Preliminary Report assessing Norfolk Island Lagoonal Reef Ecosystem Health

(April and September 2022)

This report was prepared for the Marine and Island Parks Branch, Parks Australia.

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Executive summary

As part of the Emily and Slaughter Bay reef health monitoring commissioned by Parks Australia, in-water surveys were conducted from April 8th-24th and September 11th-16th. The contracted goals for these field work periods were:

1. Ecological surveys,
2. Water quality monitoring,
3. Coral recruitment assessment,
4. Community engagement.

In response to the conditions observed during the April survey, additional work was commissioned including:

5. A winter survey to assess algal growth
6. Echinoderm surveys.
7. Survey for Fluorescent Whitening Compounds
8. Initial stable isotope analysis of particulate organic matter

Key preliminary results from this field work are:

1. There has been a large change in the benthic community structure over the period ongoing surveys have been conducted (March 2020–September 2022). While overall coral cover has remained relatively unchanged, ranging from 17 ± 3% to 31 ± 3%, there have been significant changes in other benthic types, possibly driven by anthropogenic inputs.
    a. In April 2022 there was a significant increase in the abundance (to levels greater than 30% of the benthic community) of a loosely attached red cyanobacterial mat in both Emily and Slaughter Bay. Red algae consisted of less than 10% of the benthos when surveys commenced in 2020. Increased abundance in similar red cyanobacterial mats are associated with declining coral health in other locations. This red algal mat was removed by an extremely large storm southerly storm swell over a period of 2 days in early June and was not present in the September 2022 survey period.
    b. Removal of the red cyanobacterial mat has led to an increase in macroalgae cover to over 38% of the benthos in September 2022. In March 2020 macroalgae composed between 6-8% of the benthos. Macroalgae are a major competitor to corals and have been shown to increase in growth rates with reduced water

quality. It has been suggested that increases in macroalgae can lead to phase shifts from coral dominated to algal dominated reefs under the presence of increased nutrient loading. While it is known that macroalgal abundance varies seasonally, long-term residents indicated they had not previously seen the high macroalgal densities observed in September 2022.

c. Green turfing algae, a natural part of a coral reef, have declined from approximately 37% of the benthic cover to less than 1%.

d. Given the important role that coral reefs play in coastal protection, loss of the reef structure in Emily and Slaughter Bay has the potential to affect the adjacent KAHVA World Heritage area.

2. More than 38% of two major coral types (*Montipora* and *Acropora*) exhibit signs of disease in both Emily and Slaughter Bay. These disease rates are significantly higher than other coral reefs where disease rates generally do not exceed 5%, and in some cases are significantly lower. The number of coral colonies of the two dominant genus (*Montipora* and *Acropora*) with signs of disease decreased in the April 2022 survey (25% and 33% respectively), when compared to 2021, however again increased in the September 2022 survey (44% and 39% respectively) in both Emily and Slaughter Bay. In comparison disease rates in Cemetery Bay are less, between 18-19%. Significantly, disease rates in Slaughter Bay have increased from 0% in April 2021 to 42% in September 2022.

3. Ammonium and nitrate/nitrite levels were up to 5 times higher than the default ANZECC guidelines for offshore marine ecosystems in Emily Bay and Slaughter Bay during a rainfall event when the Emily Bay creek was open in April 2022. These concentrations are similar to those observed in other periods during high rainfall events.

4. Coral recruits were identified on settlement tiles deployed in December 2021 in Cemetery, Emily and Slaughter Bays indicating that there is a supply of coral larvae for further recruitment. However initial analysis indicates lower recruitment in Emily and Slaughter Bay when compared to the less disturbed Cemetery Bay. Sampling of corals within the Bays in April found oocytes were still present in the tissue after spawning, indicating that some corals did not spawn within the bays, possibly due to stress.

5. The distribution and abundance of echinoderm populations (both sea urchin and sea cu cumber populations) in both Emily and Slaughter Bay indicate evidence of local harvesting of the populations or other impacts reducing populations. Robust urchin and sea cucumber populations are key indicators of coral reefs that are resilient to disturbances.

6. Fluorescent Whitening Compounds (FWCs) are optical brighteners found in laundry detergents and toothpaste. Water courses in the Emily and Slaughter Bay catchment (and adjacent catchments) were surveyed for the presence of these compounds. FWCs were identified throughout the Emily and Slaughter Bay catchments and at the freshwater outlet into Emily Bay, indicating continued grey water input into the catchment.

7. Stable isotopes of nitrogen and carbon can be used as tracers to identify the source of nitrogen and carbon entering the ecosystem. Sampling of Particulate Organic Matter (POM) was undertaken for ongoing monitoring.

1. ECOLOGICAL SURVEYS

As part of the on-going monitoring of the health of Emily and Slaughter Bay the project team undertook benthic surveys, coral disease surveys and fish abundance surveys.

1a. Coral Health Benthic surveys.

Surveys consisted of 7 belt transects in Emily Bay and 7 in Slaughter Bay in March 2020 (Ainsworth et al. 2021), 15 in Emily Bay and 20 in Slaughter Bay in November 2020, 15 in Emily Bay and 25 in Slaughter Bay in March 2021 and 15 in Emily Bay and 25 in Slaughter Bay in April and September 2022. For each transect (10 m) 10 photos were taken with a TG-6 Olympus underwater camera at 1m increments using a 0.5 m^2 photo quadrat to standardize the area (n = 10 photos $transect^{-1}$). The resulting photos were analysed using the online platform CoralNet with a grid of 100 points per photo. A standardised label set was uploaded to CoralNet and the data were used to describe overall benthic cover (% cover of corals, algae and sand) and coral health at Emily and Slaughter Bay in March 2020, March 2021, April 2022 and September 2022. Corals were classified as *Acropora* sp. (branch or non-branch), *Pocillopora* or *Stylophora* sp. (hybrids impossible to differentiate), *Montipora* sp. (encrusting or plating), *Acanthastrea* sp., *Porites* sp., *Goniopora* sp. and *Platygyra* sp. along with their health status (healthy, pale, bleached, recently dead). Resulting cover was summed across each transect so that each category is described as the % cover $transect^{-1}$.

