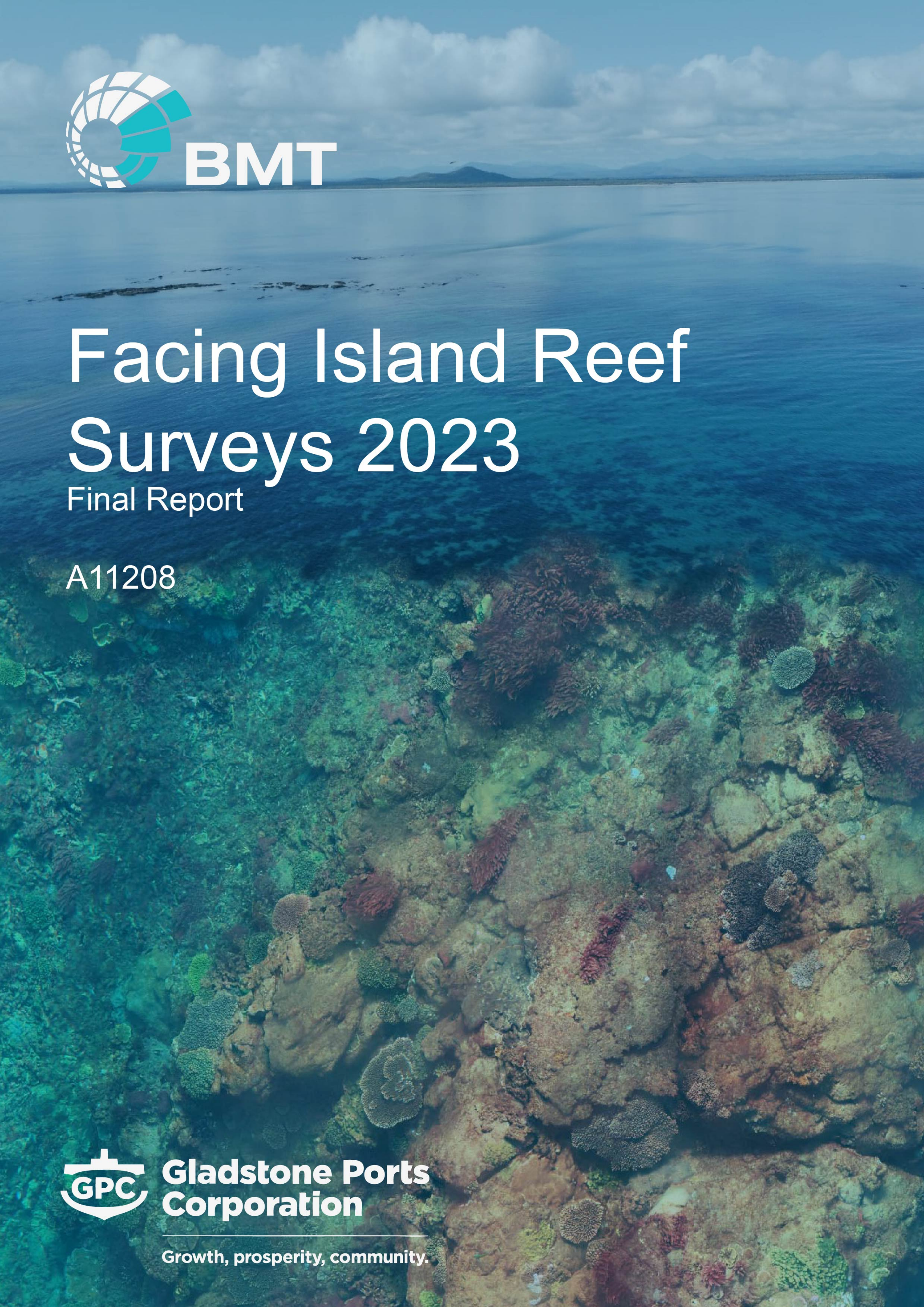

BMT

Facing Island Reef Surveys 2023

Final Report

A11208

Gladstone Ports Corporation
Growth, prosperity, community.

Document Control

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Executive Summary

The Material Relocation Area (MRA) at East Banks has a long history of use for the placement of uncontaminated capital and maintenance dredged material. Gladstone Ports Corporation (GPC) exclusively uses the site for the placement of material from maintenance dredging. Dredged material is mostly (95%) retained within the MRA, with a small fraction re-mobilised.

The Port of Gladstone Sea Dumping Permit for maintenance material prescribes a Long-term Maintenance Dredging Management Plan (LMDMP) for the dredging activities. The reef monitoring aspect of this plan seeks to test the impact hypothesis that activities (re-mobilised sediments) do not result in long-term changes to adjacent reef communities. This is established by reef condition surveys conducted every five years in accordance with Technical Advisory Consultative Committee recommendations. The closest coral reef receptor to the network of nearshore reefs is located on the eastern side of Facing Island, more than 5 km from the MRA. Some of the reefs in the receptor network have been surveyed previously at varying levels of detail allowing qualitative assessment from 2013 to present. A monitoring program established in 2013, was last surveyed in June 2018, and the present study provided quantitative comparisons against the most recent event.

The 2023 survey repeated the methodology used in 2018, consisting of four 20 m photo-transects located at each of 10 monitoring sites. Transect locations were revisited by following shot line marking the start and finish points for each transect conducted in 2018. A total of 985 benthic photos were collected giving up to an average of 24 photos per transect for analysis. Incidence of coral disease and numbers of coral recruits were quantified within 34 cm of the transect tapes directly from the first 5 m of the transect. Orthorectified image mosaics were also generated at three of the sites for side-by-side comparisons. All diving was undertaken by BMT marine scientists with ADAS commercial dive qualifications.

The 2023 survey showed that there are essentially two major community types within the monitored sites. Firstly, outer Facing Island sites and Rundle Island sites were highly similar and were coral-dominated, without the macroalgae *Sargassum*. The other major community type included sites closer to the harbour entrance, which was dominated by macroalgae and the coral genus *Turbinaria*.

Since 2018, there has been little improvement in sites at Facing Island (some non-statistically significant increases in coral cover), and a fairly large reduction in coral cover was observed at one site (FAC3). This site has become more ‘harbour entrance-like’, as its living coral cover has reduced and its macroalgal cover has increased, and one of the most tolerant genera of corals *Turbinaria* has increased in cover. In contrast, the regional reference sites (Rundle Island), have improved, with coral cover increasing. There were very minor changes in coral disease and low numbers of coral recruits at all sites.

The decline in coral cover at one of the Facing Island sites (FAC3) is intriguing because it is not widespread across Facing Island, and out of context with changes at Rundle Island and the greater region. The comparison in orthomosaics at FAC3 did show that the most loss of coral appeared over the shallowest parts of the 3D mosaic site. For a thermal impact to be the driver of change at FAC3, it is expected that other sites nearby would be affected similarly. The 2020 bleaching event in the nearby Keppel Islands resulted in very specific depth-related impacts, however, the transect data were collected at similar depth contours in nearby sites, therefore it seems unlikely that thermal bleaching was driving the change at FAC3. No crown of thorns starfish were observed in either monitoring campaign, but coral disease has been occasionally observed.

It is perhaps more likely that the reduction in coral cover at FAC3 is related to localised changes in water quality or patterns in local disease or predation. Therefore, it is unlikely that maintenance dredging activities (re-mobilised sediments) result in long-term changes to adjacent reef communities.

Over the 10 years since the inception of the 2013 the monitoring program, the annual rainfall has been above median in 7/10 of those years, associated with strong southern oscillation. The 2013 flow event remains the highest recorded overflow event for Gladstone’s water supply dam. These flow events are likely to have hindered the improvement of coral communities to date. As the southern oscillation index slows in late 2023 and there is a transition into drier and warmer conditions, the risk of catchment impacts may lessen for these communities while chances of extreme rainfall are lower.

Contents

Acronyms

Acronyms	Explanation
ADAS	Australian Diver Accreditation Scheme
AIMS	Australian Institute of Marine Science
ANOSIM	Analysis of Similarity (Primer-e routine)
BMT	British Maritime Technology
East Point Ledge	Monitoring site at East Point Ledge
EBSDS	East Banks Sea Disposal Site
enmeans	Estimated marginal means (R Library)
FAC3	Monitoring site at Facing Island Reef #3
FAC4	Monitoring site at Facing Island Reef #4
GAT	Monitoring site at Gatcombe Reef
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GHHP	Gladstone Healthy Harbour Partnership
glmmTMB	generalised linear mixed model template model builder (R Library)
GPC	Gladstone Ports Corporation
LAT	lowest astronomical tide
LMDMP	Long-term Maintenance Dredging Management Plan
MRA	Material relocation area
nMDS plot	non-metric muti-dimensional scaling plots (Primer-e routine)
NPR	Monitoring site at North Point Reef
PL	Monitoring site at Pearl Ledge
RUN1	Monitoring site at Rundle Island Reef
RUN2	Monitoring site at Rundle Island Reef
RUN3	Monitoring site at Rundle Island Reef
SCR	Monitoring site at Sable Chief Rocks
SIMPER	Similarity Percentages (Primer-e routine)

1 Introduction

The Material Relocation Area (MRA) known as the East Banks Sea Disposal Site (EBSDS) has a long history of use for the placement of uncontaminated capital and maintenance dredged material. Gladstone Ports Corporation (GPC) exclusively uses the site for the placement of material from maintenance dredging. Dredged material is mostly (95%) retained within the MRA, but a small fraction is re-mobilised and transported by waves events and currents. Therefore, the MRA functions as a largely retentive site.

The closest coral reef receptor to the network of nearshore reefs is located on the eastern side of reef communities. This reef system is located more than 5 km from the MRA (Figure 1.1).

The Port of Gladstone Sea Dumping Permit for maintenance material prescribes a Long-term Maintenance Dredging Management Plan (LMDMP) for the dredging activities. The reef monitoring aspect of this plan seeks to test the impact hypothesis that activities do not result in long-term changes to adjacent reef communities. This is established by reef condition surveys conducted every five years in accordance with Technical Advisory Consultative Committee recommendations.

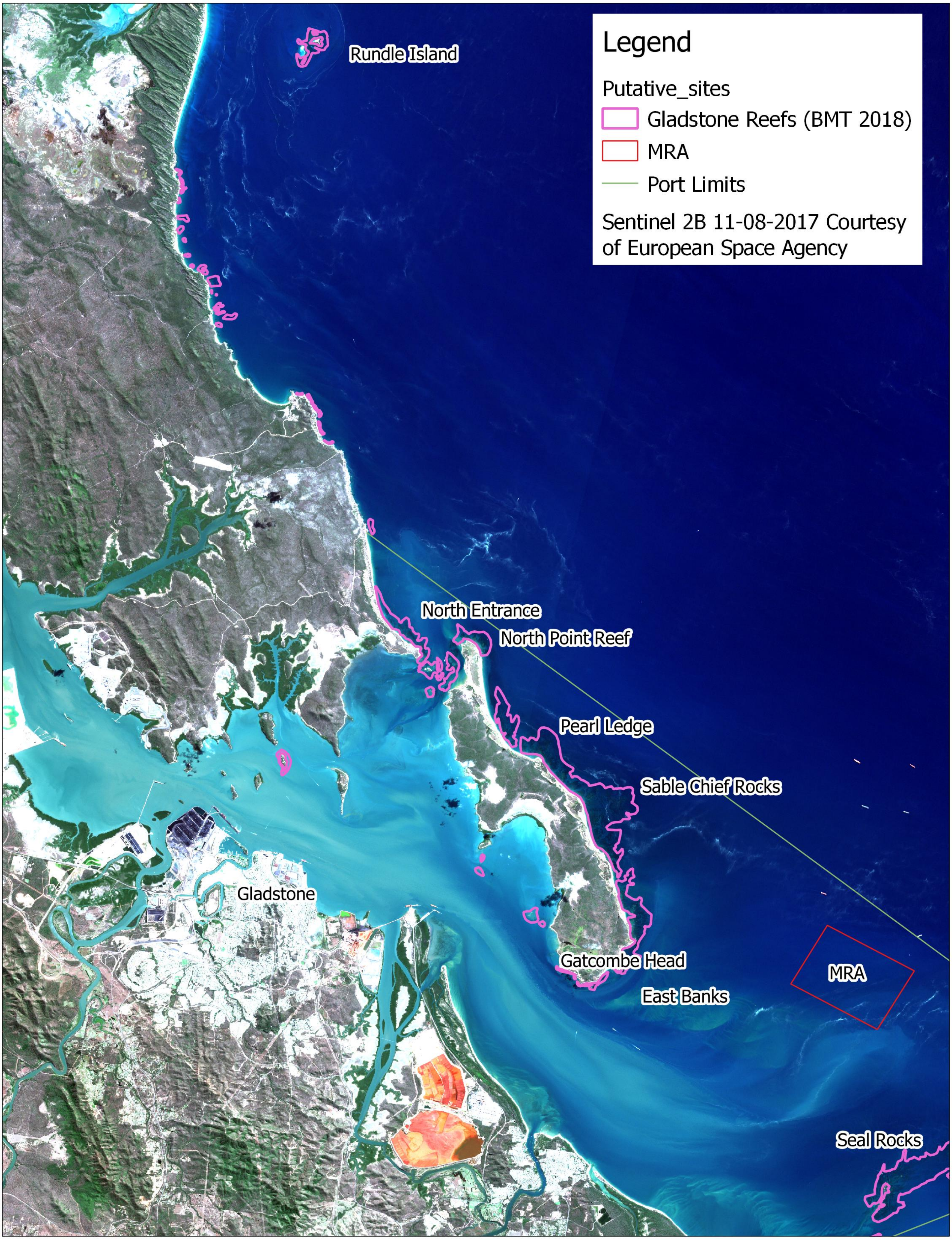
The study area for this project includes reef communities located on the eastern side of Facing Island and Rundle Island to the north of Facing Island (Figure 1.1). Rundle Island is the closest comparable reference site to outer Facing Island in terms of coral cover, exposure to wind and swell, and is remote from any potential material relocation impacts. Some of the reef systems in the study area were surveyed in 2011, 2012, and 2014 (Sea Research 2012, 2013; BMT WBM, 2015); providing a historical dataset to qualitatively assess changes over time. A quantitative monitoring program established in 2013 (Sea Research 2013) was last surveyed in June 2018 (BMT, 2018), and the present study has replicated this most recent survey methodology for maximum comparability.

1.1 Aim and Objectives

The overall aim of this study is to characterise patterns in the structure and condition of benthic and epibenthic reef communities along Facing Island and ‘control’ sites at Rundle Island. The specific objectives of this study were to:

- Compare spatial patterns in the structure and condition of epibenthic reef communities at Facing Island and Rundle Island as a part of five-year compliance monitoring program required by the LMDMP to assess the impact hypothesis that activities do not result in long-term changes to adjacent reef communities.
- Assess changes in epibenthic reef communities using sea floor imagery at representative sites over time.
- Based on the above, describe spatial and temporal patterns in within the context of environmental variability and potential human impacts.
- Repeat 3D mapping technologies at three sites to augment quantitative benthic reef monitoring.

This scientific report summarises the data collection activities and methods as a part of the 2023 monitoring campaign.



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Study Area and Previous Reef Mapping

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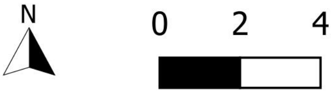

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1.2 Monitoring Program Design and Nomenclature

The original monitoring design (Sea Research, 2013) consisted of a control-impact framework, with sites east of Facing Island considered to be ‘impact’, and sites at Rundle Island considered to be ‘control’. In 2018 and 2023, the same sites were visited and differed from 2013 only in the fine-scale execution of each transect, with Sea Research performing line intercept transects, and BMT performing point counts over photos. The primary difference between the two designs is the interpretation of results, with the more modern monitoring programs interpreted in the context of patterns in ambient water quality associated with proximity to the harbour entrances.

Ideally the study terminology would follow the naming convention applied by the Great Barrier Reef Marine Park Authority’s (GBRMPA’s) spatial layer. However, individual reefs mapped by GBRMPA form a contiguous fringing reef in front of Facing Island, while other monitoring sites exist over reefs that are not mapped or named. The site labels adopted in Table 1.1 endeavour to follow GBRMPA terminology where possible within the limitations stated above.

The monitoring design clusters sites into the following regions referred to hereafter as **treatments**:

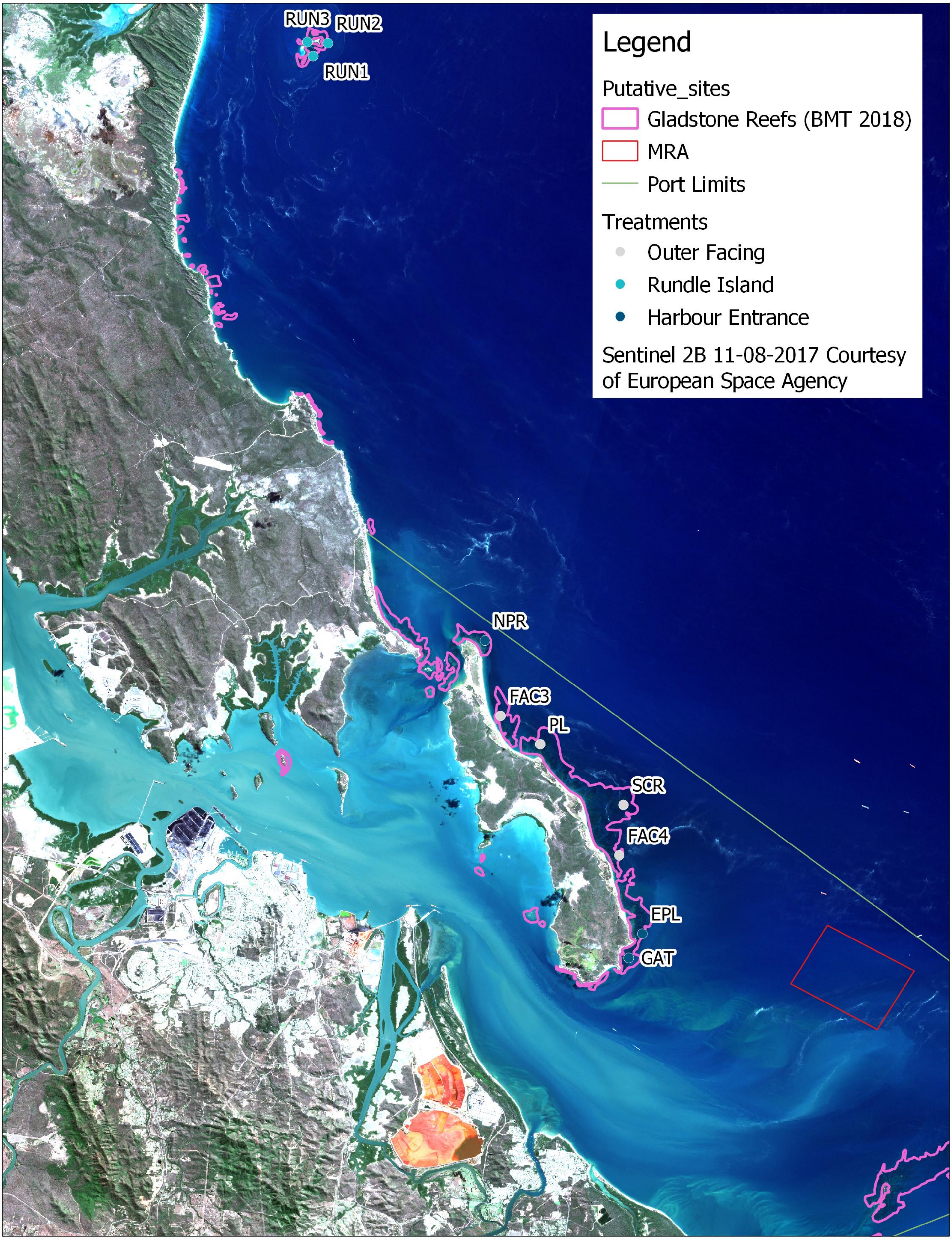
- Background sites (RUN1, RUN2, and RUN3 in Figure 1.2) - Reefs at Rundle Island represent control sites in the context of assessing potential dredging impacts. These sites are also not as strongly influenced by catchment runoff as the harbour entrance treatment.

