health (CoralWatch, 2024).

For assessment of bleaching severity on tagged colonies, divers locate the 20 tagged coral colonies located near the permanent transect. Each colony is tagged with a cattle tag and identifying number. Using the TG-7, each coral colony is photographed together with a CoralWatch card. Two scores of bleaching are assigned per colony; the CoralWatch bleaching score, which consists of matching the colony colour to the lightest and darkest values of the CoralWatch card (ie. B2, B5) and secondly a 'bleaching severity score' based on a bleaching scale adapted from Baird et al (2018); 1 = healthy, 2 = <50% bleaching, 3 = >50% or fully bleached, 4 = dead from bleaching, X = dead from other cause (ie. predation, disease, etc). This process is conducted for 20 colonies at each depth (60 colonies total).

After the underwater portion of the survey is complete, data is inputted into ALA's Biocollect CoralWatch Data Portal. ALA's CoralWatch program is an initiative created to integrate global coral health monitoring with education and citizen science with simple and effective tools such as the CoralWatch card (CoralWatch, 2024).

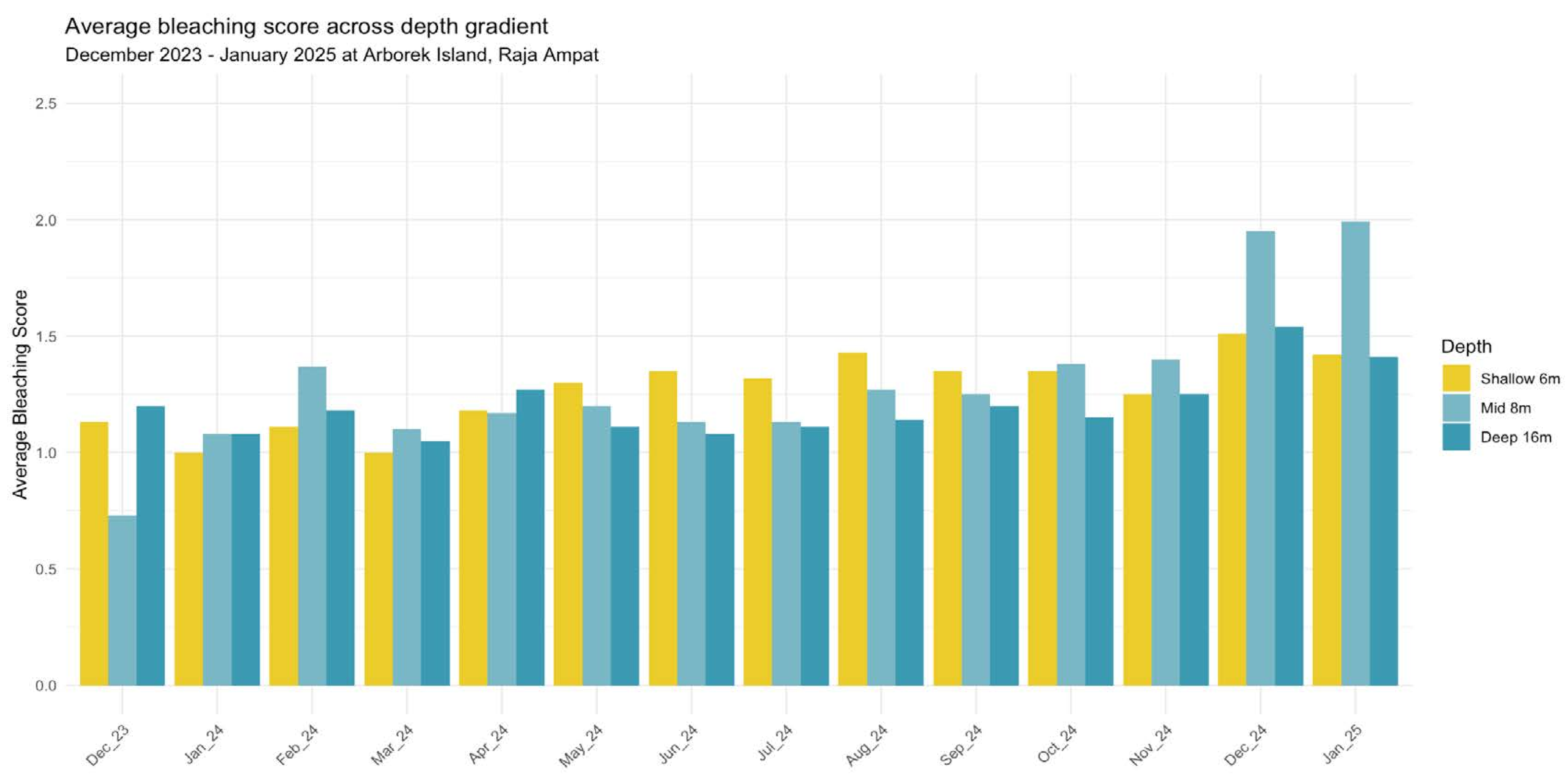

Figure 1.2. *Mean Bleaching Scores across Depth from November 2023 – January 2025 at JPP, Arborek Island. Survey depths vary from Deep at 16 metres to Mid at 8 metres to Shallow at 6 metres, with each depth containing 20 tagged coral colonies. Each coral colony was ranked by a bleaching score of 1 (no bleaching), 2 (0-50% bleached), 3 (50-100% bleached), and 4 (mortality from bleaching). These values were grouped and averaged by depth as well as month.*

RESULTS

Our data reveals a moderate to severe bleaching event unfolding at our survey site in Raja Ampat, with high prevalence and severity of bleaching recorded from August - December 2024, particularly across shallow and mid depths (Figure 1.2). Mean bleaching scores increased from 1.1 in March 2024 to 1.67 in December 2024 across all corals combined, demonstrating that a significantly higher proportion of corals on surveys were experiencing bleaching (1=healthy, 2=0-50% bleached). Notably, the mid-depth surveys in December and January recorded average bleaching scores of 2.0, indicating that bleaching prevalence was extensive at this depth. Depth had a significant effect on mean bleaching scores (ANOVA: df = 2, F = 136.6, $p < 0.05$). Figure 1.3 provides further insight into taxa-specific bleaching responses over time and the proportional impact on the coral community.

The proportional bleaching of tagged coral colonies over time is shown in Figure 1.3, with data pooled across all depths and categorized by coral morphology. Bleaching response substantially increased over the second half of the year from August-Dec 2024, with >30% all colonies in bleaching categories. This temporal increase in bleaching severity matches with our own water temperature data of increasing heat intensity between August and December 2024, as well as satellite derived 'Degree Heating weeks' (DHW) - NOAA's 5km heat stress map for West Papua region indicates that by December 2024 this region had sustained 14 DHW.

Compared to the same months in 2023 (Nov-Jan), this year's bleaching event has been considerably more prevalent (number of colonies affected) and severe (intensity of bleaching). For comparison, in January 2024 none of the tagged colonies were experiencing severe bleaching (category 3 or 4) and only 2% of colonies were experiencing mild bleaching (category 2). This year 18% of colonies are experiencing mild bleaching and another 18% are experiencing severe bleaching or mortality and 18%. The data we have recorded this year sadly demonstrates that Raja Ampat reefs are no longer removed from the threat of coral bleaching.

Bleaching response varied significantly among coral taxa (ANOVA: df = 4, f-value = 25.561, p-value < 0.05)(Figure 1.3), with branching corals and soft corals most susceptible to severe coral bleaching scores. Both branching corals and soft corals began experiencing severe bleaching (Category 3; 50-100% bleached) since as early as August, demonstrating their sensitivity to warming. In December 2024 over 50% of all branching colonies presented bleaching scores of 3 (50-100% bleached) or 4 (bleaching induced mortality) and over 75% of soft corals were severely bleached or had experienced bleaching-induced mortality by January. The early bleaching response of these susceptible coral morphologies and the constrained biological conditions of existing without symbiotic algae may explain the early mortality of these populations. Stylophora corals in the branching morphology group were some of the worst affected colonies, with 60% of Stylophora colonies (n=13) either severely bleached (category 3) or killed by bleaching (category 4) by January. Comparatively, tabular corals remained mostly unbleached (bleaching score of 1) for >90% of colonies in January despite sustained high temperatures, however some sudden mortality of a small proportion of colonies (10%) was observed during peak warming months Dec and January. The progression of this sudden mortality should be investigated

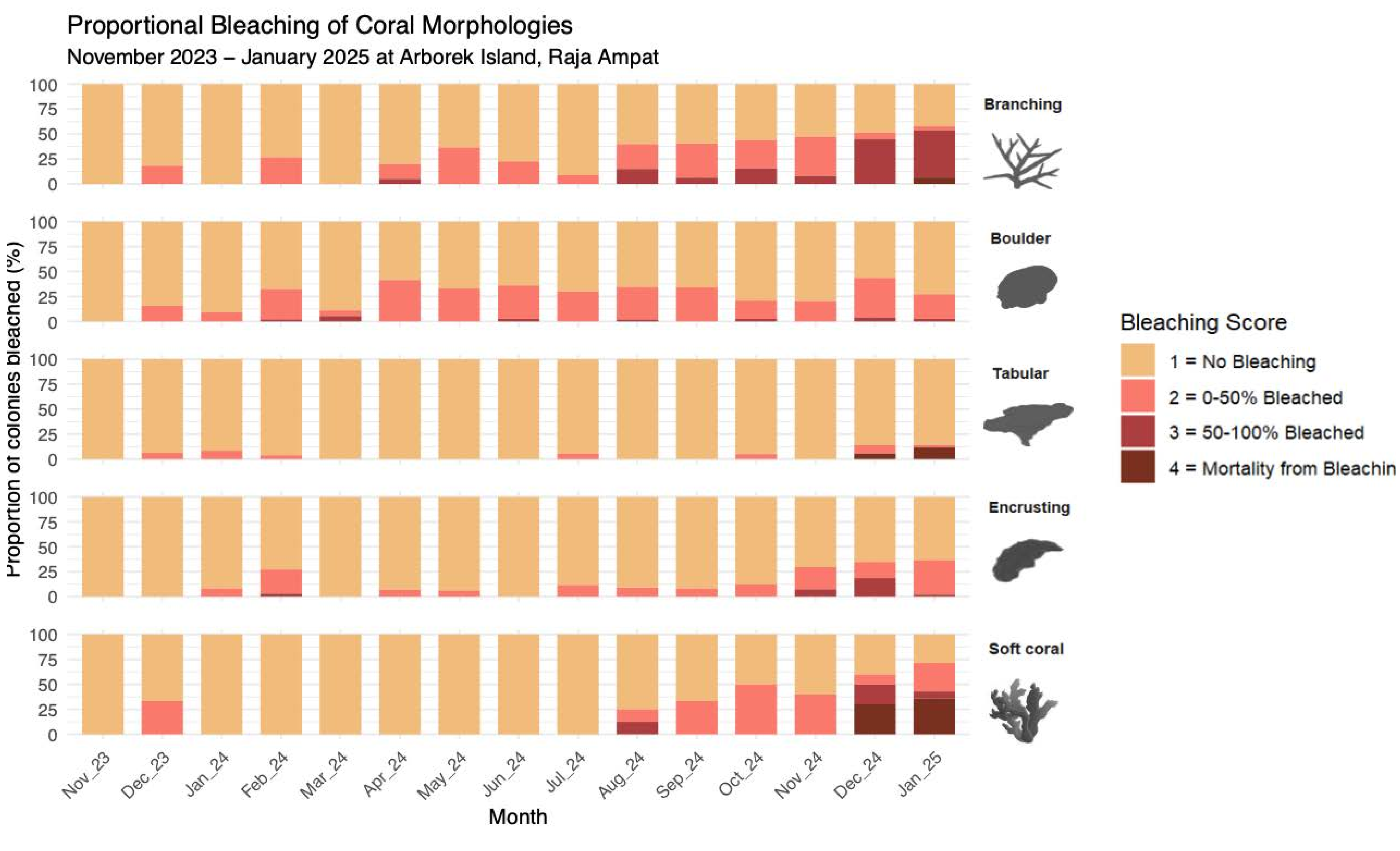

Figure 1.3. *Proportional Bleaching of tagged coral colonies (n=70) from November 2023 – January 2025 at JPP, Arborek Island. Colonies are categorized by coral morphology (Branching, Boulder, Tabular, Encrusting and Soft Coral). Bleaching scores were assigned to each tagged colony, classed from 1 (no bleaching), 2 (0-50% bleached), 3 (50-100% bleached), to 4 (mortality from bleaching). n = 60 tagged coral colonies.*

further through our photo records to understand the processes involved. Boulder and encrusting coral morphologies displayed a relatively mild bleaching response even during peak months (95% of colonies in category 2 or lower), and in January the proportion of colonies in bleaching category 2 or 3 has already reduced, suggesting recovery to the warming event and no evidence of mortality.

DISCUSSION & FUTURE GOALS

Whilst we did not observe a significant bleaching event on our local reefs in the predicted months of Nov 2023- Jan 2024, a considerable and significant increase in bleaching scores was observed towards the end of 2024, building between August and reaching alarming levels in December 2024 and January 2025. In December 2024 over 50% of branching corals were severely bleached, with bleaching-induced mortality observed across three morphological groups (branching corals, tabular corals and most notably, soft corals). High bleaching scores (>category 3) were mostly evident within the shallow and mid survey sites (Figure 1.2) and across the branching and soft coral morphologies. These findings are consistent with observations during past bleaching events around the world, with evidence that branching morphologies such as Acropora and Stylophora are among the most susceptible to thermal stress (Burn et al., 2023). Other studies have also commonly found bleaching susceptibility to decrease along a depth gradient, further supporting our findings (Baird et al., 2018). We will continue to monitor the tagged colonies for bleaching and recovery over the coming months.

Bleaching to this extent is unprecedented in this region of Indonesia which has previously been considered a thermal refugia. This bleaching data represents one of the first quantitative records of bleaching in Raja Ampat. In addition to the data recorded within this report, we have observed severe and widespread occurrences of bleaching at multiple sites around Raja Ampat. Notably, JPP Reef, the site of our permanent bleaching surveys, was among the least affected reefs in the Dampier Strait. In contrast, reefs on the eastern side of the Dampier Strait experienced the most severe bleaching, with extensive bleaching observed across multiple coral morphologies and at depths exceeding 25m (Figure 1.4, Mioskon Reef). Photogrammetry data collected by our team at these severely affected sites will be presented in next year's report. The spatial differences in bleaching in Raja Ampat is likely a combination of the lower heat stress footprint experienced on the Western side of the Dampier Strait (related to large-scale oceanic currents) and also localised upwellings around reefs on the Western side due to the higher density of reefs and narrow channels between Mansuar Island and Gam.

Although the bleaching warning issued by NOAA Coral Reef Watch in late 2023/24 did not substantiate on Raja Ampat reefs, this season (2024/25) the predictions were true and Raja Ampat unfortunately experienced its first severe and widespread bleaching event. The data we have collected contributes to ground truthing the satellite models of NOAA CoralWatch team and improving model predictions based on in situ temperature data and bleaching surveys.

Looking towards the coming year, the Barefoot science team will continue to monitor our local reefs and collect high resolution bleaching data. Working in conjunction with the new Temperature Logger sub-project, we hope to expand the Bleaching sub-project even further and research how temperature and depth may play a role in determining the occurrence of thermal stress. Understanding this complex relationship will hopefully help us to better understand Raja Ampat's susceptibility and resilience to future warming events.

Figure 1.4 *Photographs of the severe bleaching event occurring in Eastern Dampier Strait in Nov-Dec 2024. Photographs taken at Mioskon reef by Wendy Mitchell*

Temperature Loggers

INTRODUCTION

Increasing magnitude and frequency of rising sea surface temperatures is the main accelerant for mass bleaching events around the world. Thermal stress is the primary driver for bleaching of corals, based on a combination of heat intensity and duration (Degree Heating Weeks). As a purported thermal refugia, coral reefs within Raja Ampat rely heavily on cool water flushing driven by environmental factors such as upwelling and strong currents. However, there is limited understanding about how cool water flushing maintains this refuge from thermal stress in this region of the Coral Triangle. In order to fill this knowledge gap, and better understand and interpret results from our other science projects such as Bleaching and Cyanobacteria monitoring, the Barefoot science team created the Temperature Logger sub-project. An array of temperature loggers were installed under the recommendation of our collaborators at NOAA Coral Reef Watch, and whilst the temperature data informs our own projects, it also contributes to wider research projects understanding the basis of bleaching in Raja Ampat and other comparable regions. This sub-project aims to provide a consistent log of temperature fluctuations across a depth gradient within central Raja Ampat, and further facilitate a deeper understanding of this region as a thermal refugia in the face of increasing thermal stress from climate change.

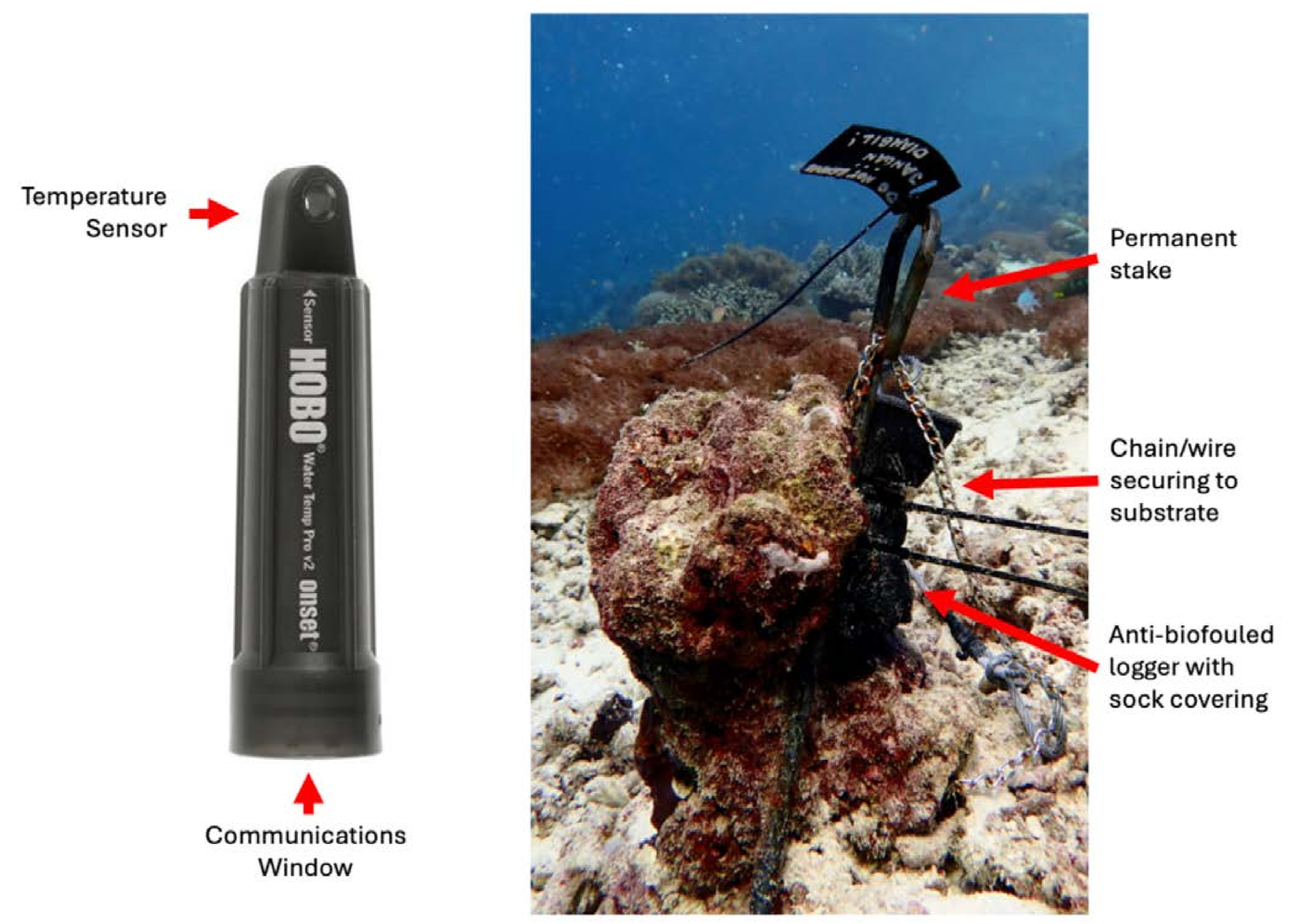

Image 1 *Diagram depicting a HOBOware V2 Temperature Logger used to collect data. Different aspects of the logger are indicated as well as an image of a deployed logger off Barefoot Jetty, complete with anti-biofoul gear and other equipment (ie. stake) to permanently secure to the substrate.*

METHODS

The Temperature Logger Project is nested within the Coral Ecology Monitoring Project at Barefoot Conservation. Initiated in June of 2024, the goal of the project is to gain further insight into temperature patterns across the central Raja Ampat regency by monitoring fluctuations in temperature across a depth gradient. Four HOBOware V2 temperature loggers were acquired, set to record one temperature data point every 5 minutes, and deployed off Barefoot Jetty on Arborek Island at four different depths of 1 metre, 5 metres, 15 metres, and 25 metres. At each depth, the loggers were secured to the benthos using a metal stake and covered with anti-biofoul gear, including electrical tape and fabric protecting the communications window (Image 1). The loggers are cleaned at least once a week by divers. Temperature loggers are downloaded every 5 months using HOBOware compatible software. Following download, the loggers are reset and re-deployed within a few hours to minimise data gaps. Temperature data is plotted in RStudio for accessible view of temperature fluctuations across a depth gradient at Barefoot Jetty.

As of January 2025 we now have two arrays of 4 HoboWare loggers collecting temperature data; 4 depths at Barefoot Jetty (presented below) and 4 depths at Yenbuba Jetty. Yenbuba jetty is a site that sustained severe bleaching during this year's warming event (more severe than Arborek) and so we wanted to capture the temperature fluctuations happening at this site. Data from these two sites will be presented in next year's report.

RESULTS

Data from the temperature loggers was last retrieved in November 2024 so does not capture the full extent of the building temperatures that peaked in December 2024 and causedwidespreadbleaching.InFebruary/March2025wewilldownload the temperature data from the bleaching event which will allow us to understand the temperature stress that corals were under.

During the five months between June to November 2024, the highest values of temperature across the four depths were in mid-October to early-November (Figure 1.5a). Average temperature across the four depths was highest in the month of October at 29.75°C (Figure 1.5a). Temperatures at the shallowest depth of 1 metre saw the biggest overall temperature fluctuations (low: 27.60°C; high: 30.87°C), whilst the deepest depth of 25 metres saw the smallest fluctuation in temperature (low: 28.05°C; high: 30.39°C) (Figure 1.5b) surprisingly these temperature ranges are not considerably different from each other, which suggests considerable mixing is happening between depths, rather than clear thermocline shoaling.

The very low temperatures experienced at the shallow depth (1m) is likely related to large rainfall events.

Looking at temperature fluctuation over a smaller time frame, we can directly compare the influence of external factors such as tidal movement. Figure 1.6 presents temperature fluctuations during a week surrounding new moon (Figure 1.6a) which generally has smaller tidal movements and weaker currents, and during week surrounding full moon (Figure 1.6b) which generally has more extreme tidal movements and strong currents and upwellings. During new moon, temperatures ranged from a high of 30.34°C to a low of 28.05°C (Figure 1.6a), however daily fluctuations remained consistently between 29-30°C for the majority of the week. During full moon on October 17, temperatures ranged from a high of 30.87°C to a low of 28.22°C (Figure 1.6b), with daily fluctuations visibly larger.

Importantly, data demonstrates that the 4 depths are well mixed, with large temperature variations (during big tides) matching up closely across the 4 depths and following the same patterns i.e. all four depths drop down to ~ 28.8°C on Oct 19th instantaneously (Figure 1.6b). This temperature profile suggests that the coolest water is being brought up to shallow depths during these timepoints, resulting in all depths reading the same temperature values. This is likely as a result of strong upwellings, and it may be that this unique hydrodynamic pattern is what is (somewhat) protecting Raja Ampat reefs from bleaching. Whilst shallow depths warm up considerably at times, probably during low tides (Figure 1.6b), it is never more than a few hours before cold pulses of water from the deep cool down these depths. The onset of bleaching this year may be related to the new baseline temperature at deeper depths which are no longer providing such cool flushing that has protected the reefs for so long. Continued monitoring of temperature data and how this matches up with bleaching is warranted for a full understanding of these processes.

DISCUSSION & FUTURE GOALS

Our results display interesting findings about thermal fluctuation in the region. We not only found these fluctuations to occur across a depth gradient, but also change in relation to external factors such as lunar cycles and season. We found that average temperature across all four depths gradually increased from July to November 2024 which was consistent with results from our Bleaching sub-project, which saw increased bleaching scores between August to November 2024. Within this steady increase in temperature, the temperature logger stationed at the shallowest depth of one metre recorded the highest thermal spikes, particularly around the October full moon.

Full moons in Raja Ampat are closely linked to increased tidal range and stronger currents, suggesting a relationship between current and thermal extremes. In contrast, all depths recorded significantly reduced fluctuations in temperature during the new moon in September 2024. This further suggests that a reduction in current reduces the occurrence of temperature extremes across a large depth gradient.

In the future, we will continue to record temperature at the four established depths off our jetty on the eastern tip of Arborek Island, as well as at our new monitoring site Yenbuba. We will collect this data every five months to provide a consistent record of temperature fluctuations not only over a depth gradient, but also under changing environmental factors from season to season. Collecting data at multiple sites and depths will demonstrate the influence of different environmental conditions on local hydrodynamics and temperature profiles. This data will be essential to further interpreting results from other projects and subprojects such as Cyanobacteria and Bleaching. This will help to further expand our understanding of the intricate relationships between temperature and these factors (ie. current). This novel subproject provides one of the first consistent records of sea surface temperature across central Raja Ampat, and is invaluable as we look to increasing research and management in the region.