In general, over the survey period coral cover has remained relatively stable in both Emily and Slaughter Bay, ranging from 17 ± 3% to 31 ± 3% (Figure 1a). However, while not explicitly examined, it was noted that there are very few small coral colonies in the bays, possibly indicating a recruitment blockage. A specific analysis of coral size classes may be able to provide information of the community age demographics.

While coral cover has not changed significantly, there have been large changes in other benthic community types. For example, there were large increases in the prevalence of red turf in both Emily and Slaughter Bay from 2020 (<10%) to greater than 30% in 2022 (Figure 1C). The red turf consisted primarily of a red cyanobacterial mat (Figure 3A-D) that was loosely covering the existing benthos (Figure 2C,D), samples of which were taken for 16s rDNA profiling to determine the member of the mat. Studies from other reef areas have found that increases in red cyanobacteria can be associated with increased nutrient in a system and are indicative of a reef area under stress (Ford et al. 2018). However, a large southerly storm swell, with waves reported to be in excess of 6 m removed this algae, with abundance falling to 0 in the September 2022 survey period.

The red alga was replaced in the September 2022 survey period by macroalgae (Figure 1B, 3E,F) that constituted over 38% of the benthic community; in comparison macroalgae made up only between 6-8% of the benthos in the March 2020 survey. Macroalgae are a major competitor to corals on a reef (Brown et al. 2020) and are known to increase in growth rates on reefs with reduced water quality (De'ath and Fabricius 2010) and can negatively impact coral growth and recruitment (Diaz-Pulido et al. 2009). It has been suggested that increases in macroalgae can lead to phase shifts from coral dominated to algal dominated reefs under the presence of increased nutrient loading, particularly on reefs with low herbivory (McCook 1999), such as Emily and Slaughter Bay. While it is known that macroalgal abundance varies seasonally, long-term residents indicated they had not previously seen the high macroalgal densities observed in September 2022.

The large increases in red and macroalgal types have led to a decline in green turfing algal abundance, a natural part of a coral reef, from approximately 37% of the benthic cover in Mar ch 2020 to less than 1% in the April and September 2022 surveys. There is significant variability across the Emily and Slaughter Bay reefs, for example analysis of the benthic community in Slaughter Bay during the April 2022 survey demonstrates there is significant variability between the eastern (Salt house), middle and western end (Pier) of the bay (Figure 2).

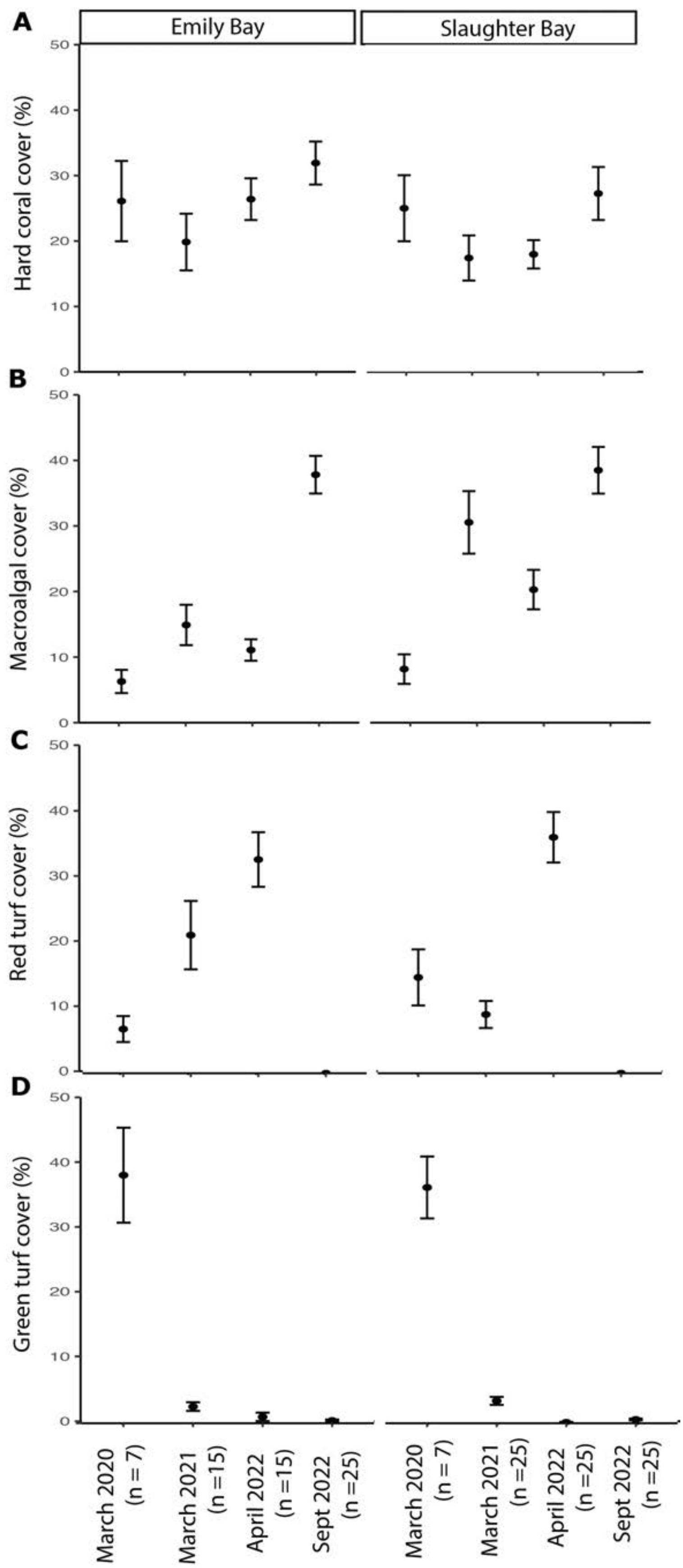

Figure 1. Benthic cover at Emily and Slaughter Bays measured during surveys conducted in 2020, 2021 (April), 2022 (April and September).