- Harbour entrance sites (NPR, EPL, and GAT in Figure 1.2) – these sites are more strongly influenced by fluvial discharges than the other two treatments. Two of the sites in this treatment (GAT, EPL) are also closest to the MRA.

- Outer Facing Island (FAC3, PL, SCR, and FAC4 in Figure 1.2) – these sites are not predicted to be grossly affected by fluvial discharges and are >10 km from the MRA, representing putative material placement impacts.

Table 1.1 Revised and previous designs and terminologies. 2023 Site colours and treatment colours are retained through the remainder of the document. Rundle Island (background) sites share a common colour (aqua) to reduce colour complexity.

BMT WBM 2015 site (GBRMPA reef Name)	2014 Data Availability	Sea Research Sites (2013)	2018 site terminology	2023 site terminology	2018 / 2023 Treatments
Gatcombe East (Facing Island #6)	Assessed	Impact 1	**GAT** (Gatcombe)	**GAT** (Gatcombe)	harbour entrance
East Point Ledge (Facing Island #5)	Assessed	Impact 2	**EPL** (East Point Ledge)	**EPL** (East Point Ledge)	harbour entrance
Facing Island #4 (Facing Island #4)	Assessed	Impact 3	**FAC4** Facing Island #4	**FAC4** Facing Island #4	outer Facing
Sable Chief Rocks Reef (Sable Chief Rocks)	Assessed	Impact 4	**SCR** (Sable Chief Rocks)	**SCR** (Sable Chief Rocks)	outer Facing
Pearl Ledge (Facing Island #3)	Assessed	Impact 5	**PL** (Pearl Ledge)	**PL** (Pearl Ledge)	outer Facing
North Facing Island (not charted or named)	Not assessed	Impact 6	**FAC3** (Facing Island #3)	**FAC3** (Facing Island #3)	outer Facing
North Entrance (North Point Reef/Facing Island #1)	Not assessed	Impact 7	**NPR** (North Point Reef)	**NPR** (North Point Reef)	harbour entrance
Rundle Island 1 (Rundle Reef)	Not assessed	Control 1	**RUN1** (Rundle Reef)	**RUN1** (Rundle Reef)	Rundle Island (background)
Rundle Island 2	Not assessed	Control 2	**RUN2** (Rundle Reef)	**RUN2** (Rundle Reef)	Rundle Island (background)
Rundle Island 3	Not assessed	Control 3	**RUN3** (Rundle Reef)	**RUN3** (Rundle Reef)	Rundle Island (background)



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2 Methods

Two sampling techniques were used in the present study:

- Quantitative (transect-based) sampling of epibenthic reef communities.
- Photogrammetry to produce 3D models.

Transect-based methods were used to perform the reef quantitative monitoring, while 3D modelling methodologies were performed to provide photomosaics at a selection of three sites for visual engagement and qualitative comparison purposes.

2.1 Coral Monitoring Transects

Data Collection

The 10 monitoring sites were revisited in the present survey (Figure 1.2) between June 13 and 15, 2023. The 2013 survey used a line intercept approach over a 50 m transects, with four replicate samples collected at each site. The 2018 and present surveys were designed to be compatible with the original sampling program, but able to be improved in the future by using photo-quadrats (taking random photos along a fixed transect) to increase sample replication and sample precision. Photo-quadrat methods are also similar to those used in the Long-term Inshore Reef Monitoring Program by AIMS (Jonker et al., 2008) and are compatible with the transect data collected by the Gladstone Healthy Harbour Partnership (GHHP, 2022).

The start of each transect location was marked with a shot line and located using a waterproof GPS unit tied to the diver’s surface float. Start and finish points for each transect conducted in 2018 were determined from point tracking on the diver tether. The 2023 survey used shot lines deployed on the start and finish points collected from the 2018 data.

Each location was surveyed along the -3 to -5 m lowest astronomical tide (LAT) contour or as appropriate given site conditions. Transects occasionally became shallower or deeper while following available reef habitat. A 20 m transect tape was lain on the substrate, and a diver swam over the substrate underneath using 12-megapixel underwater cameras capturing still images (every second) with accessory 1200 lumen lighting. Distance from the tape varied depending on visibility and macroalgal canopies encountered; however, a distance of 15-50 cm was generally adhered to as per (Jonker et al., 2008). A total of 985 benthic photos were collected giving up to an average of 24 photos per transect for analysis.

Incidence of coral disease and numbers of coral recruits were quantified within 34 cm of the transect tapes directly from the first 5 m of the transect and transcribed onto datasheets during the dive.

All diving was undertaken by BMT marine scientists with ADAS commercial dive qualifications aboard the 2c certified vessel *Cetus* using through-water surface communications (Figure 2.1).

Figure 2.1 Scientific diver undergoing a pre-dive check.

2.2 3D Mapping

Three-dimensional mapping of reefs was performed at three sites: NPR, FAC3, and SCR. These sites were deemed to have appropriately low levels of macroalgae to enable mosaic generation. As algae would not affect the calibration of images in the software.

At each site, 700-1,000 non-georeferenced photos were taken using paired wide-angle still cameras. Photos were built into 3D models using Agisoft Metascan after:

- Batch processing of photos to remove poorly focused images.
- Colour correction to bring up red tones and reduce green and blue levels.
- Removal of lens vignetting to homogenise lighting across the field of view.
- Photogrammetry using tie points at precisely known locations.
- Generation of 3D models and orthomosaics from aligned imagery.

2.3 Data Analyses

Still imagery was quantified to determine benthic cover and community composition as percent cover metrics. This was done using point-count methods with Coralnet software (Beijbom *et al.*, 2015) which were then applied to the site photographs from each plot. The Coralnet machine-learning platform enables automated or assisted classification of points on photographs (for example, classifying points as coral, rock, algae etc.). All annotations were performed by a marine scientist accepting or rejecting suggestions provided by the machine. Coral and algae were identified to the lowest practical level (typically genus). Twenty-point identifications were made per photo. Photos were selected randomly (10 per transect), giving a total of 200-point IDs per transect, from 40 photo-quadrats.

Benthic cover was determined using photo-quadrats as the unit of replication for statistical analyses. Transect-wide responses such as bleaching, disease, and recruitment counts were analysed using transect-level data. Univariate cover metrics of key taxa (total hard coral, total soft coral, total macroalgae, bleaching and recruitment) were analysed using the generalised linear mixed model package (glmmTMB) in R (Brooks et al., 2017). Frequency distributions for each variable were generated. Percent cover response variables typically had a strong zero-bias and were constrained between 0 and 1 as percent cover, meaning error structures were well approximated using a zero-inflated beta distribution, while count data were analysed using a generalised Poisson distribution.

Sampling event and treatment were considered random factors. The employed methods are resilient to many of the issues affecting this dataset including non-normality (strong zero-bias) and heteroscedacity (differing levels of variation associated with treatments).

For the present report, changes among sites, treatments, and survey events were the primary interest. Multiple comparisons among sites and events were investigated with the enmeans package, and graphs were produced with ggplot2 in R.

Raw data from Sea Research (2013) were unavailable; therefore, only qualitative visual temporal comparisons between 2013 and 2023 were made. Approximate means and standard errors for sites were digitised from the original report and re-apportioned into sites within the 2018 treatment groups by averaging means and errors in the new treatment groups.

Patterns in assemblage structure at different sites were analysed using the non-metric muti-dimensional scaling plots (nMDS), Similarity Percentages (SIMPER), and Analysis of Similarity (ANOSIM) routines using Primer 7 software package. ANOSIM and nMDS routines were used to identify differences in assemblage structure among sites and among treatments. SIMPER was used to identify taxa contributing to differences among sites and treatments and to identify possible drivers of these patterns.

3 Results and Discussion

3.1 Univariate Cover Analysis

Total hard coral cover was considered the most important response variable describing the health of the sites and treatments. Temporal changes in univariate metrics (including total hard coral cover) represented by the interaction between site and time were interpreted as potential impacts or improvements in health depending on the direction of change.

Site-level total coral cover data from the 2018 and 2023 surveys showed significant differences among the sites, and a statistically significant interaction term (Annex A, p=0.03, Figure 3.1), suggesting that some sites increased or decreased in cover compared to the rest of the group. Independent contrasts for each of the sites showed that FAC3 experienced a statistically significant decline in coral cover (Annex A, p<0.001), and RUN3 had a non-statistically significant increase in coral cover (Annex A, p=0.10). In both cases, the change in average coral cover was approximately 20%. The greatest cover of living hard coral in 2018 was at sites located at Rundle Island and the outer Facing Island sites FAC3 and SCR. However, in 2023, living coral cover at the FAC3 site had fallen into the range more typical of the remaining sites.

While there were statistically significant site-based changes in total hard coral between 2018 and 2023 at FAC3 and (non-significantly at RUN3), these did not translate to significant interactions among treatments (harbour entrance, outer Facing, and Rundle Island) through time (Figure 3.1). At a treatment level, the highest cover of coral was at Rundle Island followed by the outer reefs of Facing Island. Sites at the northern and southern extent of Facing Island (harbour entrance sites) had the lowest coral cover, and these sites are exposed to greater tidal currents and turbidity from Gladstone Harbour. Some example images of benthic communities at each of the monitoring sites are shown in Figure 3.2.

Due to a lack of raw data, no quantitative comparisons have been made between 2013 and 2018, nor have they been made between 2014 and 2018 due to different levels of transect replication. Coral cover appeared to have declined between 2013 and 2014 at harbour entrance sites, and has likely remained at similar levels in 2018 to what was observed in 2014 (Figure 3.1). The variability in cover (variability within and between sites) at the Rundle Island treatment increased dramatically in the 2018 survey, and this reflected site-level changes that occurred there. Figure 3.1 shows that RUN1 likely increased in coral cover while RUN3 likely decreased in coral cover between 2013 and 2018. This divergence in coral cover resulted in increased transect level variability (error) in treatment-level data (Figure 3.1). In 2018, site RUN3 had experienced a large dieback event, and there was active evidence of coral disease (white and brown band disease) at RUN1 and RUN3. Qualitatively, in 2023 RUN3 had experienced a substantial recovery, with hard coral cover levels approximating those observed in 2013. Fluctuations in coral cover at the Rundle Island sites are likely to be attributed to coral disease, bleaching, and subsequent recolonisation.

After an initial decline in cover between 2013 and 2014 as most harbour entrance sites, cover has appeared to remain steady, or improve at all sites except for FAC3. Changes in community underpinning these univariate data are discussed further in section 3.2.

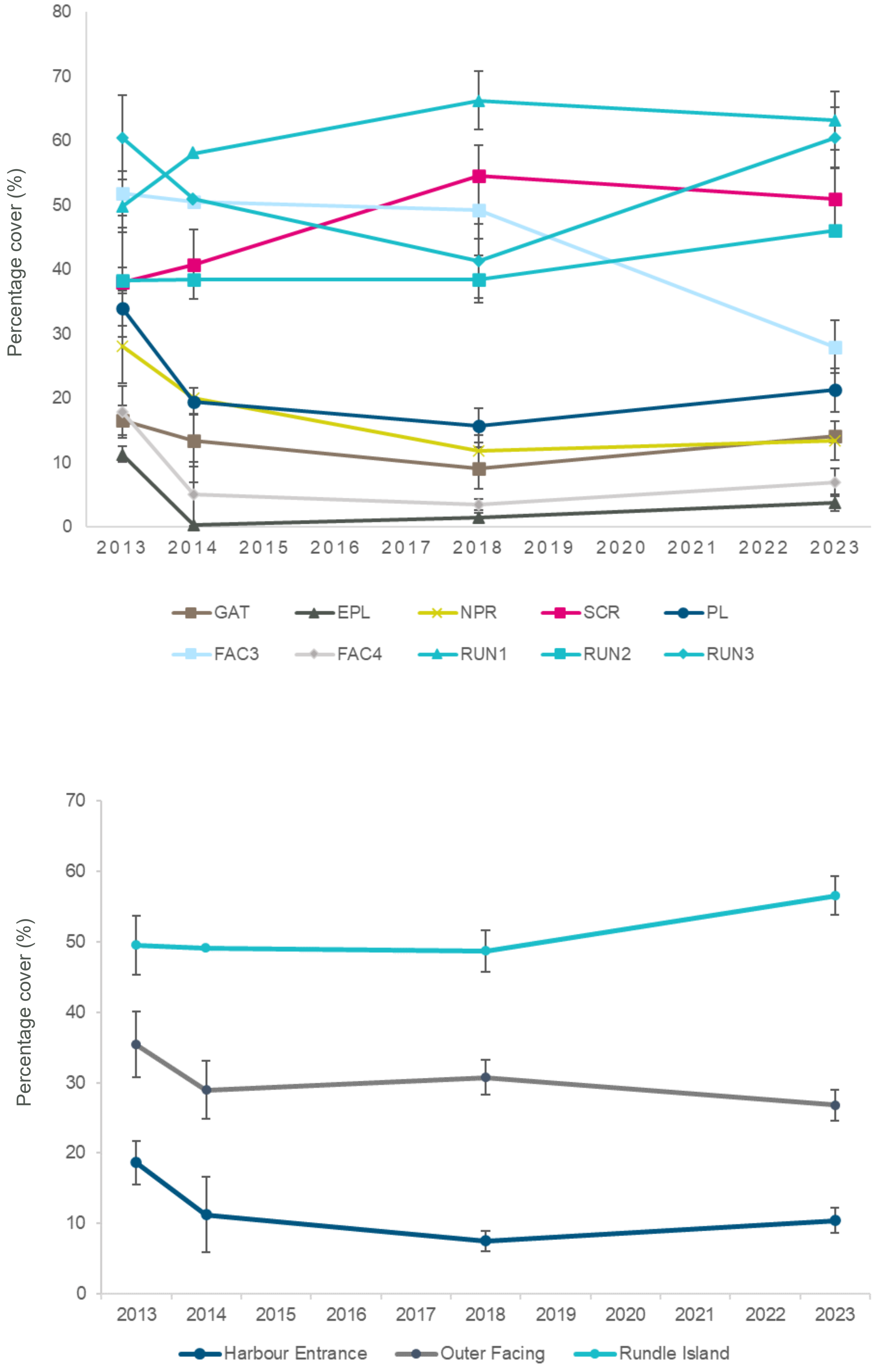


Figure 3.1 Mean hard coral cover (±SE) by site (above) and treatment (below)

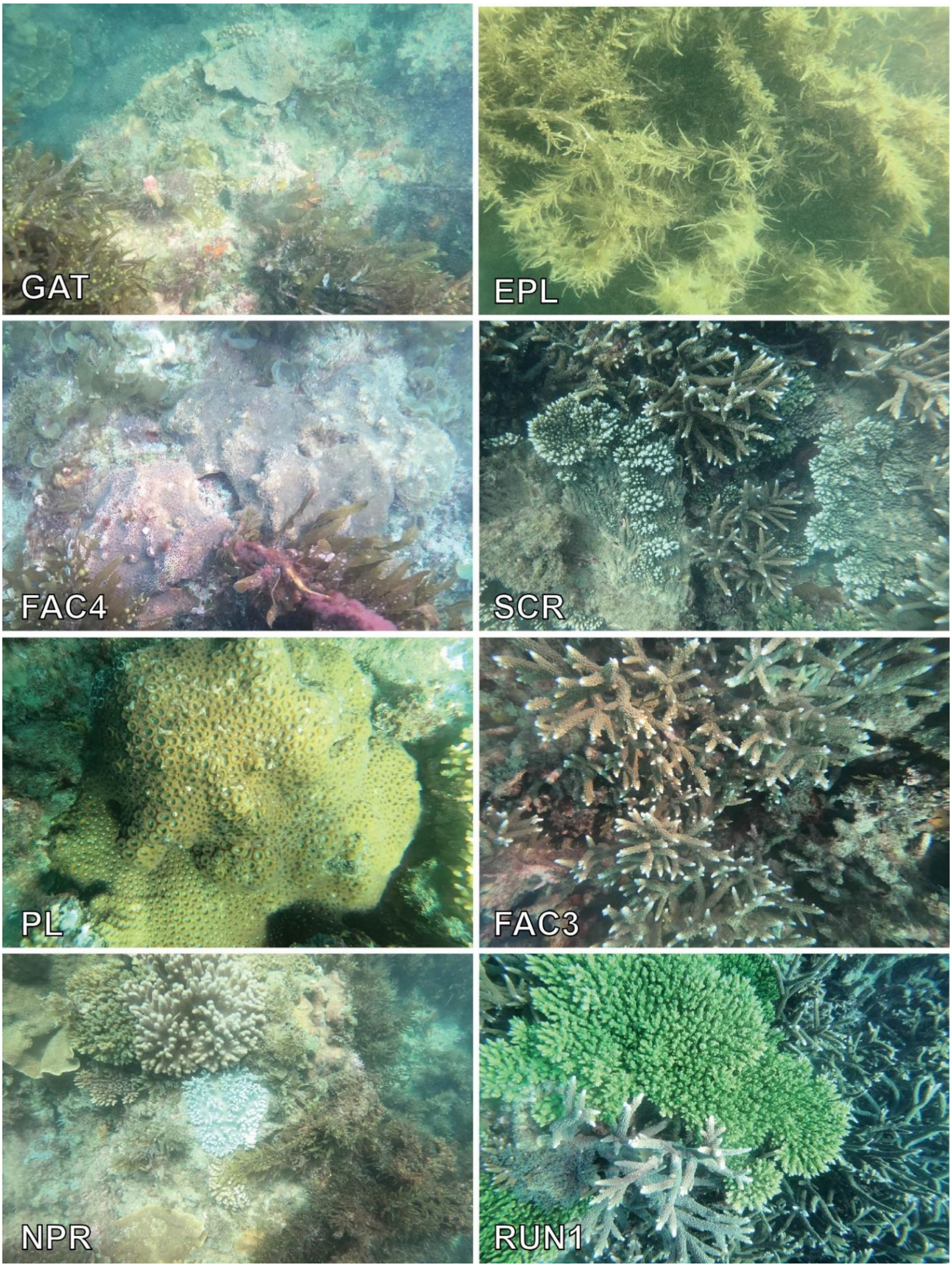


Figure 3.2 Representative photos of corals and macroalgae at a selection of monitoring sites