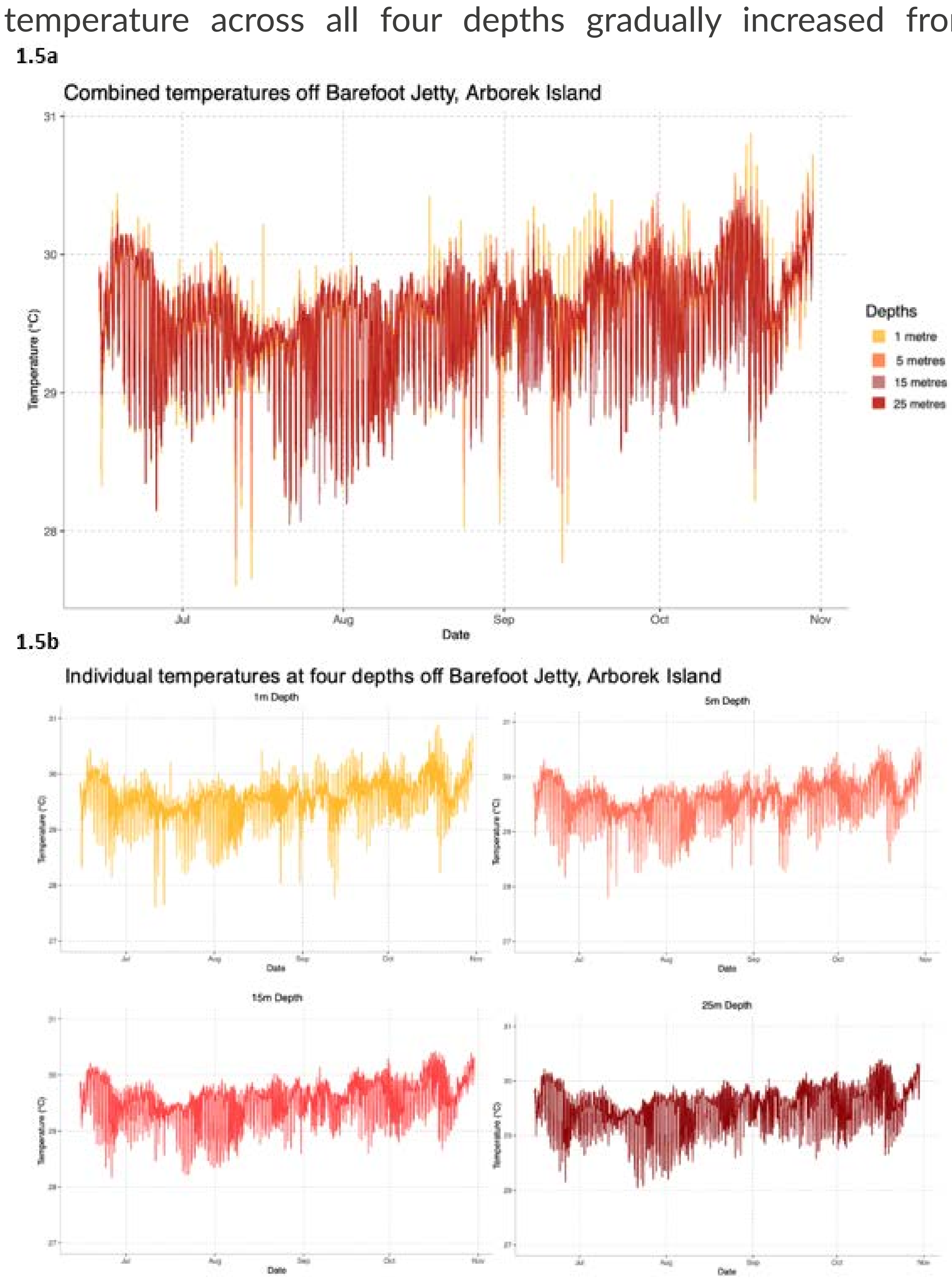

__Figure 1.5.__ Temperatures (°Celcius) at four different depths off of Barefoot Jetty, Arborek Island from June to November 2024. __1.5a.__ Combined line graph showing different temperature values by depth superimposed together. __1.5b.__ Individual line graphs separated by depth (1 metre depth, 5 metres, 15 metres, and 25 metres).

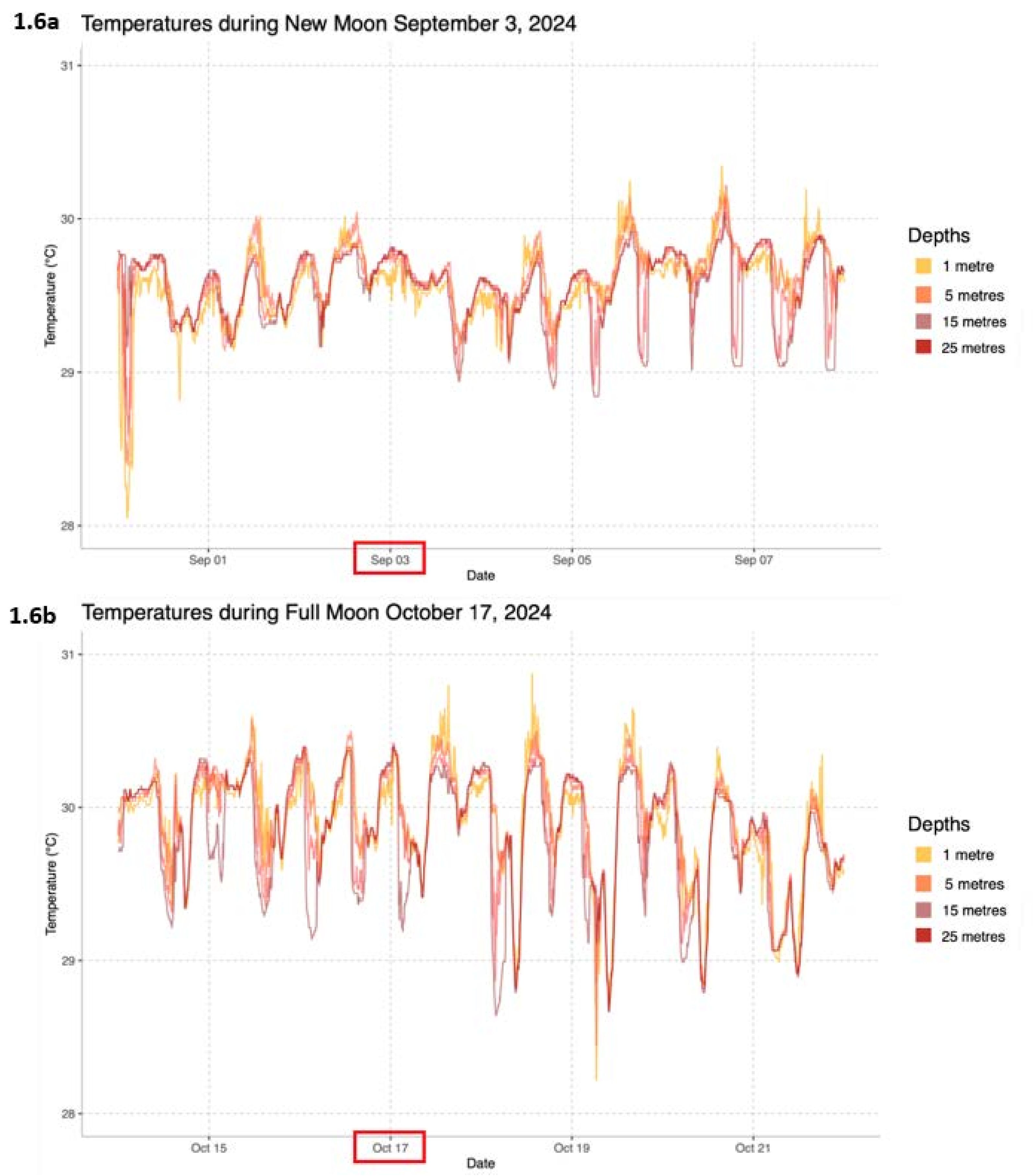

__Figure 1.6.__ Comparison of weekly temperature fluctuations during a New Moon and a Full Moon across four depths (1 metre, 5 metres, 15 metres, and 25 metres). __a.__ Combined line graph showing temperature surrounding a new moon on September 3, 2024 (highlighted in red). __b.__ Combined line graph showing temperature values surrounding a full moon on October 17, 2024 (highlighted in red).

DISCUSSION & FUTURE GOALS

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Photogrammetry

INTRODUCTION

Establishing consistent and accurate monitoring methodologies of marine ecosystems is often challenging and restricted by environmental and physical constraints, such as habitat type, tides and currents, as well as time constraints to completing complex surveys underwater. Photogrammetry is a relatively new methodology within marine research, only popularised within the past decade, and is designed to minimise these challenges. Through photogrammetry, researchers are able to construct two and three-dimensional model snapshots of reef ecosystems that capture a variety of different impacts from colony to habitat scale (Remmers et al., 2024). The Barefoot science team established the Photogrammetry sub-project in order to achieve this overarching goal of capturing a large dataset in a single survey. Specifically, the Photogrammetry sub-project aims to build on ecological intelligence of our local reefs as well as increase future monitoring capability across a range of current and future science projects.

The photogrammetry project was specifically set up to capture bleaching prevalence over a wide spatial area that incorporates multiple coral taxa and enables fate-tracking of corals through time. However, this project has additional benefits of tracking success of our restoration project and broadly capturing other changes in reef health over time. This sub-project holds huge potential for the Barefoot science program over the coming years.

Methods

Photogrammetry Surveys are conducted within the Coral Ecology Monitoring Project at Barefoot Conservation and occur fortnightly at three sites, Arborek Tip on the northeastern side of Arborek island, JPP seamount to the east of the island, and most recently Yenbuba Jetty. At all sites, a 10-metre by 10-metre plot is marked by permanent stakes in each corner. The plot at JPP is situated behind the southern protected side of the seamount at roughly 7-12 metres of depth. The plot at Arborek Tip is situated over the established Barefoot Conservation nursery frames and outplanted nursery of Acropora sp. colonies at approximately 8-15 metres of depth. The plot at Yenbuba is in front of the jetty at approximately 12-16 metres of depth.

During a survey dive, transects are laid around each of the stakes, forming a visible 10-metre by 10-metre plot. Four divers semi-deploy four SMBs and attach them to each stake, thereby demarcating each corner of the plot. Two additional divers lay five depth markers within the plot, ensuring that each marker is flat and completely visible, while a third diver records the depth of each marker as well as the depths of each stake. A depth marker is a barbell-shaped piece of metal with two white and black targets spaced 30cm apart (Figure 1.7b). Depth markers help to create perspective and scale when building the photogrammetry models. Once all the markers are placed and depths are recorded, a project scientist will then begin the survey, carrying three GoPros mounted 90cm apart on a straight metal rig. Each GoPro will be set to capture one image in linear mode, every second. The project scientist will then swim approximately 1m off the reef and complete five S-shaped flybys parallel to the reef slope followed by five flybys perpendicular to the reef slope. Each flyby should take approximately two minutes with the whole survey taking 20 minutes to complete and each GoPro capturing roughly 1,000 images (3,000 images total per survey).

Once the underwater portion of the survey is completed, all images are uploaded onto a secure hard drive and all metadata is recorded for later construction of the orthomosaic. Orthomosaic models are constructed via the Agisoft Metashape software and use thousands of images as well as necessary metadata to stitch together a single high-resolution 2-dimensional image on an xyz plane. Some of the necessary metadata, such as the recorded depths of the depth markers, are crucial to build scale and perspective within the model in order to allow for size comparisons between biological elements such as hard coral cover. Following construction of the model in Agisoft, we will use annotation software such as TagLab to segment (draw around) each coral colony and identify additional elements such as species, level of bleaching, and status (dead/alive) to every coral colony in the plot. Repeating this process for every orthomosaic we build over the years will allow us to accurately and consistently track colony growth, survival and bleaching prevalence though time, alongside other projects such as our temperature and cyanobacteria monitoring.

This year, our first orthomosaic model was built by collaborators at NOAA, however, in coming years our staff will gain training in the step-by-step process and we plan to build and analyse all future models on site at Barefoot Conservation. This year we achieved our primary goal of testing whether photogrammetry would be a feasible and accurate monitoring methodology to add to our science program and next year we hope to build on these initial steps and improve this modern monitoring technique. Data from our fortnightly photogrammetry monitoring surveys are stored and are ready for processing and analysis which will take place in 2025.

RESULTS

After a few trials perfecting our methodology, we were able to achieve the desired result of a 10m x 10m high resolution orthomosaic map. The orthomosaic model was constructed by our collaborators at NOAA Coral Reef Watch. Figure 1.7 displays a screenshot of the fully constructed orthomosaic map, where elements such as hard coral cover, reef degradation, cyanobacteria cover, or other monitoring interests can be clearly observed and analysed using this software. Figure 1.7c highlights a single coral colony (Stylophora spp.) captured in high resolution, demonstrating how fate tracking of individual coral colonies will be possible with this technique. By constructing these same orthomosaic plots over time and overlaying each map to match up coral colonies we can ascertain which individual colonies experienced bleaching, which ones recovered/died and a whole multitude of other data (Figure 1.7c).

DISCUSSION & FUTURE GOALS

The potential of the Photogrammetry subproject is immense, not only for Barefoot's science program but for marine research in central Raja Ampat as a whole. This project represents one of the first uses of this methodology in the region, whereby our photogrammetry surveys will build a large and comprehensive dataset with which we can further analyse a wide variety of topics, from colony to ecosystem-level. We already suspect that these surveys will be useful for analysing the occurrence of bleaching events as well as recovery, alongside our Bleaching subproject. Additionally, comparing our orthomosaics at JPP (natural reef) with Arborek Tip nursery (restoration site) we will be able to monitor how our manipulated outplants are establishing on the selected degraded reef, alongside our Restoration project. Furthermore, the high-quality resolution and large size of each orthomosaic means that we can use the data to help answer research questions in the future. Photogrammetry provides holistic data of an entire ecosystem, and is widely considered the future of marine monitoring methodology. We hope to be a part of this and continue to grow the subproject alongside our other important monitoring projects. Continuing to work with collaborators such as NOAA, we further hope to expand our own training in the step-by-step process of photogrammetry analysis and begin to build the orthomosaic models ourselves at Barefoot camp.

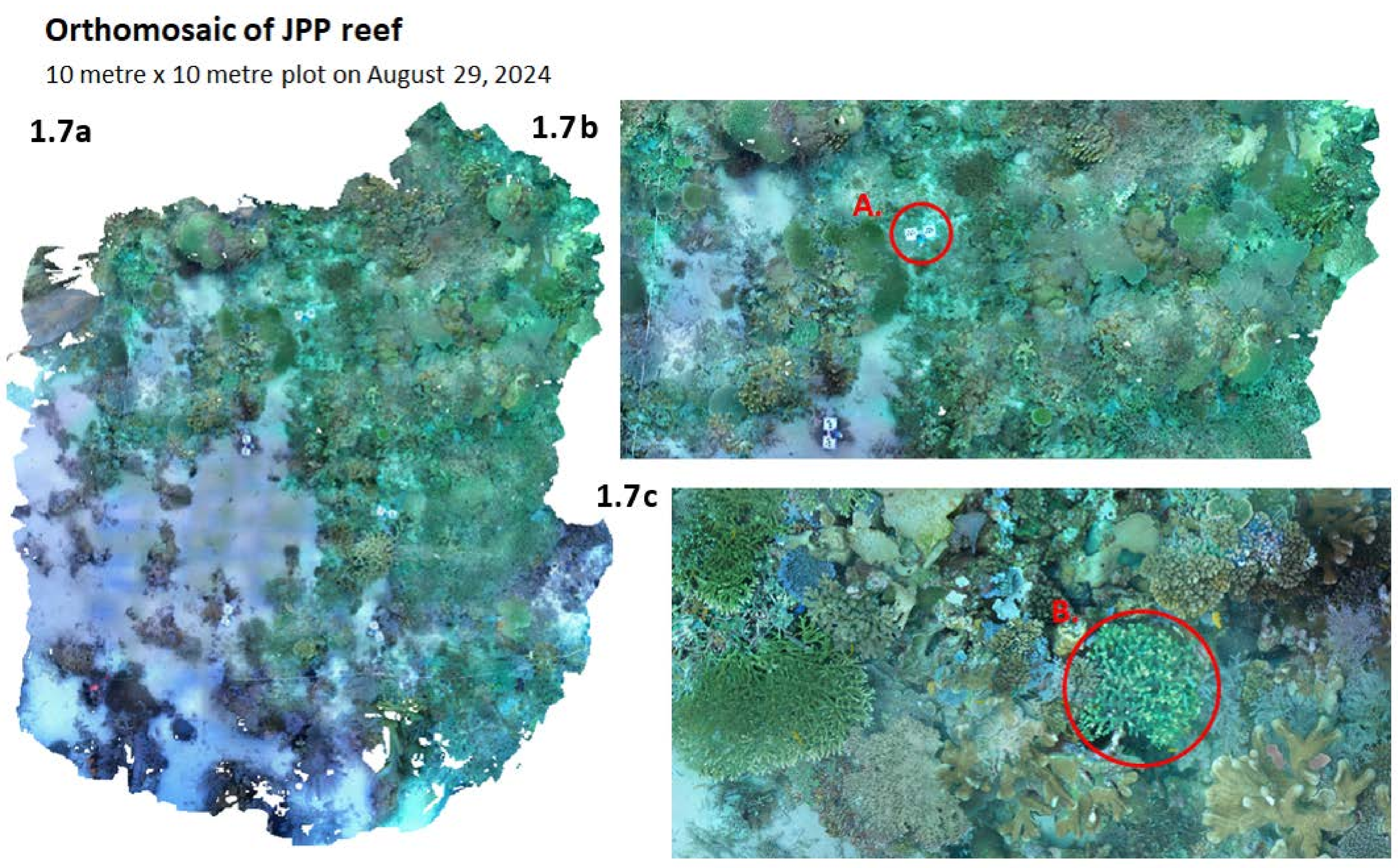


Figure 1.7. *Orthomosaic of JPP reef, 10 metre by 10 metre plot imaged on August 29, 2024.* ***a.*** *Wide view of the entire orthomosaic.* ***b.*** *Medium view of a section of the plot., Symbol A (highlighted in red) indicates depth marker used to build scale in the model.* ***c.*** *Narrow view of a smaller section of the plot, symbol B (highlighted in red) indicates a Stylophora sp., colonies which experienced a bleaching event in November and December 2024.*


Water Quality &
Cyanobacteria Project Report

INTRODUCTION

The Water Quality & Cyanobacteria Project continued in 2024 with ongoing efforts to monitor the spread of cyanobacterial mats around Dampier Strait, as well as new data collected on water quality parameters. Known to be closely linked to poor water quality, we continue to monitor the levels of cyanobacteria around the region in order to understand the threat it poses to coral reef health, while also using it as a proxy to understand more about pollution. Data of this kind is valuable for guiding government and stakeholder decisions regarding wastewater management in the region.

Cyanobacteria is one of the most diverse phylums of life on Earth, and as an evolutionary group is responsible for the presence of Oxygen on Earth and the existence of life as we know it. Despite this, cyanobacteria has been known to pose a threat to human and animal life since the late 1870s, when a report detailing its dangers was published in the journal Nature (Francis, 1878). Cyanobacteria are a type of photosynthetic microbe found in almost every environment on Earth. Often termed "blue-green algae", they are technically not, as they are prokaryotes (have no organelles) and not part of the evolutionary group of eukaryotes, which can be classed as algae. On coral reefs, filamentous cyanobacteria are of particular interest. This is the type of cyanobacteria addressed in this report. These cyanobacteria are able to form microbial mats which proliferate exponentially under the right conditions. As these mats attach to the ocean floor (substrate) and grow rapidly, they can compete with hard corals and other important, reef-building species, and threaten the healthy growth and turnover of coral reefs around the world. Cyanobacteria prevent coral larvae from settling on the substrate, while also killing new coral recruits with the release of cyanotoxins (Kuffner et al., 2006). Cyanobacteria have been a part of Earth's ecosystems for billions of years, but the introduction of nutrients from human sources, as well as warmer ocean conditions, provides an opportunity for cyanobacteria to upset the balance of reef ecosystems.

In Raja Ampat, the rapid growth of tourism since 2017 has placed strain on local sanitation systems. Most communities in West Papua rely on basic sanitation, such as leach pit toilets, which were sufficient for local populations but are inadequate for the sudden and considerable influx of tourists. Concerns have been raised about the seepage of these inappropriate and overloaded systems into the marine environment, as they introduce excess nutrients and pathogens to coral reefs.

Nutrient upload - the introduction of nutritive chemical elements and compounds into an ecosystem - can stimulate cyanobacteria growth. Similarly to plants and algae, cyanobacteria require nutrients to grow. The primary nutrients required by cyanobacteria are Nitrogen and Phosphorus, both of which are present at high levels in sewage/blackwater. Some cyanobacteria, including filamentous species, are capable of fixing Nitrogen from seawater, a process which gives them a competitive advantage over less harmful types of algae and other benthic (bottom-dwelling) organisms. In fact, nutrient availability has been found to be the greatest predictor of cyanobacterial biomass (Bonilla et al., 2023). In Raja Ampat, we have noticed an increase in cyanobacterial mat presence on the reef in recent years. This appears to be closely tied with the rapid increase in tourism in the region, but may also be precipitated by rising sea temperatures, which accelerate cyanobacterial cell division. As nutrient upload is the main predictor of cyanobacterial biomass, we can infer that the observed increase in cyanobacteria on Raja Ampat's reefs is due to greater levels of nutrients entering the ocean. The cyanobacteria monitoring project continued in 2024 with the objective of recording cyanobacterial mat proliferation around Arborek island and searching for correlations with external factors such as nutrient upload or presence of tourism operations. As well as providing an indicator for harmful levels of nutrients in the water, cyanobacteria also poses a direct threat to other organisms on the reef. Cyanobacteria produce toxins which are harmful to animal and plant life. These cyanotoxins bioaccumulate in target fishery species which can pose a threat to human health when consumed, with similar symptoms to the algae-caused Ciguatera fish poisoning. As well as harming humans, cyanotoxins enable cyanobacterial mats to compete with young coral colonies establishing on the reef, hindering hard coral growth.

Coupled with the severe coral bleaching observed in late 2024, there is the potential for a perfect storm of degrading factors to make landfall on the reefs of Raja Ampat. Following mass bleaching events, corals expel their zooxanthellae into the water, this also leads to a considerable increase in nutrient availability (Tebbett et al., 2022). If cyanobacteria is already commonplace on reefs, higher nutrient levels combined with bleaching-weakened corals provide an opportunity for cyanobacterial mats to smother and poison well-established, adult hard corals. Without appropriate solutions to minimize high levels of nutrients reaching the water, these reefs will have no resilience to the bleaching events which will surely increase in frequency and severity with rising global sea temperatures.

We hope that the Water Quality and Cyanobacteria Monitoring Project produces findings which lead to improved wastewater management guidance for tourism operations in Raja Ampat. By addressing this issue, we aim to mitigate cyanobacteria proliferation, protect reef ecosystems, and enhance human health in the region.

METHODOLOGY

Data collection commenced in June 2023 using video transects, however methodologies were redesigned in June 2024 to make use of improved monitoring techniques and analysis software. Data from June- December 2024 is used for the majority of analysis within this report, however long-term trends from 2023-present are presented in Figure 2.5.

Four key sites were surveyed monthly for a baseline understanding of cyanobacterial mat proliferation over time. Ad-hoc surveys were also conducted when cyanobacteria levels at other sites were noticeably high.

1. SITE SELECTION

Four key monitoring sites were selected around Arborek island with efforts to maximise the range of reef health and tourism impact sampled. The sites were Barefoot Jetty, Main Jetty, West Arborek and Manta Sandy (see Figure 2.1). GPS devices were used to ensure surveys were conducted at the same survey location each time.

The Barefoot Jetty survey site (0°33'54.0"S 130°31'12.0"E) begins at the Barefoot jetty and leads Eastwards towards Arborek island's Eastern tip. Barefoot Jetty was chosen with efforts to monitor Barefoot Conservation's nutrient upload via sewage onto the reef. With up to 25 volunteers at a time, the project represents a large proportion of tourism on the island and therefore there is a great necessity to monitor our impact. Composition of this site is predominantly rubble, with interspersed hard coral bommies and soft coral (Xenia sp.) dominant in areas. The Barefoot Jetty survey site also covered some of the Barefoot Conservation restoration area, with outplanted corals and the coral nursery which aim to stabilise rubble on the reef and enable recruitment of hard coral. Whether this stabilisation had any impact on cyanobacterial mat proliferation was of interest, as we hypothesise that it may provide some shelter for cyanobacterial growth, or enable other space occupiers (hard coral, soft coral) to grow instead and compete with cyanobacterial mats. This site frequently experiences strong currents. On the Eastern tip of the reef it is subject to very high rates of water flow on falling tides. In summary, the Barefoot Jetty site represents a somewhat-degraded reef, highly exposed to current, with a relatively low amount of hard coral cover and a potential nutrient upload due to the proximity to Barefoot Camp.

The Main Jetty survey site (0°33'48.3"S 130°31'07.3"E) begins at the jetty and leads Westwards along the North side of Arborek island. Main Jetty was chosen to match the conditions of Barefoot Jetty, with the main difference being proximity to sources of nutrient upload. Main Jetty is situated next to multiple homestays and a substantial public toilet and thus we predicted there may be a greater nutrient upload. This site also has similar levels of degradation and a section with restoration efforts. The site is exposed to similar levels of water movement as Barefoot Jetty. In summary, the Main Jetty site was chosen to mirror the conditions of Barefoot Jetty, yet with greater proximity to tourism operations.

The West Arborek survey site (0°33'59.6"S 130°30'24.9"E) begins at the Western tip of Arborek's fringing reef, and heads North-East. West Arborek was chosen to act as a control site with minimal impact from tourism, as it is at the greatest distance from Arborek's land area possible, while still being on the same reef. We predicted that this would provide a site on the island with minimal nutrient upload from tourism operations.

Figure 2.1. *Map of four key cyanobacteria monitoring sites around Arborek island. Scale shown in bottom left-hand corner. Image taken from Google Earth.*

The site has similar bottom composition to Barefoot and Main Jetties, with less rubble and degraded reef. The composition consists of coral bommies interspersed with rubble and a larger proportion of sand, and in some places and depths, uninterrupted hard coral cover. The site is less degraded than Barefoot and Main jetty with respect to coral damage, however some signs of damage can be observed. The site also exhibits very different currents to Barefoot and Main Jetty. Situated on the Western end of the reef, it is exposed to strong currents on a rising tide. Due to the seabed topography, water flow generally does not reach the high speeds seen at the opposite end of the island, but the site is still highly exposed to current.

The Manta Sandy survey site (0°34’47.8”S 130°32’31.9”E) begins 20m to the right (reef left-hand shoulder) of the dive site entry buoy, and extends towards the buoy and the manta ray cleaning station. Manta Sandy was chosen as a key site to represent a reef with heavy degradation (due to historic blast fishing) and high impact of dive tourism. The bottom composition at Manta Sandy appears dominated by macroalgae and soft coral, with limited hard coral and near-negligible presence of exposed abiotic substrates (rubble, sand, rock) within the survey site. Manta Sandy is one of the most visited dive sites in Raja Ampat, with over 120 divers a day during peak tourism season (booked to dive, BLUD). Due to the presence of large numbers of divers and liveaboard boats in close proximity to Manta Sandy, we anticipated it may be a site most likely to be disturbed by diver presence via impacting ecosystem functions; and also by boat presence via dumping of blackwater. In summary, Manta Sandy represents a highly-degraded site due to historic exploitation, as well as receiving the greatest impact from tourism.

2. SURVEY DESIGN

Cyanobacteria survey methodology was designed to align with methodologies used by other monitoring groups in Raja Ampat. Cyanobacteria surveys were conducted at two depths (8m, 12m) for each of the 4 key sites, and each depth was surveyed every month. These depths were chosen due to observation of cyanobacterial mats. Each survey consists of a 50m photo-transect. An underwater camera (OM Systems TG-7, PT-059 housing) and rig were used to take photos each metre (50 photos per survey) along the transect at a set distance from the substrate, in order to capture a standardised area of the reef. While moving along the transect, the position of the rig over the transect also alternated sides, in order to maximise the area of reef covered. The rig was positioned at the 0.9m mark for each photo, so that the distance (metre mark) along the transect could be seen in each photo, with the lateral edge of the rig being approximately 10cm away from the transect on alternating sides (Figure 2.2). The TG-7 camera was used in underwater wide mode, with white balance set at depth to ensure photos were taken with clear imaging of the substrate.