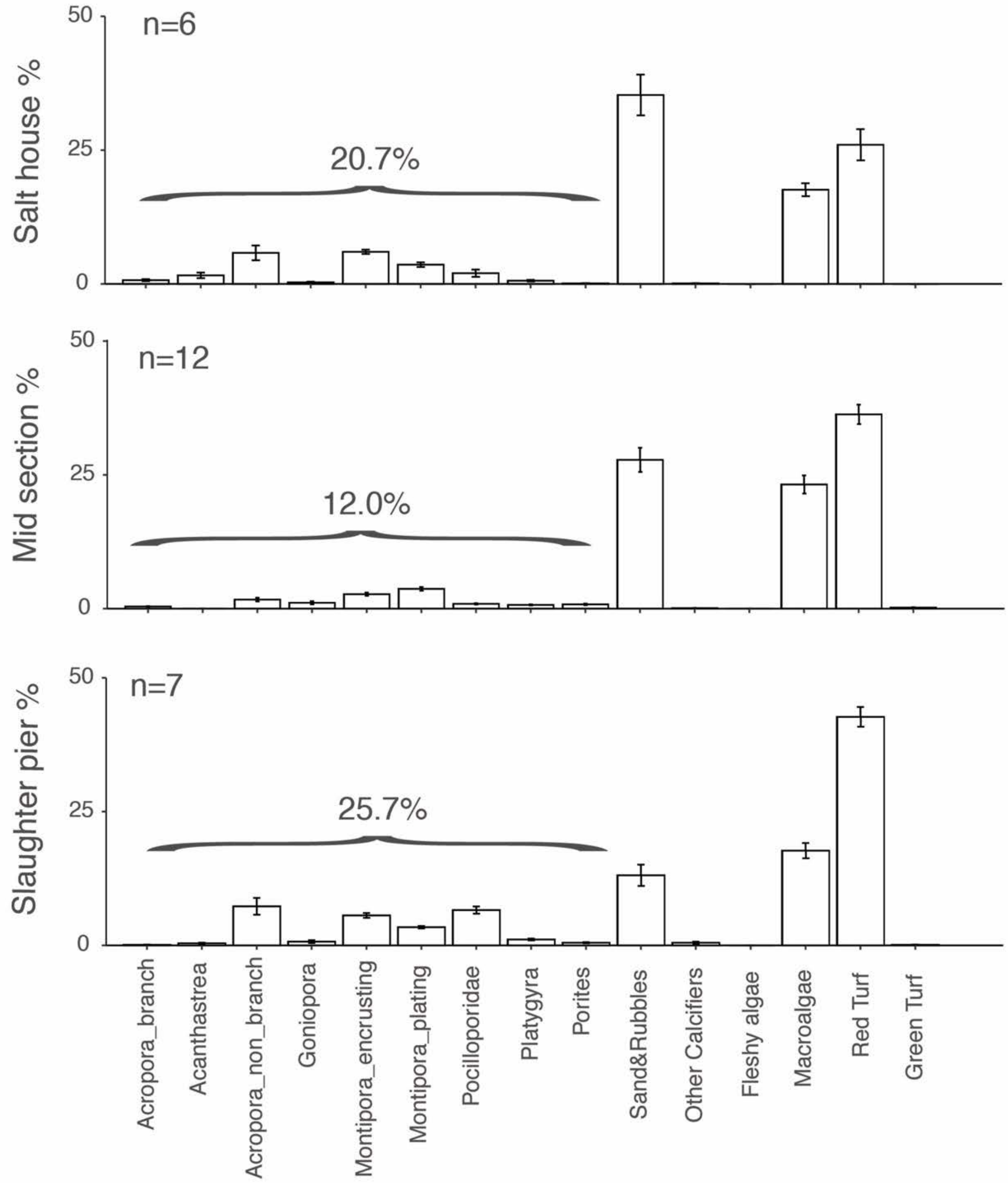

Figure 2. Benthic cover in three sections (Salthouse, mid, and Pier) of Slaughter Bay measured during surveys conducted in April 2022.