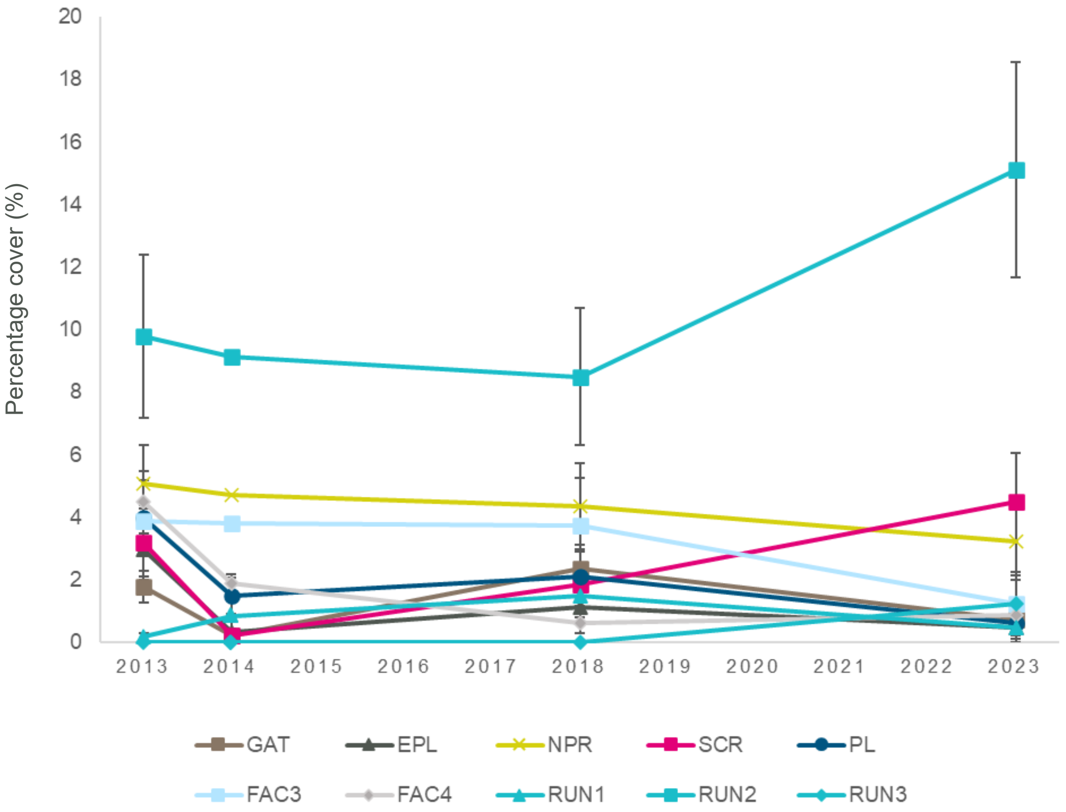
Total soft coral was typically observed at low levels (<5%) across most sites except RUN2 (Figure 3.3), where mean cover increased from approximately 9% to 15%, but this did not represented a statistically significant temporal change (p>0.05). Otherwise, there were no clear patterns in the change of total soft coral cover among sites or treatment groups.

Macroalgae was present at all survey sites in moderate abundance with highest cover seen at harbour entrance sites and lowest at Rundle Island sites (Figure 3.4). Generally, total algae cover followed an inverse distribution to coral cover – i.e., typically where macroalgal cover was higher, cover of corals was lower. For site-based data, there were significant differences for total algae among events, sites, and the interaction between sites and events. There were significant increases in total algae at sites FAC3, EPL, GAT, and SCR (Figure 3.4, Annex A). These site-based changes also resulted in significant changes among treatments, where harbour entrance and outer Facing Island treatments increased in total algae compared to Rundle Island represented by significant interaction term (Annex A, p<0.01). Increased cover of algae at harbour entrance and outer Facing Island treatments is consistent with possible reduced water quality in these locations.

The contribution of macroalgae and turfing algae to total algal cover was examined at each site. At sites where coral cover was highest (Rundle Island sites and SCR at outer Facing Island) the algal community was dominated by low lying algal turfs. Algal communities at other sites were comprised of both macroalgae (largely *Sargassum*) and turfing algae. This relationship is discussed further in section 3.2. Dense macroalgae can form large canopies that shade the substrate, potentially outcompeting corals (McCook et al., 2001); however, both macroalgae and turfing algae can inhibit coral recruitment and survival (Arnold et al., 2010, Doropoulos, et al., 2021). Phase shifts between coral and algal dominated communities have been well documented in the literature and may be caused by many ecological processes or environmental conditions (McManus and Polsenberg 2004). In the present survey, cover of hard corals and macroalgae were generally inversely related and a reduction in hard coral cover at FAC3 was met with an increase in macroalgal cover.

Again, qualitative visual comparisons were made for data collected prior to 2018; raw data were not available for 2013 and only a subset of sites were sampled in 2014. Changes in algal cover should be considered cautiously, given the uncertainty regarding the analysis of turfing algae in 2013. However, given the likely reductions in hard coral cover observed at outer Facing Island and harbour entrance sites, a commensurate increase in algal cover would be expected, and is consistent with the patterns observed in Figure 3.4. The inclusion of turfing and macroalgae was consistent methodologically between 2014 and 2023, and a slight reduction in algal cover after 2014 is consistent with some recovery in years after the 2013 floods at harbour entrance sites. Similarly, fluctuations in macroalgae at Rundle Island appear after potential dieback and recovery events driven largely by changes at RUN3.

Looking at site-based data, it is probable that most sites apart from RUN1, RUN2, and SCR have had increased algal cover between 2013 and 2023. Algal cover was probably similar between 2013 and 2018 at sites RUN1 and RUN2. Qualitatively, the site SCR appeared to have less algae in 2023 than it did in 2013. Given higher levels of hard coral cover across the same temporal comparison at SCR, this would appear to be a long-term improvement in the relative contribution of coral to algae.



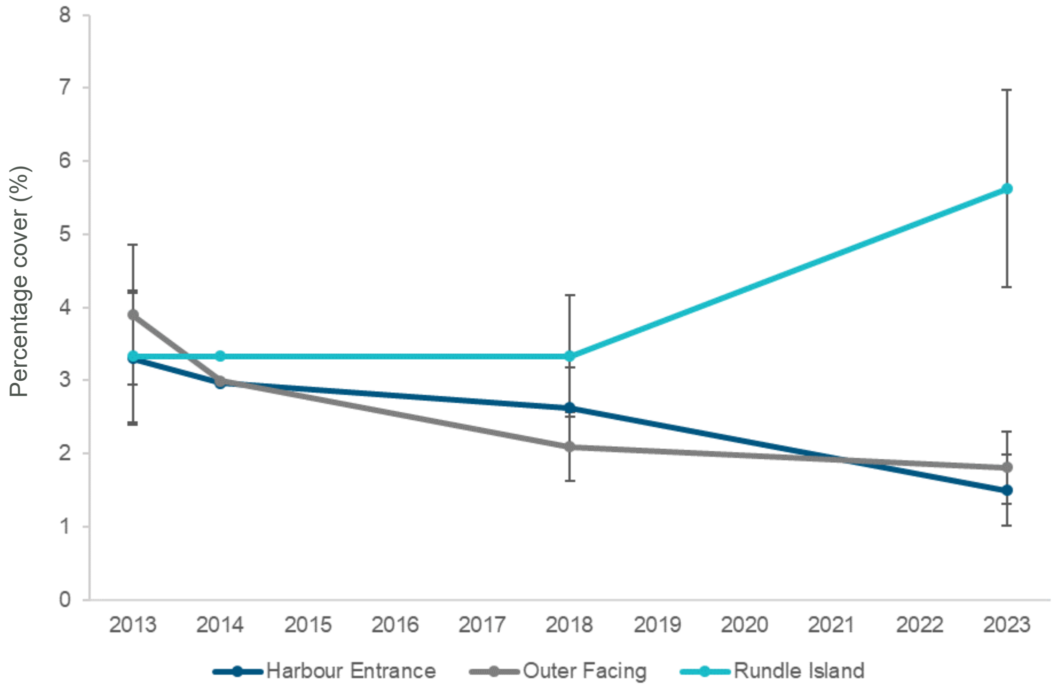


Figure 3.3 Mean soft coral cover (±SE) by site (top) and treatment (bottom)

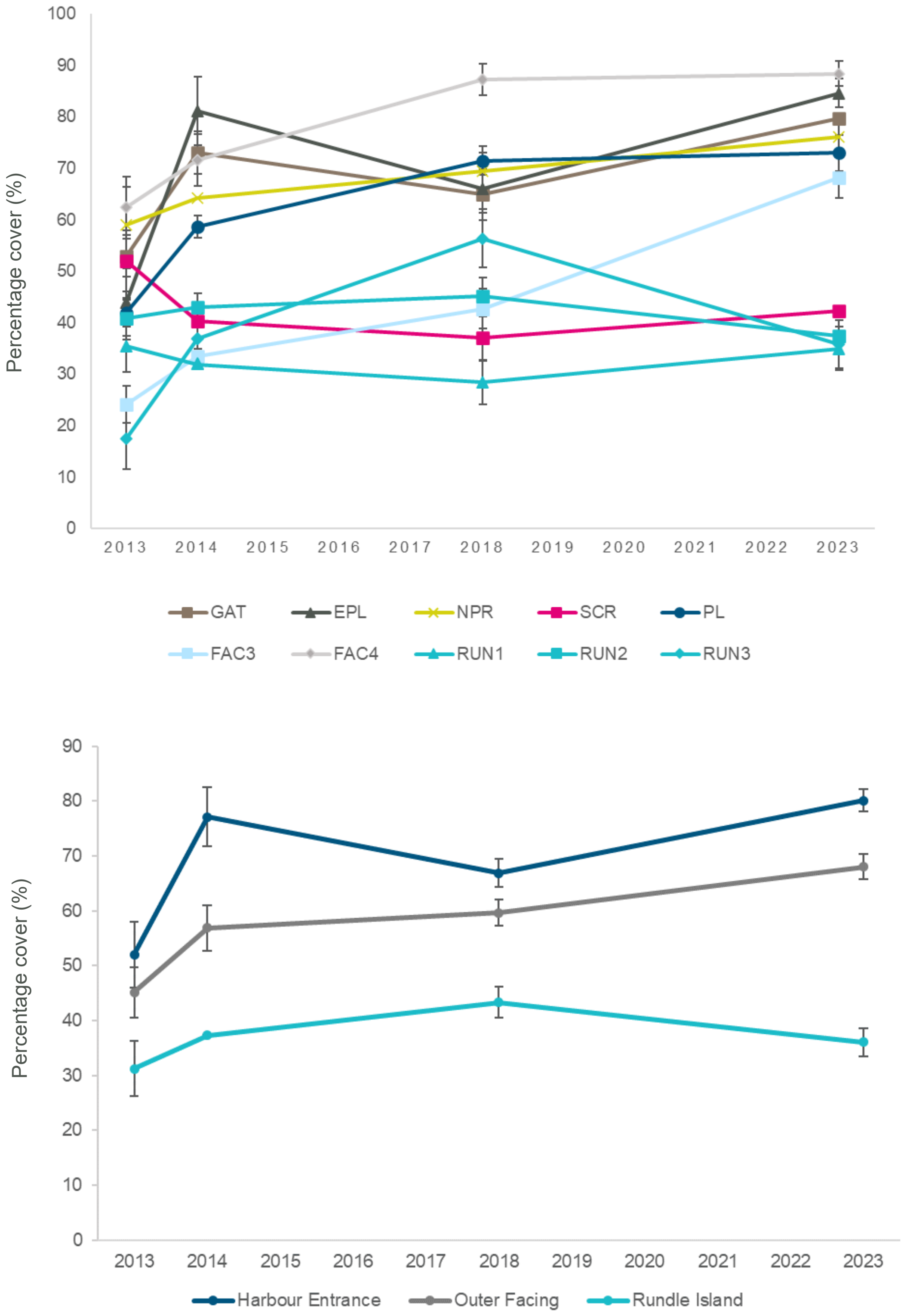


Figure 3.4 Mean total algae (turf and macroalgae) (±SE) by site (top) and treatment (bottom)

3.2 Multivariate Cover Analysis

Figure 3.5 shows nMDS ordinations that describe patterns in the similarities of benthic communities among sites and times in two-dimensional space. Samples with similar communities are positioned closer together, while samples with dissimilar communities are positioned further apart. Almost all sites fell into one of two very distinct communities that were distinguished at the 60% Bray Curtis similarity level:

- Rundle Island sites and outer Facing Island sites FAC3 and SCR had similar communities, grouping together at the 60% similarity level on the right side of the ordination. Notably, FAC3 moved upwards and to the left of the plot in 2023, falling into a level of 40% similarity, mid-way between the original group and the remaining sites.

- Harbour entrance sites and outer Facing Island sites FAC4 and PL were more similar to one another and were grouped close together on the left-hand site of the plot.

These two clusters represent a community dominated by macroalgae (particularly *Sargassum*, and *Lobophora*) on the left side, and a community with much less macroalgae, dominated by coral genera including *Acropora, Montipora,* and *Pocillopora* on the right. The community on the left side is comprised of species that are typically more tolerant of turbidity and freshwater input.

Movement in community space in Figure 3.5 shows that all of the sites on the left side of the plot (harbour entrance and some outer Facing Island sites) moved upwards between 2018 and 2023, which was the dominant direction of change. Based on vector information in Figure 3.5, this movement was related to increases in the macroalgae taxa *Padina,* and *Asparagopsis,* as well as increases in the coral *Turbinaria.* The directions of change in community space between 2018 and 2023 for sites on the right side of Figure 3.5 (Rundle Island and outer Facing Island) were much more variable, with some sites such as RUN3 moving in opposing directions to closely geographically located sites such as RUN1.

Some of these changes in community space may be related to changes in the foliose algae *Padina* and *Lobophora,* which occupy almost opposing vector positions in Figure 3.5. Depending on the stage of growth and the density of epiphytic algae covering these taxa, it can be difficult to distinguish between them. Some movement upwards and downwards within the plot may be related to artificial/ or real changes in cover alternating between *Lobophora* and *Padina.*

In order to better understand what community changes were driving these patterns, SIMPER routines were run to examine changes between times among sites (Annex B), and bubble plots were produced for six taxa contributing most to community to community change (Figure 3.6, Figure 3.7). Bubble plots show the root-transformed mean cover for each site, with larger bubble-areas related to greater cover contributions.

For *Acropora,* the strong left-right plot separation is visible, and most sites had reasonably consistent levels of cover between 2018 and 2023, with the exceptions being EPL, where *Acropora* was absent in 2018, and was detected at low levels in 2023, and RUN2, where there was more cover in 2023 (Figure 3.6). For *Montipora,* a similar split was evident, with sites on the right side of the plot having more cover than those on the left (Figure 3.6). Notable changes include the reduction of *Montipora* at FAC3, and complete absence at FAC4 in 2023.

Porites was one of the most dynamic cover types between 2018 and 20123. For *Porites,* the 2023 communities typically had much less cover than those in 2018, with 2018 occurrences becoming absences in 2023 at RUN1, RUN3, GAT, and SCR (Figure 3.6). Reductions were also observed at all remaining sites except for EPL.