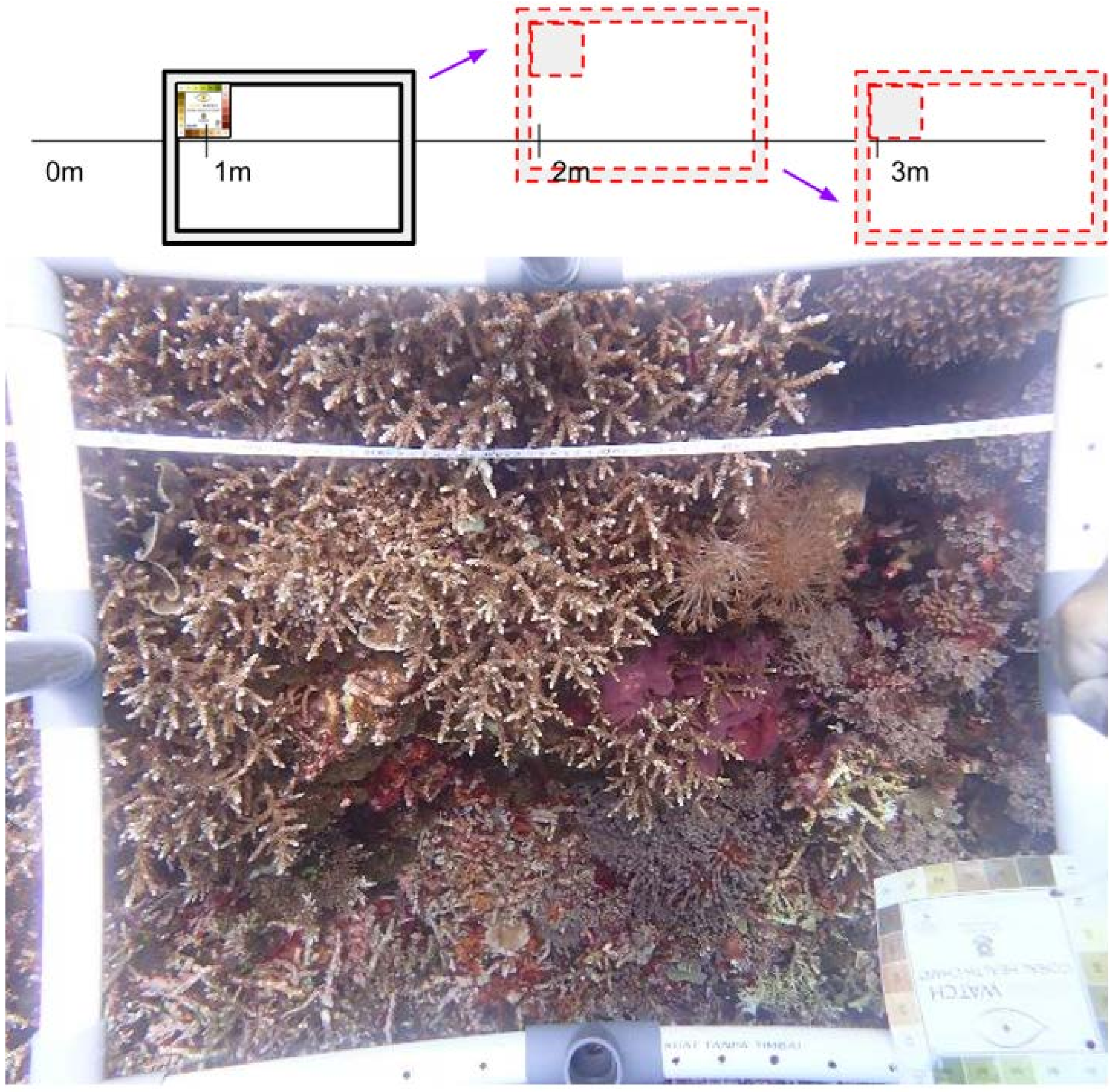


Figure 2.2. *Map of four key cyanobacteria monitoring sites around Arborek island. Scale shown in bottom left-hRig positioning (above) and photo example (below) for cyanobacteria monitoring survey.*

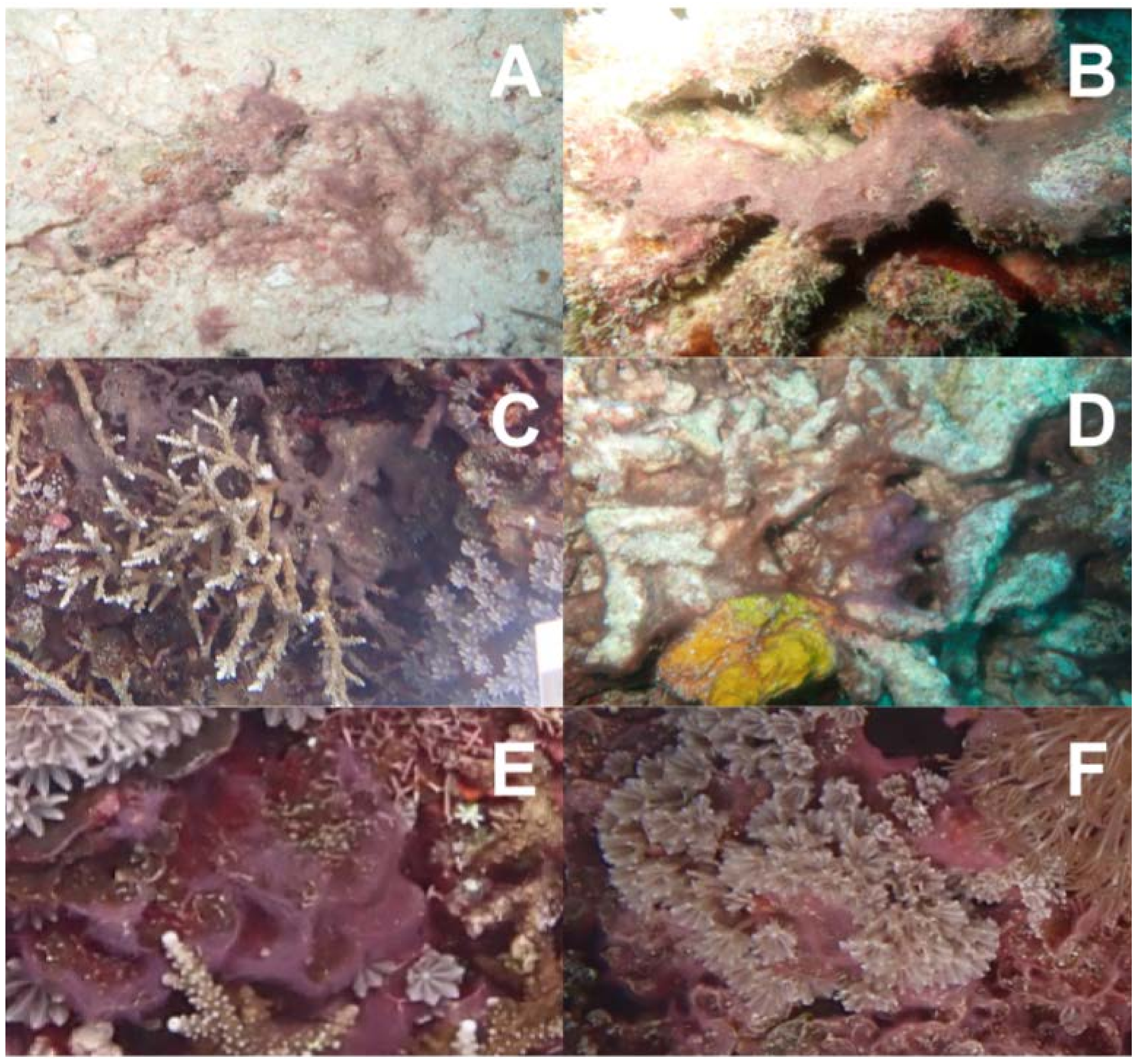


Figure 2.3. *Cyanobacterial mats growing on different substrates. A - Sand, B - Rock, C - Hard Coral, D - Rubble, E - Macroalgae, F - Soft Coral*

3. REEFCLOUD ANALYSIS

All photoquadrats from cyanobacteria monitoring surveys were uploaded to ReefCloud (Australian Institute of Marine Science) for artificial intelligence (AI) assisted analysis. Using ReefCloud accelerated post-dive photo-analysis, improving accuracy of substrate identification while enabling us to keep up with the quantity of data collected during these surveys.

ReefCloud uses machine-learning and pattern-recognition to semi-automate identification of substrate types. 30 points were randomly placed on each image, and the substrate beneath each point was identified. Initially this was carried out by project scientists and volunteers, but over time the AI was able to increasingly successfully identify substrates. Recently, the AI has been able to identify substrates with over 95% accuracy, with final checking by humans still remaining to ensure validity.

We created a label set with 44 different substrate types to classify bottom composition, including soft coral, hard coral, rock and rubble, and cyanobacteria on macroalgae, soft coral, hard coral, rock, rubble and sand (Figure 2.3). This label set is available for use or inspection on request (barefootscienceteam@gmail.com).

RESULTS

1. BASELINE BOTTOM COMPOSITION

Figure 2.4 illustrates the relative cover of different substrates (hard coral, soft coral, rubble etc) at each monitoring site and depth, proportional cyanobacteria coverage is depicted in purple. Benthic composition was found to vary considerably between sites. Proportional cover of cyanobacteria was considerably highest at Manta Sandy (8% at 8m depth; 9% at 12m depth), at all other sites it was below 1% for both depths, except West Arborek 8m (1.6%).

Rubble was one of the main components of all dive sites' bottom composition. Notably it was over 50% at one depth for Barefoot Jetty, Main Jetty and West Arborek. Manta Sandy exhibited a macroalgae and soft coral dominated system, with soft coral cover being 52% and 26% at 8m and 12m respectively. Manta Sandy also had the highest percentage of hard coral cover (31% at 8m). Manta Sandy had a lower abiotic substrate composition (6% and 26% for 8m and 12m respectively). All sites had higher hard coral cover at 8m than 12m, and Barefoot Jetty had the lowest hard coral cover of any site (12% at 8m; 3% at 12m respectively).

2. CYANOBACTERIA GROWTH OVER TIME

Cyanobacterial mat coverage (hereafter referred to as cyanobacteria cover) varied noticeably over time. Long-term trends indicate a slight decline in cyanobacteria cover at Manta Sandy and Barefoot Jetty between mid-2023 and mid-2024 (Figure 2.5), however, from August to November 2024, when monthly monitoring began, cyanobacteria cover increased across all four key sites.

By November 2024, mean cyanobacteria cover exceeded 1% of benthic coverage at all survey sites, and notably, coverage at Manta Sandy reached 12%. Cyanobacteria cover at Manta Sandy remained consistently higher than at other sites, only dropping below 5% in September before rising again to 12% in November which was likely a seasonal fluctuation.

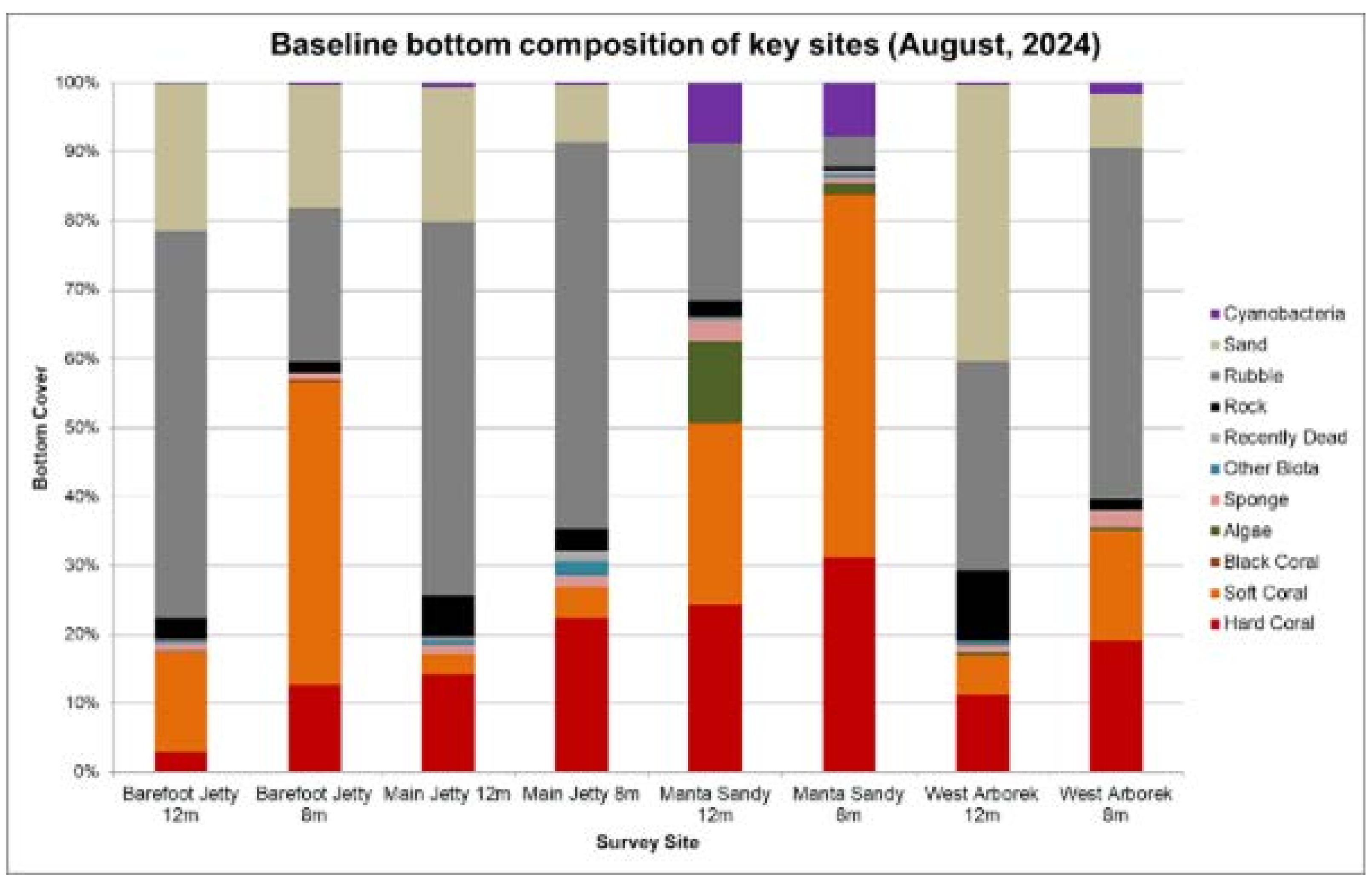


Figure 2.4. Relative frequency of different benthic groups at all key sites and both depths (August 2024). Cyanobacteria is displayed at the top of each bar for viewing ease.

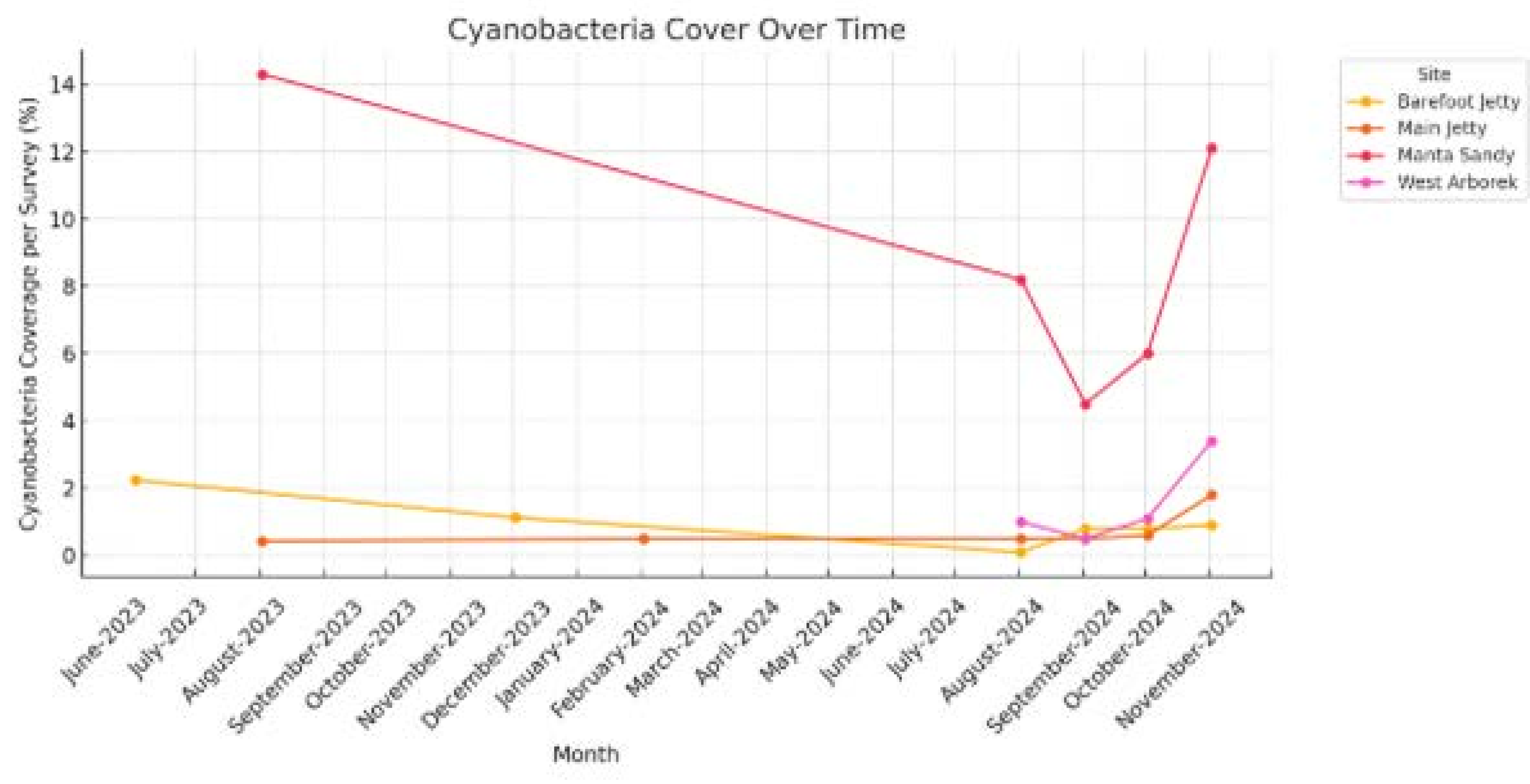
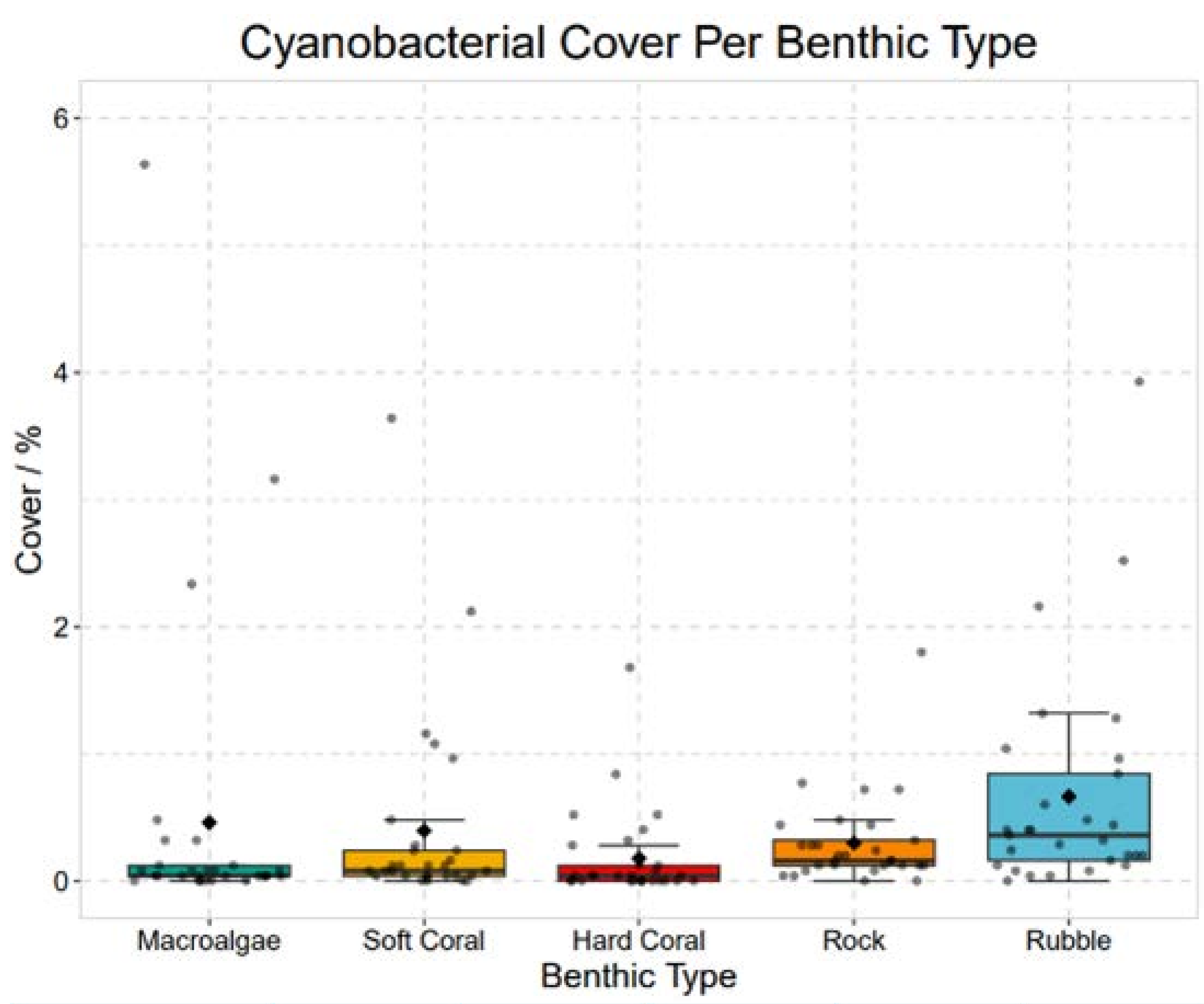


***Figure 2.5.** Cyanobacterial mat coverage over time for each dive site*

From August to November, all sites exhibited an overall increasing trend. Cyanobacteria cover at Barefoot Jetty, Main Jetty, and West Arborek increased more than 3.5-fold, with Barefoot Jetty experiencing the largest increase (4.8-fold). Manta Sandy cyanobacteria cover remains consistently high, but only increased by a factor of 1.5.

3. SUBSTRATE SUSCEPTIBILITY

Cyanobacterial mat proliferation was found to vary slightly depending on substrate type, however this difference was not significant between any groups in a one-way ANOVA ($p>0.1$). The mean values for each substrate are displayed in Table 2.1 with all data presented in Figure 2.6. Each point on Figure 2.6 represents the coverage of cyanobacteria on the given substrate for a single survey. The highest percentage of cyanobacteria coverage within a survey was cyanobacteria on macroalgae (5.64%) which was reported from Manta Sandy at the 12m depth in August 2024. Overall cyanobacterial coverage was highest on rubble and lowest on hard coral (Figure 2.6).



SUBSTRATE	MACROALGAE	SOFT CORAL	HARD CORAL	ROCK	RUBBLE
MEAN COVERAGE %	1.53	1.32	0.59	0.99	2.21

***Table 2.1.** Mean values of cyanobacterial coverage for different substrate types. Coverage is calculated as % of a survey which displayed cyanobacteria growth on that substrate.*

DISCUSSION

This project investigated spatiotemporal trends in cyanobacterial coverage. Examining spatial distribution of cyanobacterial mats provides insight into the environmental and human factors driving increases in cyanobacteria prevalence. Analysing temporal trends helps track its trajectory over time, capturing both seasonal patterns and informing predictions for future scenarios.

Monitoring key sites has revealed concerning trends, particularly at Manta Sandy, where cyanobacterial mat coverage is significantly higher than at any other site. Recent surveys recorded nearly 12% total coverage. Manta Sandy is one of the most visited dive sites in Raja Ampat, with over 120 divers per day during peak tourism season. Liveaboard boats, which frequently visit the site, are known to release blackwater (untreated sewage), leading to excessive nutrient loading in localized areas. Our data suggests that increasing cyanobacteria coverage at Manta Sandy is strongly linked to wastewater nutrient input, combined with the site's ideal conditions for proliferation.

Manta Sandy has undergone a phase shift to macroalgae and fast-growing coral dominance, likely reducing the reef's resilience to cyanobacteria. Fast-growing corals, which now dominate the site, have weak immune defenses compared to slow-growing hard corals, making the reef more susceptible to cyanobacterial proliferation. Due to its overfishing and loss of hard coral cover, Manta Sandy may also host fewer herbivore species than other reefs around the island. Top-down control by grazing is one of the main ways cyanobacteria can be removed from reefs, and perhaps, due to its loss of large and healthy herbivore populations (fish and urchins) Manta Sandy lacks the control measures to limit cyanobacterial proliferation.

Cyanobacterial coverage at Manta Sandy exhibited fluctuations, with a considerable decline observed in September 2024. This may be attributed to changes in water currents caused by the lunar cycle, as increased water movement is known to reduce cyanobacteria coverage by dislodging mats from the substrate (Tebbett et al., 2022). Tidal currents and the associated water movement in Raja Ampat vary drastically between different phases of the moon, and better understanding of the relationship between currents and cyanobacterial coverage may hold the key to understanding the nature of cyanobacteria dynamics in the region. To explore this further, we plan to measure water flow rates and investigate their impact on cyanobacteria proliferation. It is also possible that fluctuations are due to stochastic effects, and continued monitoring over the next year will help clarify these patterns.

In November we saw the beginning of the peak tourism season in the area, with the number of liveaboards located around the island going from 0 to over 5 a day, and the number of visitors to dive sites such as Manta Sandy increasing from around 10 (just Barefoot) to over 120. This beginning of the peak tourism season is also simultaneous with the spike in cyanobacteria observed at all sites around Arborek. Whether this relationship is causal remains to be seen, but if cyanobacteria levels drop after the tourism season is over (February) we may infer that tourism is responsible for the observed increase in cyanobacteria.

As part of the cyanobacteria monitoring program we also began measuring water quality at all the key sites, as well as a control (open ocean) site. We found that the content of blackwater was above the Indonesian National Water Quality Standards regulation limit at all key sites, and over 6x the limit at Main Jetty, and 4.5x the limit at West Arborek (particulates per 100mL seawater). The full results, which were analysed at KBL Lab in Jakarta, are available upon request (Barefootscienceteam@gmail.com). These findings reinforce the conclusion that nutrient pollution is a major driver of reef degradation in this region. Moving forward, regular water quality testing will be a key component of this project as we implement our first sanitation solution pilot project.

Following the mass bleaching event which began in late November 2024, we observed cyanobacteria-mediated mortality of severely bleached colonies. This aligns with other studies' findings that weakened corals cannot defend themselves from cyanobacterial proliferation, and is direct evidence that during bleaching events, cyanobacteria can reduce reef recovery by smothering hard corals and killing them. In 2025, we will visit some of the most severely affected reefs, to measure percentage mortality of coral colonies, and investigate the presence of cyanobacteria and whether it is a contributing factor. This data will also be captured as part of our photogrammetry project.

Also see Antipatharian Project Report (section 4) for prevalence of cyanobacteria on black corals.

FUTURE DIRECTIONS

Moving into 2025, the cyanobacteria project will continue to monitor the four key sites however we will also be adding an additional 4 sites to our monitoring programme. This will provide a better indication of spatial patterns of cyanobacteria coverage. After the tourism season and present bleaching event are over, we will have an unprecedented opportunity to measure the impacts of these stressors and cyanobacteria's role in reef degradation, this will be captured through our cyanobacteria surveys but also our photogrammetry data.

One of the primary aims of this project is to investigate the environmental stressors which are leading to changes in cyanobacteria coverage and reef degradation. We recognise that collecting water quality parameter data is pivotal to this, so we will continue to collect water quality data over time. We hope to acquire equipment to measure water quality on-site to monitor its change over the year. Collecting data on water movements will be a useful addition to this dataset, to investigate why cyanobacteria proliferates in some areas and not others. Raja Ampat is famed for its strong currents, and perhaps these may be its best defense against the spread of cyanobacteria.

We will continue to use ReefCloud software to analyse photo quadrat data which will improve the accuracy of the automated substrate classification over time. With increasingly efficient methods for analysing this data we may integrate this asset with other projects such as Photogrammetry to upscale the monitoring of Raja Ampat's reefs in terms of accuracy and breadth of monitored sites.