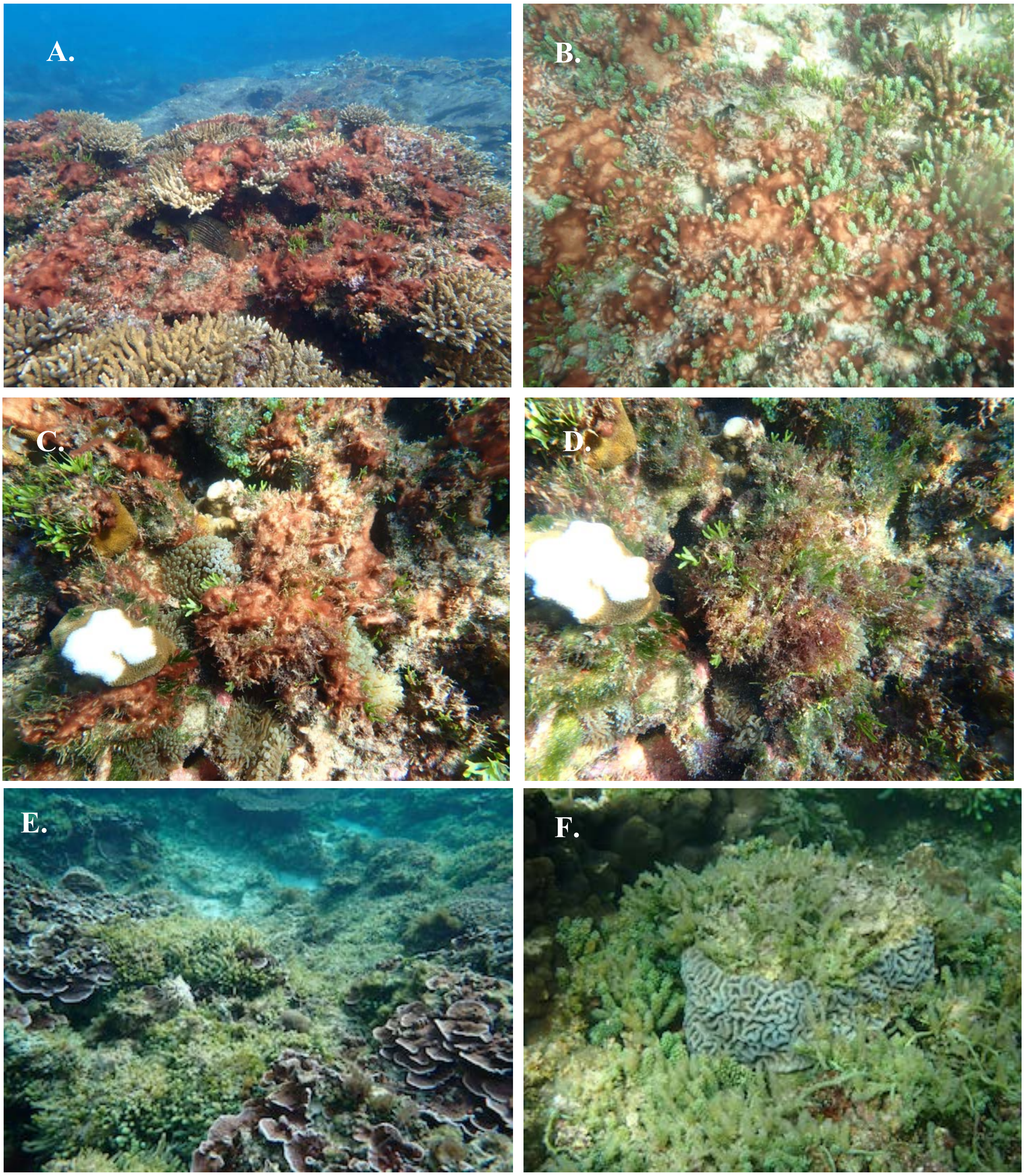

Figure 3. Examples of red cyanobacterial mats (A-D) and macroalgae (E,F) seen in Emily and Slaughter Bay in April 2022 and September 2022 respectively. Examples of the red cyanobacteria associated with (A) corals and (B) green algae. The red cyanobacteria mat covers the existing benthos (C) which can be seen when the cyanobacteria is removed (D), note position of the white coral for orientation. Representative images of macroalgae competition with coral in September 2022 (E,F).

1b. Coral Bleaching Benthic surveys

Initial surveys of Emily and Slaughter Bay were commenced after a coral bleaching event in 2020- analysis of the 2021 and 2022 surveys shows no evidence of widespread coral bleaching (Figure 4) despite reports of extensive coral bleaching on the Great Barrier Reef (GBR).

This is despite surrounding ocean temperatures leading to an accumulation of possible thermal stress, indicated by the Degree Heating Week (DHW) metric (Figure 5), as assessed by satellite sea surface monitoring by National Oceanographic and Atmospheric Administration (NOAA) at a 5 km resolution. Generally, a DHW of 4 leads to coral bleaching while a DHW value of 8 is correlated to wide-scale coral bleaching, the virtual station for Norfolk Island indicated DHW values above 6. These results indicate that the oceanographic drivers of coral bleaching on the GBR can be disconnected from those that affect Norfolk Island and that the particular water-flow conditions of the bays generate unique conditions that may modify bleaching risks.