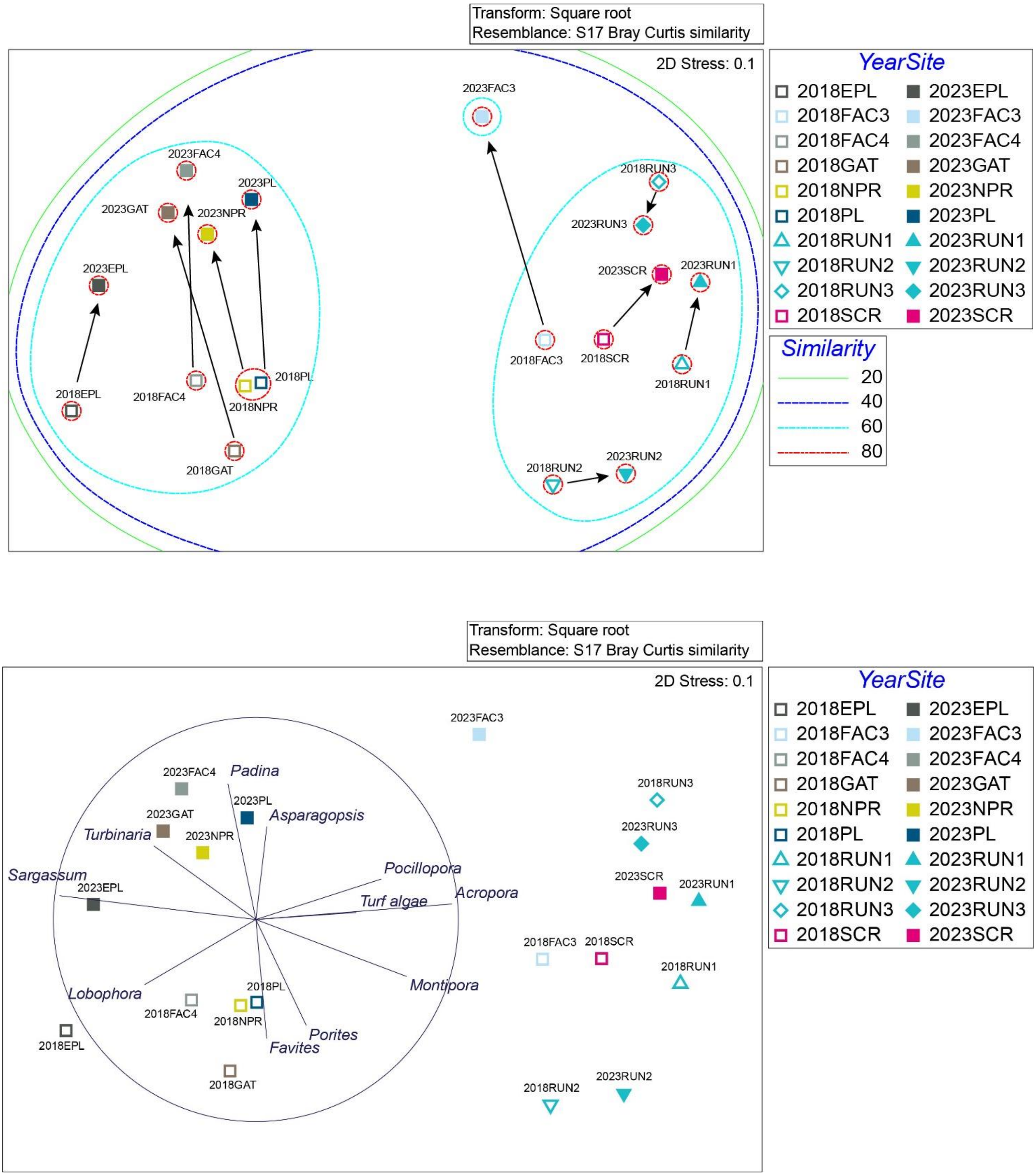


Figure 3.5 nMDS ordinations showing site-averaged data, with directions of change in community space between 2018 and 2023 shown with arrows (above), and with contributions of major structuring elements shown as vectors (below).

Turbinaria on the other hand showed an almost inverse trend to *Porites,* with most sites either remaining consistent, or increasing in cover between 2018 and 2023 (Figure 3.6). This was particularly evident at the harbour entrance and inner Facing Island sites. *Turbinaria* recruits had been the most abundant recruiting taxon in the 2018 surveys, and the survival and growth of these colonies may have resulted in the observed increase in 2023.

The changes in cover for the four primary algal taxa show a mixture of highly localised and evenly spread cover distributions. *Sargassum* was extremely dominant in the left side of the plot, and virtually absent from the right side of Figure 3.7. While present at SCR in 2018, it was not recorded there in 2023. *Sargassum* was recorded at FAC3 for the first time in 2023, coinciding with a loss in living coral cover (section 3.1). For harbour entrance and inner Facing Island sites, there was a slight increase in the cover of *Sargassum* in 2023.

Asparagopsis was also not recorded in 2018 at any sites yet was found in low cover at FAC4 and FAC3 in 2023. This taxon is extremely prevalent inside Gladstone Harbour and has been the dominant macroalgae at Manning Reef for GPC's concurrent restoration program (BMT, 2023).

Turfing algae was ubiquitously distributed across the sites and varied little between sites or times. *Padina* was more prevalent and of higher cover in 2023 than 2018, but these changes may also be real or artificial shifts in the cover of *Lobophora* as discussed earlier. For example, at EPL SIMPER results (Annex B) show that the changes in *Padina* and *Lobophora* were the 5th and 6th most influential taxa for differences between the two time periods. In 2018 the average coverages of *Padina* and *Lobophora* were 0 and 2.48%, respectively, while in 2023, they were 0.84 and 1.81, respectively. The 2023 total for these two taxa was 2.65, which was similar to the total for *Lobophora* in 2018, and it is possible that the split between these taxa in different survey years are not as different as they appear and are a result of identification disparities.

Accepting the potential confusion between *Lobophora* and *Padina,* other changes in taxa are highly unlikely to suffer from misidentification and changes in all of the coral genera should be considered real within the bounds of statistical error associated with the program.

The two most divergent sites between 2018 and 2023 were FAC3 and RUN3, based on the direction and magnitude of community change. SIMPER results for the 10 most influential taxa at FAC3 show these changes were the result of reduced cover of *Acropora, Montipora, Porites* and sand, and increased cover of the algae *Laurencia, Asparagopsis, Padina*, turf algae, and *Sargassum*, as well as *Favia* (Annex B). At RUN3, there was an increase in *Acropora, Montipora, Padina,* sand, *Lobophora, Dictyota,* and *Pocillopora,* while there were less turf algae, *Porites* (none), and *Stylophora* (none).

Based on univariate analyses (section 3.1) RUN2 showed an increase in soft coral between 2018 and 2023. Changes in the soft coral community (based on SIMPER) included increases in *Cladiella*, *Sarcophyton,* and *Sinularia,* and a reduction in *Lobophytum.*

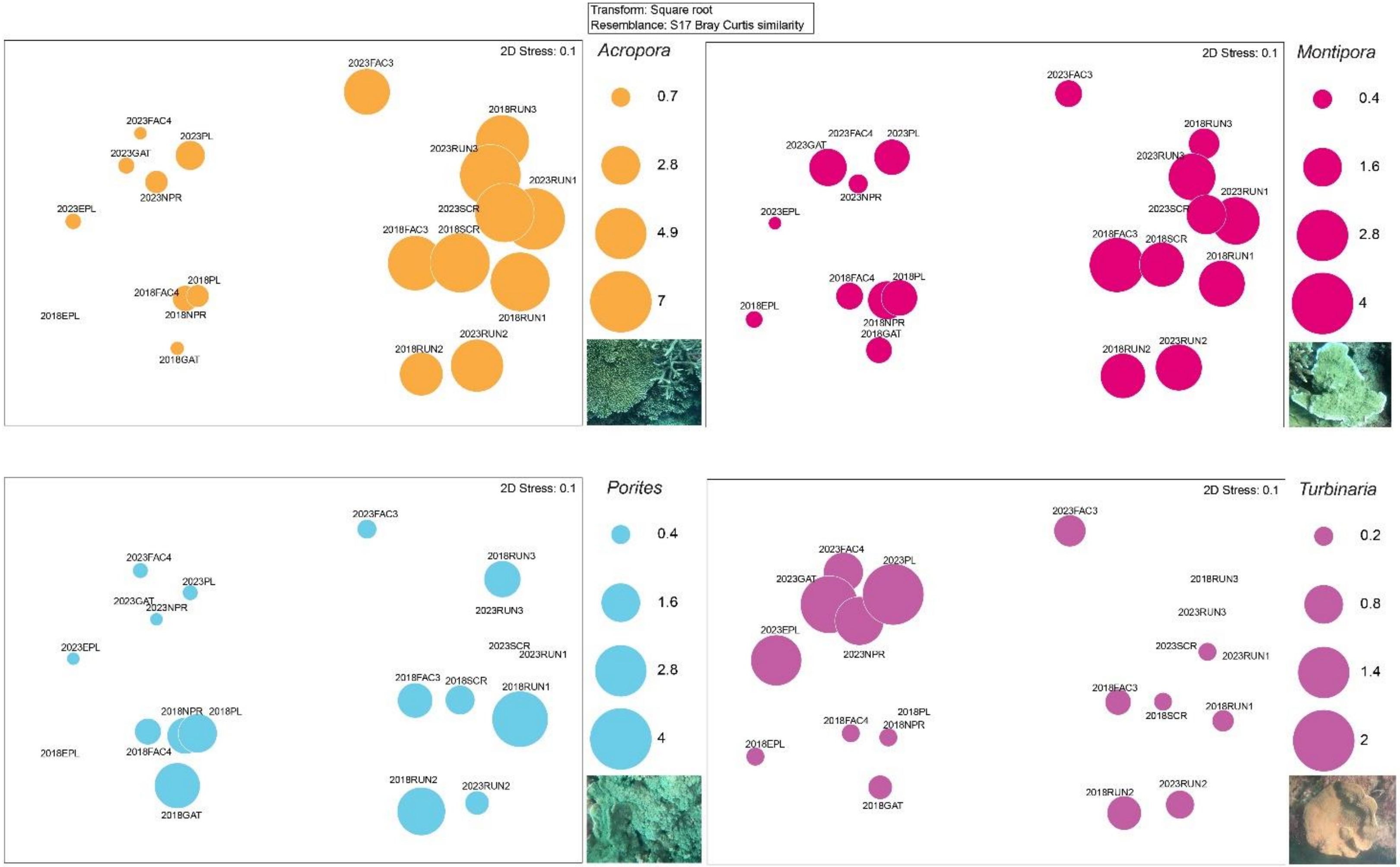


Figure 3.6 Bubble plots showing percent cover representations (square root transformed) of key coral genera including *Acropora, Montipora, Porites,* and *Turbinaria.*

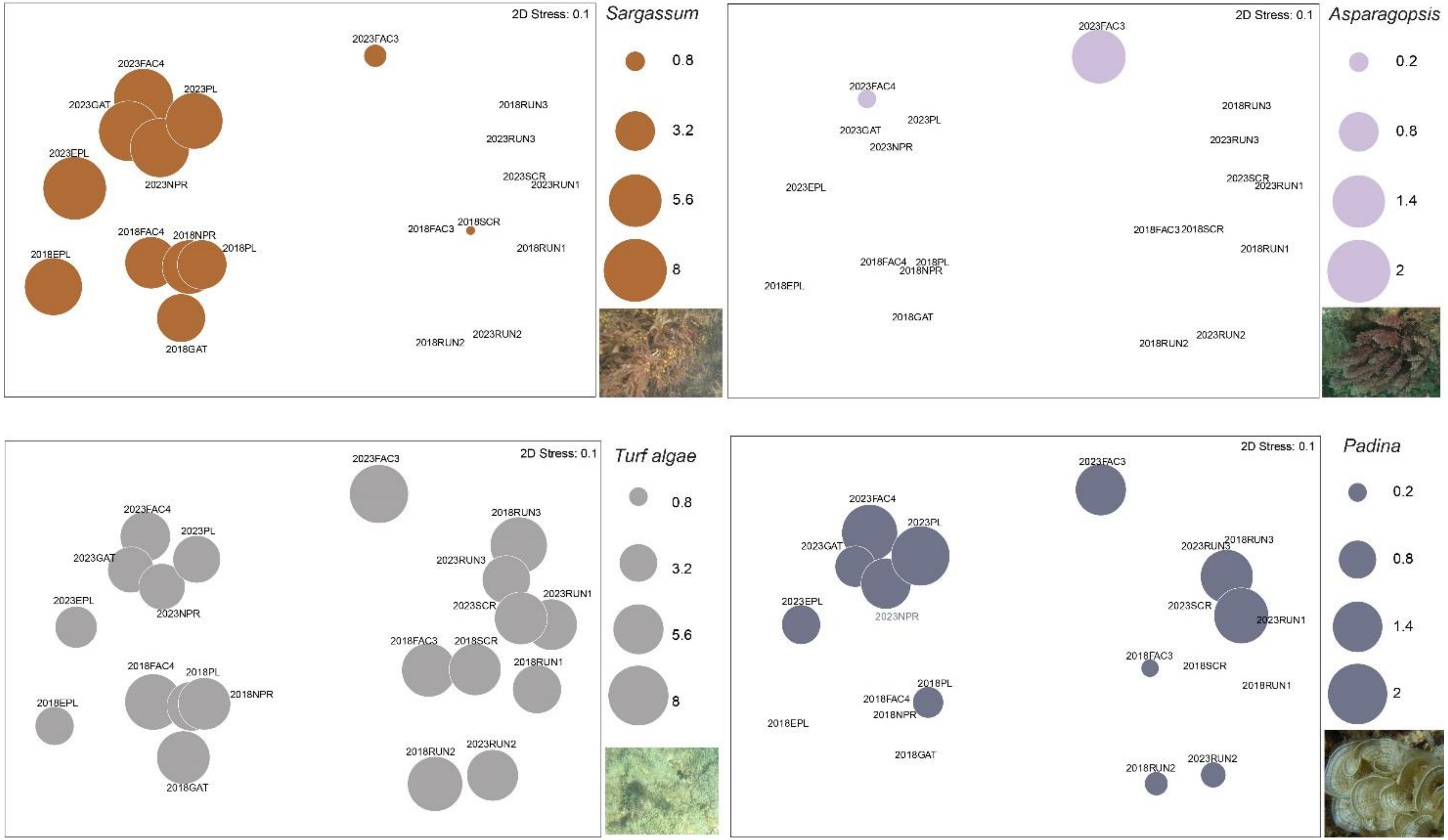


Figure 3.7 Bubble plots showing percent cover representations (square root transformed) of key algal taxa including *Sargassum, Asparagopsis,* turf algae and *Padina*

3.3 Coral Disease and Recruitment

Coral Disease

Coral bleaching was observed at more sites than coral banding disease and again, it was observed most frequently at Rundle Island (Figure 3.8). In 2018 bleaching was observed at all sites except NPR and GAT, whereas in in 2023 it was observed at five of the 10 sites (FAC3, PL, RUN1, RUN3, and SCR). Bleaching was generally restricted to occasional colonies, except at RUN3, where it was more extensive. Bleaching tended to be on partial colonies of *Acropora,* which led to relatively high counts at RUN3 where partial bleaching was common in part of one of the larger staghorn fields. No evidence of widespread thermal bleaching was observed. In many cases, thin algal coatings were on adjacent tissues suggesting that colonies had recently experienced mortality. It is possible that some bleaching counts were actually coral disease, as partial colony bleaching and coral disease can be difficult to distinguish. Sample imagery of this recently deceased coral and white band diseases are shown in Figure 3.9.

Incidence of white and brown band diseases, bleached colony counts, and recruit counts are shown in Figure 3.8. White and brown band diseases were recorded collectively and show that incidences of coral disease appeared highest at Rundle Island, specifically at RUN3 in 2018, but this was not observed in 2023. In 2023, banding was also observed at RUN1 and GAT. Incidences of banding were too few for statistical comparisons.

One count of tissue necrosis occurred in a soft coral (*Cladiella*) in 2023 (Figure 3.9). There appeared to be some turfing algae developing over the recently disturbed tissue.

Coral Recruit Densities 2018

Figure 3.8 shows that the total number of coral recruits varied with statistical significance among sites and treatments (Annex A), but there were no significant interactions at the $\alpha = 0.05$ level, for time versus treatment or time versus and site. Both of these interactions had p values of 0.09 (Annex A). Typically recruit counts were similar or may have increased slightly in 2023 compared to 2018, except for sites FAC3 and SCR, which had lower recruit counts.

At the treatment level between 2018 and 2023, outer Facing Island sites had reductions in recruit counts that made them more similar to the remaining treatments in 2023. It should be noted that recruitment counts may be lower than recorded at some harbour entrance sites where *Sargassum* canopies were extensive. At these sites, particularly EPL and GAT, macroalgae often became entangled in the camera array and occasionally obstructed the view of the camera and the diver, and counts were made with these limitations.

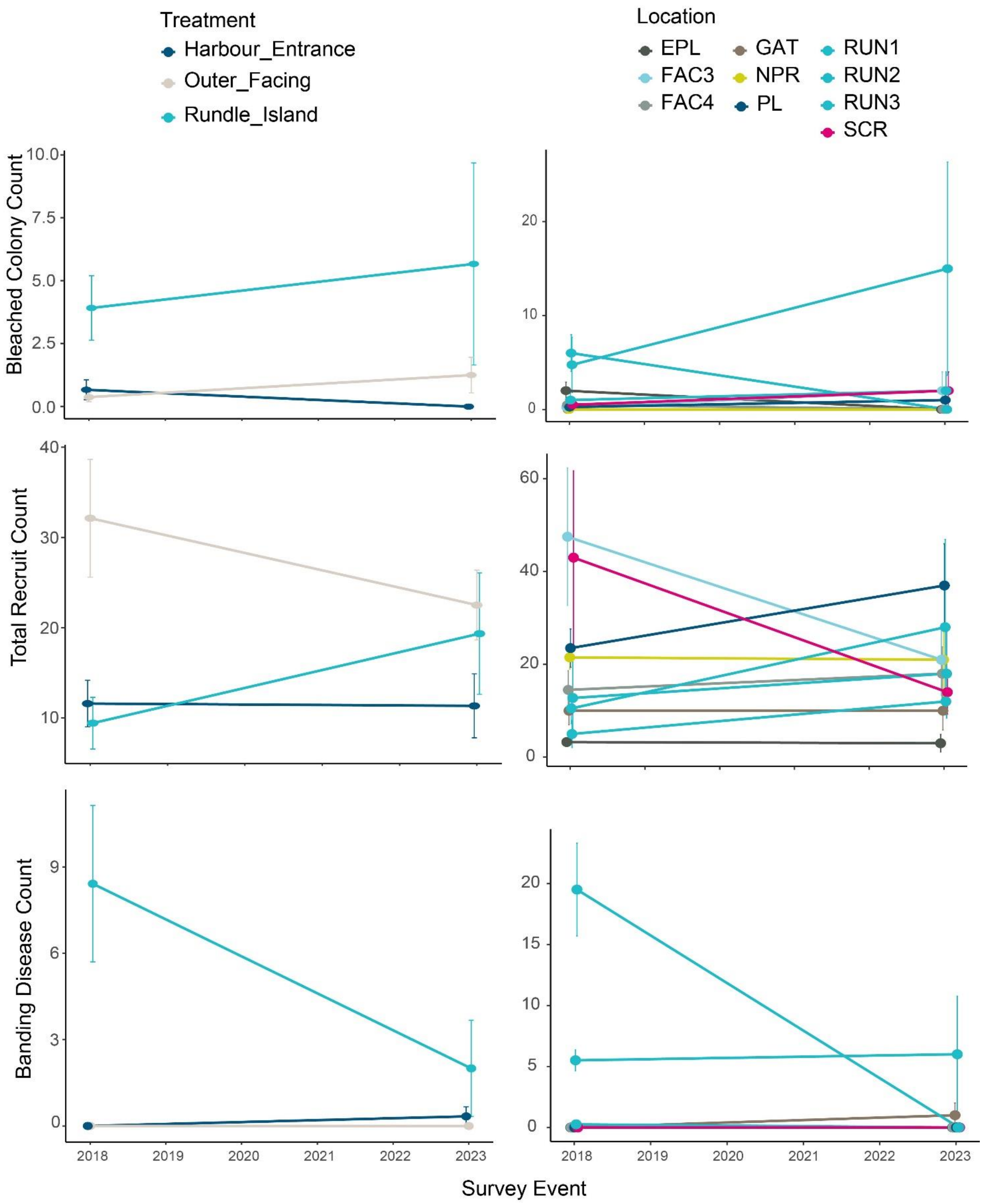


Figure 3.8 Mean (+/- SE) observations of bleached colonies (top), recruit counts (middle) and banding disease (below). Left column organised by treatment, right column by site.