We will continue to study the degradation of Raja Ampat's reefs and their threats, and work to provide solutions which will benefit the entire ecosystem and the people whose livelihoods depend on it. We hope that the data arising from this project will be useful for mobilising action on water management solutions, to reduce the polluting of reefs in the area. The data presented in this report should be a call-to-action for urgent intervention.

Marine Debris Project Report

INTRODUCTION

One of the biggest threats to the beauty of Raja Ampat is its waste problem. With tourism in the region rapidly expanding and limited waste management facilities in Waisai for the increasing population, vast amounts of plastic waste are entering the ocean and being carried by currents and dispersed across the archipelago. Additionally, plastic debris from other regions of Indonesia and beyond accumulates in the Dampier Strait, traveling thousands of miles within massive floating trash patches, corralled by local currents. Over time, exposure to UV radiation and wave action breaks plastics down into microplastics, which infiltrate the water column. Both macroplastics and microplastics pose a serious risk to marine life—blocking digestive tracts, leaching harmful chemicals, and disrupting hormonal functions. On Arborek, we experience great quantities of waste temporarily washing ashore before being swept away again by the tides and winds, creating an ongoing cycle of pollution.

Over the past year, Barefoot Conservation has continued its Marine Debris and Beach Clean-up program, with dedicated staff and volunteers working to mitigate the waste problem on Arborek through regular beach cleans. However, tackling this crisis requires more than local action—systemic change is urgently needed. Without significant improvements to the waste management infrastructure of Raja Ampat and its inhabited islands, plastic pollution will only intensify. We hope that the data arising from this project, that we share with the local government and other environmental groups, will aid in mobilising action on the waste problem in this region.

Figure 3.1. *Marine Debris Project beach clean-ups occur twice weekly at 4 sites around Arborek Island.*

METHODS

Barefoot's marine debris project aims to remove large quantities of waste from the sea, but it also aims to quantify the abundance and composition of waste types which are littering the shores. This year the frequency of our beach cleans were increased to twice per week, at four designated sites, meaning each site is cleaned fortnightly. The four sites cumulatively surround the majority of the island and range from approximately 200m-300m (Figure 3.5). Beach cleans are attended by all Barefoot volunteers and staff, as well as the Ocean Warrior group of local children who are rewarded for their involvement in the clean-up initiative with stamps in their Ocean Warriors booklet (towards prizes).

Once all trash has been collected from the site, it is brought to Barefoot camp to be weighed, separated into 14 categories, and counted by our volunteers and Ocean Warriors. Trash is separated into 14 categories which encompass major materials like metal, glass, cardboard etc. but also capture particular problem objects on Arborek including, plastic cups and plastic ice pop containers. Once separated and counted, certain trash will be disposed of alongside Barefoot waste (cardboard, glass and metal) whilst the rest of the waste is taken to a more secure landfill site in Waisai outside the MPA.

RESULTS

In 2024 a total of 1,351kg (1.4 tonnes!) was collected and removed from Arborek shorelines. This included over 4,400 hard plastics, 3,773 single-use plastic cups, 3,673 plastic wrappers and 2069 plastic bottles, among multiple other items (Figure 3.2). Figure 3.3 presents the composition of this total waste. Plastic wrappers and hard plastics were the biggest contributors, both accounting for 18% of total waste. Hard plastic usually consists of bottle tops, lighters and fuel containers. One of our major concerns is the quantity of single-use plastic cups which we observe regularly on beach cleans (Figure 3.3b). These cups are sold cheaply and are a popular way to drink chilled water, including by communities in Raja Ampat.

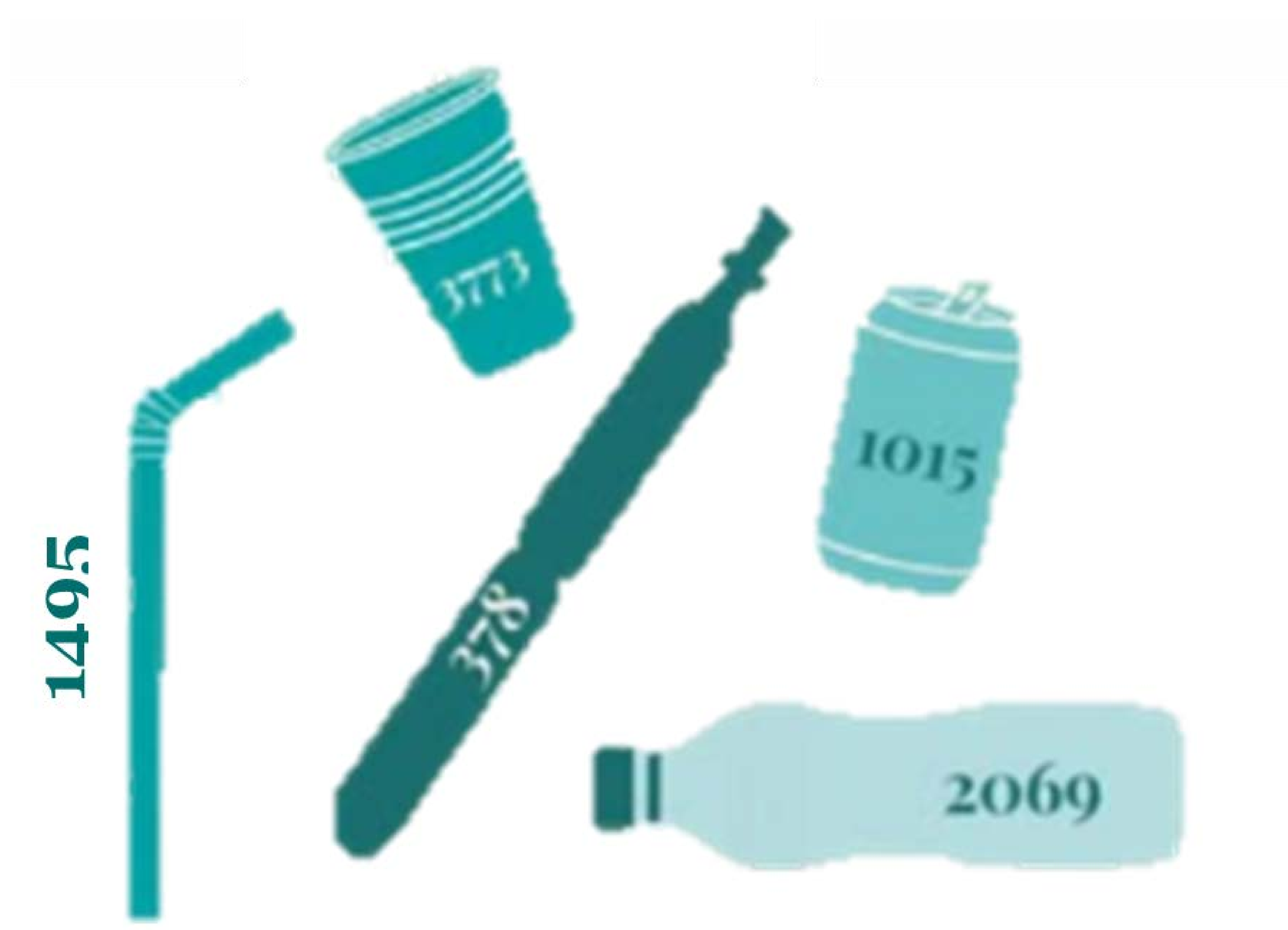


Figure 3.2. *Snapshot of some of the major contributors of waste collected in October 2024.*

Figure 3.4 presents the variation in waste collected over the course of the year. The dashed line represents the point at which 1 ton of waste was collected, which was a devastating milestone to be reached. The highest quantities of waste were collected between May to September. These temporal differences can likely be accounted for by seasonal changes in wind patterns across Raja Ampat. From June to September strong winds emanating from the south produce a higher frequency of storms and wave energy resulting in the transportation of larger quantities of trash to coastal areas (Yuanike et al., 2023). These higher quantities may also reflect the sampling effort we had in these months.

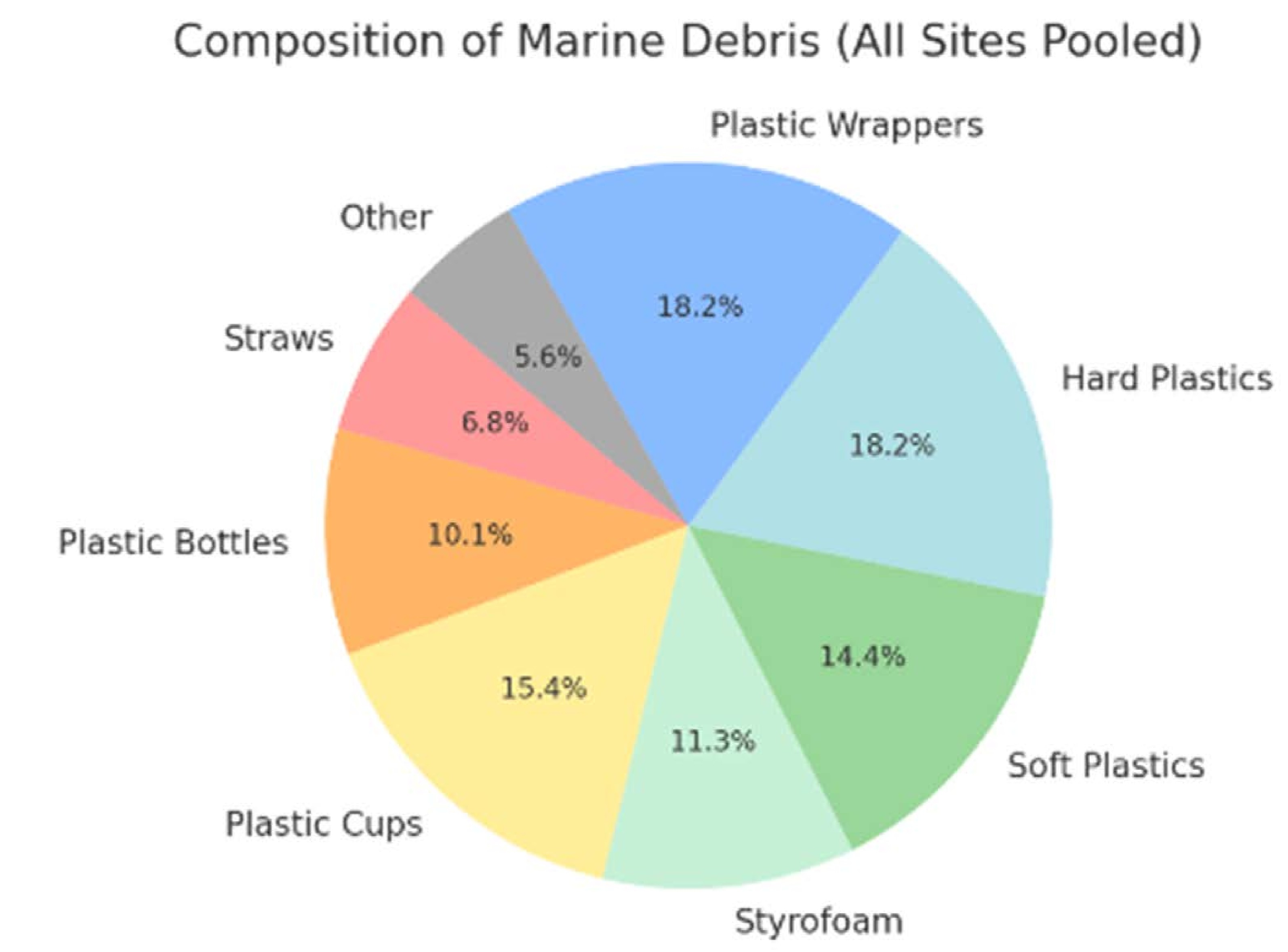


Figure 3.3. a *Relative proportions of marine debris collected during 2024 beach cleans (all data pooled)* ***b*** *single use plastic cups are a major contributor, shown after sorting* ***c*** *single use plastic cups*

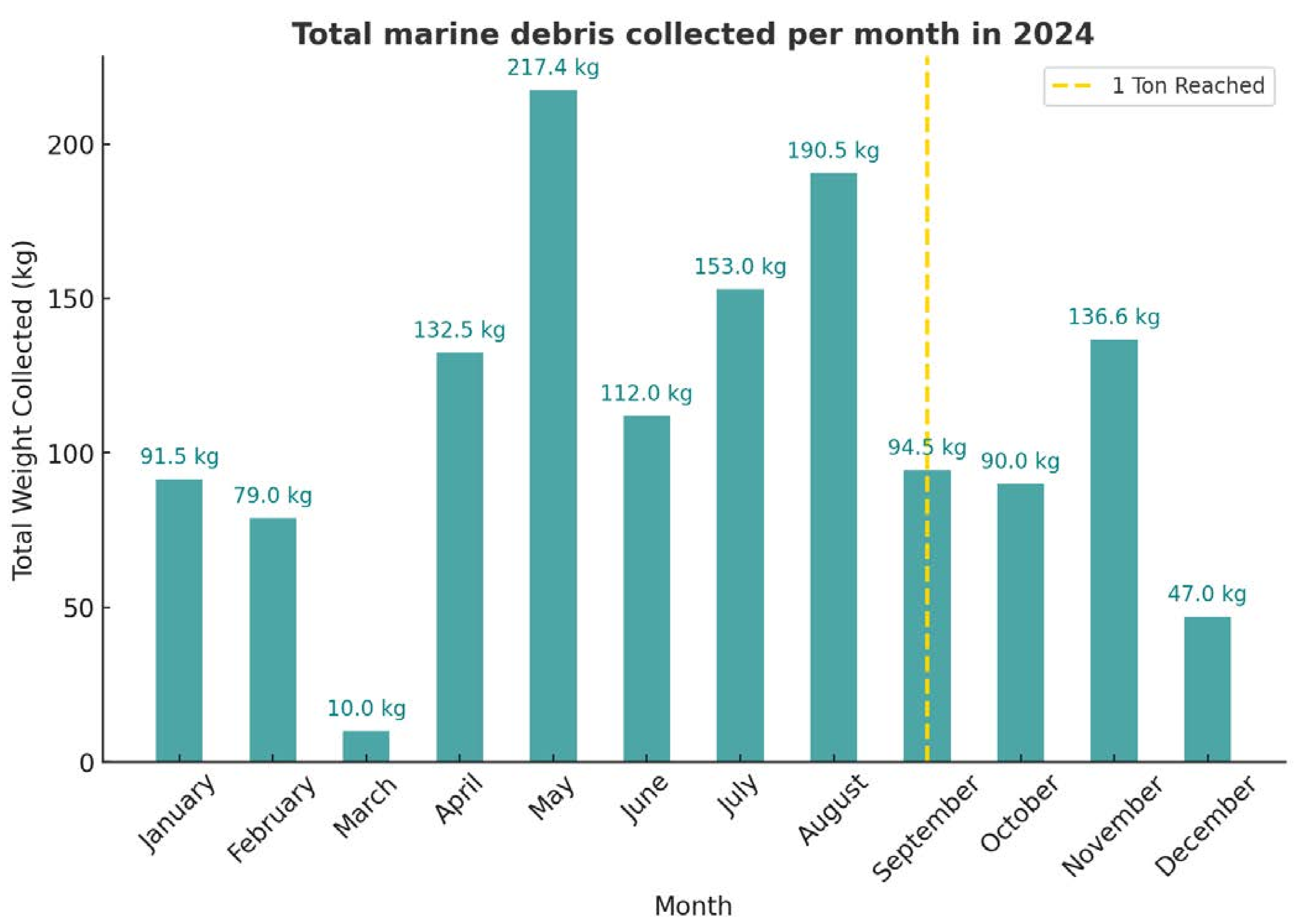
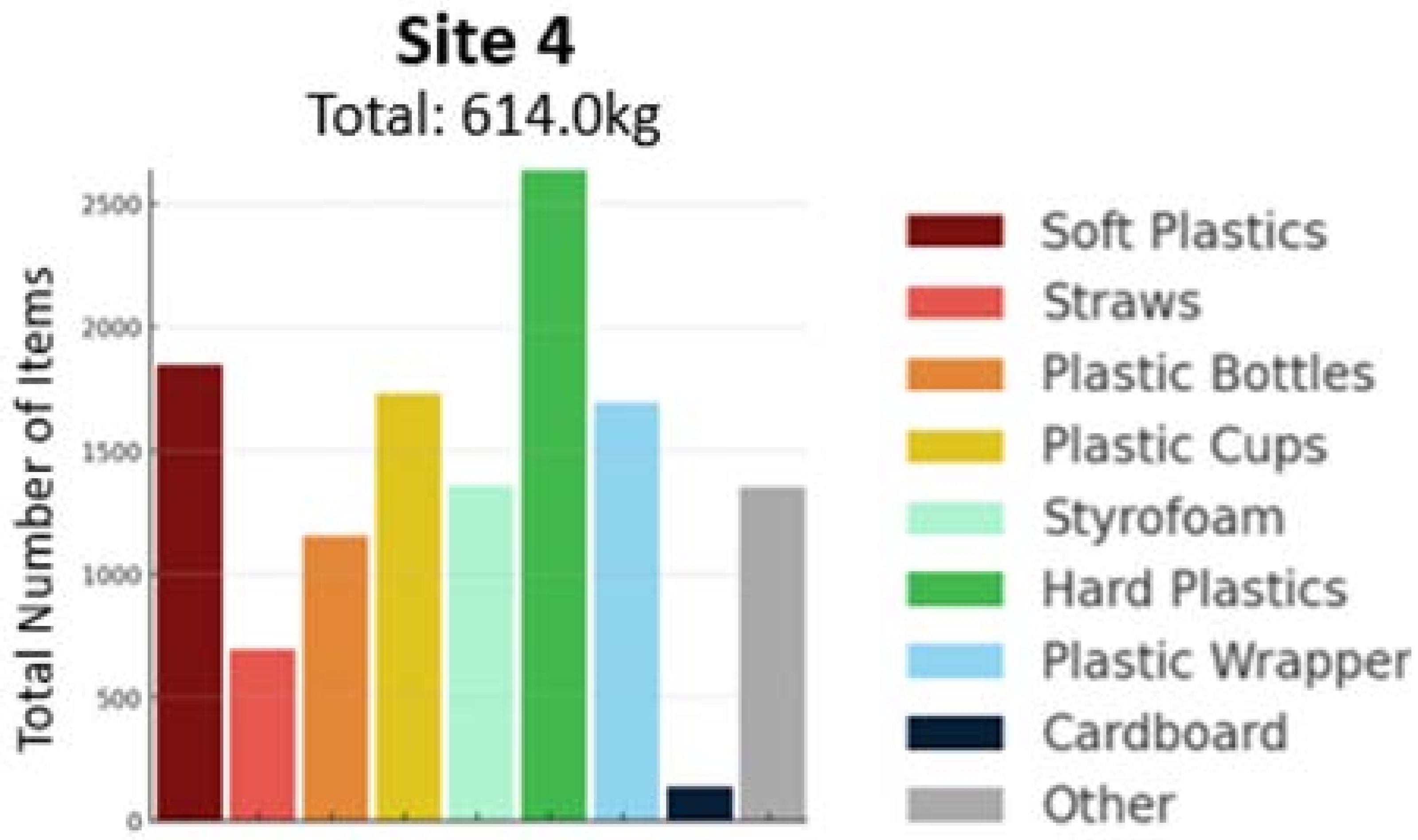


Figure 3.4. *Total weight of waste collected each month during beach cleans, presented from January – December 2024 with 1 ton (cumulative for 2024) milestone highlighted in month of October*

Figure 3.5 presents the quantity and composition of waste collected, split by survey site. Site 4, which is at the North-West side of the island consistently received the most waste volume (46% of total). This considerable difference is likely due to the prevailing wind direction which sweeps plastic into the mangroves of this site from South-westerly direction , where it becomes caught. The spread of plastics found at each site was relatively consistent with plastic cups and soft plastics (incl. plastic wrappers) the most common waste types at all locations. Considerably more hard plastic items were found at Site 4 which may be because these larger items get trapped in the mangroves.



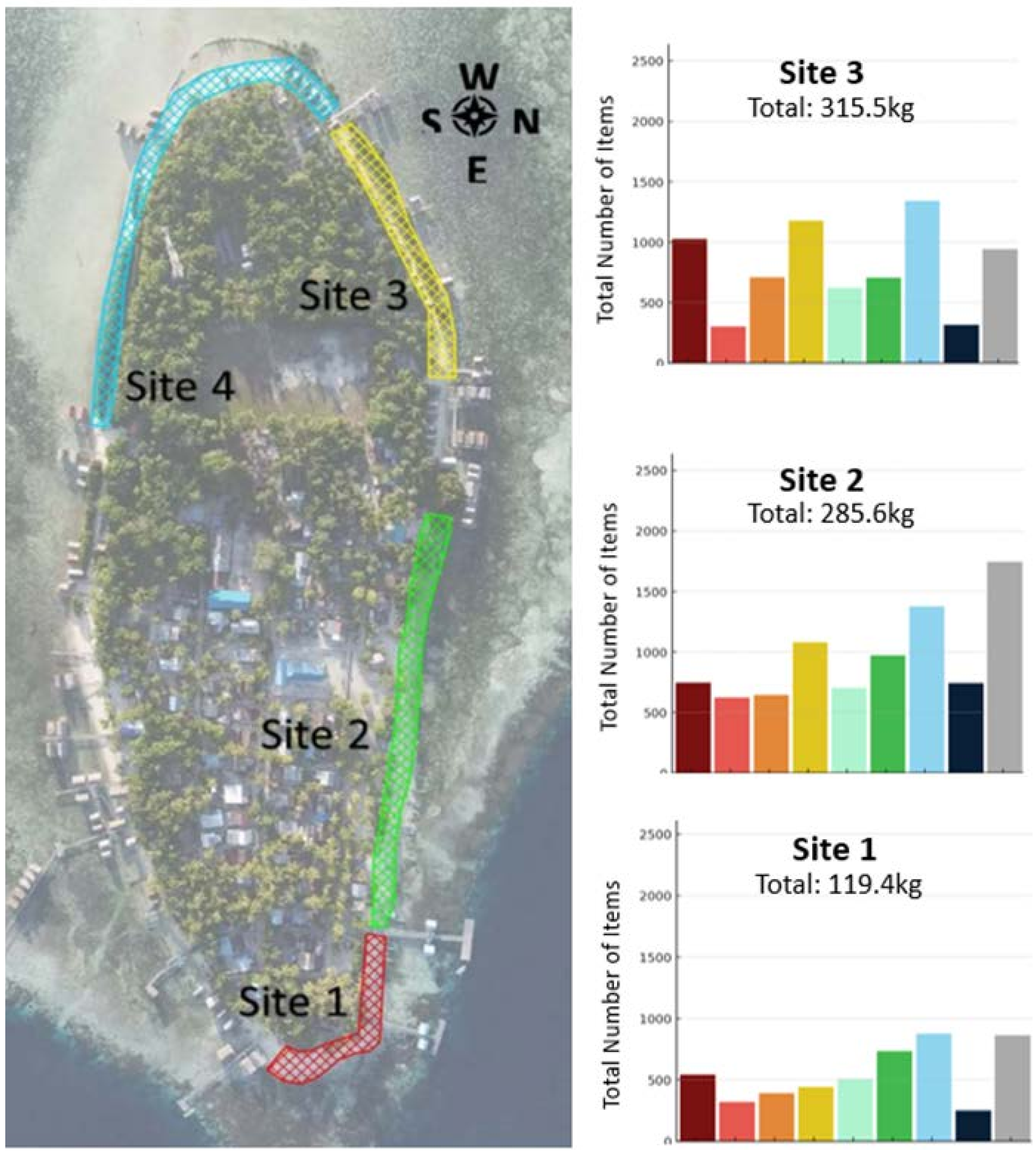


Figure 3.5. *Arborek Island with 4 survey sites marked. Relative composition of waste types collected at each site over the year are presented as bar charts along with total weight collected from each site.*

FUTURE DIRECTION

The data we have collected, which clearly outlines the extent of the waste issue in Raja Ampat and also highlights the most problematic waste types (plastic cups, wrappers, bottles), is vital for informing local level management solutions. Without a good understanding of the issue in hand and where the waste is coming from, it is very difficult to come up with a solution. We now have 2+ years of this fine-scale data which we have been providing to BLUD UPTD (MPA managers). With the knowledge

Antipatharia (Black Coral) Project Report

INTRODUCTION

Black coral (family Antipatharia) is a unique group of deep-sea corals known for their striking dark skeletons, which have historically been prized for use in jewellery and ornamentation. Unlike the more familiar reef-building corals (Scleractinia), black corals belong to a distinct group that thrives in deeper, cooler waters, often beyond the reach of traditional coral reef habitats. Black corals play a vital role in supporting marine biodiversity by providing habitat and shelter for a wide variety of marine organisms, including fish, crustaceans, and invertebrates. Often found in nutrient-rich, low-light environments such as mesophotic zones, these corals contribute to the overall health and stability of deeper ocean ecosystems. However, their slow growth—often less than 1 cm per year—and remarkable longevity, with some colonies exceeding 4,000 years in age, make them particularly vulnerable to overexploitation. Black coral harvesting for jewellery has historically posed a significant threat to their populations, leading to their protection under various conservation laws. Conservation efforts, including the establishment of marine protected areas (MPAs) and regulations limiting harvest, aim to safeguard these slow-growing species.

In Raja Ampat very little is known about black corals, including their diversity and distribution. By collecting data on Black Corals, we will be contributing to the understanding of this unique coral Order in the region. Through dedicated monitoring and research, this project will enhance the understanding of black corals in Raja Ampat, supporting long-term conservation strategies to protect these ecologically significant organisms.

SURVEY METHOD

To assess the spatial distribution of black corals, we surveyed 12 study sites in central Raja Ampat. At each site, we conducted visual transects to quantify black coral abundance and species distribution.

Each survey consisted of 100-meter transects laid at two depths: 8m and 12m. Observers worked in buddy pairs, swimming along the transect tape and systematically searching for black corals within a 3-meter-wide belt (1.5 m on either side of the tape).

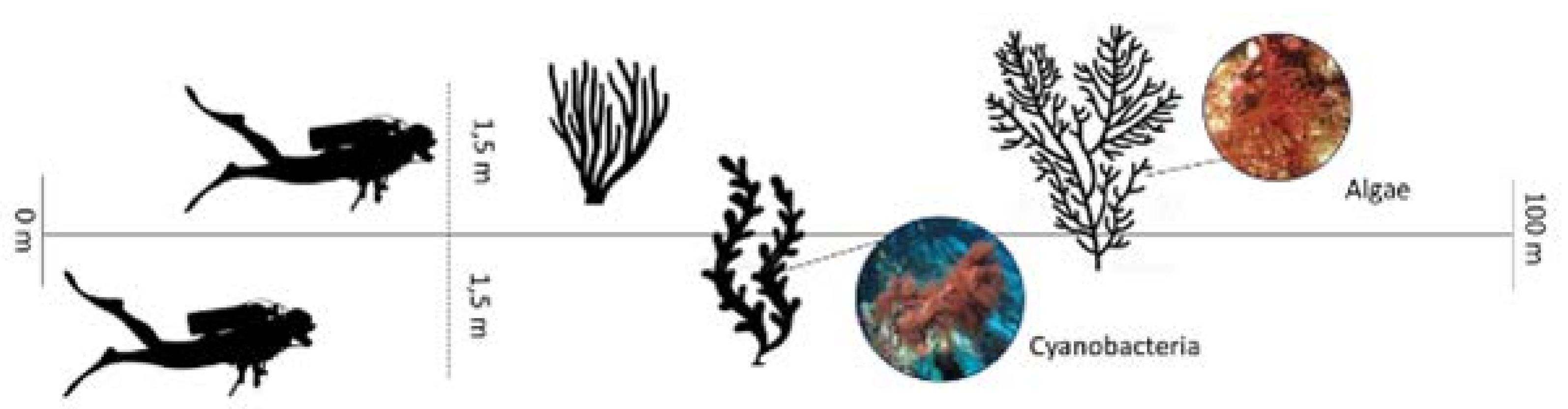


Figure 4.1. *Survey methodology during black coral surveys. Buddy pairs search 3m belt transect recording black coral abundance, growth form, and presence of cyanobacteria or algae on the black corals.*

For each black coral encountered, the following data were recorded:

- Growth form, categorized into four types (Table 1: Whip 1, Whip 2, Bushy, Leafy).
- Size, measured as width (for branching forms) or length (for whip forms) in centimeters.