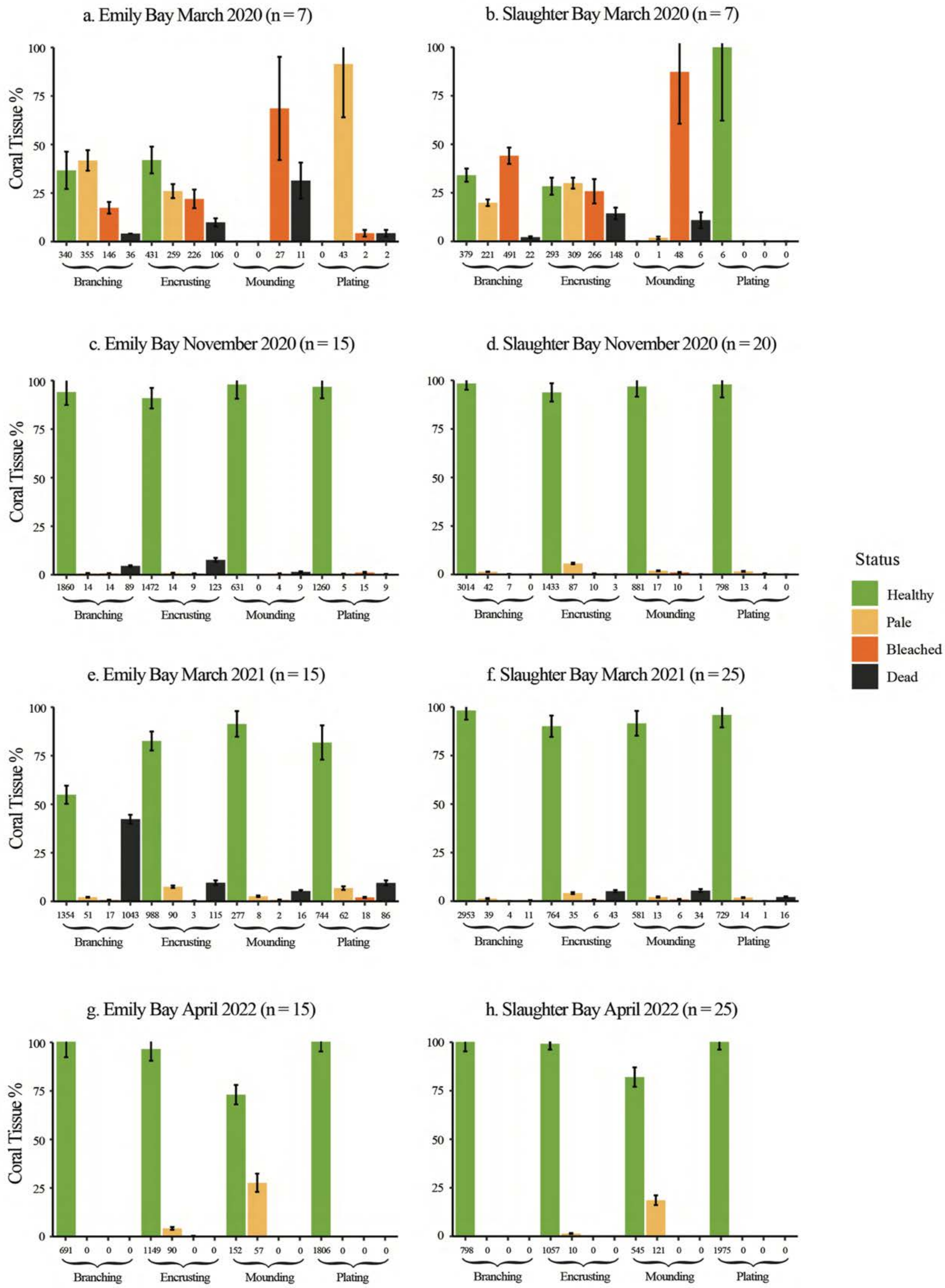

Figure 4. Coral bleaching status across Emily and Slaughter Bay in 2020, 2021 and 2022.

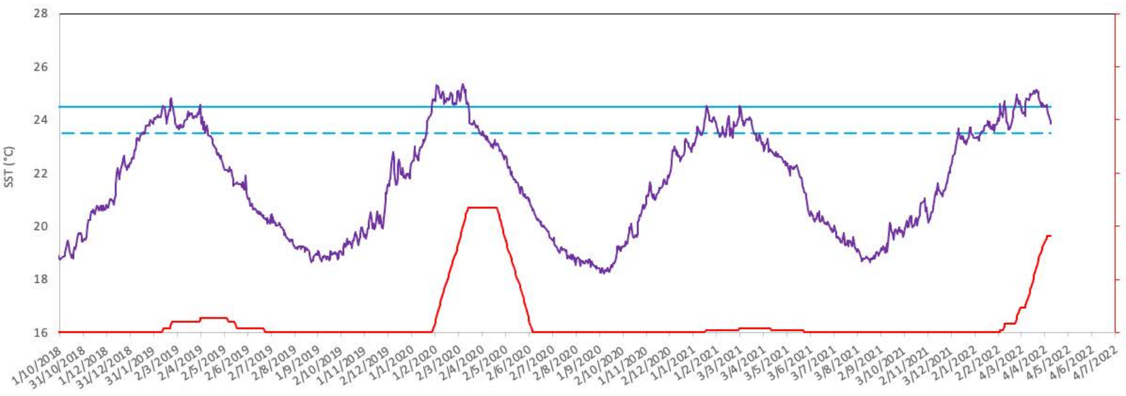

Figure 5. Sea surface temperature (SST; purple line), degree heating week (DHW; red line), maximum monthly mean (blue dashed line) and maximum monthly mean +1 °C (blue line) - satellite measurements at Emily Bay.

1c. Coral Disease Benthic surveys

Previous surveys in 2020 and 2021 identified significant disease prevalence in the corals of Emily and Slaughter Bay. To quantify prevalence (i.e. the proportion of community infected) of *Montipora* White Syndrome, *Acropora* White Syndrome and *Acropora* Growth Anomalies ecological surveys were conducted within the lagoon. For *Montipora* taxa disease was assessed in December 2020, April 2021 and April 2022 and September 2022. For *Acropora* taxa disease was assessed in April 2021 and April 2022. At each time point, 12-replicate belt-transects were conducted with 6 belt-transects laid in both EB and SB respectively (Figure 5A). Survey methods involved placing a 10 m transect line along the benthos parallel to the depth contours of the reef structure at approximately 1-2 m depth. All transects were placed at least 10 m apart. Transect sites were semi-fixed (i.e., a permanent reef marker was not used, but the same reef area was re-visited at the repeat time point). All colonies of *Montipora* and *Acropora* over 10 cm in diameter and within a 1 m belt on either side of the transect were monitored for signs of disease. Disease prevalence was calculated for each belt-transect by dividing the number of colonies showing signs of disease by the total number of colonies present within a transect.

Coral disease prevalence for the two major coral genera in Emily and Slaughter Bay is relatively high when compared to other coral reefs. Overall *Montipora* white syndrome was affecting 44% of colonies in both bays in September 2022 (Table 1) and is similar between Emily Bay (42%) and Slaughter Bay (45%, Figure 5). *Montipora* disease prevalence was lowest during the survey period in April 2022 (Figure 5) but again increased in the September sampling.

In the latest September survey *Acropora* white syndrome rate were similar across both bays, 47% in Emily Bay and 42% in Slaughter Bay (Figure 5). Since April 2021 *Acropora* disease rates in Emily Bay has remained stable, varying between 46% and 58%, in contrast white syndrome in Slaughter Bay has significantly increased, from 0% disease colonies in April 202 1 increasing steadily to the current prevalence of 42%. Surveys of the adjacent Cemetery Bay in April and September 2022 found disease prevalence of 19% and 18% respectively.

The disease prevalence rates for both *Montipora* and *Acropora* are significantly higher than seen in other reef systems. For example, at Heron Island on the Great Barrier Reef all disease, of all corals varied between 1.9 and 4.2 %, with plating *Acropora's* having the highest prevalence levels of 12% (Haapkylä et al. 2010), while other *Acropora* growth forms all had prevalence rates below 3%. During these surveys *Montipora's* were only found with a disease prevalence of 3.3% (Haapkylä et al. 2010). During an Acroporid white syndrome disease outbreak at Heron Island peak mean prevalence rates of 8.1% were seen with a maximum of 14% at one site. Studies from other locations, for example the Red Sea where disease prevalence was found to be less then 0.5% (Aeby et al. 2021), have also generally found disease prevalence rates of less than 5%. As such the relatively high disease prevalence rates at Norfolk Island are of concern. As yet there is no data available on the mortality or recovery of diseased colonies, this information is of particular importance given the high prevalence rates seen.