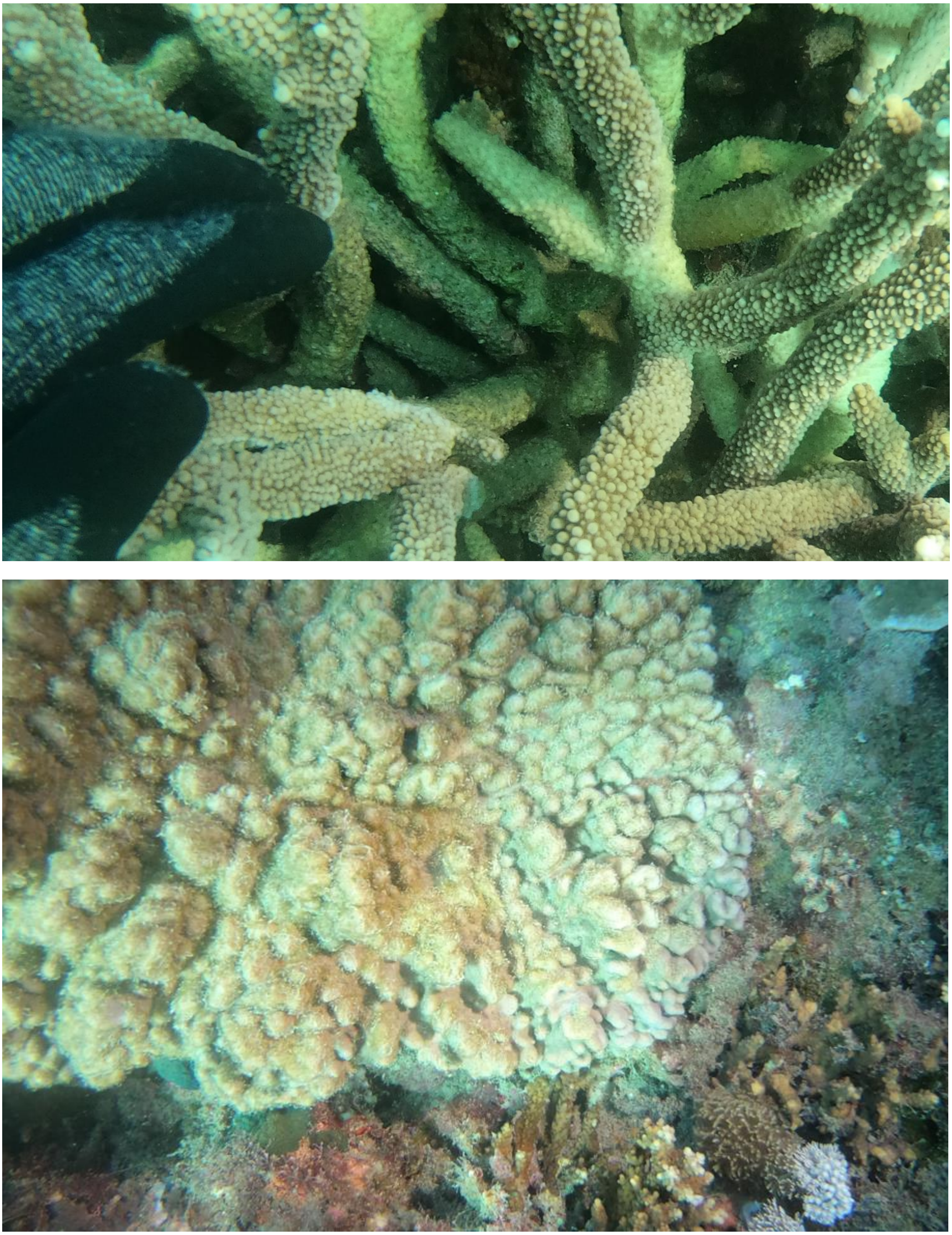


Figure 3.9 White band disease in *Acropora* at RUN3 and tissue necrosis in *Cladiella* at RUN2

3.4 3D Models

Three 3D models were produced at a subset of monitoring sites, including NPR, SCR, and FAC3. The model locations at FAC3 were identical between 2018 and 2023, and therefore are directly comparable. The models at NPR are located on the same ridge of bedrock in slightly different locations. Similarly, the 3D location at SCR was shifted slightly east to utilise a patch reef for better mosaic production. The 2018 model at SCR was only partially fulfilled due to a heavily repeating pattern in staghorn coral. Side by side images from 2018 and 2023 for the three locations are shown in Figure 3.10 to Figure 3.12. Colour in all cases appears redder in the shallower parts of the model due to loss of the red spectrum of light at greater depths.

The model generated at FAC3 shows a large bombora rising approximately 4 m up from the seafloor (Figure 3.10). Numerous plating acroporid corals and soft corals can be seen on and around the outcrop, including a large, bleached coral in 2018. Some holes in the image are present along steep surfaces of the model. The 2023 model is more complete than the 2018 model due to improvements in collection technique. Comparison between the two images shows the loss of much of the plating and branching *Acropora* from the uppermost parts of the bombora. These areas of significant loss are shown as yellow polygons in Figure 3.10. While the comparison shows the loss of many of these shallower corals, the growth and new recruitment of many other coral colonies is also visible, particularly the green colonies of *Acropora* and *Pocillopora.* The other very obvious visual difference is the appearance of many large clumps of *Asparagopsis* macroalgae (as red clumps in 2023). The visual differences observed at the FAC3 model are consistent with the univariate and multivariate transect data.

The models at NPR shows reef elevated above the sea floor as a series of ridges running north to south and entering the sea floor obliquely (Figure 3.11). A range of faviid and soft corals can be seen atop these ridges. The inter-reefal substrate consists of rubble and sand with bedforms and macroalgae. The macroalgae can be seen sitting mostly on the inter-reefal substrate directly adjacent to the reef ridges. The 2023 image, while located in a slightly different part of the ridge, suggests that the cover of soft and hard corals atop these ridges remain relatively healthy and diverse. Gaps in the models occurred where macroalgae was moving and could not be matched in different photos.

The 2018 model generated for SCR shows two large coral outcroppings in the corner of a field of Acropora (Figure 3.12). The site contains numerous plating acroporid corals amongst dense stands Acropora. Part of the capture area could not be built into the 3D model due to extremely homogeneous view fields, where 100% *Acropora* was present in many images. Sufficient overlap between distinguishing features could not be achieved due to a combination of substrate homogeneity and water clarity. The 2023 location used a patch-reef just east of the old location with the intent of being able to envelope the site with sand to produce model without gaps. The 2023 model shows a mixture of plating and branching *Acropora,* as well as several soft corals. Some of the plates have recently died, which was typical of the transect data at SCR, and one of the large central plate coral colonies is experiencing a white-band infection over half its tissue.

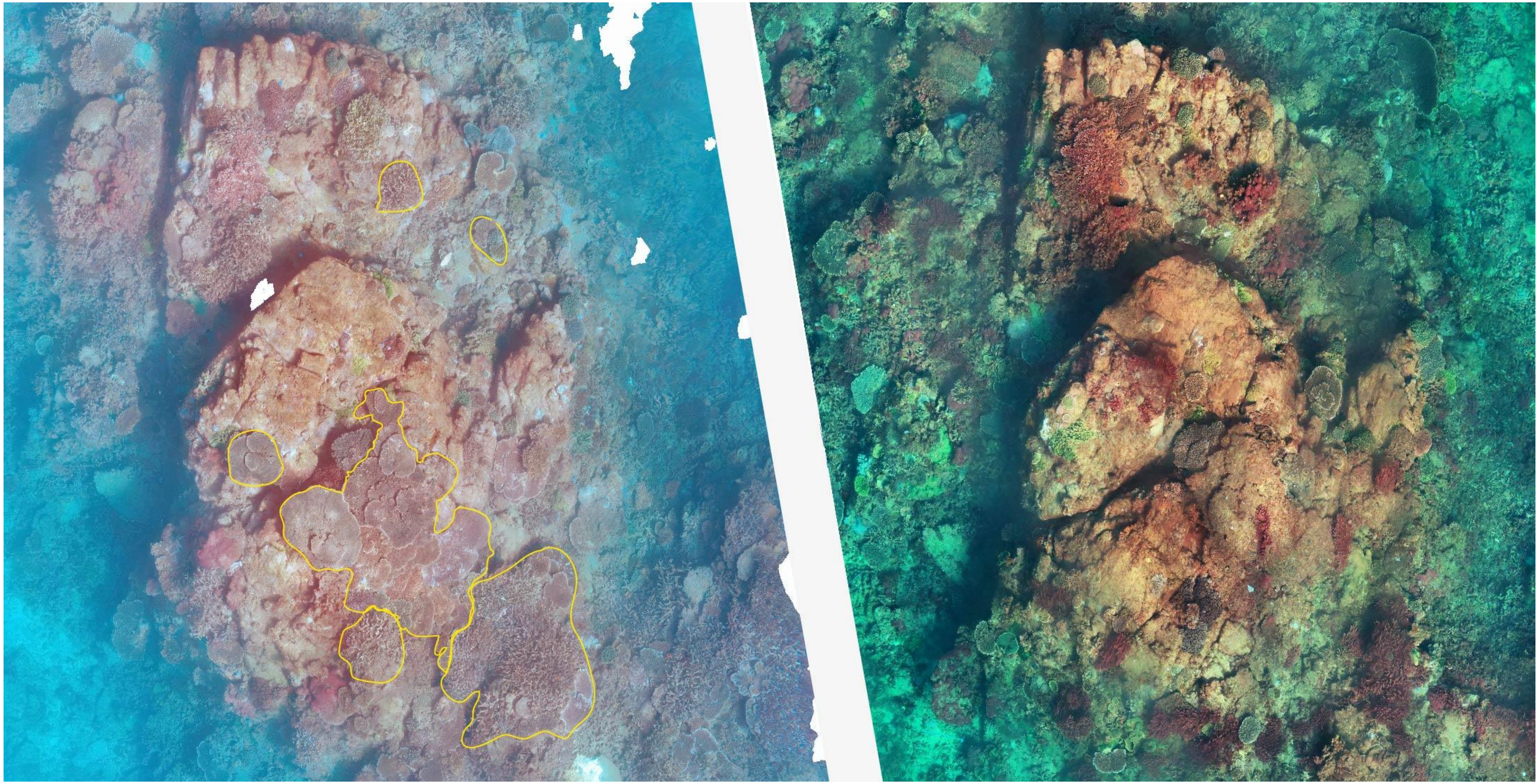


Figure 3.10 Orthomosaics of FAC3 in 2018 (left) and 2023 (right). Yellow lines show some corals that perished between 2018 and 2023.

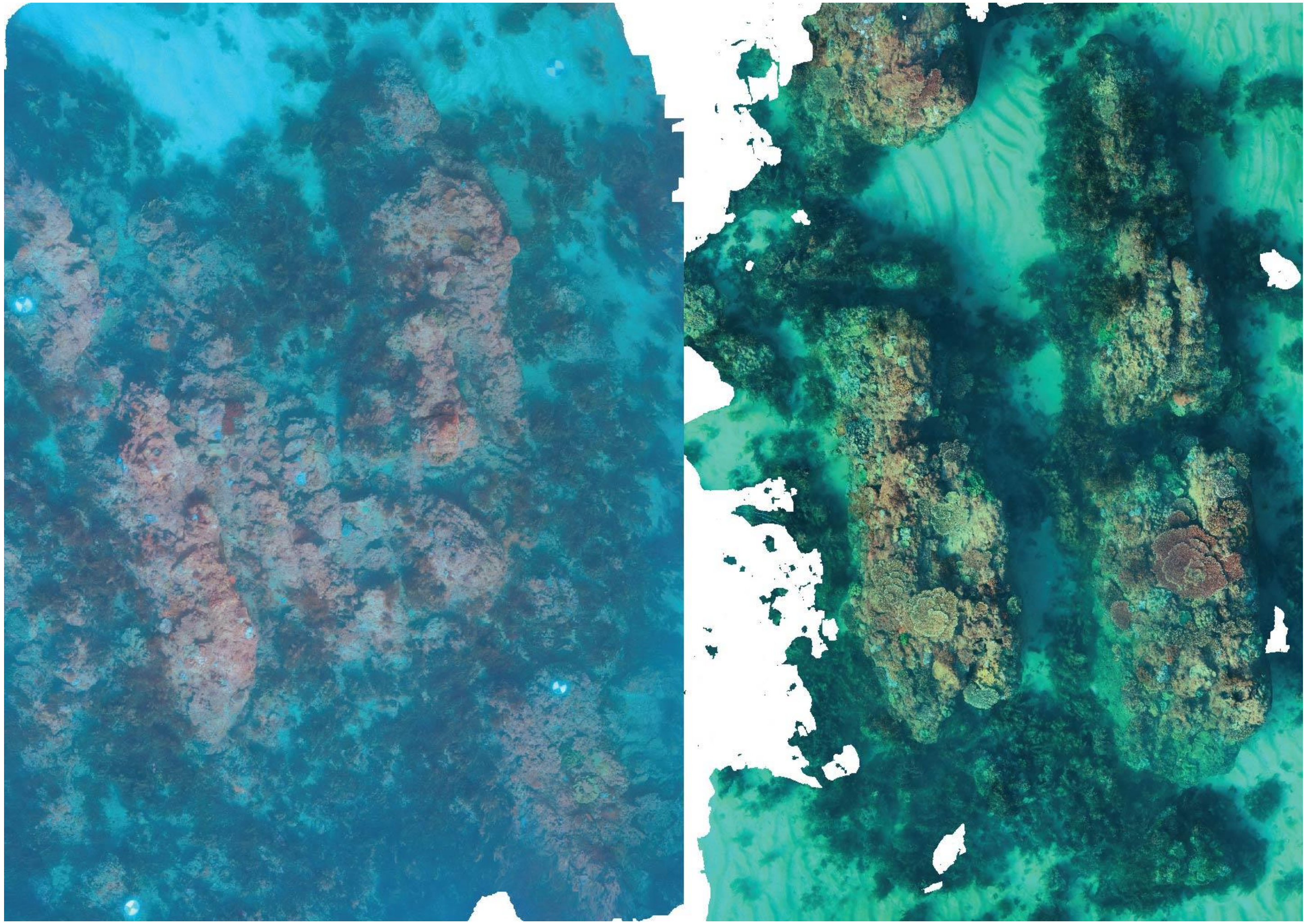


Figure 3.11 Orthomosaics at NPR in 2018 (left) and 2023 (right).

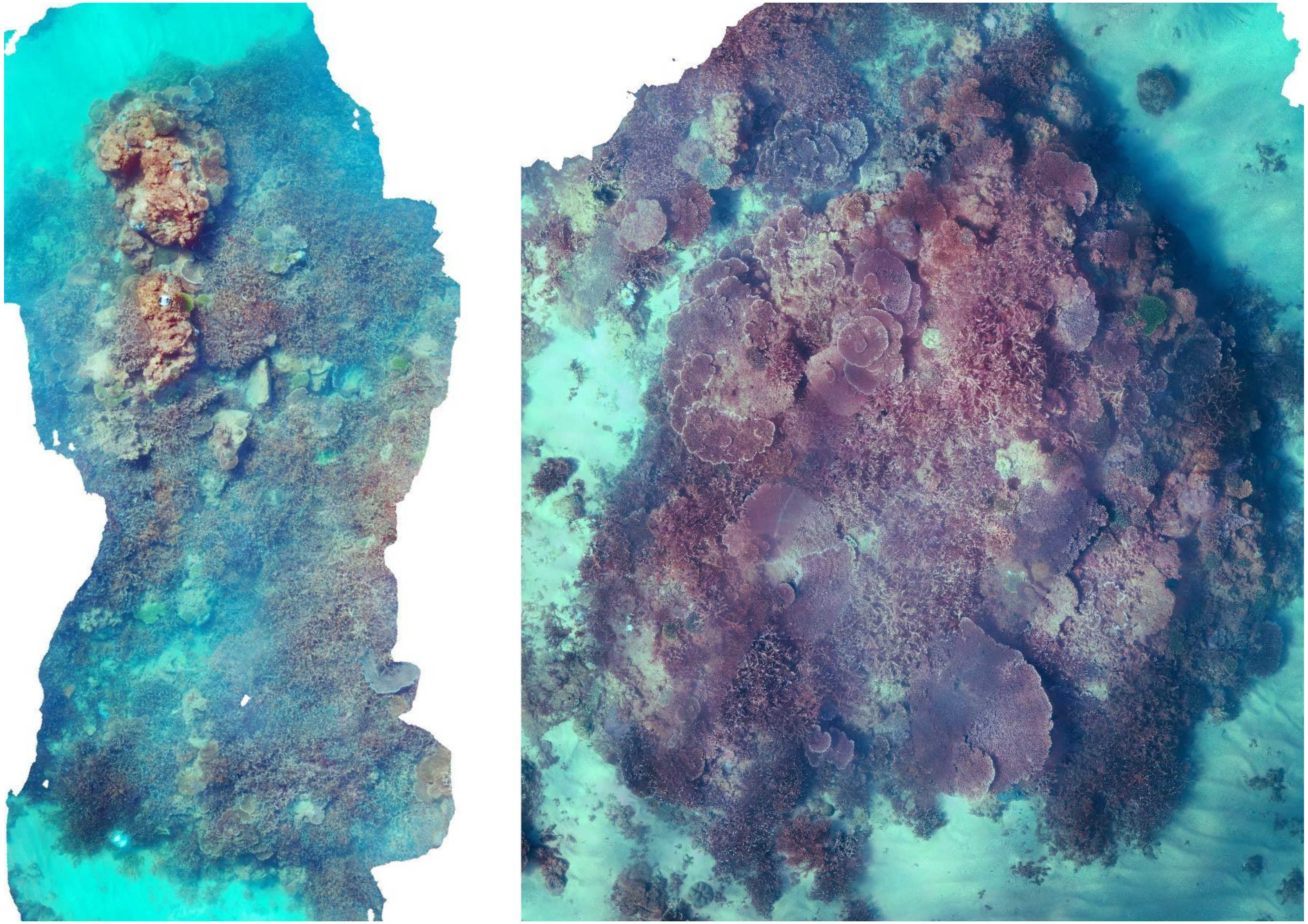


Figure 3.12 Orthomosaics at SCR in 2018 (left) and 2023 (right).