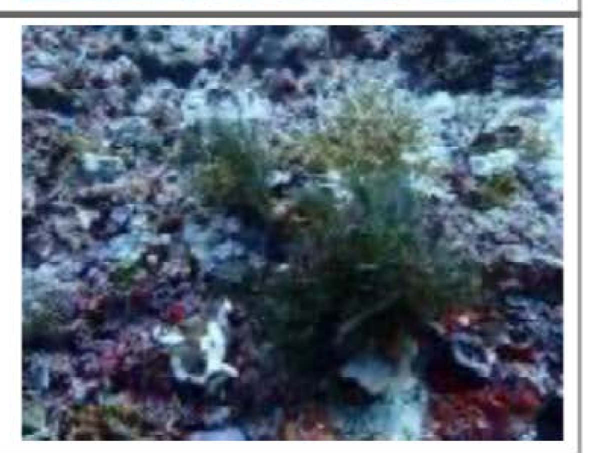
Whip 1		**Bushy**	
Whip 2		**Leafy**	

Table 4.1. *Classification of black corals during survey dives is grouped by 4 major growth forms – Whip 1, Whip 2, Bushy and Leafy*

RESULTS

In 2024 we had a total of 558 sightings of 4 target black coral around Arborek Island and Central Raja Ampat. Kalabia Homestay have the most black coral sightings consisting of 72 black coral which consist of 61 'whip 1', and 11 'whip 2'. Main Jetty recorded the least sightings of black coral with only 24 sightings of black coral. The spatial differences in abundance may be caused by underwater condition and human interaction, for example Main Jetty which has the lowest abundance of black corals also has the highest rate of human activity, with many boats, irresponsible divers and increased pollution.

In addition to recording the distribution and species diversity of Black Corals around the region, we also monitored the prevalence and coverage of cyanobacteria and macroalgae on black corals (Figure 4.3; Figure 4.4). Of all black coral colonies surveyed (n=1,125) 6.76% had cyanobacteria presence, whilst 10.76% had macroalgae presence, 1.24% of all colonies had both cyanobacteria and macroalgae present on the same colony. The proportional coverage was found to differ by growth form (Figure 4.4). Some sites had extreme proportions of cyanobacteria, for example 53.6% of all black coral colonies surveyed at West Mansuar (n=28) had cyanobacteria coverage. Other sites with high proportions of cyanobacteria coverage were Barefoot Jetty (25% colonies) and Mangrove reef (18%) of colonies.

We propose that nutrient pollution, resulting from inappropriate sanitation systems in Raja Ampat, is responsible for the high prevalence of cyanobacteria and macroalgae at some sites, which both thrive in nutrient rich conditions. This data suggests that black corals are highly susceptible to cyanobacteria interactions, possibly due to their extensive structures which are often positioned into the current. Further research into the association between black corals and cyanobacteria/macroalgae will allow us to understand future impacts and management strategies.

FUTURE DIRECTION

Future plans for black coral surveys are to target more sites and explore different depth profiles, as well as monitoring of specific tagged colonies of interest for health assessments. Establishing a long-term monitoring programs that tracks the health and

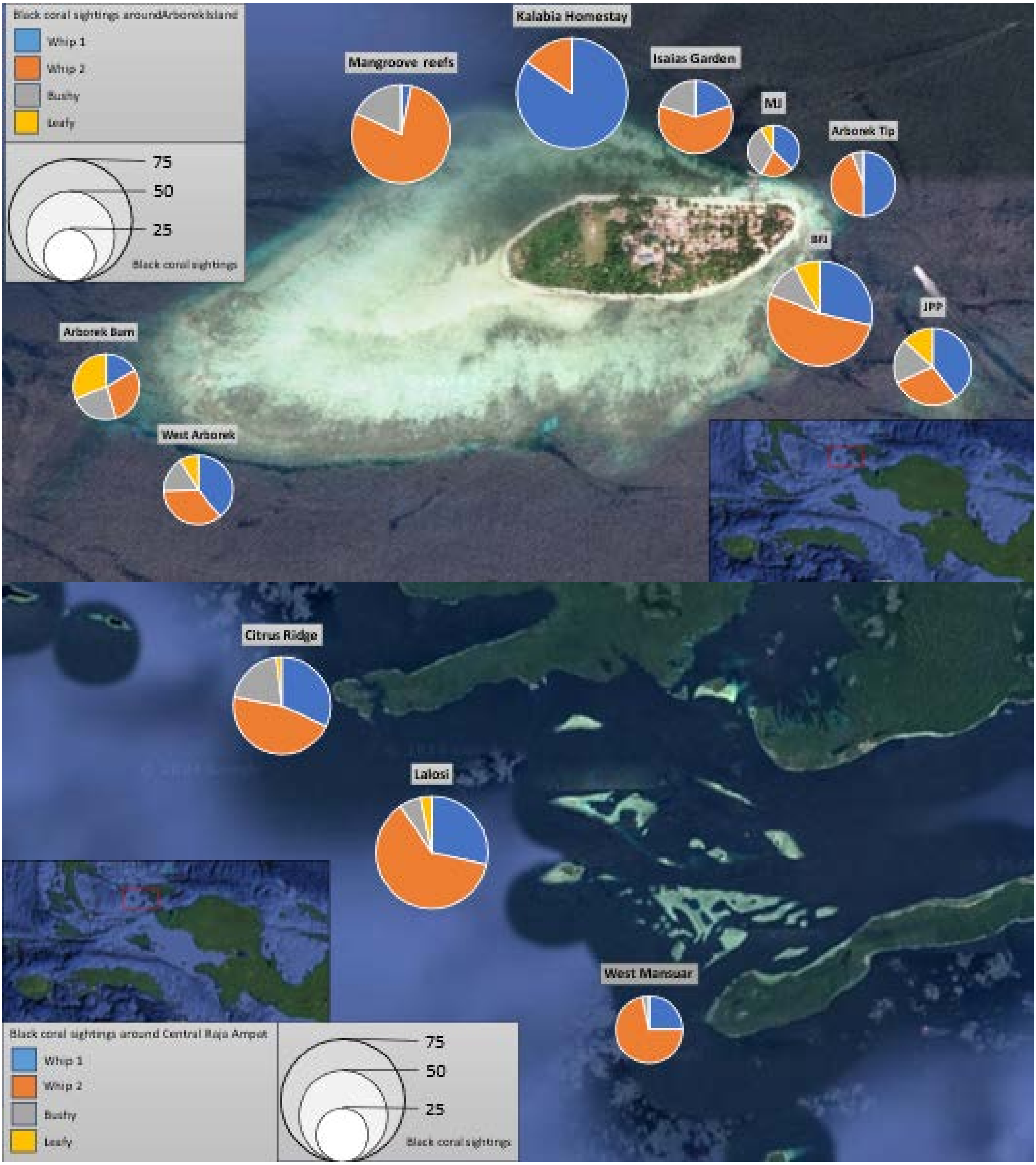


Figure 4.2. *Distribution and abundance of Black Coral sightings around a Arborek Island and b Central Raja Ampat. Pie charts present the proportion of each black coral growth form recorded at each site. Size of pie charts represents the abundance of recorded sightings at each location. Both depths are pooled. n=1,125*

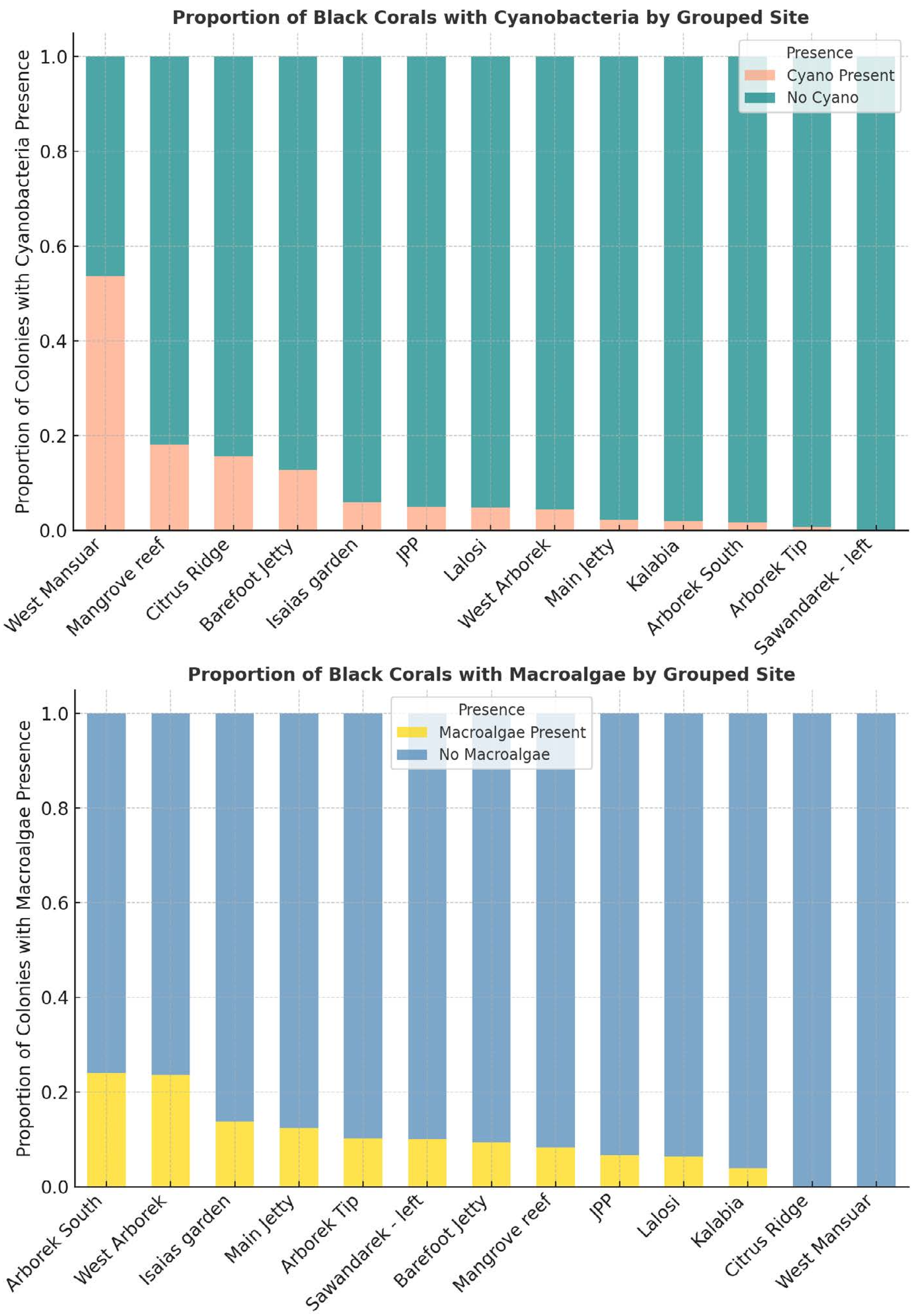


Figure 4.3. *Proportion of black coral colonies observed with presence of a cyanobacteria and b macroalgae, separated by dive site.*

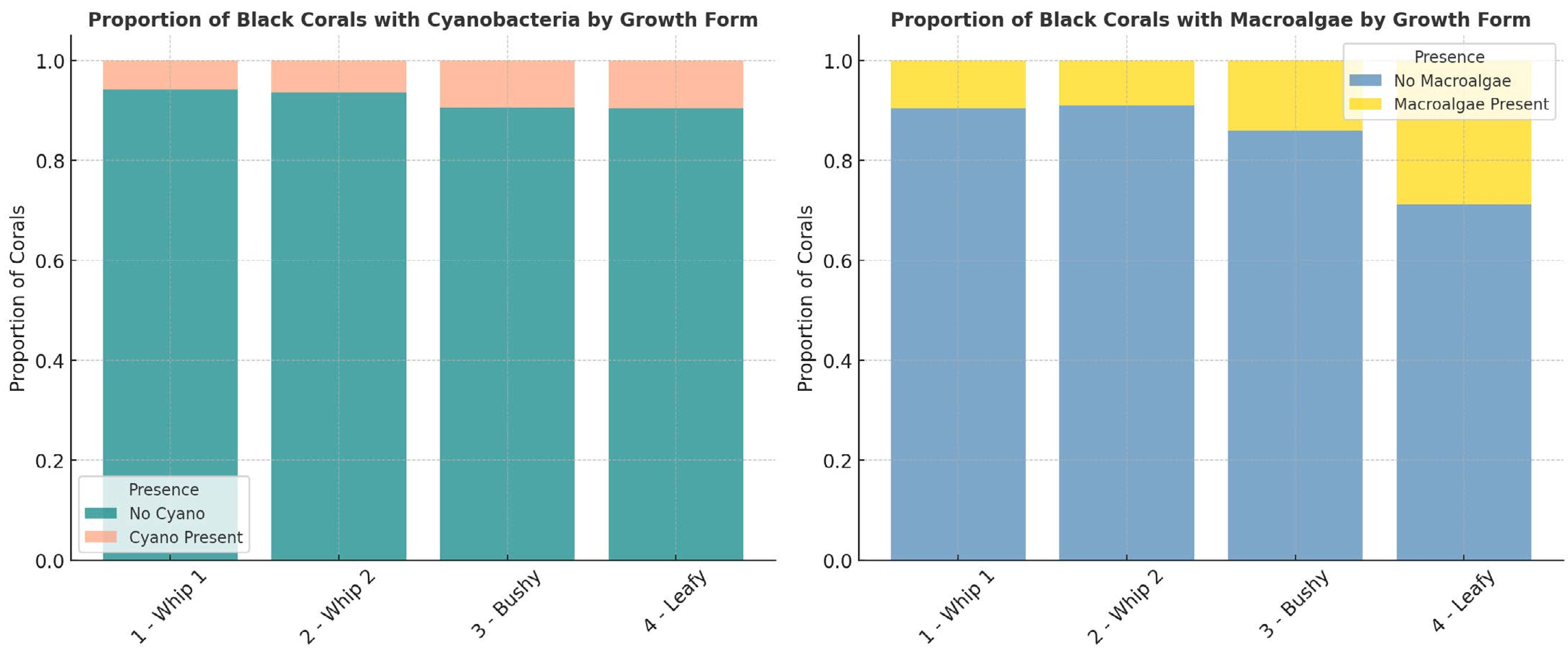


Figure 4.4. *Proportion of black coral colonies with a cyanobacteria presence and b macroalgae presence, separated by black coral growth form*

Reef Check Project Report

INTRODUCTION

Long-term monitoring of the reefs surrounding Arborek Island has been conducted since 2016, emphasizing the importance of tracking changes in coral reef health over time. The Reef Check method has been used to assess the health of coral reef ecosystems, focusing on key indicators such as benthic cover, fish abundance, and invertebrate abundance. Fish and invertebrate indicators were selected based on their economic and ecological value, and their sensitivity to human impact. To support this initiative, teams of citizen scientist volunteer divers have been trained to collect data on coral reef health. The involvement of citizen scientists is crucial in expanding the scope and frequency of monitoring, as they play a vital role in gathering large-scale data over time.

Around Arborek Island, nine core survey sites and four additional sites were strategically chosen to represent diverse reef habitats and levels of human impact, both naturally occurring and influenced by anthropogenic factors. Among these, Barefoot Jetty and Main Jetty have been selected as “impacted sites”, where coral reefs experience direct and sustained pressure from human activities, including recreational diving, tourism, and boat traffic. In 2024, we have been monitoring these sites at least every six months, with a total of 71 surveys conducted across all sites. The impacted sites have been surveyed at least four times within a year, at two different depths. The data collected from these surveys are reported annually to local policy makers in Waisai, The Raja Ampat Marine Park Authority and Management Unit (BLUD UPTD), and Reef Check Indonesia, thereby contributing to informed decision-making and sustainable management of the reef ecosystem.

METHODS

100m line transects are deployed along the reef, this transect is split into four 20m segments, separated by 5m gaps where no data is collected. The Belt Transect method was used for the fish survey, covering a 5 m wide area (2.5 m on each side of the transect line). Fish observed within this area, including those up to 5 m above the transect line, were recorded. The survey targeted nine indicator fish, chosen for their ecological importance and sensitivity to human impacts. Following the fish survey, a belt transect of the same dimensions (5 m wide) was used to record invertebrates. Divers swam in an S-shaped pattern within the transect area to thoroughly search for the nine target invertebrates. To assess benthic composition, the substrate survey used the Point Intercept Transect (PIT) method. Observers recorded the substrate type directly beneath the transect line at 0.5 m intervals, resulting in 200 data points per 100 m line transect.

RESULTS

1. TEMPORAL VARIATION IN FISH ABUNDANCE AT IMPACTED SITES FROM 2022 TO 2024

Figure 5.1 presents data from Barefoot Jetty and Main Jetty, where fish abundance was compared over time (2022-2024). At Barefoot Jetty, the mean abundance of butterflyfish, which are critical indicators of coral reef health, declined from 4.69 in 2022 to 3.84 in 2024. This decrease likely reflected changes in coral

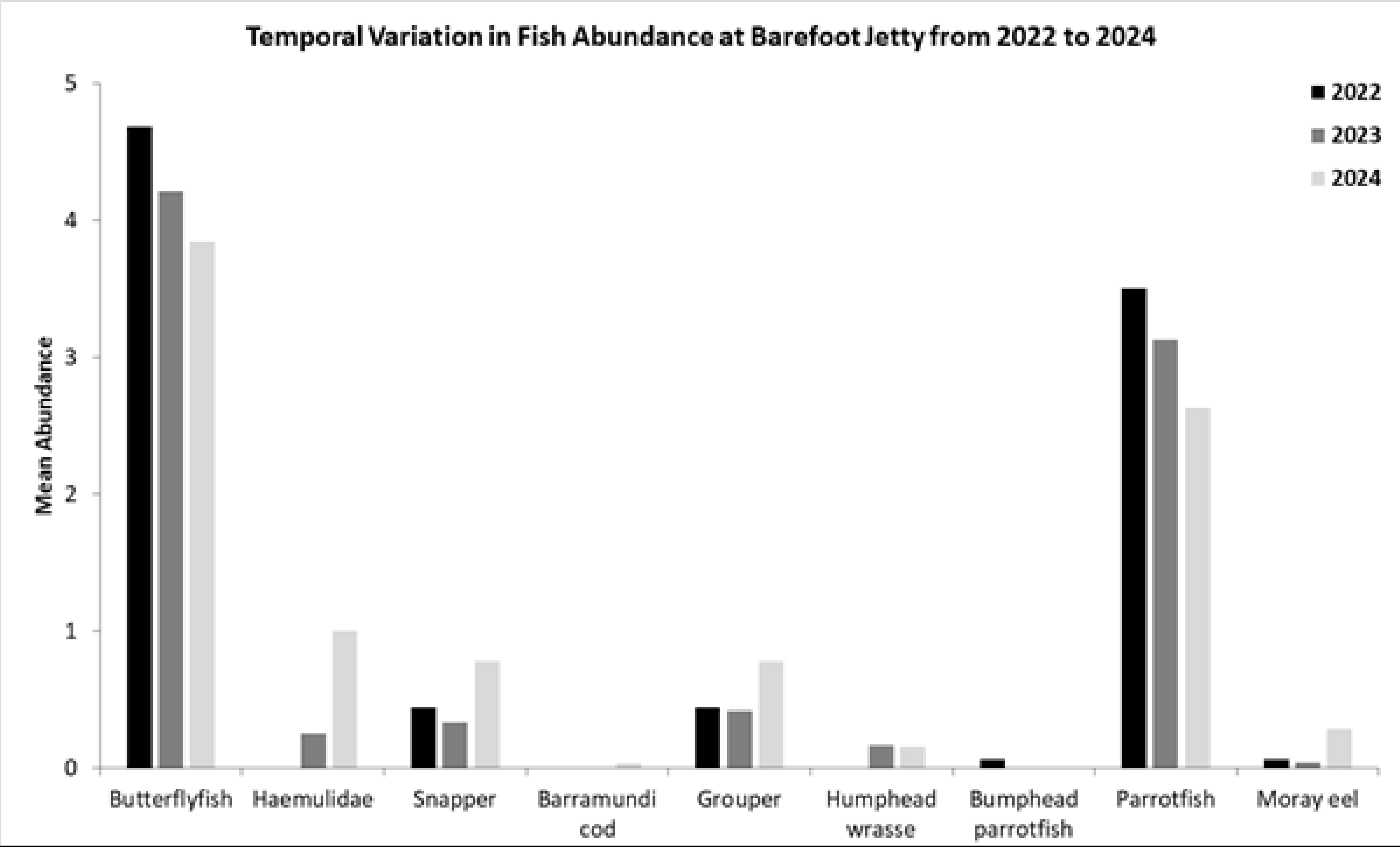


Table 5.1a. *Temporal variation in fish abundance at two impacted sites: a Barefoot Jetty and b Main Jetty from 2022 to 2024.*

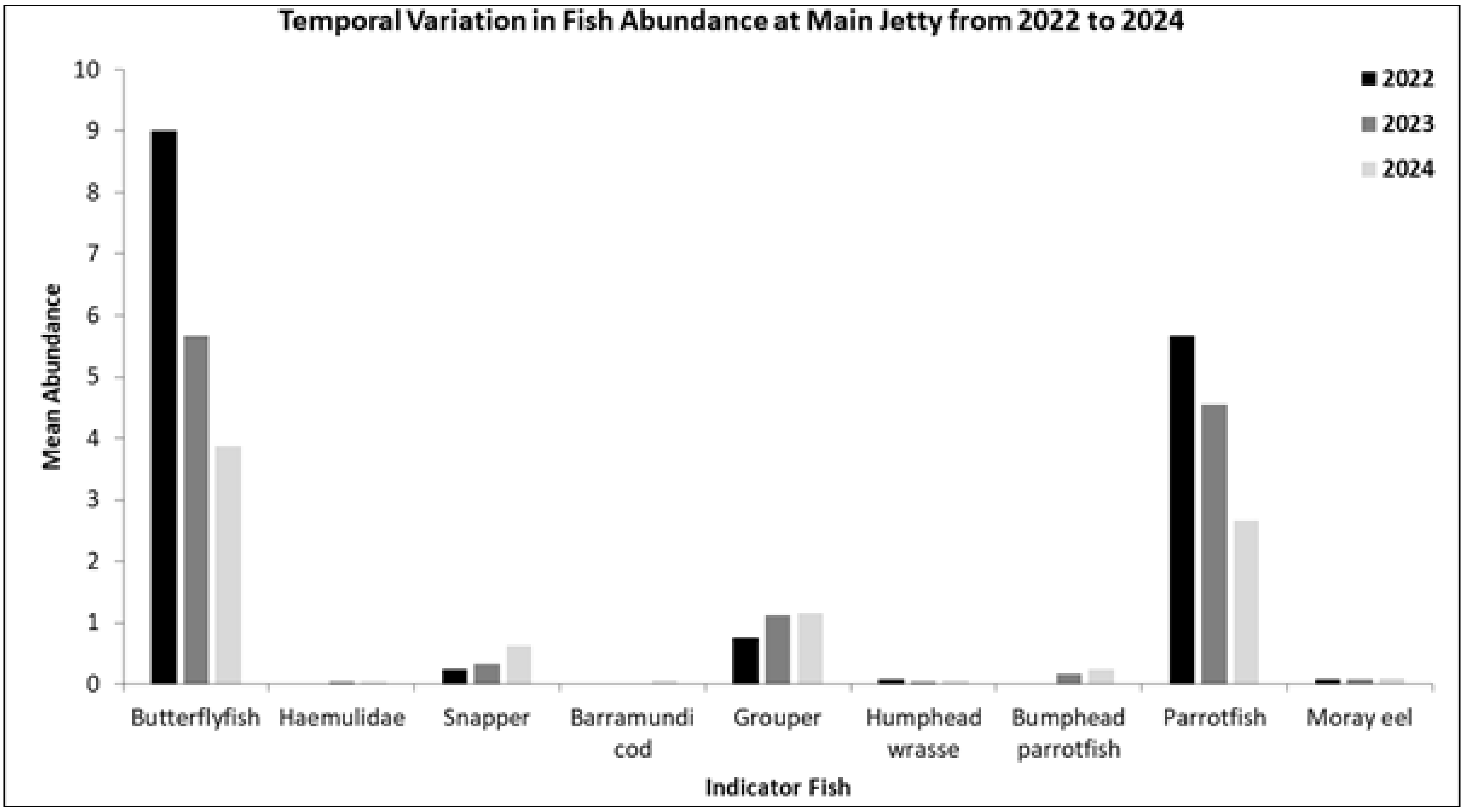


Table 5.1b. *Temporal variation in fish abundance at two impacted sites: a Barefoot Jetty and b Main Jetty from 2022 to 2024.*

cover and benthic composition within the area, which mostly consisted of rubble and soft coral (Figure 5.3). Such conditions provide limited structural complexity and fewer food resources for obligate corallivorous species like butterflyfish. As butterflyfish are not a target fishing species it is unlikely to represent fishing pressure. Parrotfish displayed a similar trend, with a decline from 3.50 in 2022 to 2.63 in 2024. In contrast, the abundance of snapper and grouper increased over time, both rising from 0.44 in 2022 to 0.78 in 2024. Haemulidae, which were absent in 2022, also showed an upward trend, increasing to 1.00 in 2024. This positive trend could suggest that certain species are able to adapt to the changing habitat structure at Barefoot Jetty.

At Main Jetty, butterflyfish showed a similar decline over the three years, with mean abundance dropping from 9.00 in 2022 to 5.67 in 2023 and further to 3.88 in 2024. Considering that Main Jetty was dominated by rubble, which increased over the years (Figure 5.4), reductions in live coral and the physical structure they provide were likely to have flow-on effects on reef fish populations. However, such effects may take several years to become fully evident. Parrotfish were the second most abundant species but also experienced a decline, from 5.67 in 2022 to 2.66 in 2024. Grouper and snapper abundance, in contrast, increased over time. Groupers are known to hunt primarily on the seafloor and often seek refuge in coral crevices. Despite the reduction in coral cover, the remaining hard coral substrates may still provide sufficient shelter and hunting grounds for grouper fish, supporting their continued presence and growth in abundance. Meanwhile, humphead wrasse and bumphead parrotfish showed consistently low abundance throughout the study period. This is to be expected, as the bumphead parrotfish are listed as vulnerable and the humphead or napoleon wrasse as endangered on the International Union for Conservation of Nature (IUCN) Red List. Their low numbers reflect ongoing pressures on these species, which are particularly sensitive to habitat degradation and overfishing.

2. TEMPORAL VARIATION IN INVERTEBRATE ABUNDANCE AT IMPACTED SITES FROM 2022 TO 2024

Figure 5.2 (next page) shows the trends in the abundance of selected invertebrate species across the two impacted sites over time (2022-2024). At Barefoot Jetty, Diadema sea urchins reached a peak in abundance in 2023 (0.75) before decreasing to 0.47 in 2024. Despite this decline, their mean abundance in 2024 remained relatively high, indicating a healthy population that plays a crucial role in controlling algal growth on coral reefs and maintaining reef health. However, other sea urchin species, such as pencil urchins, were present at low numbers but became absent by 2024, while collector urchins appeared only in 2024. Giant clams showed a steady decline over the three years, with their abundance shifting from 0.63 in 2022 to 0.34 in 2024. As giant clams play a crucial role in filtering water, their reduced numbers diminish their ability to maintain water quality within the reef environment. Banded coral shrimp were abundant in 2022 (0.31) but dropped sharply to 0.04 in 2023 before slightly recovering to 0.13 in 2024. Coral predators, such as crown-of-thorns starfish (COTs), showed an increase in abundance over time but remained at low numbers, which can be seen as a positive sign. The low numbers of COTs were also relevant given the low hard coral cover at Barefoot Jetty (Figure 5.3), which already limited the availability of COTs' primary food source.