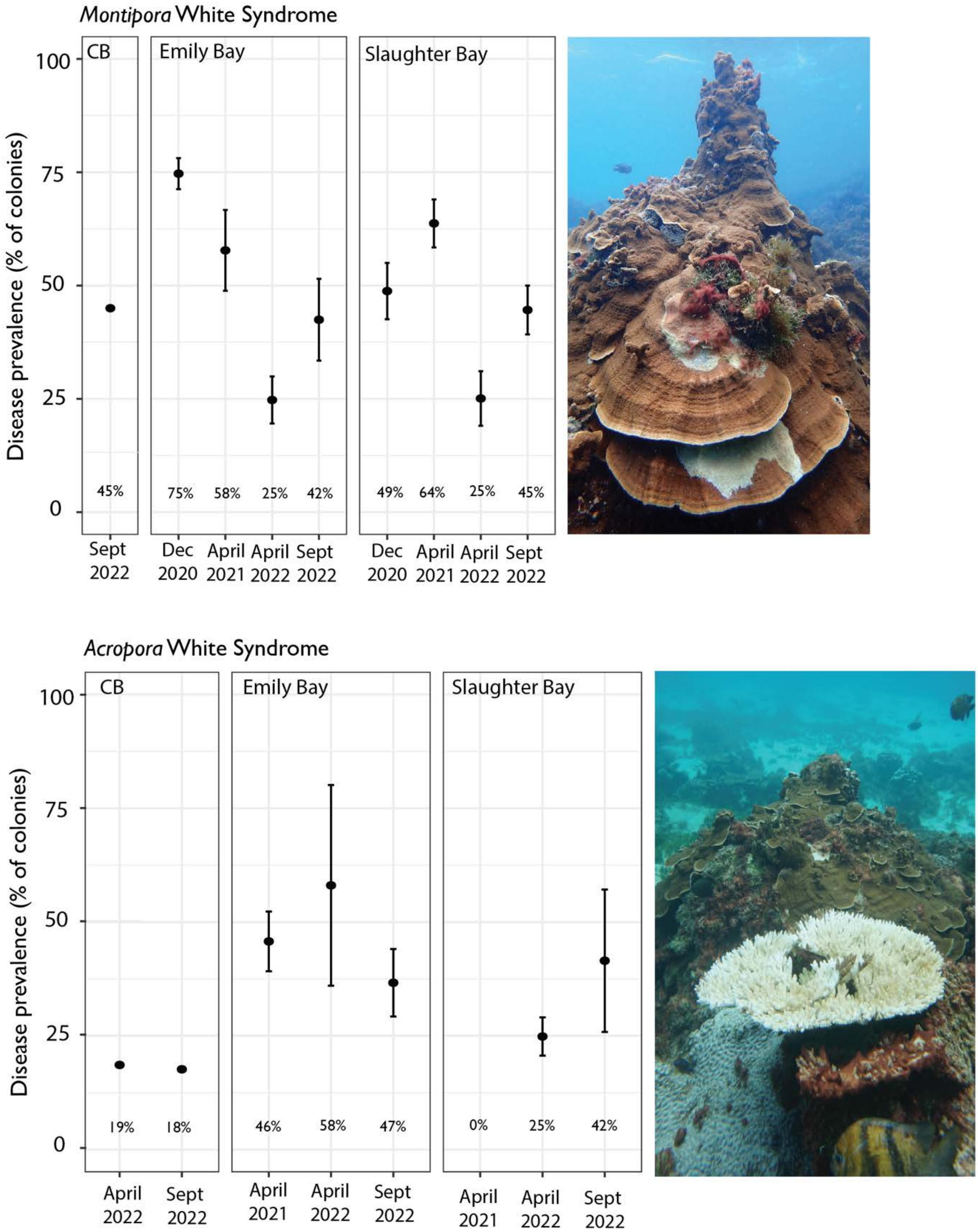

Figure 5. Disease prevalence levels recorded over time for *Montipora* White Syndrome (A) and *Acropora* White Syndrome (B). Values are mean ± se.

Table 1. Total disease prevalence of White Syndrome within the lagoon over time.

Time	Taxa	Mean lagoon prevalence
December 2020	***Montipora***	**61.7%** ± 5.1
April 2021	***Montipora***	**60.7%** ± 5
April 2022	***Montipora***	**25%** ± 3.8
September 2022	***Montipora***	**44%** ± 5
April 2021	***Acropora***	**46%** ± 6.6 (only in Emily Bay)
April 2022	***Acropora***	**33%** ± 11
September 2022	***Acropora***	**39%** ± 9

1d. Fish community surveys

To increase understanding of the ecology of Emily and Slaughter Bay a comprehensive fish survey for baseline data was undertaken in April 2022. This consisted of 12 approximately 200 m long transects 2 m in width which were taken for 3D benthic reconstruction and fish surveys along with 30 remote underwater video (RUV; Figure 6) drops (approximately 90 minutes of footage for each drop) of the sand and coral communities. This video footage will be used to analyse the diversity of fish communities in different habitats.

Figure 6. Remote underwater video deployment to monitor fish communities. These cameras were deployed on the reef and sand benthic communities for approximately 90 minutes at a time

2. WATER QUALITY MONITORING

The major anthropogenic influences on Emily and Slaughter Bay are associated with terrestrial nutrient inputs into the bay. Rainfall data was obtained from the Australian Bureau of Meteorology for the station number 200288 (29.0389° S, 167.9408° E) located at Norfolk Island airport. The lagoonal system of Norfolk Island is affected by freshwater incursion, sedimentation and flooding that influence the benthic community structure and health. When abnormal rainfall events are associated with high seawater temperature, the benthic community can experience stress and shifts in its composition. The environmental data reported below show that high rainfall events occurred in the summers of 2020 and 2022. To determine the impact of these events 17 water samples were taken along the shoreline of Emily andSlaughter Bay on the 15th April (Figure 8) while Emily Bay creek was flowing to determine ammonium and nitrate/nitrite (NOx) concentrations. Ammonium concentrations were highest at the Emily Bay creek (111 μg/L) and decreased as distance increased from the source. Ammonium levels in all samples throughout Emily and Slaughter Bay, in addition to one site to the west of the Slaughter Bay pier were above the default ANZECC guideline levels (20μg/L). NOx concentrations were also higher than the default ANZECC guidelines (25 μg/L) across all samples although did not demonstrate the same spatial decrease as seen for ammonium. This is likely due to the fact that ammonium is more readily assimilated by photosynthetic organisms. Samples were also taken around the island for stable isotope analysis