4 Conclusions and Regional Context

The surveys show that there are essentially two major community types within the monitored sites:

1. the outer Facing Island sites and Rundle Island sites, which are coral dominated and without *Sargassum*, and

2. the sites closer to the harbour entrance which are dominated by macroalgae and the coral *Turbinaria.*

Since 2018, there has not been much improvement in sites at Facing Island, and a fairly large reduction in coral cover was observed at one of the sites (FAC3). This site has become more ‘harbour entrance-like’, as its living coral cover has reduced and its macroalgal cover has increased, and one of the most tolerant genera of corals *Turbinaria* has increased in cover.

To compare this with Rundle Island, changes have largely been positive, with increasing coral cover evident, particularly at site RUN3. Therefore, the change observed at FAC3 is intriguing because it is not widespread across Facing Island, and out of context with what is happening at Rundle Island and the greater region. For a thermal impact to be the driver of change at FAC3, it is expected that other sites nearby would be affected similarly. Whilst only one site experienced a significant reduction in hard coral cover, overall there was a higher cover of turfing and macroalgae at harbour entrance and outer Facing Island treatments between 2018 and 2023 compared to the Rundle Island background. Rundle Island is distant from any catchment impacts, therefore, offers good insight into regional thermal impacts, but offers little environmental control for catchment impacts.

Long-term monitoring in the nearby Keppel Islands (Thompson et al., 2023) have shown thermal bleaching has occurred in 2006, 2020 and 2022, with substantial mortality recorded after the 2020 event. High water temperatures recorded elsewhere in the GBRMP during 2017 did not result in severe bleaching on the southern GBR (Swains or Capricorn-Bunker group), with the southernmost severe bleaching restricted to the Mackay Region (Thompson et al., 2023).

During the 2020 bleaching event, the proportion of coral lost in the Keppel Islands was significantly greater at the shallower 2 m depth contour compared to the adjacent 5 m monitoring contour (Thompson et al., 2023). Some of the changes at FAC3 may be related to bleaching in the shallowest waters, occurring after 2020. The comparison in orthomosaics at FAC3 did show that the most loss of coral appeared over the shallowest parts of the 3D mosaic site. However, the transect data were collected at similar depth contours in nearby sites, therefore it seems unlikely that thermal bleaching is driving the change at FAC3.

The sudden presence of *Sargassum* and *Asparagopsis* at FAC3 is interesting and may be causal (competing with corals) or coincidental filling the space left by the loss of coral. Site PL and FAC4 are positioned on either side of the SCR site (to the north and south, respectively). While *Sargassum* is virtually absent at SCR, it is extremely abundant on either side (at PL and FAC4), then falls away in abundance with further distance north to FAC3. In other words, the distribution of *Sargassum* does not follow a consistent gradient with distance away from each harbour entrance toward SCR; FAC3 is the outlier in this gradient.

It is perhaps more likely that the reduction in coral cover at FAC3 is related to highly localised changes in water quality or patterns in local disease or predation. FAC3 is not the closest site to the MRA, and this does not appear consistent with material placement impact or any potential post placement dispersion from the MRA. No crown of thorns starfish were observed in either monitoring campaign, but coral disease has been readily observed. A longer-term remote sensing assessment between 2018 and 2023 may provide more information on any localised changes in observable water quality signals, such as chlorophyll-a and turbidity. It may also provide some context for the observable plumes generated by maintenance material placement and catchment runoff, if there are satellite captures coinciding with material placement.

Looking more broadly over all sites, hard coral cover shows a general trend of plateauing or rising gently between 2018 and 2023. This is consistent with monitoring in the Keppel Island group showing a general up-trend in coral cover since flooding in 2011 and 2013 (Figure 4.1).

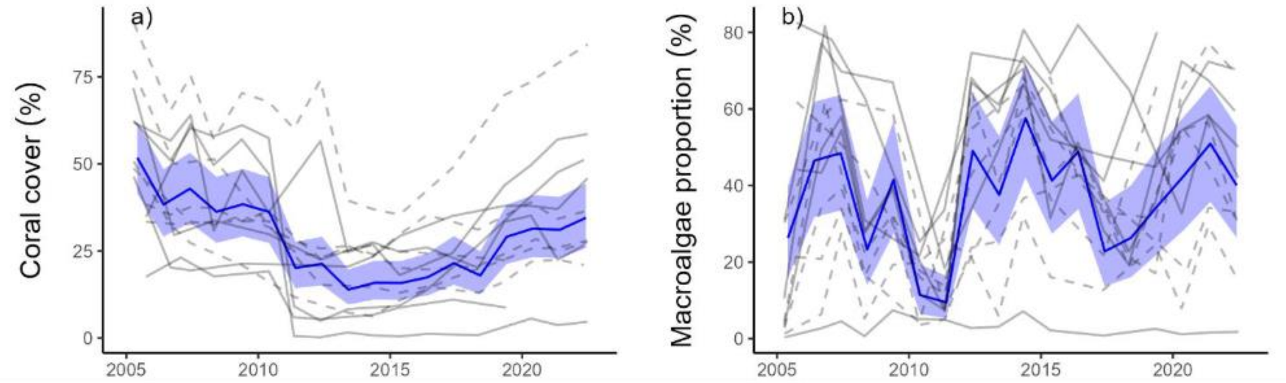


Figure 4.1 Fitzroy region indicator trends for coral cover (a) and proportion of macroalgae (b) (Thompson et al., 2023).

The GHHP collects health scores for reefs in Gladstone including Manning, Facing, Rat Island and Farmer's Reefs as well as Seal Rocks Reef in the outer harbour. None of these sites overlap with the current monitoring, but some are located on the adjacent landward shore of Facing Island. Scores are determined based on normalised indicators including hard coral cover, juvenile density, macroalgae cover, and change in hard coral cover. Neither raw nor summarised individual indicator data are available for the entire monitoring period (2015 -2022) in technical reports, but overall coral indicator scores are shown in Figure 4.2 (Figure 3.6 in GHHP, 2022).

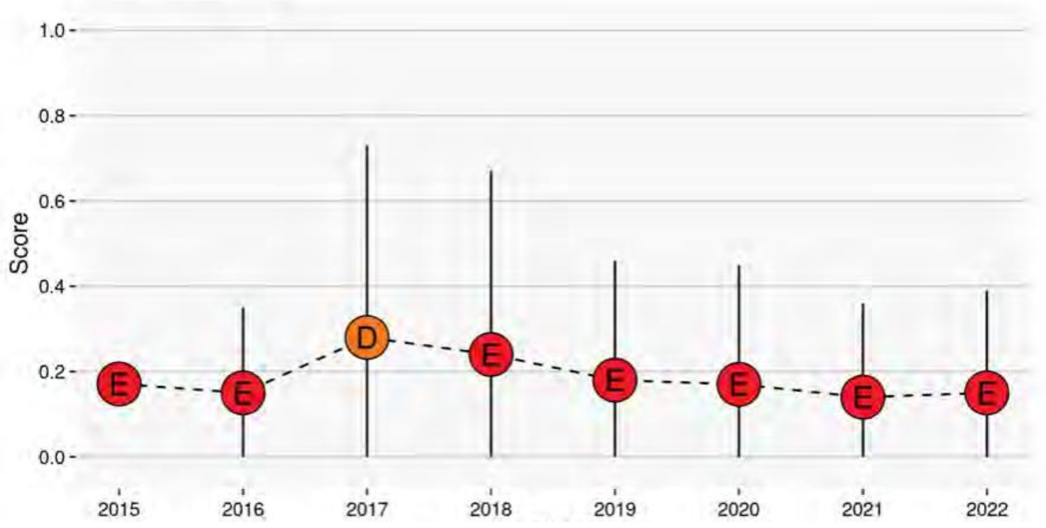


Figure 4.2 Trends in the Gladstone Harbour coral score for coral between 2015 and 2022. Error bars represent the 95% bootstrap confidence interval (GHHP 2022)

The GHHP monitoring suggests that coral health in the harbour has remained low between 2015 and 2022, but it is not possible to determine specifically how hard coral cover alone has changed across this period with the publicly available data.

Unlike observations made between 2009 and 2014 where some reefs inside Facing Island had lost all living coral cover over the length of a transect, no such drastic decreases or increase in living coral cover were observed in 2023 at any of the monitoring sites. Although recovery since 2013 has been relatively slow and somewhat inconsistent, it should be noted that much of this has occurred over a wetter than usual period. While the southern GBR has been sheltered from the effects of thermal bleaching, larger impacts have been felt from floods in 2011 and 2013. Over the last 10 years (since the 2013 inception of the monitoring program), the annual rainfall has been above median in 7/10 of those years, associated with strong southern oscillation indices (Figure 4.3). As the southern oscillation index slows in 2023 and there is a transition into drier and warmer conditions, the risk of catchment impacts may lessen for these communities while chances of extreme rainfall are lower.

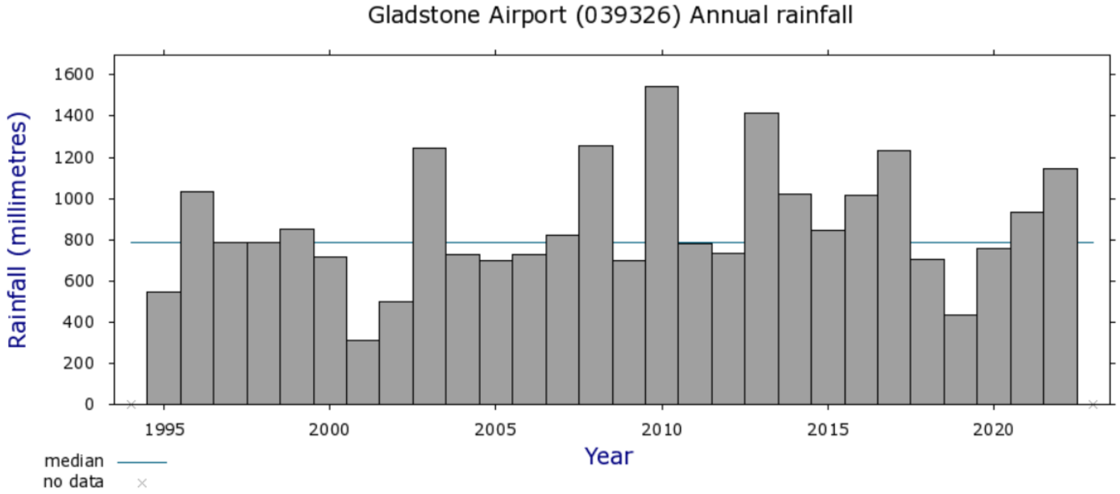


Figure 4.3 Annual Rainfall for Gladstone Airport (BoM station 039326)