At Main Jetty, Diadema sea urchins showed a decline from an initial abundance of 0.33 in 2022 to only 0.06 by 2024. Other species, such as pencil urchins and collector urchins, disappeared entirely by 2023 and 2024. This trend raises concerns about the potential long-term loss of these two species from the site, which could potentially impact the control of algal growth on the reef. On the other hand, giant clams showed an increase in 2023, from 0.17 in 2022 to 0.33, before declining slightly to 0.28 in 2024. Banded coral shrimp displayed a more stable pattern compared to Barefoot Jetty, rising from 0 in 2022 to 0.21 in 2023 and remaining relatively high at 0.19 in 2024. Lobsters were not recorded at Main Jetty during the study period. It will be crucial to monitor lobster abundance in the coming years, as their recovery or further decline could have significant ecological and economic implications.

3. TPROPORTION OF BENTHIC COMPONENTS IN THE SURVEYED SITES

Figure 5.3 (next page) highlights that Arborek Tip had the highest hard coral proportion (49%) of all the surveyed sites, indicating a healthy reef system with a balanced composition of benthic components. In contrast, South Arborek had the lowest hard coral proportion (4%). Despite this, South Arborek showed a slight improvement, increasing by 2% from the previous year

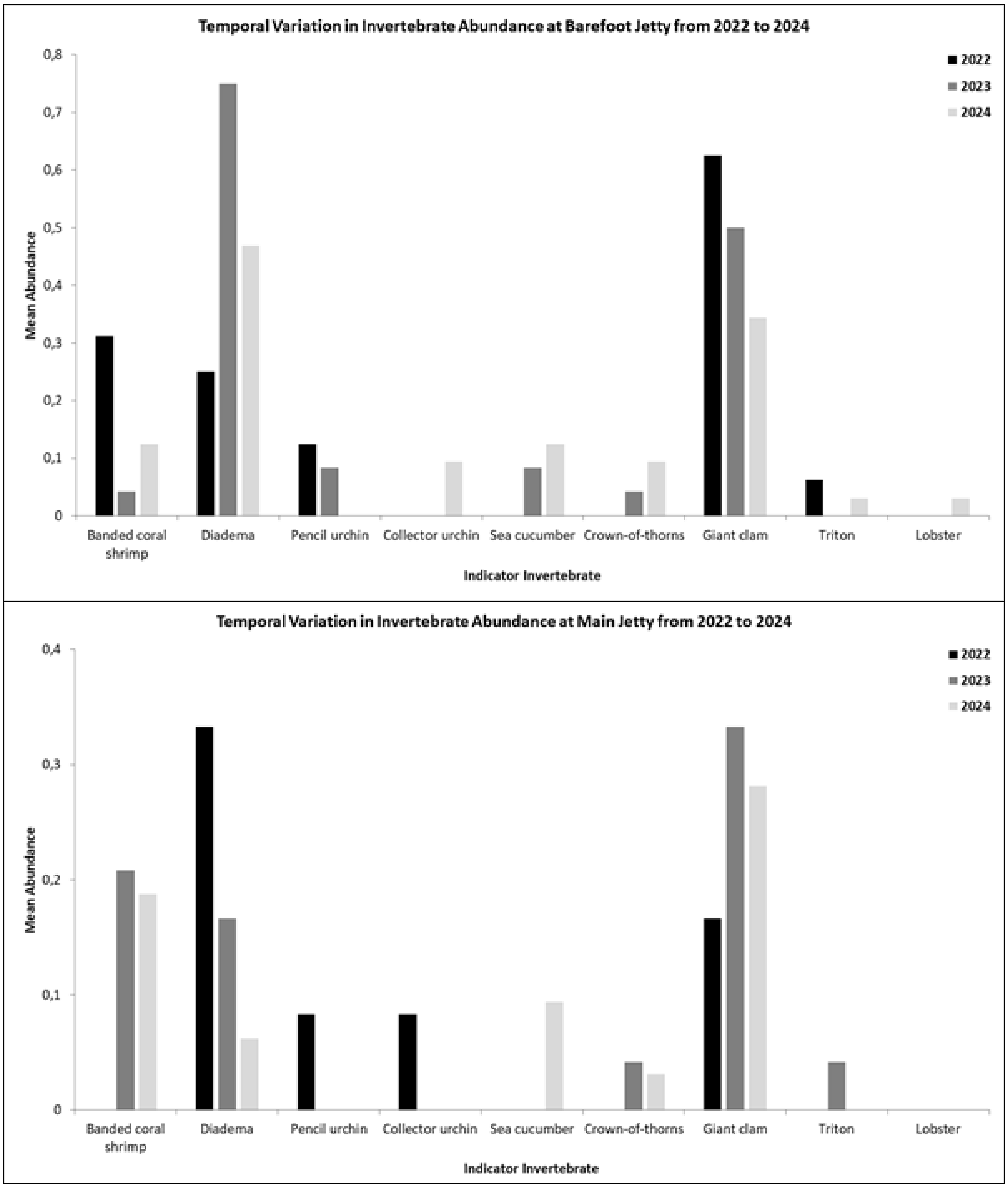


Table 5.2. *Temporal variation in invertebrate abundance at two impacted sites a Barefoot Jetty and b Main Jetty from 2022 to 2024.*

Figure 5.3 highlights that Arborek Tip had the highest hard coral proportion (49%) of all the surveyed sites, indicating a healthy reef system with a balanced composition of benthic components. In contrast, South Arborek had the lowest hard coral proportion (4%). Despite this, South Arborek showed a slight improvement, increasing by 2% from the previous year (see Barefoot Report, 2023). This site was predominantly dominated by soft corals, which comprised 76% of its benthic composition. Recently killed coral was relatively minimal across most sites, suggesting low levels of recent coral mortality, with the highest values observed at South-West Arborek and JPP, although only 2%.

Certain sites, such as Juan's Bay, West Arborek, and Manta Sandy, exhibited higher nutrient indicator algae (NIA) cover compared to other sites, which may indicate the presence of nutrient loads in these areas. This matches with data presented in the cyanobacteria section. In Juan's Bay, despite having a relatively high hard coral proportion (37%), the presence of NIA suggests that a water quality assessment is necessary to better understand and address potential nutrient enrichment. Besides that, rubble cover had high values in some areas, particularly at Isaias Garden, Main Jetty, and West Mansuar, with values of 47%, 45%, and 43%, respectively. These values exceeded those of the living components, and this imbalance suggested that physical or natural disturbances, either ongoing or from past events, had likely led to the breakage of coral colonies, resulting in increased rubble.

4. TEMPORAL VARIATION IN BENTHIC COVER AT IMPACTED SITES FROM 2022 TO 2024

Comparisons of surveys conducted from 2022 to 2024 revealed fluctuations in hard coral cover at Barefoot Jetty. Hard coral cover decreased from 27% in 2022 to 13% in 2023, followed by a recovery to 17% in 2024 (see figure 5.4 on next page). The proportion of recently killed coral remained low throughout the study period, recorded at 1% in 2022 and 2024, with no coral mortality observed in 2023. However, rubble cover showed a different trend, increasing from 26% in 2022 to a peak of 33% in 2023 before decreasing slightly to 30% in 2024. This decline in rubble cover was likely due to the survey area at this site extending into the restoration area, where coral cover had increased drastically by 2024 (see Figure 6.3 in the Reef Restoration project section), allowing the rubble areas to stabilize.

Hard coral cover at Main Jetty declined from 32% in 2022 to 29% in both 2023 and 2024, showing a stable yet declining trend over the three years. This decline was accompanied by a consistent increase in rubble cover, from 37% in 2022 to 45% in 2024. This shift was likely influenced by the effects of divers and tourism on the local reefs, as Main Jetty is frequently visited, leading to physical disturbances that may have caused coral breakage and the accumulation of rubble. Importantly, recently killed coral remained relatively low at 1% throughout the three years, indicating that coral mortality has been minimal in recent times.

FUTURE DIRECTIONS

Based on the findings from 2024, the Reef Check Project for 2025 will continue to focus on monitoring and assessing coral reef health at nine core sites and four additional sites, with the addition of a new site located on the southeast side of Arborek Island. Based on our observations, this area has a high number of homestays, marking it as a focal point for our survey. We will

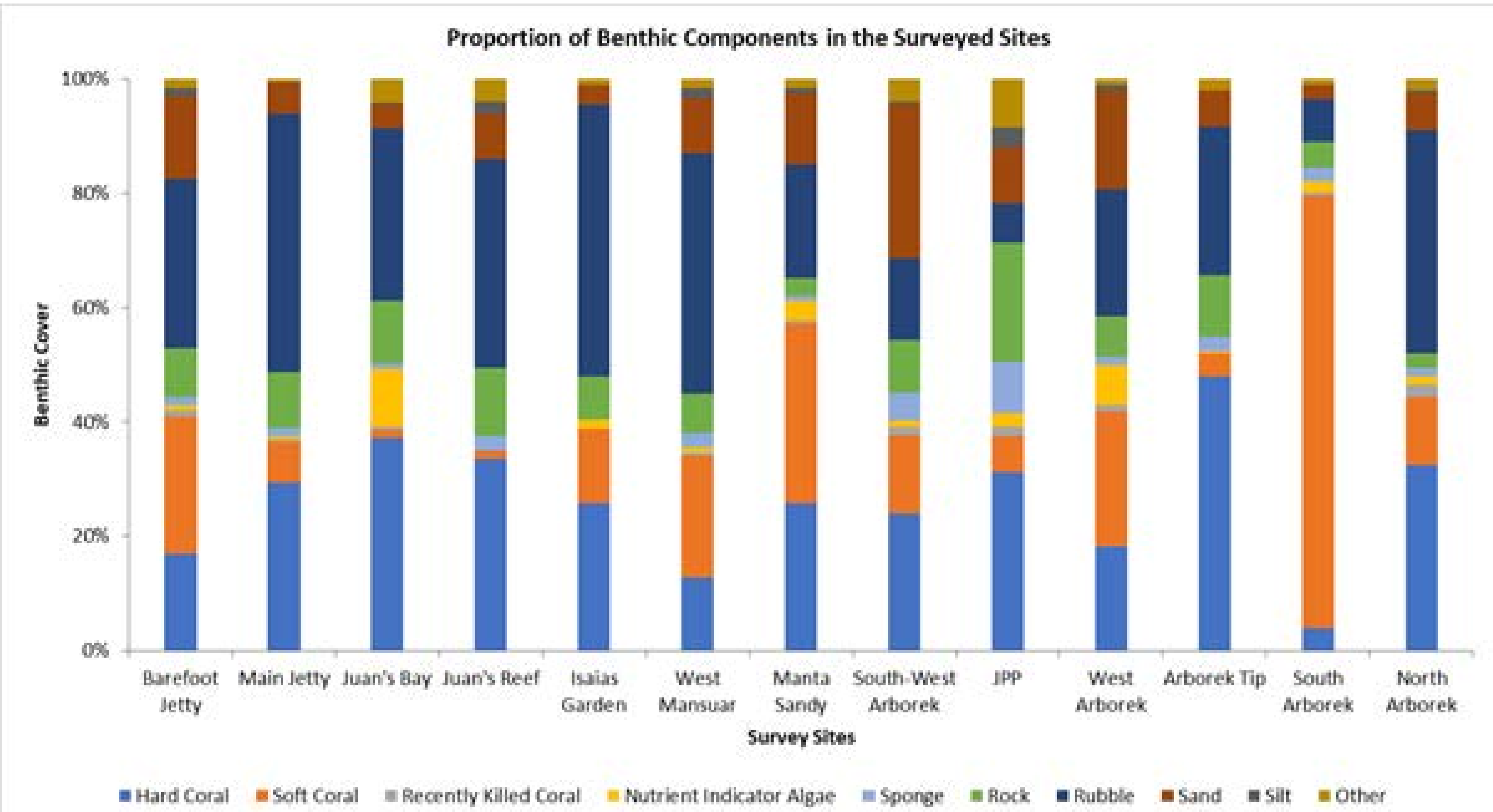
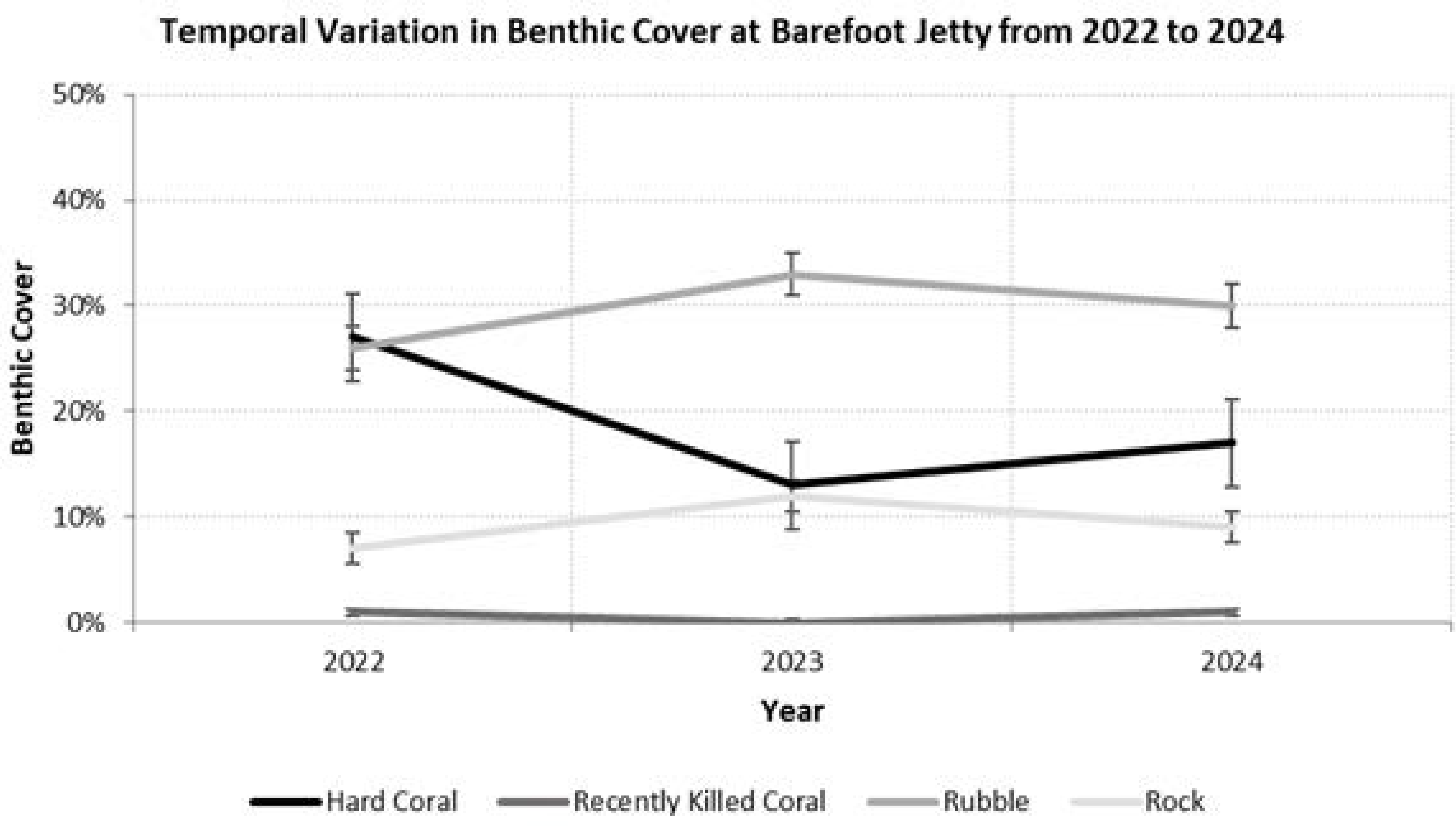


Table 5.3. *Proportion of benthic components across Reef Check's 9 core and 3 additional surveyed sites in 2024.*

assess the impact of this development on the health of the coral reefs over time. Monitoring will also focus on species that have shown a decline in numbers over time to ensure their sustainability. Special attention will be given to impacted sites, particularly Main Jetty, where hard coral cover continues to decrease, as well as declines in butterflyfish and parrotfish populations, which play vital roles in the ecosystem. We will also ensure that surveys are consistently conducted at the same points using GPS starting points and, where possible, installing marker stakes to maintain consistency and comparability over time.



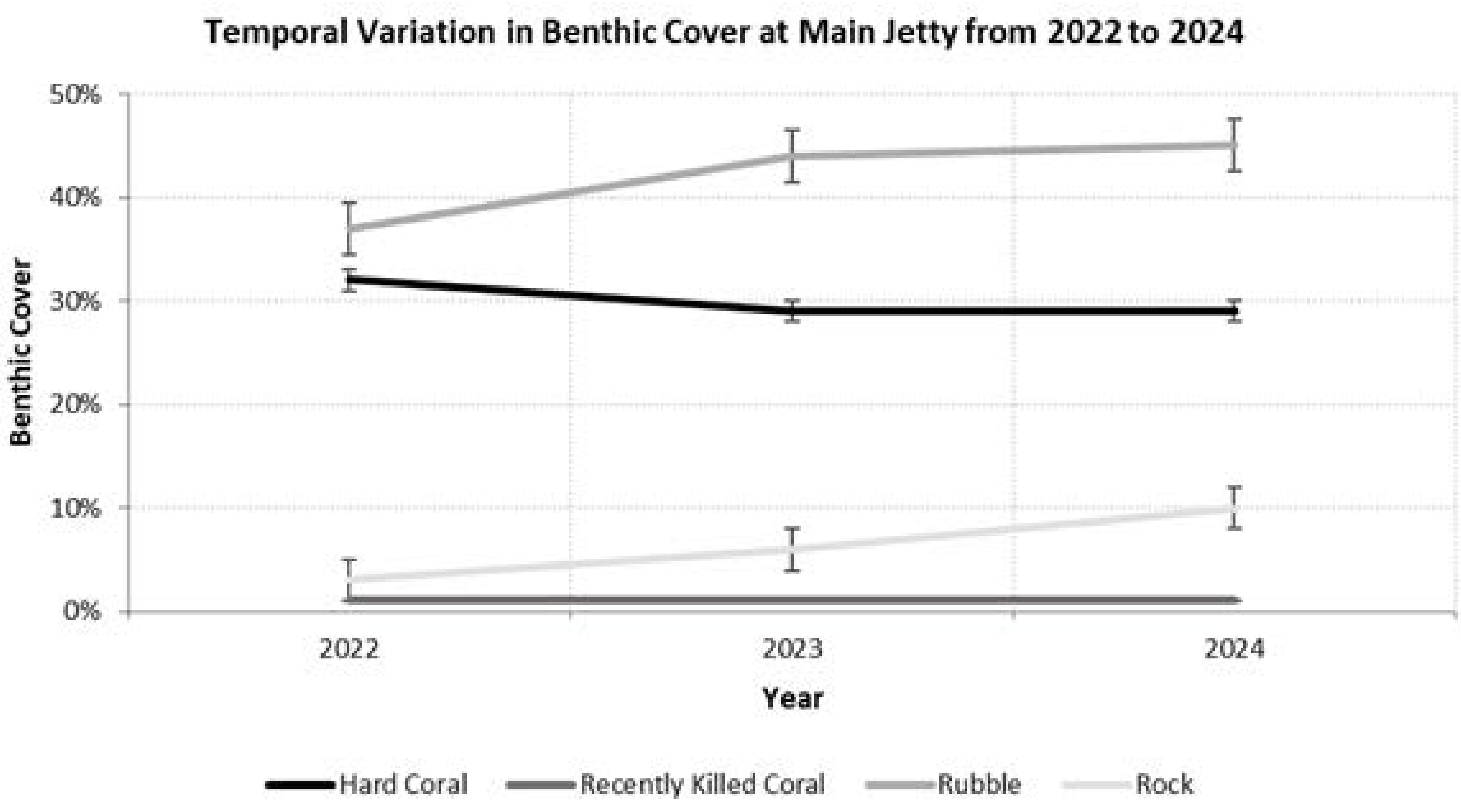


Figure 5.4. *Temporal variation in benthic cover at two impacted sites a Barefoot Jetty and b Main Jetty from 2022 to 2024.*

Reef Restoration Project Report

INTRODUCTION

The reef restoration project was initiated with three major aims: 1) to restore an acutely degraded section of Arborek reef that was not naturally recovering, 2) to educate and engage the local children about corals and how to preserve them as they face unprecedented threats, and 3) to improve restoration science 'best practice' by undertaking research projects on different restoration techniques and addressing critical knowledge gaps. Given these three aims, it was essential to address the various barriers to natural reef recovery, including physical and ecological challenges. One of the most significant issues identified at the site was the presence of unattached rubble. This rubble can act as a "killing field" for corals, inhibiting the survival of coral recruits, preventing the establishment of mature coral colonies, and contributing to further degradation by rolling and impacting remaining live coral colonies during high surge conditions (Ceccarelli et al., 2020). This highlights the urgent need for effective substrate stabilization in reef restoration efforts, particularly in areas where rubble accumulation is a major issue. In response to these challenges, we set up stabilization frames in December 2022. These frames were placed to stabilize the rubble, preventing it from falling down slopes and allowing the rubble underneath to consolidate.

With coral bleaching emerging as a new threat to Raja Ampat, we decided to largely pause the restoration project in 2024, recognizing that additional stress such as fragmenting and outplanting colonies could be harmful. This year focused primarily on maintaining the corals already in our nurseries, and monitoring the success of our efforts so far. To maintain optimal conditions in the coral nurseries, we conducted regular cleaning on a weekly basis, removing coral competitors that grew on the structures. This helped reduce competition for space and ensured the best possible environment for corals to thrive. To evaluate the success of the stabilization approach, we began monitoring the outcomes of substrate stabilization using aerial photos to track visual progress at three key intervals: September 2023 (month 9), January 2024 (month 13), and November 2024 (month 23). During these periods, we assessed trends in hard coral coverage on three stabilization frames within the nurseries. The results were as expected, showing an increase in hard coral coverage over time, which demonstrated the success of the stabilization frames in securing the rubble and supporting coral growth at the degraded site.

Ecosystem-level monitoring continues to be conducted quarterly at the restoration site which covers an area of approximately 900 m², and is where restoration efforts have been focused. Long-term monitoring of this site will be conducted for a minimum of five years and collects data on coral coverage, structural complexity, coral recruitment (juveniles), fish biomass and invertebrates, as well as additional ecological parameters to provide a holistic assessment of restoration effectiveness.

METHODS

To monitor the outcomes of substrate stabilization in coral nurseries, aerial photos of the stabilization frames were captured at three key time points: September 2023, January 2024, and November 2024. The photos were taken using an Olympus TG-7 camera, ensuring that the entire stabilization frame was visible in each image for a comprehensive visual assessment. These aerial images were then analyzed using ReefCloud, an AI-powered platform designed to automatically process and quantify coral reef data from imagery. The 50 point analysis was applied to each photo, with three frames assessed at each of the three time points. This approach ensured that the analysis captured a representative sample of the coral cover, with a focus on understanding changes in coral coverage over time.

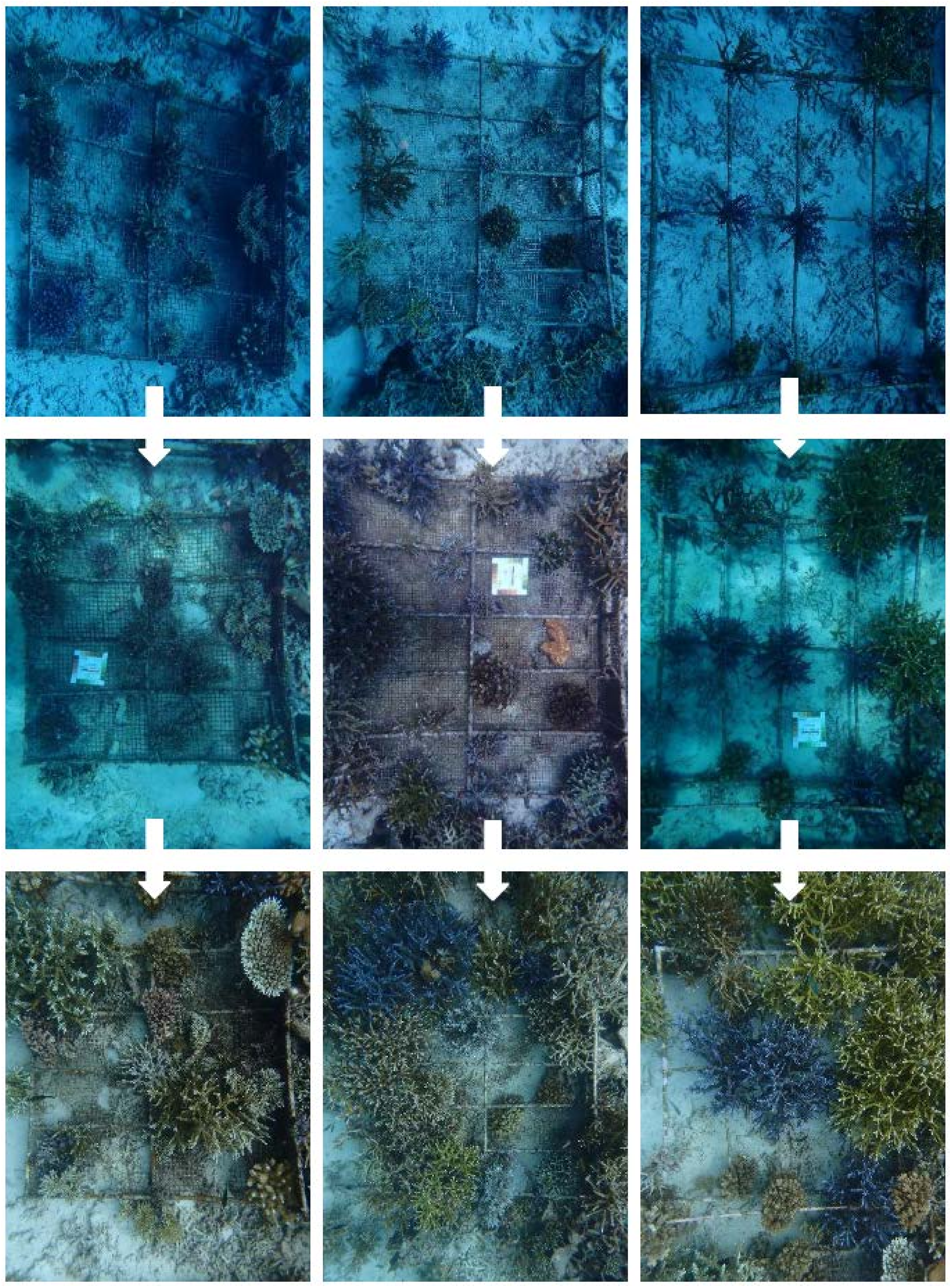


Figure 6.1. *Monitoring the outcomes of substrate stabilization: Aerial photos of frames showing visual progress from September 2023 (month 9), January 2024 (month 13), and November 2024 (month 23).*

RESULTS

1. TRENDS IN CORAL COVERAGE ON STABILIZATION FRAMES IN CORAL NURSERIES ACROSS THREE TIME POINTS

Figure 6.2 (next page) presents consistent growth in coral coverage across all stabilization frames over the monitoring period, with varying rates of increase among the frames. In September 2023, nine months after deployment, coral coverage ranged between 25% and 33%. By January 2024, coral coverage showed steady growth, increasing by an additional 15- 20% from the September 2023 values. The highest increase was observed in November 2024, with coral coverage continuing to expand across all frames. Frame 2 showed the highest growth, reaching 86%, nearly covering the entire frame (Figure 6.2). This consistent upward trend underscores the positive outcomes of the restoration effort, with the successful growth of planted corals on the stabilization frames. Importantly, the rubble underneath the frames appears to be consolidating, which aligns with the aim of this project to stabilize loose substrate and support reef recovery. Figure 6.3 demonstrates the changing landscape of the rubble field, where coral is not only growing on the stabilisation frames themselves, but the entire region has become stabilised. This is due to a combination of the stabilisation frames but also the ropes of staghorn corals that were transplanted directly onto the substrate to form natural coral ‘shelves’ which stopped rubble movement. Figure 6.3c shows the extensive coral growth which is now naturally colonising this area, enabled by consolidation of mobile rubble. We are happy that this pilot project is effectively restoring this restoration area with a diversity of different coral species, it is also enabling a diverse range of larvae from nearby reefs to settle and repopulate. Weekly nursery cleaning likely contributed to this success by effectively controlling coral competitors such as algae, sponges, and tunicates, which were frequently observed growing on the frames. One cause of concern, however, is the increased prevalence of cyanobacteria around the stabilisation frames, which may be related to the newly stabilised substrate. Ongoing monitoring of this trend is underway and will be useful to inform future stabilisation strategies.