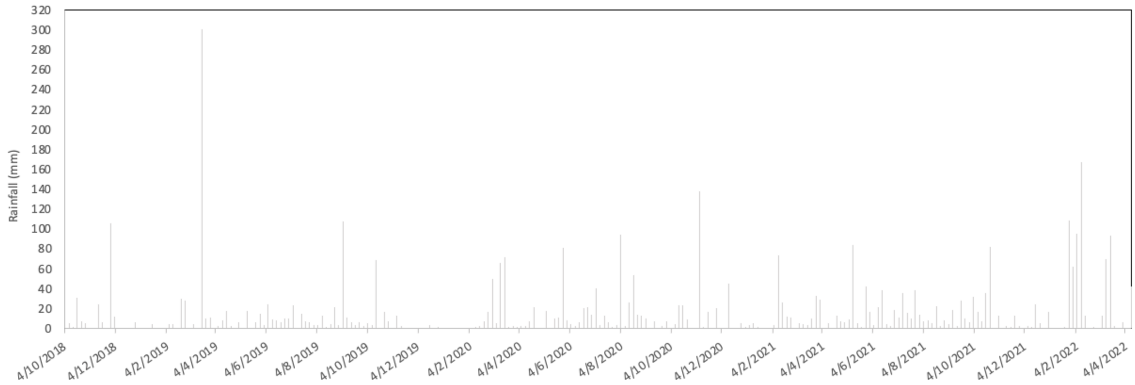

Figure 7. Rainfall recorded at Norfolk Island meteorological station from the 4th of October 2018 to the 4th of April 2022.

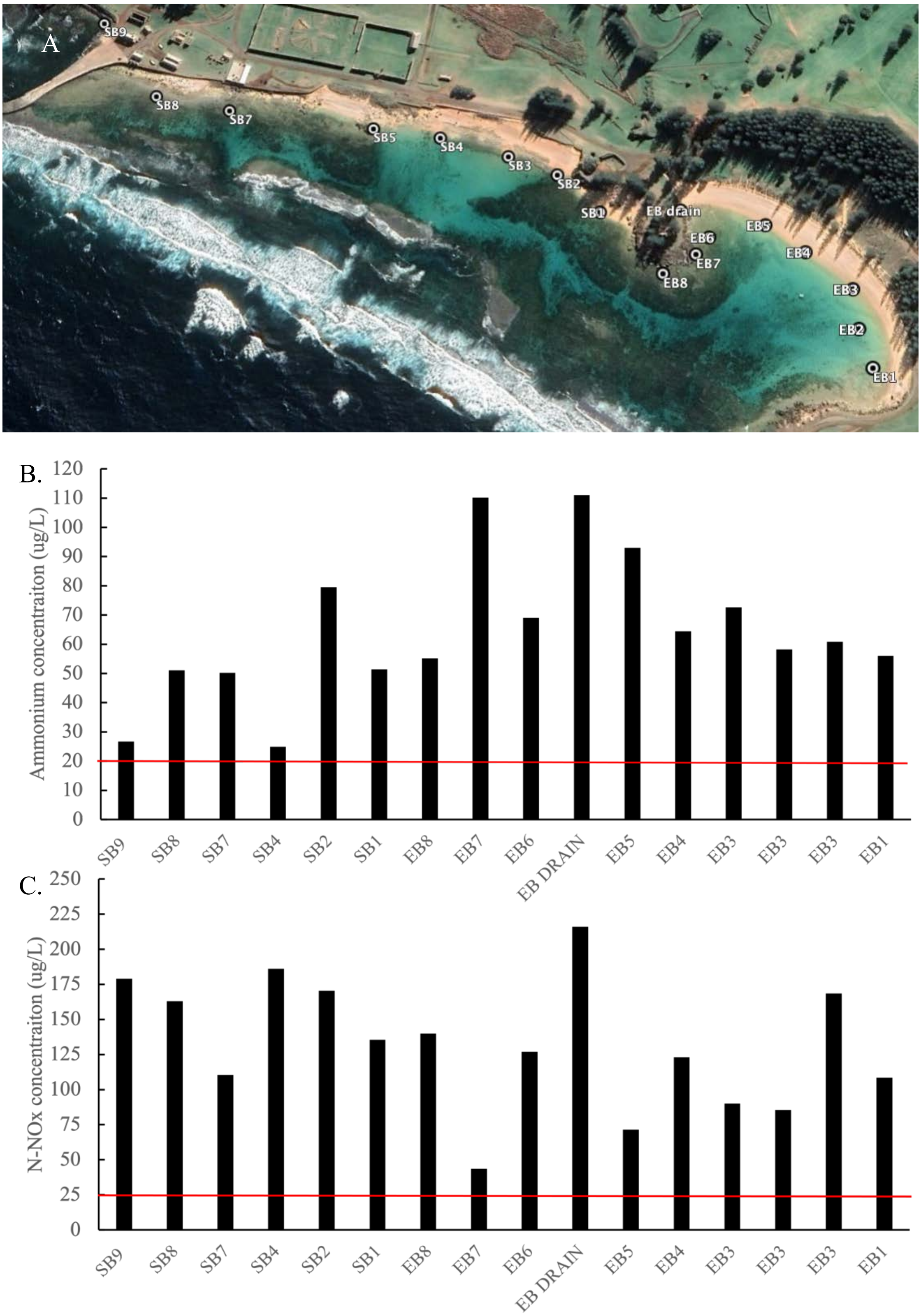

Figure 8. Nutrient concentrations across Emily and Slaughter Bay while the Emily Bay outlet was open (15th April 2022). (A) locations of sampling, (B) ammonium concentrations, (C) nitrate/nitrite (NOx) concentrations. Red lines indicate ANZECC default guideline thresholds.