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Annex A Generalised Linear Model Results

```
> mod_Soft_Coral_Sites <- glmmTMB(Soft_coral_percent_cover ~  factor(Event) * L
ocation, data=ccover_select, family=beta_family())
> summary(mod_Soft_Coral_Sites)
 Family: beta  ( logit )
Formula:          Soft_coral_percent_cover ~ factor(Event) * Location
Data: ccover_select

     AIC      BIC   logLik deviance df.resid 
 -5605.9  -5507.6   2824.0  -5647.9      779 


Dispersion parameter for beta family (): 8.57 

Conditional model:
                                Estimate Std. Error z value Pr(>|z|)    
(Intercept)                    -3.517004   0.166336 -21.144  < 2e-16 ***
factor(Event)2023              -0.097330   0.221792  -0.439  0.66078    
LocationFAC3                    0.190002   0.220590   0.861  0.38905    
LocationFAC4                   -0.035924   0.221578  -0.162  0.87121    
LocationGAT                     0.162604   0.220728   0.737  0.46132    
LocationNPR                     0.281045   0.220095   1.277  0.20163    
LocationPL                      0.107236   0.220990   0.485  0.62750    
LocationRUN1                    0.007519   0.221413   0.034  0.97291    
LocationRUN2                    0.572615   0.218099   2.625  0.00865 ** 
LocationRUN3                   -0.126775   0.221889  -0.571  0.56777    
LocationSCR                     0.100590   0.221020   0.455  0.64903    
factor(Event)2023:LocationFAC3 -0.119559   0.312874  -0.382  0.70236    
factor(Event)2023:LocationFAC4  0.083699   0.313639   0.267  0.78957    
factor(Event)2023:LocationGAT  -0.136909   0.313088  -0.437  0.66190    
factor(Event)2023:LocationNPR  -0.075959   0.312105  -0.243  0.80771    
factor(Event)2023:LocationPL   -0.045828   0.313184  -0.146  0.88366    
factor(Event)2023:LocationRUN1  0.012134   0.313589   0.039  0.96913    
factor(Event)2023:LocationRUN2  0.486103   0.305558   1.591  0.11164    
factor(Event)2023:LocationRUN3  0.157886   0.313901   0.503  0.61498    
factor(Event)2023:LocationSCR   0.179786   0.312530   0.575  0.56512    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Soft_Coral_Sites)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Soft_coral_percent_cover
                         Chisq Df Pr(>Chisq)    
factor(Event)           0.3099  1     0.5777    
Location               49.8431  9  1.153e-07 ***
factor(Event):Location  6.7922  9     0.6587    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> mod_Soft_Coral_treat <- glmmTMB(Soft_coral_percent_cover ~  factor(Event) * T
reatment, data=ccover_select, family=beta_family())
> summary(mod_Soft_Coral_treat)
 Family: beta  ( logit )
Formula:          Soft_coral_percent_cover ~ factor(Event) * Treatment
Data: ccover_select

     AIC      BIC   logLik deviance df.resid 
 -5591.3  -5558.5   2802.6  -5605.3      793 


Dispersion parameter for beta family (): 8.01 

Conditional model:
                                     Estimate Std. Error z value Pr(>|z|)    
(Intercept)                          -3.32452    0.10551 -31.508   <2e-16 ***
factor(Event)2023                    -0.16388    0.12789  -1.281    0.200    
TreatmentOuter_Facing                -0.05382    0.11937  -0.451    0.652    
TreatmentRundle_Island               -0.02669    0.12756  -0.209    0.834    
factor(Event)2023:Treat_Outer_Facing  0.09113    0.16920   0.539    0.590    
factor(Event)2023:Treat_Rundle_Island  0.23597    0.18057   1.307    0.191    
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Soft_Coral_treat)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Soft_coral_percent_cover
                         Chisq Df Pr(>Chisq)
factor(Event)           0.6482  1     0.4207
Treatment               1.5959  2     0.4503
factor(Event):Treatment 1.7442  2     0.4181
>
> mod_Hard_coral_Sites <- glmmTMB(Hard_coral_percent_cover ~ factor(Event) * Lo
cation, data=ccover_select, family=beta_family())
> summary(mod_Hard_coral_Sites)
 Family: beta  ( logit )
Formula:          Hard_coral_percent_cover ~ factor(Event) * Location
Data: ccover_select

     AIC      BIC   logLik deviance df.resid
 -1807.9  -1709.5    925.0  -1849.9      779


Dispersion parameter for beta family (): 1.74

Conditional model:
                                 Estimate Std. Error z value Pr(>|z|)
(Intercept)                    -2.2099571  0.1747325 -12.648  < 2e-16 ***
factor(Event)2023               0.0856886  0.2409131   0.356  0.72208
LocationFAC3                    2.1923848  0.2512088   8.727  < 2e-16 ***
LocationFAC4                    0.2328270  0.2417495   0.963  0.33550
LocationGAT                     0.2941085  0.2421033   1.215  0.22444
LocationNPR                     0.5623198  0.2436603   2.308  0.02101 *
LocationPL                      0.7901673  0.2449507   3.226  0.00126 **
LocationRUN1                    2.9159716  0.2538610  11.486  < 2e-16 ***
LocationRUN2                    1.8523115  0.2498611   7.413 1.23e-13 ***
LocationRUN3                    2.1715806  0.2511265   8.647  < 2e-16 ***
LocationSCR                     2.4685368  0.2522930   9.784  < 2e-16 ***
factor(Event)2023:LocationFAC3 -1.0295383  0.3508457  -2.934  0.00334 **
factor(Event)2023:LocationFAC4 -0.0968126  0.3421618  -0.283  0.77722
factor(Event)2023:LocationGAT  -0.0072710  0.3430091  -0.021  0.98309
factor(Event)2023:LocationNPR  -0.1335647  0.3446283  -0.388  0.69834
factor(Event)2023:LocationPL   -0.0003414  0.3467702  -0.001  0.99921
factor(Event)2023:LocationRUN1 -0.2187339  0.3502998  -0.624  0.53235
factor(Event)2023:LocationRUN2 -0.0928171  0.3508460  -0.265  0.79135
factor(Event)2023:LocationRUN3  0.3273361  0.3510770   0.932  0.35114
factor(Event)2023:LocationSCR  -0.5040875  0.3511719  -1.435  0.15116
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Hard_coral_Sites)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Hard_coral_percent_cover
                         Chisq Df Pr(>Chisq)
factor(Event)            1.140  1    0.28566
Location               482.324  9    < 2e-16 ***
factor(Event):Location  18.419  9    0.03061 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> mod_Hard_coral_Treat <- glmmTMB(Hard_coral_percent_cover ~ factor(Event) * Tr
eatment, data=ccover_select, family=beta_family())
> summary(mod_Hard_coral_Treat)
 Family: beta  ( logit )
Formula:          Hard_coral_percent_cover ~ factor(Event) * Treatment
Data: ccover_select

     AIC      BIC   logLik deviance df.resid
 -1651.6  -1618.8    832.8  -1665.6      793
```

```
Dispersion parameter for beta family (): 1.35 

Conditional model:
                                       Estimate Std. Error z value Pr(>|z|)    
(Intercept)                            -1.74474    0.10829 -16.112  < 2e-16 ***
factor(Event)2023                       0.04467    0.14447   0.309    0.757    
TreatmentOuter_Facing                   0.87571    0.13898   6.301 2.96e-10 ***
TreatmentRundle_Island                  1.84244    0.15526  11.866  < 2e-16 ***
factor(Event)2023:Treat_Outer_Facing   -0.26166    0.19524  -1.340    0.180    
factor(Event)2023:Treat_Rundle_Island   0.03056    0.21262   0.144    0.886    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Hard_coral_Treat)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Hard_coral_percent_cover
                           Chisq Df Pr(>Chisq)    
factor(Event)             0.3682  1     0.5440    
Treatment               267.9135  2     <2e-16 ***
factor(Event):Treatment   2.6900  2     0.2605    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> 
> mod_Total_algae_Sites <- glmmTMB(Total_algae_percent_cover ~ factor(Event) * 
Location, data=ccover_select, family=beta_family())
> summary(mod_Total_algae_Sites)
 Family: beta  ( logit )
Formula:          Total_algae_percent_cover ~ factor(Event) * Location
Data: ccover_select

     AIC      BIC   logLik deviance df.resid 
 -2523.1  -2424.7   1282.5  -2565.1      779 


Dispersion parameter for beta family (): 1.82 

Conditional model:
                               Estimate Std. Error z value Pr(>|z|)    
(Intercept)                     0.20660    0.17874   1.156  0.24774    
factor(Event)2023               0.70962    0.25242   2.811  0.00493 ** 
LocationFAC3                   -2.36794    0.25099  -9.435  < 2e-16 ***
LocationFAC4                   -0.65377    0.25307  -2.583  0.00978 ** 
LocationGAT                    -1.30374    0.25327  -5.148 2.64e-07 ***
LocationNPR                    -0.63045    0.25305  -2.491  0.01272 *  
LocationPL                     -0.77216    0.25315  -3.050  0.00229 ** 
LocationRUN1                   -2.56853    0.25033 -10.261  < 2e-16 ***
LocationRUN2                   -2.45849    0.25069  -9.807  < 2e-16 ***
LocationRUN3                   -2.40592    0.25086  -9.591  < 2e-16 ***
LocationSCR                    -2.51587    0.25050 -10.043  < 2e-16 ***
factor(Event)2023:LocationFAC3 -0.13533    0.35042  -0.386  0.69936    
factor(Event)2023:LocationFAC4 -0.05747    0.35668  -0.161  0.87199    
factor(Event)2023:LocationGAT   0.74267    0.35626   2.085  0.03710 *  
factor(Event)2023:LocationNPR  -0.48584    0.35687  -1.361  0.17338    
factor(Event)2023:LocationPL   -0.32347    0.35668  -0.907  0.36446    
factor(Event)2023:LocationRUN1 -0.59053    0.34762  -1.699  0.08936 .  
factor(Event)2023:LocationRUN2 -0.53717    0.34856  -1.541  0.12328    
factor(Event)2023:LocationRUN3 -0.27487    0.34975  -0.786  0.43192    
factor(Event)2023:LocationSCR  -0.50068    0.34827  -1.438  0.15054    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Total_algae_Sites)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Total_algae_percent_cover
                         Chisq Df Pr(>Chisq)    
factor(Event)           37.216  1  1.057e-09 ***
```

```
Location               544.509  9  < 2.2e-16 ***
factor(Event):Location  22.475  9   0.007489 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> mod_Total_algae_Treat <- glmmTMB(Total_algae_percent_cover ~ factor(Event) *
Treatment, data=ccover_select, family=beta_family())
> summary(mod_Total_algae_Treat)
 Family: beta  ( logit )
Formula:          Total_algae_percent_cover ~ factor(Event) * Treatment
Data: ccover_select

     AIC      BIC   logLik deviance df.resid
 -2324.8  -2292.0   1169.4  -2338.8      793


Dispersion parameter for beta family (): 1.32

Conditional model:
                                         Estimate Std. Error z value Pr(>|z|)
(Intercept)                             -0.3973     0.1108  -3.586 0.000336 ***
factor(Event)2023                        0.7142     0.1574   4.538 5.67e-06 ***
TreatmentOuter_Facing                   -0.9986     0.1443  -6.918 4.58e-12 ***
TreatmentRundle_Island                  -1.6081     0.1519 -10.589  < 2e-16 ***
factor(Event)2023:Treat_Outer_Facing    -0.2939     0.2034  -1.445 0.148419
factor(Event)2023:Treat_Rundle_Island   -0.4997     0.2124  -2.353 0.018637 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Total_algae_Treat)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Total_algae_percent_cover
                           Chisq Df Pr(>Chisq)
factor(Event)            27.4719  1  1.594e-07 ***
Treatment               271.1756  2  < 2.2e-16 ***
factor(Event):Treatment   5.5521  2    0.06228 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

 > mod_Macroalgae_sites<- glmmTMB(Macroalgae_pc ~ factor(Event) * Location, data=ccover_se
 ly=beta_family())
 > summary(Macroalgae_sites)
  Family: beta  ( logit )
 Formula:          Macroalgae_pc ~ factor(Event) * Location
 Data: ccover_select

      AIC      BIC   logLik deviance df.resid
  -2523.1  -2424.7   1282.5  -2565.1      779


 Dispersion parameter for beta family (): 1.82

 Conditional model:
                                Estimate Std. Error z value Pr(>|z|)
 (Intercept)                     0.20660    0.17874   1.156  0.24774
 factor(Event)2023               0.70962    0.25242   2.811  0.00493 **
 LocationFAC3                   -2.36794    0.25099  -9.435  < 2e-16 ***
 LocationFAC4                   -0.65377    0.25307  -2.583  0.00978 **
 LocationGAT                    -1.30374    0.25327  -5.148 2.64e-07 ***
 LocationNPR                    -0.63045    0.25305  -2.491  0.01272 *
 LocationPL                     -0.77216    0.25315  -3.050  0.00229 **
 LocationRUN1                   -2.56853    0.25033 -10.261  < 2e-16 ***
 LocationRUN2                   -2.45849    0.25069  -9.807  < 2e-16 ***
 LocationRUN3                   -2.40592    0.25086  -9.591  < 2e-16 ***
 LocationSCR                    -2.51587    0.25050 -10.043  < 2e-16 ***
 factor(Event)2023:LocationFAC3 -0.13533    0.35042  -0.386  0.69936
 factor(Event)2023:LocationFAC4 -0.05747    0.35668  -0.161  0.87199
```

```
factor(Event)2023:LocationGAT   0.74267    0.35626   2.085  0.03710 *
factor(Event)2023:LocationNPR  -0.48584    0.35687  -1.361  0.17338
factor(Event)2023:LocationPL   -0.32347    0.35668  -0.907  0.36446
factor(Event)2023:LocationRUN1 -0.59053    0.34762  -1.699  0.08936 .
factor(Event)2023:LocationRUN2 -0.53717    0.34856  -1.541  0.12328
factor(Event)2023:LocationRUN3 -0.27487    0.34975  -0.786  0.43192
factor(Event)2023:LocationSCR  -0.50068    0.34827  -1.438  0.15054
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Macroalgae_sites)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Macroalgae_pc
                         Chisq Df Pr(>Chisq)
factor(Event)           37.216  1  1.057e-09 ***
Location               544.509  9  < 2.2e-16 ***
factor(Event):Location  22.475  9   0.007489 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> mod_Macroalgae_Treatment <- glmmTMB(Macroalgae_pc ~ factor(Event) * Treatment, data=ccc
, family=beta_family())
> summary(mod_Macroalgae_Treatment)
 Family: beta  ( logit )
Formula:          Macroalgae_pc ~ factor(Event) * Treatment
Data: ccover_select

     AIC      BIC   logLik deviance df.resid
 -2324.8  -2292.0   1169.4  -2338.8      793


Dispersion parameter for beta family (): 1.32

Conditional model:
                                         Estimate Std. Error z value Pr(>|z|)
(Intercept)                              -0.3973     0.1108  -3.586 0.000336 ***
factor(Event)2023                         0.7142     0.1574   4.538 5.67e-06 ***
TreatmentOuter_Facing                    -0.9986     0.1443  -6.918 4.58e-12 ***
TreatmentRundle_Island                   -1.6081     0.1519 -10.589  < 2e-16 ***
factor(Event)2023:TreatmentOuter_Facing  -0.2939     0.2034  -1.445 0.148419
factor(Event)2023:TreatmentRundle_Island -0.4997     0.2124  -2.353 0.018637 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(mod_Macroalgae_Treatment)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Macroalgae_pc
                           Chisq Df Pr(>Chisq)
factor(Event)            27.4719  1  1.594e-07 ***
Treatment               271.1756  2  < 2.2e-16 ***
factor(Event):Treatment   5.5521  2    0.06228 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

>
> Recruit_counts_Site <- glmmTMB(Total_Recruits ~ factor(Event) * Site, data=cc
over, genpois())
> summary(Recruit_counts_Site)
 Family: genpois  ( log )
Formula:          Total_Recruits ~ factor(Event) * Site
Data: ccover

     AIC      BIC   logLik deviance df.resid
   633.3    683.3   -295.6    591.3       59


Overdispersion parameter for genpois family (): 14.8
```

```
Conditional model:
                               Estimate Std. Error z value Pr(>|z|)    
(Intercept)                      1.9623     0.4473   4.387 1.15e-05 ***
factor(Event)2023               -0.7097     0.7909  -0.897 0.369552    
SiteFAC3                     1.8821     0.5037   3.737 0.000186 ***
SiteFAC4                     0.9496     0.5520   1.720 0.085381 .
SiteGAT                      0.7180     0.5626   1.276 0.201868
SiteNPR                      1.3953     0.5214   2.676 0.007454 **
SitePL                       1.4283     0.5212   2.741 0.006135 **
SiteRUN1                     0.6745     0.5733   1.177 0.239382
SiteRUN2                    -0.5517     0.7916  -0.697 0.485844
SiteRUN3                     0.6160     0.5730   1.075 0.282374
SiteSCR                      1.6416     0.5171   3.175 0.001498 **
factor(Event)2023:SiteFAC3  -0.4049     0.9382  -0.432 0.666091
factor(Event)2023:SiteFAC4   0.8177     0.9224   0.887 0.375313
factor(Event)2023:SiteGAT    0.3469     0.9832   0.353 0.724230
factor(Event)2023:SiteNPR    0.5213     0.8958   0.582 0.560651
factor(Event)2023:SitePL     1.0261     0.8787   1.168 0.242875
factor(Event)2023:SiteRUN1  -0.2637     1.1107  -0.237 0.812305
factor(Event)2023:SiteRUN2   2.1856     1.0830   2.018 0.043573 *
factor(Event)2023:SiteRUN3   0.4730     0.9984   0.474 0.635625
factor(Event)2023:SiteSCR   -0.3534     0.9495  -0.372 0.709764
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(Recruit_counts_Site)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Total_Recruits
                         Chisq Df Pr(>Chisq)    
factor(Event)           2.0064  1    0.15663    
Site               40.4058  9  6.414e-06 ***
factor(Event):Site 14.7824  9    0.09709 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> Recruit_counts_Treatment <- glmmTMB(Total_Recruits ~ factor(Event) * Site, da
ta=ccover, genpois())
> summary(Recruit_counts_Treatment)
 Family: genpois  ( log )
Formula:          Total_Recruits ~ factor(Event) * Site
Data: ccover

     AIC      BIC   logLik deviance df.resid 
   633.3    683.3   -295.6    591.3       59 


Overdispersion parameter for genpois family (): 14.8

Conditional model:
                               Estimate Std. Error z value Pr(>|z|)    
(Intercept)                      1.9623     0.4473   4.387 1.15e-05 ***
factor(Event)2023               -0.7097     0.7909  -0.897 0.369552    
SiteFAC3                     1.8821     0.5037   3.737 0.000186 ***
SiteFAC4                     0.9496     0.5520   1.720 0.085381 .
SiteGAT                      0.7180     0.5626   1.276 0.201868
SiteNPR                      1.3953     0.5214   2.676 0.007454 **
SitePL                       1.4283     0.5212   2.741 0.006135 **
SiteRUN1                     0.6745     0.5733   1.177 0.239382
SiteRUN2                    -0.5517     0.7916  -0.697 0.485844
SiteRUN3                     0.6160     0.5730   1.075 0.282374
SiteSCR                      1.6416     0.5171   3.175 0.001498 **
factor(Event)2023:SiteFAC3  -0.4049     0.9382  -0.432 0.666091
factor(Event)2023:SiteFAC4   0.8177     0.9224   0.887 0.375313
factor(Event)2023:SiteGAT    0.3469     0.9832   0.353 0.724230
factor(Event)2023:SiteNPR    0.5213     0.8958   0.582 0.560651
factor(Event)2023:SitePL     1.0261     0.8787   1.168 0.242875
factor(Event)2023:SiteRUN1  -0.2637     1.1107  -0.237 0.812305
factor(Event)2023:SiteRUN2   2.1856     1.0830   2.018 0.043573 *
```

```
factor(Event)2023:SiteRUN3   0.4730     0.9984   0.474 0.635625
factor(Event)2023:SiteSCR   -0.3534     0.9495  -0.372 0.709764
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(Recruit_counts_Treatment)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Total_Recruits
                         Chisq Df Pr(>Chisq)
factor(Event)           2.0064  1    0.15663
Site               40.4058  9  6.414e-06 ***
factor(Event):Site 14.7824  9    0.09709 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
>
> Bleaching_counts_Treatment <- glmmTMB(Bleaching ~ factor(Event) * Treatment,
data=ccover, genpois())
> summary(Bleaching_counts_Treatment)
 Family: genpois  ( log )
Formula:          Bleaching ~ factor(Event) * Treatment
Data: ccover

     AIC      BIC   logLik deviance df.resid
   211.2    227.9    -98.6    197.2       73


Dispersion parameter for genpois family (): 24.4

Conditional model:
                                           Estimate Std. Error z value Pr(>|z|)
(Intercept)                               3.545e-01  6.803e-01   0.521   0.6023
factor(Event)2023                        -1.989e+01  1.120e+04  -0.002   0.9986
TreatmentOuter_Facing                    -7.445e-02  7.590e-01  -0.098   0.9219
TreatmentRundle_Island                    1.436e+00  6.613e-01   2.171   0.0299
*
factor(Event)2023:TreatmentOuter_Facing   1.974e+01  1.120e+04   0.002   0.9986
factor(Event)2023:TreatmentRundle_Island  1.864e+01  1.120e+04   0.002   0.9987
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> Anova(Bleaching_counts_Treatment)
Analysis of Deviance Table (Type II Wald chisquare tests)

Response: Bleaching
                         Chisq Df Pr(>Chisq)
factor(Event)           3.6195  2    0.16369
Treatment               8.9905  3    0.02942 *
factor(Event):Treatment 1.1937  2    0.55054
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

>
> # Independant contrasts
> emmeans(Soft_Coral_Sites, pairwise ~ Event | Site)
$emmeans
Location = EPL:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.52 0.166 Inf     -3.84     -3.19
  2023  -3.61 0.167 Inf     -3.94     -3.29

Location = FAC3:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.33 0.164 Inf     -3.65     -3.01
  2023  -3.54 0.167 Inf     -3.87     -3.22

Location = FAC4:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.55 0.167 Inf     -3.88     -3.23
  2023  -3.57 0.167 Inf     -3.89     -3.24
```

```
Location = GAT:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.35 0.165 Inf     -3.68     -3.03
  2023  -3.59 0.167 Inf     -3.92     -3.26

Location = NPR:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.24 0.163 Inf     -3.56     -2.92
  2023  -3.41 0.165 Inf     -3.73     -3.09

Location = PL:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.41 0.165 Inf     -3.73     -3.09
  2023  -3.55 0.167 Inf     -3.88     -3.23

Location = RUN1:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.51 0.166 Inf     -3.84     -3.18
  2023  -3.59 0.167 Inf     -3.92     -3.27

Location = RUN2:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -2.94 0.158 Inf     -3.25     -2.63
  2023  -2.56 0.150 Inf     -2.85     -2.26

Location = RUN3:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.64 0.168 Inf     -3.97     -3.32
  2023  -3.58 0.167 Inf     -3.91     -3.26

Location = SCR:
 Event emmean    SE  df asymp.LCL asymp.UCL
  2018  -3.42 0.165 Inf     -3.74     -3.09
  2023  -3.33 0.164 Inf     -3.66     -3.01

Results are given on the logit (not the response) scale.
Confidence level used: 0.95

$contrasts
Location = EPL:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.0973 0.222 Inf   0.439  0.6608

Location = FAC3:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.2169 0.221 Inf   0.983  0.3257

Location = FAC4:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.0136 0.222 Inf   0.061  0.9510

Location = GAT:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.2342 0.221 Inf   1.060  0.2892

Location = NPR:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.1733 0.220 Inf   0.789  0.4301

Location = PL:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.1432 0.221 Inf   0.647  0.5174

Location = RUN1:
 contrast               estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.0852 0.222 Inf   0.384  0.7008
```

```
Location = RUN2:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023  -0.3888 0.210 Inf  -1.850  0.0643

Location = RUN3:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023  -0.0606 0.222 Inf  -0.273  0.7851

Location = SCR:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023  -0.0825 0.220 Inf  -0.374  0.7080

Results are given on the log odds ratio (not the response) scale.


> emmeans(Hard_Coral_Sites, pairwise ~ Event | Site)
$emmeans
Location = EPL:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -2.2100 0.175 Inf   -2.5524  -1.86749
  2023 -2.1243 0.175 Inf   -2.4677  -1.78085

Location = FAC3:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.0176 0.181 Inf   -0.3715   0.33636
  2023 -0.9614 0.180 Inf   -1.3144  -0.60846

Location = FAC4:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -1.9771 0.176 Inf   -2.3222  -1.63210
  2023 -1.9883 0.176 Inf   -2.3332  -1.64335

Location = GAT:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -1.9158 0.176 Inf   -2.2615  -1.57016
  2023 -1.8374 0.177 Inf   -2.1839  -1.49092

Location = NPR:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -1.6476 0.178 Inf   -1.9960  -1.29923
  2023 -1.6955 0.178 Inf   -2.0435  -1.34757

Location = PL:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -1.4198 0.179 Inf   -1.7702  -1.06942
  2023 -1.3344 0.179 Inf   -1.6854  -0.98345

Location = RUN1:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  0.7060 0.180 Inf    0.3524   1.05963
  2023  0.5730 0.181 Inf    0.2192   0.92676

Location = RUN2:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.3576 0.181 Inf   -0.7116  -0.00374
  2023 -0.3648 0.181 Inf   -0.7187  -0.01087

Location = RUN3:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.0384 0.181 Inf   -0.3923   0.31556
  2023  0.3746 0.181 Inf    0.0207   0.72855

Location = SCR:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  0.2586 0.181 Inf   -0.0953   0.61250
  2023 -0.1598 0.181 Inf   -0.5137   0.19411

Results are given on the logit (not the response) scale.
```

```
Confidence level used: 0.95

$contrasts
Location = EPL:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023 -0.08569 0.241 Inf  -0.356  0.7221

Location = FAC3:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023  0.94385 0.255 Inf   3.701  0.0002

Location = FAC4:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023  0.01112 0.243 Inf   0.046  0.9635

Location = GAT:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023 -0.07842 0.244 Inf  -0.321  0.7481

Location = NPR:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023  0.04788 0.246 Inf   0.194  0.8460

Location = PL:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023 -0.08535 0.249 Inf  -0.342  0.7322

Location = RUN1:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023  0.13305 0.254 Inf   0.523  0.6008

Location = RUN2:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023  0.00713 0.255 Inf   0.028  0.9777

Location = RUN3:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023 -0.41302 0.255 Inf  -1.617  0.1058

Location = SCR:
 contrast             estimate    SE  df z.ratio p.value
 Event2018 - Event2023  0.41840 0.255 Inf   1.638  0.1015

Results are given on the log odds ratio (not the response) scale.


> emmeans(mod_Algae_Sits, pairwise ~ Event | Sites)
$emmeans
Location = EPL:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  0.8266 0.180 Inf     0.475    1.1786
  2023  1.5051 0.178 Inf     1.157    1.8533

Location = FAC3:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.3335 0.180 Inf    -0.686    0.0191
  2023  0.6779 0.180 Inf     0.326    1.0303

Location = FAC4:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  1.5298 0.178 Inf     1.182    1.8778
  2023  1.6720 0.177 Inf     1.325    2.0187

Location = GAT:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  0.7273 0.180 Inf     0.375    1.0795
  2023  1.3755 0.178 Inf     1.026    1.7248
```

```
Location = NPR:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  0.6659 0.180 Inf     0.313    1.0182
  2023  1.0093 0.179 Inf     0.658    1.3608

Location = PL:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018  0.6977 0.180 Inf     0.345    1.0500
  2023  0.9434 0.179 Inf     0.592    1.2951

Location = RUN1:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.9511 0.179 Inf    -1.303   -0.5994
  2023 -0.6266 0.180 Inf    -0.979   -0.2742

Location = RUN2:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.2643 0.180 Inf    -0.617    0.0883
  2023 -0.4337 0.180 Inf    -0.786   -0.0811

Location = RUN3:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.1028 0.180 Inf    -0.455    0.2498
  2023 -0.4898 0.180 Inf    -0.842   -0.1373

Location = SCR:
 Event  emmean    SE  df asymp.LCL asymp.UCL
  2018 -0.6119 0.180 Inf    -0.964   -0.2595
  2023 -0.0793 0.180 Inf    -0.432    0.2733

Results are given on the logit (not the response) scale.
Confidence level used: 0.95

$contrasts
Location = EPL:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.679 0.251 Inf  -2.708  0.0068

Location = FAC3:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -1.011 0.255 Inf  -3.970  0.0001

Location = FAC4:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.142 0.247 Inf  -0.576  0.5646

Location = GAT:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.648 0.251 Inf  -2.579  0.0099

Location = NPR:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.343 0.253 Inf  -1.359  0.1740

Location = PL:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.246 0.253 Inf  -0.972  0.3311

Location = RUN1:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.325 0.253 Inf  -1.283  0.1994

Location = RUN2:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.169 0.254 Inf   0.666  0.5053

Location = RUN3:
```

```
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023    0.387 0.254 Inf   1.522  0.1280

Location = SCR:
 contrast              estimate    SE  df z.ratio p.value
 Event2018 - Event2023   -0.533 0.254 Inf  -2.095  0.0362

Results are given on the log odds ratio (not the response) scale
```