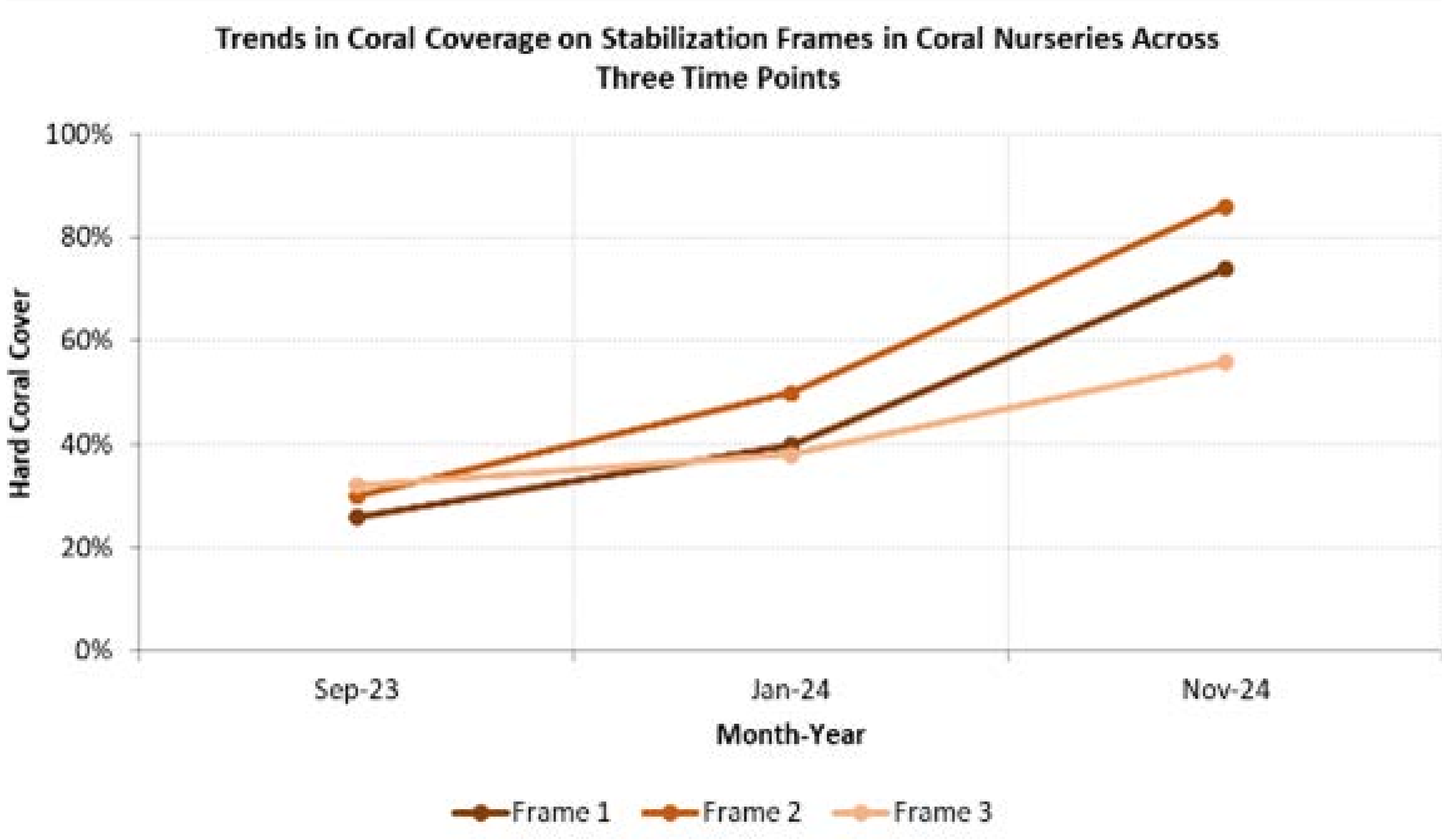


Figure 6.2. Trends in hard coral coverage on three stabilization frames within coral nurseries, assessed over three time points: September 2023, January 2024, and November 2024.

FUTURE PLANS

For the Reef Restoration Project in 2025, the primary focus will be to expand the stabilization efforts as we continue monitoring the impacts of coral bleaching to Raja Ampat reefs and deciding the future of the restoration project. Additional stabilisation frames will be installed and corals that are damaged will be replaced. Ecosystem-level monitoring program will continue, providing valuable insights into reef-scale changes resulting from the restoration efforts. The monitoring will focus on key ecological parameters such as benthic cover, structural complexity, coral diversity at the genus level, coral recruitment, coral condition, and the abundance and diversity of herbivores and corallivores. These combined parameters will offer a holistic assessment of the restoration’s effectiveness. Monitoring will be conducted at three different sites: the restoration site, an unrestored site, and a control reference site. These comparative sites will allow for a thorough evaluation of the restoration’s success relative to undisturbed and untreated areas. Monitoring will take place every three months to capture seasonal variations and track the temporal dynamics of coral health and the broader reef ecosystem.

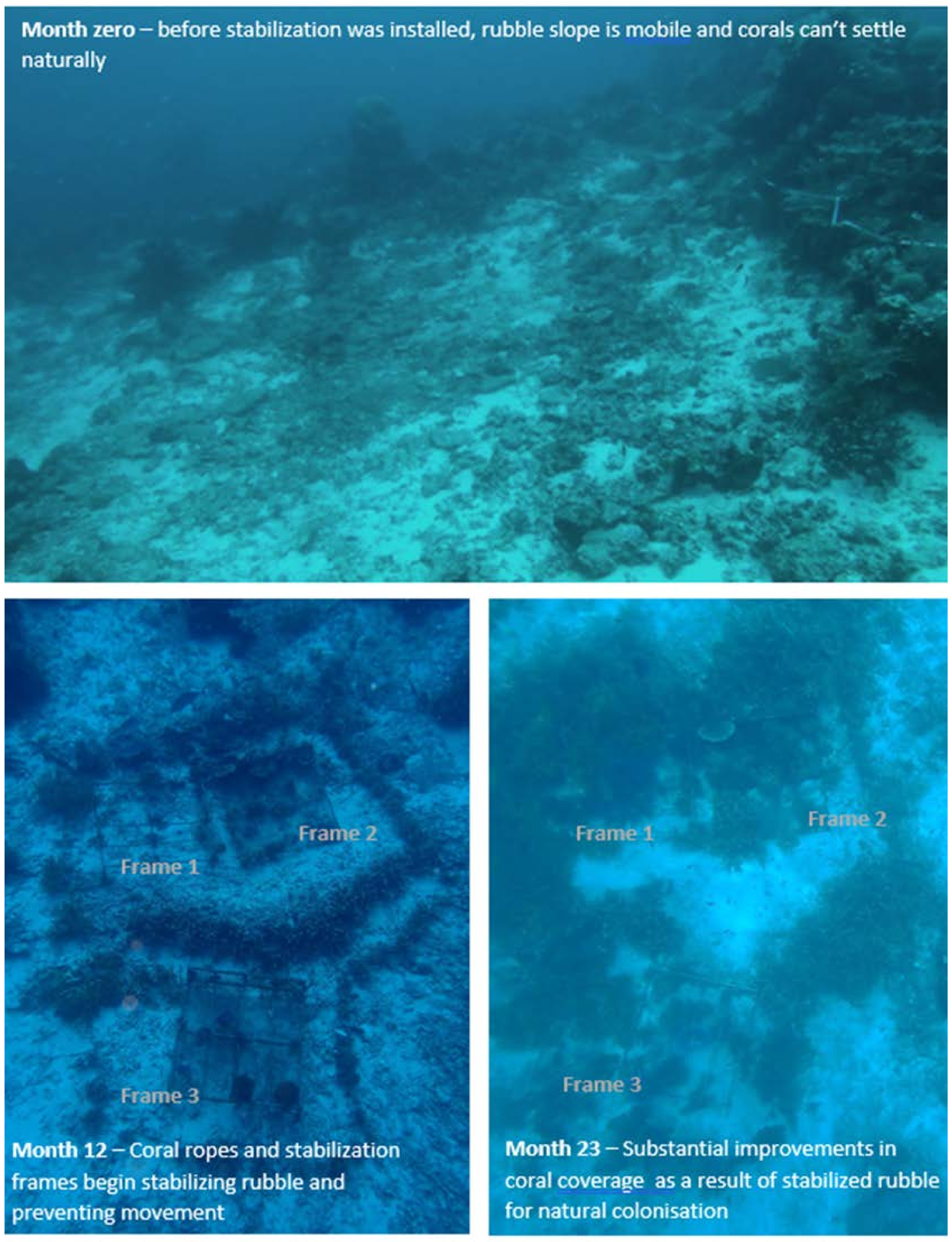


Figure 6.3. The loose rubble field of our Restoration Site a before intervention; b with stabilisation frames installed and staghorn rope barriers, after 12 months; c after 23 months with considerable coral colonisation of the rubble field.

Manta Ray Project Report

INTRODUCTION

Manta rays are charismatic megafauna of the Mobulidae family which inhabit the reefs of Raja Ampat. Both species of manta ray; Mobula alfredi and Mobula birostris, can be encountered in the Dampier strait. M.alfredi or 'reef mantas' are considerably more common and can be regularly observed during dives in the manta season (September to April), as well as encountered on boat trips during these months as large feeding aggregations can be found surface feeding on plankton. M.birostris or 'oceanic mantas' are more rare due to their largely pelagic lifestyle, however we occasionally sight oceanic mantas at Blue Magic cleaning station which is renowned for supporting transient oceanic populations.

Figure 7.1. *Multiple manta rays visiting a cleaning station named Manta Ridge whilst divers photograph for IDs*

Manta rays are listed as 'vulnerable' (reef manta) and 'endangered' (oceanic manta) by the IUCN red list, meaning their global populations are decreasing. This is due to the numerous threats they face including overfishing for their gill plates, bycatch, habitat degradation, pollution and unregulated tourism. Within Indonesia, manta rays have received full protection since 2014 (MMAF No.4/KEPMEN-KP/2014) with Raja Ampat holding the highest level of protection as an established shark and ray sanctuary since 2012. This has enabled populations to thrive within the area resulting in Raja Ampat hosting the second largest reef manta ray population in the world with 1800+ individuals identified (Setyawan., 2023). Although the population in this region is protected, the main threat these elasmobranchs face is unmanaged and unregulated tourism (Setyawan et al., 2022). With Raja Ampat's eco-tourism industry increasing annually and the area becoming more popular and accessible to tourists this may become a persistent issue. Furthermore, with little literature published on manta rays in this region, there is a lack of understanding of their distribution patterns and how an increase in exposure to people may negatively affect populations. Therefore, the manta project at Barefoot Conservation, with its growing database of individuals movement patterns, offers vital data which can be used to further our understanding of these species and thus identify if further management is required.

METHODS

Our manta research employs a citizen science-based approach to collect photo-identification (photo ID) data and record manta ray sightings at key dive sites in Raja Ampat. Manta ray photo ID is a non-invasive technique used to identify individual rays based on unique ventral spot patterns (Figure 7.2). During each dive, volunteers and researchers take photographs of the ventral (underside) of each manta ray encountered to capture their unique 'fingerprint'.

Figure 7.2. *Manta rays are photographed during surveys to capture the unique ventral spot pattern that identifies them. a Chevron (normal) colour morphs and b melanistic (black) colour morphs are both common to site in Dampier Strait*

Barefoot conducts training for volunteers and staff on manta ecology/behaviour, threats, how to responsibly interact with mantas (following Manta Trust's Code of Conduct), and how to ID manta rays. Following training, volunteers, alongside our marine scientists and divemasters, assist in data collection during designated manta ray dives. Surveys are conducted at the primary manta cleaning and feeding sites: Manta Ridge, Manta Sandy, Stairway to Heaven, Blue Magic and West Arborek. In addition to capturing photo IDs, an assigned staff or volunteer will collect data on the mantas observed such as recording manta species, colour morph (chevron or melanistic; Figure 7.2), size, sex, maturity, injury types/locations, pregnancies and behavioural observations (e.g., cleaning, feeding, courtship, or cruising). Environmental variables such as visibility, current strength, and water temperature are also collected. Additionally, we collect data on the number of divers and liveaboard boats at the manta dive sites, and record any misconduct observed, which is important for monitoring the scale of dive tourism in the region.

Following the dive, ID images are reviewed and compared to our existing database to determine whether the manta is a new individual or a resighted individual. The database maintains detailed records for each identified manta ray, including unique ID number, date and time of observation, location of observation and all of the environmental and demographic information on on the manta ray observed. New individuals are added to the database, while resightings contribute to long-term population monitoring and movement studies. All collected data are compiled into the project database and shared with local and manta ray research projects. Through our database we are able to ascertain the size of the local population, the seasonality and residency of individuals, pregnancies, recovery of injuries and much more.

In May of 2024, BLUD UPTD (Raja Ampat MPA managers) held a meeting for multiple stakeholders around Raja Ampat to discuss sustainable manta-based tourism in Raja Ampat (Figure 7.3) ("Pemanfaatan Habitat Penting Pari Manta di Kawasan Konservasi Perairan Area III Selat Dampier"). Barefoot scientist Reyhan Arifin attended and presented our Manta Report to the session leaders. Edy Setyawan, a leading manta scientist, gave a presentation about the life cycle of manta rays and reinforced the etiquette that divers and snorkelers should be following when encountering manta rays. A group discussion was held about how best to protect popular manta dive sites in Raja Ampat from irresponsible tourism and how to maintain that strict regulations are upheld. Some of the regulations that were discussed were:

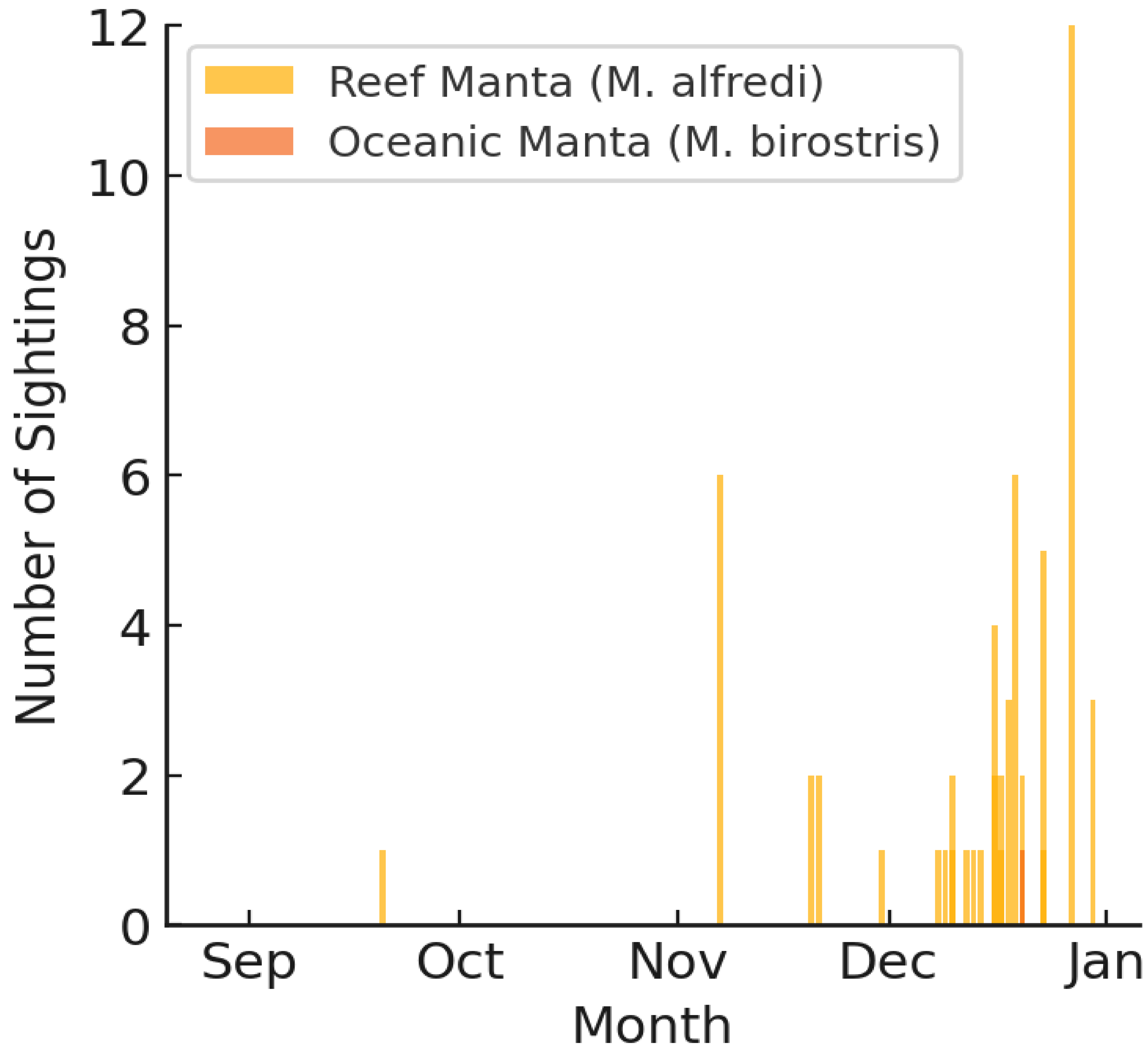
• Local businesses (dive shops, resorts and homestays) should be given priority at Manta dive sites over visiting liveaboard boats
• Diveguides visiting manta dive sites should be properly certified
• Dive sites should be booked 3 days in advance
A ratio of 1 guide to 3 visitors should be maintained whilst diving
• Manta Ridge, an important cleaning station for manta rays
• Penalties should be established for any companies failing to follow Code of Conduct, for example prohibited diving at manta dive sites for 3 months and a fine from BLUD

Figure 7.3. Project Scientist Reyhan Arifin attends meeting regarding "Utilization of Important Habitat for Manta rays in the Dampier Strait Area III Marine Conservation Area" with other manta stakeholders in Raja Ampat

RESULTS

2024 SEASON

A total of 62 manta rays have been recorded so far this season between September and December 2024 (Figure 7.4). The highest number of sightings occurred in December, with a total of 50 mantas observed in this month. Notably, this season started very late with few sightings occurring prior to November which is significantly later than most seasons. The vast majority of manta observations (98%) were of reef manta rays (Mobula alfredi), with only one oceanic manta ray (Mobula birostris) recorded so far this season. Manta ray observations were



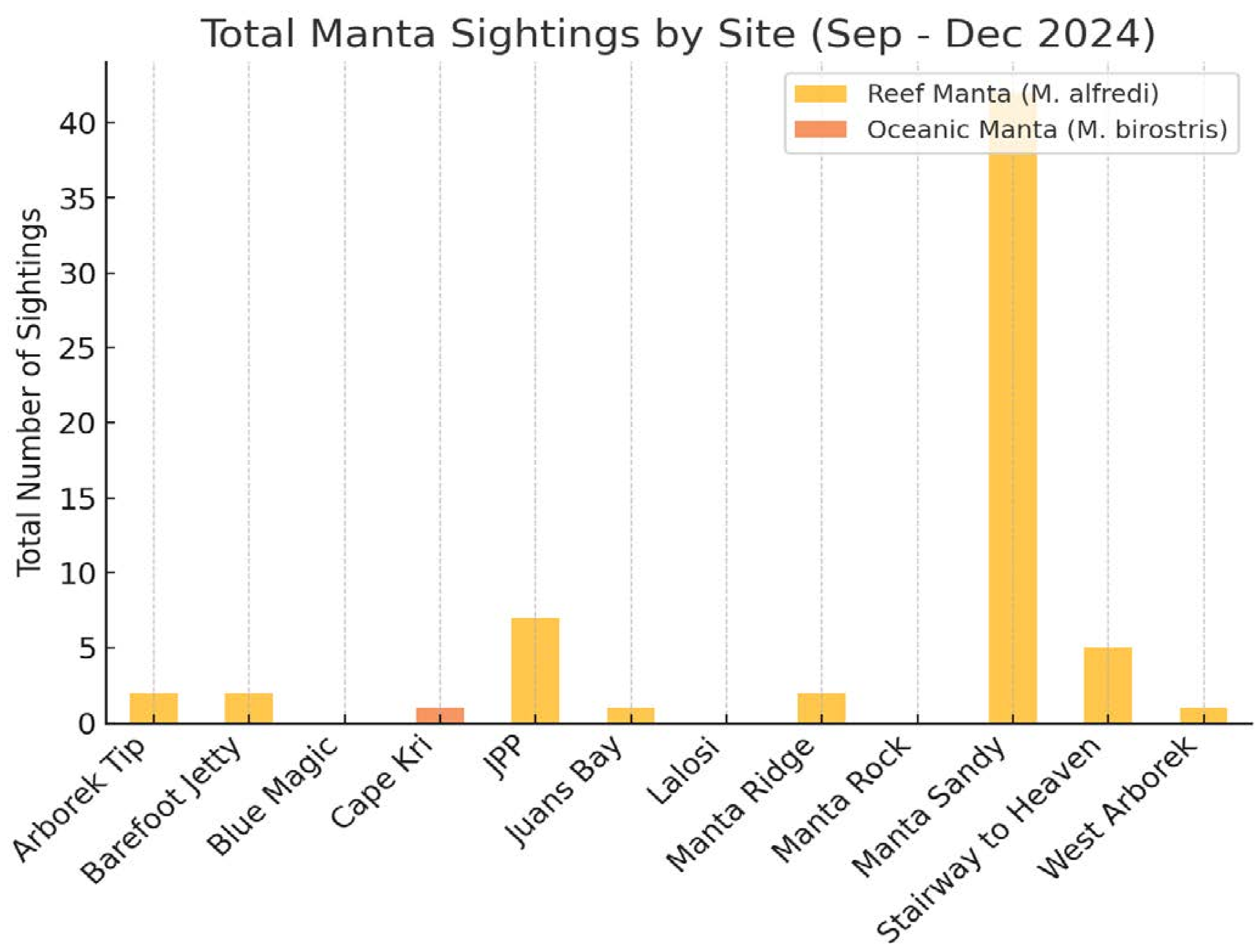


Figure 7.4. a Temporal variation in manta ray sightings (all sites pooled) for the current manta season (Sep – Dec 2024), each bar depicts one survey date; b Sightings grouped by site

recorded across multiple sites (Figure 7.4b). The highest number of sightings were recorded at Manta Sandy, accounting for 68% of all observations. Manta Sandy is a cleaning station with high visitation rates by other divers where multiple manta rays are often encountered cleaning. We observed a considerably lower proportion of manta rays at Manta ridge this year which reflects our lower visitation to this site. Of the six visits, only 2 mantas have been recorded. In addition to our observations recorded from manta survey dives to Manta Sandy, Manta Ridge, Manta Rock and Blue Magic, we also observed unexpected manta observations during dives to Arborek Tip, Barefoot Jetty, JPP, Juan's Bay, Stairway to Heaven and West Arborek. We also unexpectedly encountered an oceanic manta during a dive to Cape Kri.

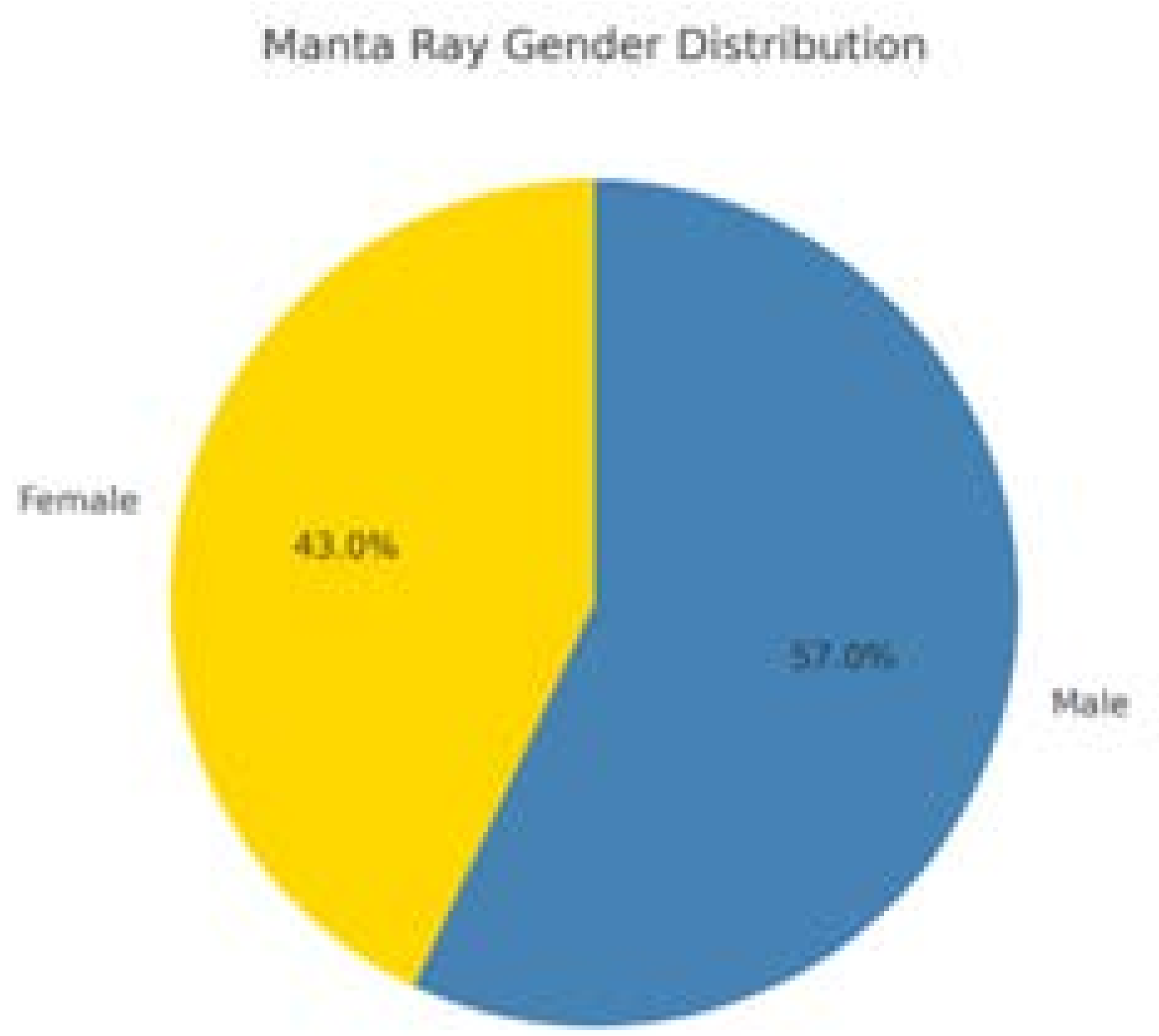
Demographic data on the mantas observed in 2024 are presented in Figure 7.5. Of all mantas recorded on surveys, 68% were 'chevron' colouration (normal) and 32% were recorded with melanistic (black) colouration, see Figure 7.2 as an example of the two colour morphs. This ratio was very similar to last year's observations of 66% chevron and 34% melanistic. For sex ratios we observed 57% females and 43% males.