The ANZECC guidelines described above come from the 2000 default trigger guidelines and are designed to provide a generic starting point for water quality assessment. ANZECC now recommends that trigger levels are developed for specific locations based upon the identification of community values and management goals for the area (https://www.waterquality.gov.au/anz-guidelines).

3. CORAL RECRUITMENT ASSESSMENT

Coral recruitment tiles (Figure 9a) were deployed in Cemetery, Emily and Slaughter Bays in December 2021 to assess if there was a potential for coral recruitment into the Bays. (Plates were also deployed at the Chord however these were lost with the large wave action seen in 2022 at this site.) Possible coral spawning was observed in December, January and February by the local community. The tiles were collected in April 2022 and those for Cemetery and Slaughter Bay were visually surveyed on site for the presence of coral recruits (Figure 9). All tiles were returned to UNSW and will be further assessed using dissecting microscopes (including those from Emily Bay that were not analysed at Norfolk Island). The initial counts indicate high levels of recruitment in Cemetery Bay (115 recruits/recruitment block), with recruit abundance similar to that seen at Heron Island on the GBR (Dunstan and Johnson 1998). Recruitment rates were lower (39 and 19 recruits) in the initial counts for the Slaughter Bay settlement plates. Histopathology samples of *Monitpora* and *Acropora* collected in April 2022 identified the presence of oocytes in the tissues in both diseased and healthy individuals indicating they did not spawn. Retention and subsequent reabsorption of oocytes in corals has been linked to stress (Szmant and Gassman 1990) and subsequent reduction in reproductive output of the population. Elevated nitrogen and phosphorus levels have also been linked to reduced reproductive outputs in corals (Ward and Harrison 2000).

4. COMMUNITY EVENT

A public presentation of the research findings was given at Emily Bay on the 21st April 2022 by Associate Professors Tracy Ainsworth, Bill Leggat and Jane Williamson. The event was well attended with over 50 people attending. PDFs of the talks have been sent to Parks Australia staff. Discussion were also had with a number of community members who are interested in participating in the citizen science monitoring, a number of these people have already supplied photos to the research team. Initial planning has been undertaken for a Facebook page that will act as an information portal for the citizen science project, subsequent discussions with Norfolk Island community members has indicated that a dedicated website would be a suitable addition to this approach.

Figure 9. Coral settlement tiles deployed in December 2021 and recovered in April 2022. (A) The series of 4 tiles were attached to bricks and deployed in situ at Cemetery, Emily and Slau ghter Bays and were (B) then recovered. Tiles were visually surveyed for the presence of coral recruits (C, D and E) amongst the other organisms (F) that had settled on the tiles.

5. ECHINODERM SURVEY

Robust echinoderm populations (both sea urchin and sea cucumbers) are an indication of a resilient reef environment. Both urchins and cucumbers play important herbivory roles to reduce algal competition with corals, this is particularly important for Emily, Slaughter and Cemetery Bay as members of the local community have indicated that harvesting of echinoderms occurs in some instances in the Bays. To generate baseline data for echinoderm populations an initial daytime survey was conducted to identify the species present (e.g, Figure 10), preferred substrate, and estimates of abundance.

Figure 10. Common echinoderms seen in Emily and Slaughter Bays (A) *Tripneustes gratilla*, (B) *Heliocidaris tuberculata*, (C) *Diadema sp.* (D) *Holothuria hilla,* (E) *Holothuria leucospilota,* (F) *Holthuria atria..*

In total 441 echinoderms were found in the initial survey of Emily and Slaughter Bay, the maj ority of which were the sea urchins *H. tuberculata* (53%) and *T. gratilla* (26%) (Table 2). Further survey in Western Slaughter Bay identified another 93 echinoderms while a survey conducted in Cemetery Bay found 97 echinoderms. Anecdotal observations from 2020 coral surveys suggest that Cemetery Bay cucumber populations were larger in 2020.

Table 2. Preliminary estimates of echinoderm populations in Emily and Slaughter Bay

Species	Sand	Coral	Rubble	Algae	Crevice
Holothuria atria	2	0	1	0	1
Holothuria hilla	1	0	1	0	1
Holothuria leucospilota	10	1	1	1	2
Stichopus sp.	1	0	1	2	1
Heliocidaris tuberculata	23	25	9	10	166
Tripneustes gratilla	8	20	31	39	17
Diadema sp.	4	6	4	0	46
Echinometra mathaei	0	0	0	0	4

6. SURVEY OF FLUORESCENT WHITENING COMPOUNDS

Fluorescent Whitening Compounds (FWCs) are synthetic chemicals added to laundry detergents, and other products such as toothpaste, to act as optical brighteners. Given they do not occur naturally in the environment their detection in the environment provides an additional source of information indicating grey water inputs from human sources. Assays for the presence of FWCs were conducted at 14 sites throughout the Emily and Slaughter Bay catchment (Figure 11) and were found in all watercourses examined. FWCs were not identified in any ocean site apart from in Emily Bay where the terrestrially derived water enters the bay (Figure 11). FWCs are rapidly degraded by ultra-violet light, therefore their presence throughout the catchment indicates continued grey water inputs into the system.

Figure 11. Presence of Fluorescent Whitening compound in the Emily and Slaughter Bay catchments. Sampling sites are identified with a red dot, the presence of FWCs is indicated by a red arrow.

7. STABLE ISOTOPSE ANALYSIS

Stable isotope analysis provides a method to determine the possible sources of carbon and nitrogen. Carbon and nitrogen isotope values represent a natural tracer in the environment that is conservative and predictable (we know what happens as the isotope signature moves through the food web). Samples were taken for analysis of stable isotope signature from a variety of sites including Emily Bay, Slaughter Bay, Cascades, Bomboras and Ansons Bay and wastewater disposal sites.

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