Figure 7.6 presents data from multiple years (2020-2024), showing the total number of mantas recorded in each month, for each year. Although there is considerable variation among years, the seasonal pattern is apparent with densities of mantas first increasing around September/October and remaining high until March/April. Few mantas are observed between June-September.

FUTURE DIRECTION

In 2025 we will focus on strengthening collaborations with other manta research organizations to enhance data collection and conservation efforts. Given increasing concerns about sites where manta sightings have notably declined (i.e. Manta Ridge), targeted research will help to assess whether anthropogenic pressures or ecological shifts are influencing manta behaviour. Accordingly, next year we will conduct investigation into potential factors influencing manta spatial patterns and the delayed start of the manta season including environmental drivers such as changing oceanographic conditions and climate variability, and also human impacts (e.g., diver interactions and over tourism). To achieve this, additional variables will be incorporated into our data collection and target analysis of the drivers of temporal and spatial patterns will be investigated.

A deeper understanding of the central Raja Ampat manta subpopulation, and factors that influence this population, will be valuable in informing BLUD on appropriate conservation



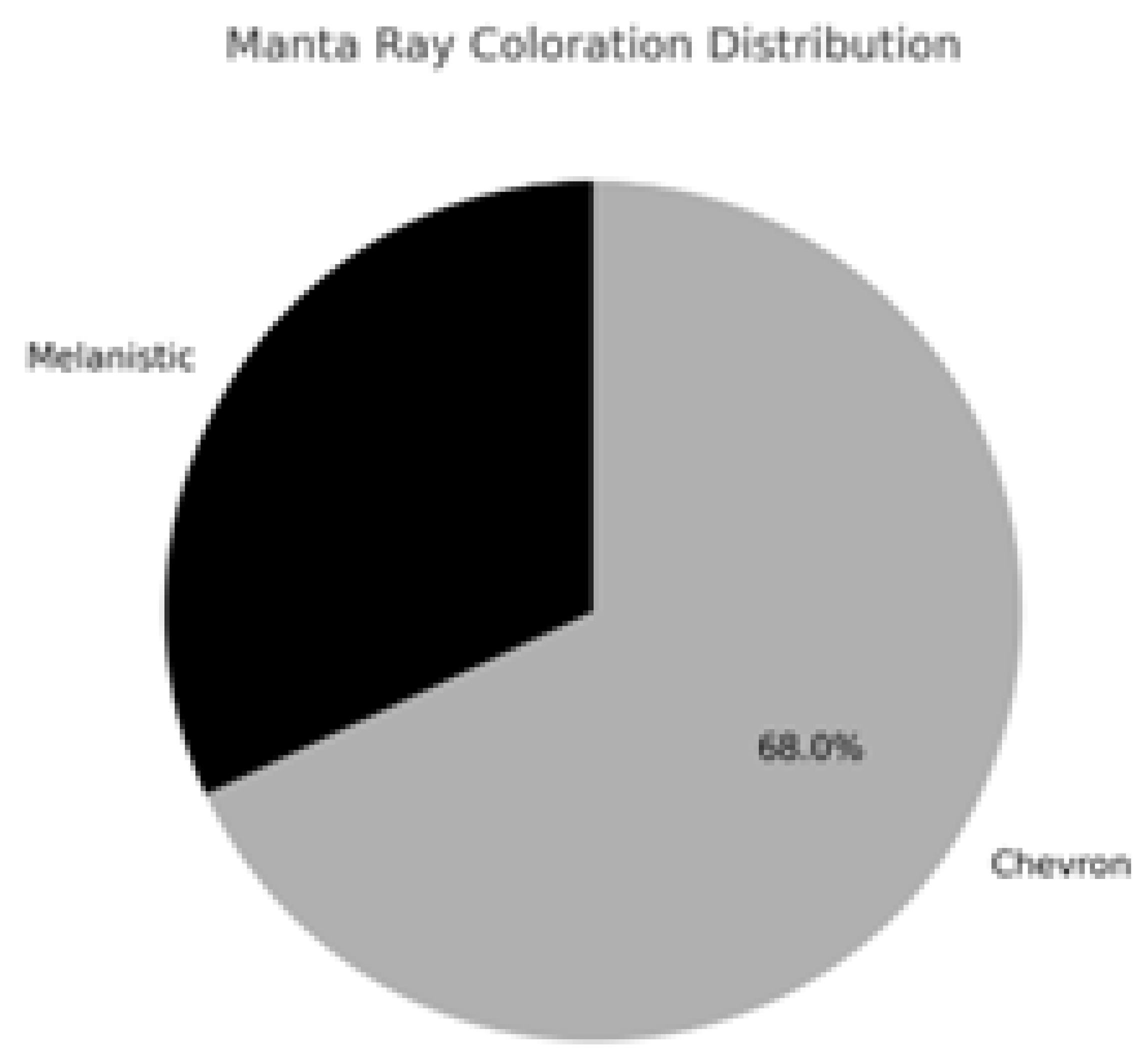


Figure 7.5. *Pie charts summarising the percentage demographics a colour morph and b sex within the Barefoot database*

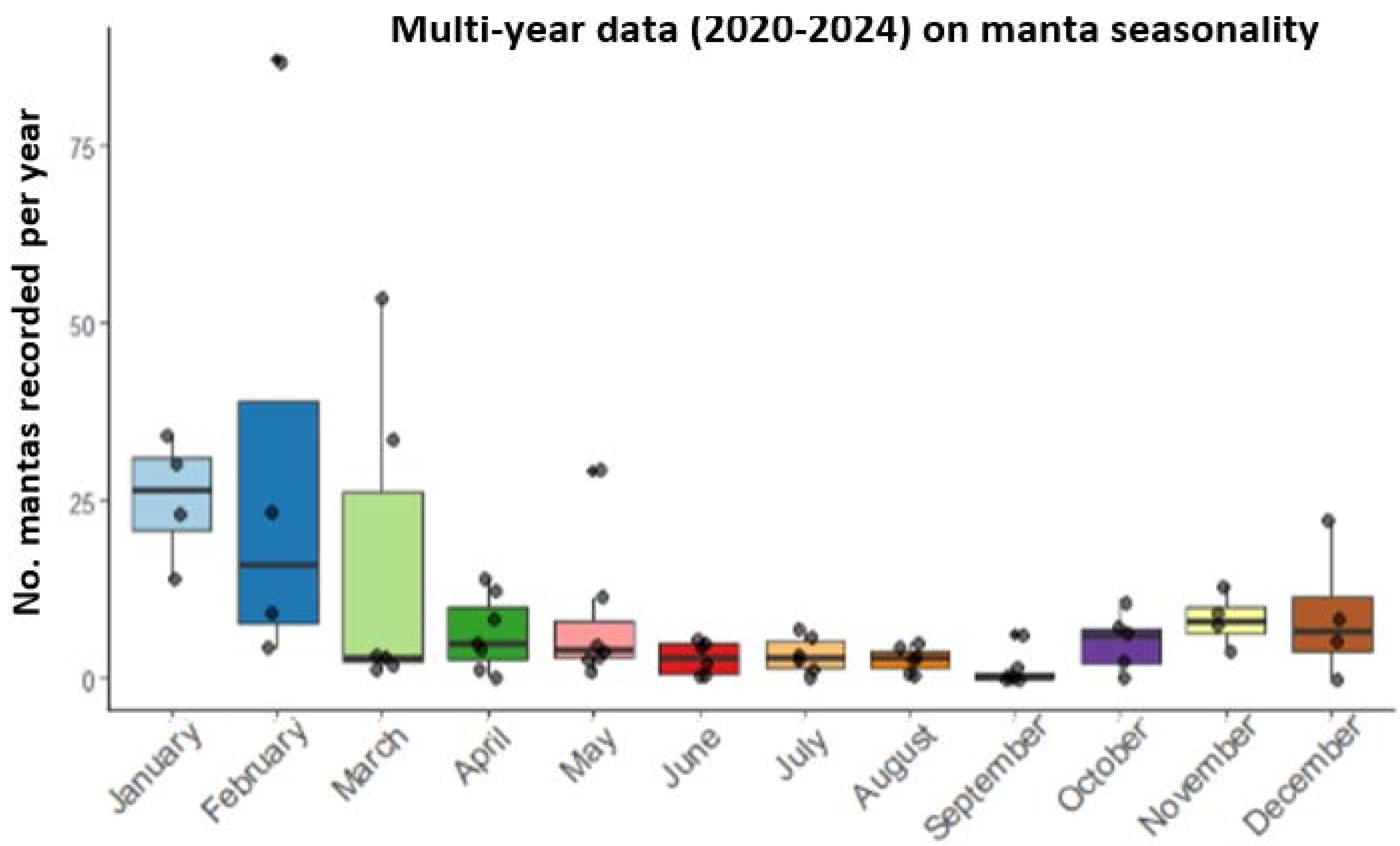


Figure 7.6. *Annual variation in manta sightings. Data is pooled from 2020 – 2024, each point represents the number of sightings in a single year*

Community Outreach & Education Project Report

TEACHING AT ARBOREK SCHOOL

Barefoot volunteers and staff teach at Arborek school every Thursday. The lessons are primarily focused on teaching English to the children, as this language skill will open up multiple opportunities to these children if they want to work away from Arborek in the future. English classes involve games and songs to engage the primary school aged children and their English has come a long way! Marine science classes are also taught with the help of our Indonesian-speaking staff members and topics such as coral bleaching, marine debris and coral restoration have been taught this year. For environmental awareness occasions like World Manta day we run special focused activities to educate the children about the topic.

Figure 8.1. *Barefoot volunteers teach English classes at Arborek school every Thursday*

SIGNED MEMORANDUM OF UNDERSTANDING WITH UNIVERSITY PAPUA

In June 2024 our Head of Science, Josie Chandler, Project Scientist, Reyhan Arifin, and Director of Barefoot Conservaiton, Theodora Damarany, attended a Zoom meeting with representatives from University of Papua to discuss the collaboration between UNIPA Faculty of Marine Science and Barefoot Conservation. Following the successful meeting, a Memorandum of Understanding was signed between both parties which is an exciting development for our collaboration over the next several years. Barefoot Conservation is looking forward to providing research and training internships for 2 university students each year. The internships will last 3-6 months and will involve the student conducting a research project as well as receiving diving certification and training in reef health monitoring techniques. We are excited for the two-way knowledge exchange of this collaboration.

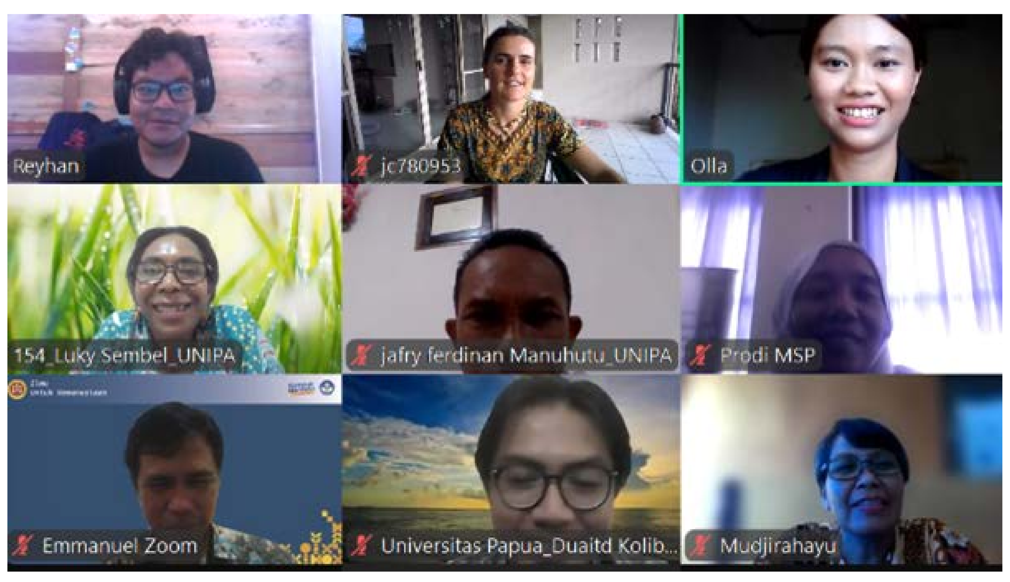


Figure 8.2. *Barefoot team attend a Zoom meeting with University of Papua Fisheries and Marine Science department to discuss the internship programme for university students and the Memorandum of Understanding between the two institutions*

OCEAN WARRIORS PROGRAMME

Our Ocean Warriors programme is going strong after being re-established in 2022. Ocean Warriors is a project which was originally set-up by the team at Child Aid Papua, however we combined forces in 2022 and set up an Arborek branch of the programme. The Ocean Warriors programme involves running environmental activities for the local children and incentivising participation with games and prizes (like Ocean Warriors t-shirts). This project aims to involve the children of Arborek in environmental initiatives and get them excited and passionate about protecting their environment, given the new challenges it is facing. The project launch involved providing over 50 pairs of goggles and masks for the Ocean Warriors, which we still see actively used as part of Ocean Warriors marine activities.

All children on Arborek have Ocean Warrior booklets that they made themselves on launch day. After partaking in a beach clean or another 'environmental good deed' they receive stamps in their books and receive prizes for gaining a certain number of stamps. This year prizes involved a trip to ReShark shark hatchery (see below) and the presentation of lots of Ocean Warriors t-shirts.

Sorting and counting the waste types each week is a valuable exercise for both the children and staff/volunteers as it highlights the trash types which are contributing the most to marine debris. We hope that these marine debris activities not only clean up the beaches but also lead to generational changes in the future.

Figure 8.3. *The Ocean Warriors programme is an initiative for the local children of Arborek which rewards environmental 'good deeds' with stamps and prizes, activities include beach cleans and snorkels*

TWO VISITS TO RESHARK HATCHERY

To celebrate Shark Awareness day this year Barefoot took a group of elementary students from Arborek to visit Raja Ampat Research and Conservation Centre (RARCC) Shark Hatchery at nearby Kri Island. The children learnt about the StAR project which is rewilding Zebra sharks back to the reefs of Raja Ampat. In recent years, zebra shark populations in Raja Ampat have undergone dramatic declines in the wake of threats like habitat degradation and overharvesting due to shark finning. So much so that Zebra sharks have been functionally extinct in the Raja Ampat region, this project is attempting to resestablish populations in Raja Ampat through two shark hatcheries. The children of Arborek loved learning about it from the amazing staff at the hatchery. So much so that the children promised to gather food for the young sharks in the nursery!

We visited RARCC again to watch the release of a juvenile shark Seren! Seren is one of more than 300 zebra sharks that will be set free in an effort to recover zebra shark populations in the Raja Ampat area. We hope that when these kids grow up, seeing Zebra sharks around their house reefs becomes the norm.

TEACHING SCIENTIFIC MONITORING METHODS TO STUDENTS

In February Child Aid Papua students spent the day learning different marine science survey techniques through practical workshops alongside Barefoot's scientists and volunteers. They were able to gain some new refined skills, as well as getting a taste of what it's like to work as a marine scientist in the field.

On the 13th of February, students of Child Aid Papua visited Barefoot Conservation to learn about scientific survey techniques used by marine scientists. Lessons began on land, with our Project scientists splitting into groups and explaining data collection methodologies such as Point Intercept Transects and photo quadrats. Students then tried out the methodologies in the water, collecting their own data on fish abundance and coral coverage. After some experience collecting data with our science team, the students learnt about data input and analysis. Students learnt how to input their fish data into scientific spreadsheets and for photoquadrat data they were taught the process of analysing the photo for benthic coverage using CPCe computer software.

We hope that these classes and field experience allowed the students to experience what it is like to be a marine scientist in the field, learning about marine ecosystem monitoring. We look forward to repeating the workshops with more students.

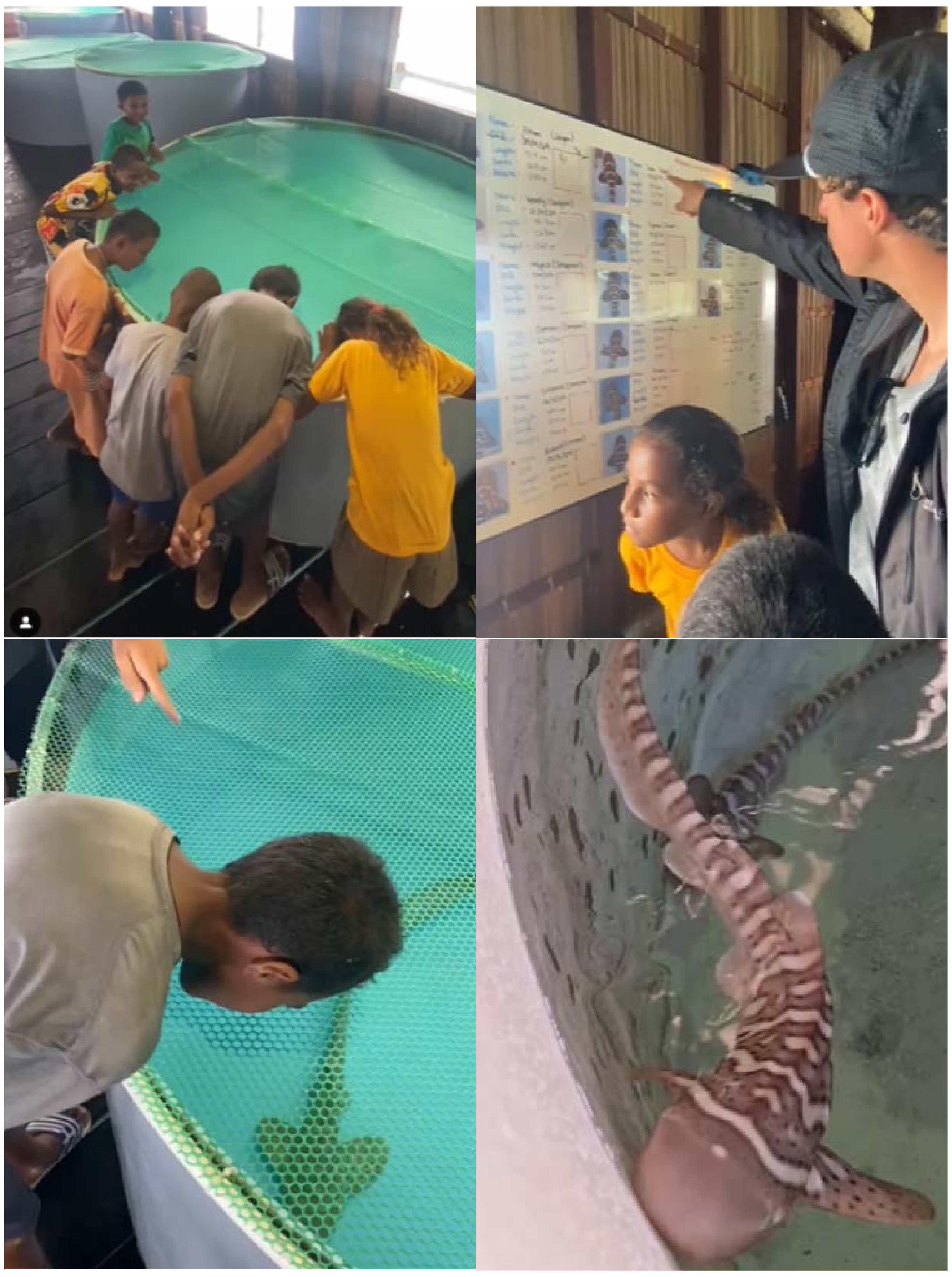


Figure 8.4. *The Barefoot science team and Arborek children during their visit to ReShark shark hatchery on Kri Island*

Figure 8.5. *Child Aid Papua students learning about scientific data collection techniques and what it's like to be a marine scientist*

DIVE TRAINING WITH BAREFOOT CREW

Our Barefoot boat crew Saka, Maikel and Papa Klara gained their PADI Open Water and Advance Open Water scuba diving certificates! They were already pros above the surface, making sure we get to dives safely and now they are also underwater experts as well.

Figure 8.6. *Barefoot boat crew Saka, Maikel and Papa Klara gained their PADI Open Water Diving qualifications and their Advanced Open Water diving qualifications this year*

DIVE TRAINING WITH CHILD AID PAPUA

In June this year we invited some enthusiastic students from Child Aid Papua to experience scuba diving with our Barefoot Divemasters and Instructors. As expected, the kids were complete naturals underwater and we hope that this experience has ignited a new passion or even a taste of a new career path in diving or research.

Figure 8.7. *Child Aid Papua high school students tried out scuba diving with Barefoot scuba instructors and Divemasters*

CORAL BLEACHING CLASSES AND SCUBA DIVING EXCURSION WITH LOCALS

In December we were extremely concerned to witness the first severe bleaching event occurring in Raja Ampat, and of course, so were the local community. Engagement on the issue with the locals highlighted their feelings of concern and the many questions they had on the issue, including some misinformation. In response to these questions we prepared a presentation in Bahasa Indonesia about coral bleaching so that the locals could understand the science underpinning the coral's response, and know what to look for and expect. The presentation was given by our highly knowledgeable coral scientist Septya Putri who answered all questions on the issue.

The coral bleaching presentation was followed up with an excursion to Yenbuba reef where our boat crew dived to witness the corals bleaching up close.

Additionally, an infographic on coral bleaching was prepared in Indonesian by our Project Manager Iris and was made available to anyone in the village that wanted to learn more about it.

Figure 8.7. *Barefoot Science Officer Septya Putri presented on the topic of coral bleaching for local staff and community members, the presentation was followed by a field trip to see the coral bleaching at Yenbuba Island. Bleaching infographics in Bahasa were also handed out to interested community members.*

MEETING ON THE MANAGEMENT OF THE RAJA AMPAT ISLANDS MPA

In January 2025 our Science Officer, Septya Putri, and Project Manager, Iris Uijttewaal, attended a meeting at Aston Hotel in Sorong to partake in a discussion about the future management of the Raja Ampat MPA. We were grateful for the opportunity to discuss some of the major ecological issues that we are witnessing at Arborek (waste water management, marine debris, diver behaviour). The passionate speeches given by other stakeholders in attendance demonstrated that many people also had concerns and reccomendations for the future of Raja Ampat MPA. We look forward to collaborating with stakeholders and BLUD UPTD on addressing some of the key issues discussed in the meeting.

Figure 8.8. *Barefoot Head of Operations Iris Uijttewaal and Science Officer Septya Putri attended the Raja Ampat MPA management meeting in Sorong and contributed to the discussion on waste water management*

***AKNOWLEDGEMENTS & PARTNERS**

Our special thanks goes out to, first & foremost, Simon Barden, for founding Barefoot Conservation back in 2012 and managing the organisation on a daily basis, jumping hurdles and seeking out exciting opportunities to increase our impact every step of the way.

Secondly, we would like to thank our Head of Science, Josie Chandler, for her inexhaustible drive to establish new and level up exciting science projects at Barefoot Conservation while involving the local community wherever possible, fueled by a passion for marine conservation which inspires the team every day.

None of the projects would have been possible without the Barefoot Conservation management team on site, led by our determined and relentlessly hardworking Head of Operations, Iris Uijttewaal. The team works long days every day to make sure data is being collected, science is moving forward and volunteers are being trained to a high quality standard. Thank you both current and previous team members (either voluntarily or on payroll) for your relentless dedication to marine conservation and community development the past year. Special thanks go to Matthew Perrodou for his tireless commitment to the Marine Debris Project and Ocean Warriors Programme.
The local staff are the absolute backbone of Barefoot Conservations, without skippers, compressor operators, cooks and maintenance work Barefoot Conservation camp would simply not be operational. Thank you Pak Manto, Papa Ribka, Papa Klara, Sakarius, Maikel, Teni and Kelvin.
We look forward to continue to conduct marine science research, collect data, expand community projects and education in 2025.

Partners involved are:
• The Regional Public Service Agency Regional Technical Implementing Unit (BLUD UPTD) in the Management of the Conservation Area (KKP) of the Raja Ampat Islands
• POKJA Manta - BLUD UPTD Raja Ampat, Konservasi Indonesia, Waisai
• Universitas Papua – Fakultas Perikanan dan Ilmu Kelautan
• Erika Gress, James Cook University
• Wendy Mitchell, independent photographer and conservationist
• NOAA Coral Reef Watch, Reef Check Indonesia, CoralWatch and Raja Ampat Manta Conservation Research
• Child Aid Papua, Sawinggrai Village
• The Community of Arborek Island

REFERENCES

Bonilla, S., Aguilera, A., Aubriot, L., Huszar, V., Almanza, V., Haakonsson, S., Izaguirre, I., O'Farrell, I., Salazar, A., Becker, V., Cremella, B., Ferragut, C., Hernandez, E., Palacio, H., Rodrigues, L. C., Sampaio da Silva, L. H., Santana, L. M., Santos, J., Somma, A., & Ortega, L. (2023). Nutrients and not temperature are the key drivers for cyanobacterial biomass in the Americas. Harmful Algae, 121, 102367.
https://doi.org/10.1016/j.hal.2022.102367

Briddon, C. L., Szekeres, E., Hegedüs, A., Nicoară, M., Chiriac, C., Stockenreiter, M., & Drugă, B. (2022). The combined impact of low temperatures and shifting phosphorus availability on the competitive ability of cyanobacteria. Scientific Reports, 12(1).
https://doi.org/10.1038/s41598-022-20580-2

Crisp, S. K., Tebbett, S. B., & Bellwood, D. R. (2022). A critical evaluation of benthic phase shift studies on coral reefs. Marine Environmental Research, 178, 105667.
https://doi.org/10.1016/j.marenvres.2022.105667

Francis, G. (1878). Poisonous Australian Lake. Nature, 18(444), 11–12.
https://doi.org/10.1038/018011d0

Kuffner, I., Walters, L., Becerro, M., Paul, V., Ritson-Williams, R., & Beach, K. (2006). Inhibition of coral recruitment by macroalgae and cyanobacteria. Marine Ecology Progress Series, 323, 107–117.
https://doi.org/10.3354/meps323107

Paul, V. J., Thacker, R. W., Banks, K., & Golubic, S. (2005). Benthic cyanobacterial bloom impacts the reefs of South Florida (Broward County, USA). Coral Reefs, 24(4), 693–697.
https://doi.org/10.1007/s00338-005-0061-x

Pinzón C., J. H., Dornberger, L., Beach-Letendre, J., Weil, E., & Mydlarz, L. D. (2014). The link between immunity and life history traits in scleractinian corals. PeerJ, 2, e628.
https://doi.org/10.7717/peerj.628

Puyana, M. (2018). The Fate of Corals: Will They Overcome Competition with Algae and Cyanobacteria in a Changing Environment? Corals in a Changing World.
https://doi.org/10.5772/intechopen.71568

Tebbett, S. B., Streit, R. P., Morais, J., Schlaefer, J. A., Swan, S., & Bellwood, D. R. (2022). Benthic cyanobacterial mat formation during severe coral bleaching at Lizard Island: The mediating role of water currents. Marine Environmental Research, 181, 105752.
https://doi.org/10.1016/j.marenvres.2022.105752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