Annex B SIMPER Results

Groups ***2018 EPL & 2023 EPL***
Average dissimilarity = 31.19

```
             Group 2018EPL   Group 2023EPL
Species      Av.Abund Av.Abund Av.Diss      Diss/SD Contrib%Cum.%
Sand         5.043.07           4.74           1.39     15.1915.19
Sargassum              6.61           7.96     3.16     1.38    10.13 25.32
Turbinaria             0.18           1.35     2.47     2.83     7.91 33.22
Turf algae             3.30           3.85     1.99     1.54     6.38 39.60
Dictyota               0.89           0.60     1.86     1.45     5.95 45.55
Padina                 0.00           0.84     1.76     1.46     5.63 51.18
Lobophora              2.48           1.81     1.69     1.54     5.42 56.60
Amphiroa               0.60           0.60     1.27     1.45     4.06 60.67
Sarcophyton            0.43           0.35     1.18     1.07     3.78 64.44
Sinularia              0.56           0.00     1.13     0.96     3.63 68.07
Favia                  0.00           0.48     1.03     0.90     3.32 71.39
Acropora               0.00           0.47     0.95     0.56     3.04 74.44
Hypnea                 0.00           0.43     0.88     0.94     2.82 77.25
Montipora              0.31           0.18     0.84     0.79     2.70 79.95
Pseudosiderastrea     0.35            0.00     0.72     0.56     2.32 82.27
Favites                0.35           0.00     0.72     0.97     2.31 84.58
CCA                    1.27           1.15     0.67     0.94     2.16 86.74
Other_Ma               0.31           0.00     0.67     0.56     2.15 88.89
Goniastrea             0.18           0.18     0.57     0.75     1.82 90.71
```

Groups ***2018 FAC3 & 2023 FAC3***
Average dissimilarity = 45.83

```
             Group 2018FAC3  Group 2023FAC3
Species            Av.Abund        Av.Abund Av.Diss Diss/SD  Contrib% Cum.%
Montipora              3.12            0.77    4.27    2.37      9.32  9.32
Acropora               5.49            3.92    3.74    1.46      8.16 17.48
Laurencia              0.00            1.50    2.72    7.51      5.93 23.41
Asparagopsis           0.00            1.46    2.59    1.75      5.64 29.05
Padina                 0.18            1.44    2.27    2.31      4.95 34.00
Favia                  1.56            1.73    2.21    1.51      4.83 38.83
Turf algae             6.37            7.57    2.18    1.40      4.76 43.59
Sargassum              0.00            1.04    1.93    1.50      4.22 47.81
Porites                1.29            0.40    1.93    2.03      4.21 52.02
Sand                   1.26            0.53    1.90    1.15      4.14 56.16
Lobophora              1.04            0.00    1.85    5.97      4.05 60.21
Sinularia              1.15            0.53    1.66    1.45      3.62 63.83
Alveopora              0.00            0.85    1.51    0.95      3.29 67.12
Cladiella              0.76            0.40    1.50    0.97      3.28 70.40
CCA                    1.09            0.61    1.44    2.01      3.13 73.53
Dictyota               0.18            0.91    1.29    1.91      2.82 76.35
Sponge                 0.35            0.86    1.23    1.56      2.69 79.04
Hypnea                 0.00            0.65    1.21    0.89      2.63 81.67
Platygyra              0.66            0.43    0.95    1.18      2.07 83.74
Turbinaria             0.35            0.53    0.94    1.08      2.05 85.79
Favites                0.50            0.43    0.90    1.10      1.96 87.75
Pocillopora            0.35            0.48    0.86    1.16      1.88 89.64
Hydnophora              0.35           0.00    0.66     0.96      1.43 91.07
```

Groups ***2018 FAC4 & 2023 FAC4***
Average dissimilarity = 40.54

```
             Group 2018FAC4  Group 2023FAC4
Species            Av.Abund        Av.Abund Av.Diss Diss/SD  Contrib% Cum.%
Lobophora              2.29            0.43    3.65    2.37      9.00  9.00
Padina                 0.00            1.73    3.36    2.63      8.30 17.30
Sargassum              5.39            7.00    3.08    1.29      7.61 24.91
```

```
Hypnea                  0.00           1.59    3.07     2.62     7.58 32.49
Sand                    2.01           1.06    2.89     1.66     7.12 39.61
Turf algae              6.94           5.51    2.78     2.08     6.86 46.47
Favia                   0.78           1.52    2.26     1.46     5.58 52.05
Other_Ma                0.91           0.00    1.78     3.84     4.38 56.43
Montipora               0.77           0.00    1.52     0.91     3.75 60.17
Turbinaria              0.18           0.82    1.43     1.27     3.53 63.70
CCA                     1.35           1.15    1.36     1.20     3.36 67.06
Other_invert            0.68           0.00    1.32     1.59     3.25 70.31
Porites                 0.73           0.25    1.27     1.33     3.12 73.43
Platygyra               0.25           0.47    1.20     0.77     2.96 76.39
Peyssonnelia            0.00           0.60    1.16     1.59     2.86 79.24
Sponge                  0.53           0.50    0.97     1.52     2.40 81.65
Lobophytum              0.31           0.35    0.96     0.77     2.38 84.02
Amphiroa                0.48           0.00    0.92     0.92     2.28 86.31
Dictyota                0.98           1.17    0.69     1.12     1.71 88.02
Sinularia               0.35           0.18    0.68     0.97     1.68 89.69
Acropora                0.00           0.31    0.64     0.56     1.57 91.26
```

Groups ***2018 GAT & 2023 GAT***
Average dissimilarity = 46.78

```
              Group 2018GAT Group 2023GAT
Species            Av.Abund      Av.Abund Av.Diss  Diss/SD Contrib% Cum.%
Sand                   4.56          1.34    5.92     2.96    12.66 12.66
Sargassum              4.70          7.25    4.95     1.67    10.59 23.25
Porites                2.18          0.00    3.98     2.40     8.51 31.75
Turf algae             6.22          4.65    2.97     1.58     6.36 38.11
Turbinaria             0.31          1.73    2.58     2.01     5.51 43.62
Montipora              0.72          1.49    2.37     1.34     5.07 48.69
Peyssonnelia           0.00          1.25    2.35     2.24     5.02 53.71
Lobophora              1.35          0.35    1.88     1.96     4.02 57.73
Padina                 0.00          0.91    1.61     1.60     3.43 61.17
Acanthastrea           0.00          0.86    1.45     0.86     3.10 64.27
Goniastrea             0.73          1.06    1.44     1.21     3.09 67.35
Sinularia              0.79          0.18    1.42     1.10     3.03 70.38
Platygyra              0.53          0.68    1.13     1.38     2.41 72.79
Sponge                 0.00          0.60    1.11     1.56     2.38 75.17
Favia                  0.00          0.65    1.10     0.94     2.36 77.53
Sarcophyton            0.78          0.56    1.05     1.85     2.25 79.78
Dictyota               0.53          0.25    0.95     1.60     2.02 81.80
Echinopora             0.00          0.48    0.93     0.92     1.99 83.79
Acropora               0.35          0.50    0.90     1.26     1.93 85.71
Lobophytum             0.48          0.00    0.87     0.89     1.86 87.57
Astreopora             0.00          0.48    0.82     0.93     1.76 89.33
CCA                    1.35          1.61    0.82     1.64     1.76 91.09
```

Groups ***2018 NPR & 2023 NPR***
Average dissimilarity = 43.29

```
              Group 2018NPR Group 2023NPR
Species            Av.Abund      Av.Abund Av.Diss  Diss/SD Contrib% Cum.%
Sargassum              5.84          6.94    2.80     1.37     6.47  6.47
CCA                    1.76          0.18    2.72     2.43     6.29 12.76
Padina                 0.00          1.39    2.39     3.25     5.53 18.29
Montipora              1.55          0.40    2.34     1.43     5.41 23.70
Favia                  0.84          1.74    2.18     1.64     5.04 28.74
Acropora               1.22          0.96    2.08     1.29     4.80 33.54
Porites                1.39          0.18    2.03     1.53     4.69 38.23
Lobophora              1.72          0.56    1.98     1.95     4.57 42.80
Turf algae             5.35          4.69    1.97     1.16     4.56 47.36
Turbinaria             0.18          1.23    1.89     1.09     4.37 51.73
Cladiella              0.00          1.03    1.71     0.96     3.95 55.68
```

```
Amphiroa              0.98           0.00    1.70    4.79      3.93 59.61
Sand                  2.73           2.40    1.63    2.40      3.76 63.37
Acanthastrea          0.00           0.85    1.47    6.81      3.40 66.77
Sinularia             1.47           0.79    1.45    1.31      3.35 70.12
Favites               0.88           0.35    1.45    1.32      3.35 73.46
Dictyota              0.40           0.73    1.31    1.51      3.04 76.50
Sarcophyton           0.79           0.18    1.30    0.85      3.00 79.50
Goniastrea            0.43           0.85    1.21    1.12      2.79 82.29
Pocillopora           0.00           0.68    1.14    1.61      2.63 84.93
Sponge                0.61           0.43    1.04    1.21      2.41 87.34
Lobophytum            0.43           0.00    0.75    0.95      1.74 89.08
Symphyllia            0.35           0.00    0.60    0.96      1.39 90.47
```

Groups ***2018 PL & 2023 PL***
Average dissimilarity = 42.95

```
                  Group 2018PL  Group 2023PL
Species               Av.Abund      Av.Abund  Av.Diss  Diss/SD  Contrib%  Cum.%
Lobophora                 2.84          0.35     4.04     4.32      9.40   9.40
Turbinaria                0.00          1.96     3.20     2.77      7.44  16.84
Sand                      2.42          1.83     2.77     1.51      6.45  23.30
Sargassum                 4.84          6.39     2.58     1.30      6.00  29.30
Padina                    0.53          1.92     2.24     2.67      5.23  34.52
Porites                   1.58          0.25     2.14     2.00      4.99  39.51
Turf algae                5.99          4.96     1.93     1.12      4.49  44.00
Montipora                 1.36          1.34     1.89     1.44      4.40  48.40
Acropora                  0.93          1.61     1.74     1.57      4.06  52.46
Favia                     2.30          2.15     1.68     1.86      3.90  56.37
Hypnea                    0.00          1.01     1.63     3.36      3.79  60.15
Pocillopora               0.35          1.03     1.56     1.33      3.64  63.79
Sinularia                 1.00          0.25     1.33     1.80      3.10  66.89
Amphiroa                  1.18          0.35     1.32     1.63      3.07  69.96
Dictyota                  0.18          0.86     1.25     1.23      2.92  72.88
Sarcophyton               0.73          0.00     1.18     1.52      2.74  75.62
Montastraea               0.18          0.59     1.07     0.72      2.48  78.11
Platygyra                 0.43          0.78     0.99     1.22      2.30  80.40
Favites                   0.61          0.53     0.98     1.25      2.28  82.68
CCA                       1.10          0.68     0.93     1.01      2.16  84.84
Cladiella                 0.00          0.53     0.86     1.67      2.01  86.85
Pseudosiderastrea         0.48          0.00     0.78     0.91      1.82  88.67
Sponge                    0.18          0.48     0.77     0.99      1.79  90.46
```

Groups ***2018 RUN1 & 2023 RUN1***
Average dissimilarity = 39.35

```
             Group 2018RUN1  Group 2023RUN1
Species            Av.Abund        Av.Abund  Av.Diss  Diss/SD  Contrib%  Cum.%
Porites                3.28            0.00     7.11     4.63     18.06  18.06
Goniastrea             1.58            0.00     3.44     3.01      8.73  26.79
Acropora               6.41            7.00     2.88     1.26      7.31  34.10
Turf algae             5.20            5.78     2.77     1.41      7.04  41.14
Pocillopora            1.34            1.32     2.05     1.20      5.21  46.35
Sponge                 0.68            0.48     2.00     0.97      5.08  51.43
Sand                   0.88            0.25     1.95     1.04      4.94  56.37
Montipora              2.25            2.39     1.93     1.39      4.92  61.28
Sinularia              0.84            0.00     1.78     1.50      4.54  65.82
Acanthastrea           0.00            0.68     1.41     0.56      3.57  69.39
Hydnophora             0.18            0.53     1.29     0.74      3.29  72.68
Platygyra              0.00            0.50     1.14     0.56      2.89  75.57
Astreopora             0.40            0.00     0.84     0.56      2.15  77.72
Cladiella              0.18            0.31     0.83     0.78      2.10  79.82
```

```
Dictyota                0.00           0.35     0.80     0.97       2.03  81.85
Hypnea                  0.00           0.35     0.76     0.97       1.93  83.78
Favites                 0.35           0.00     0.73     0.56       1.87  85.65
Sarcophyton             0.25           0.18     0.73     0.80       1.85  87.50
Ascidian                0.31           0.00     0.64     0.56       1.62  89.12
Palythoa              0.00              0.31        0.63        0.56            1.60
      90.71
```

Groups 2018 RUN2 & 2023 RUN2
Average dissimilarity = 40.13

```
            Group 2018RUN2  Group 2023RUN2
Species           Av.Abund        Av.Abund  Av.Diss  Diss/SD  Contrib%  Cum.%
Acropora              3.44            5.07     3.81     1.50      9.48   9.48
Porites               2.43            0.60     2.96     2.06      7.38  16.86
Cladiella             0.00            1.55     2.45     1.49      6.12  22.98
Dictyota              0.18            1.63     2.34     2.69      5.84  28.82
Sponge                1.17            0.35     1.87     1.25      4.67  33.49
Sarcophyton           1.73            2.49     1.83     1.36      4.55  38.04
Sand                  1.27            0.68     1.77     1.37      4.41  42.45
Platygyra             1.05            1.00     1.70     2.31      4.23  46.68
Favites               1.44            0.74     1.55     1.48      3.87  50.55
Turf algae            6.63            5.83     1.46     1.55      3.63  54.18
Montipora             2.12            2.26     1.45     1.41      3.60  57.78
Montastraea           0.00            0.86     1.43     0.85      3.56  61.34
Sinularia             1.36            1.92     1.41     1.08      3.51  64.85
Alveopora             0.00            0.92     1.41     0.56      3.51  68.36
Hydnophora            0.53            0.61     1.39     1.03      3.47  71.83
Favia                 0.79            0.53     1.28     1.19      3.19  75.02
Goniopora             0.78            0.25     1.12     1.32      2.79  77.82
Goniastrea            1.32            1.12     1.09     1.17      2.71  80.52
Turbinaria            0.61            0.43     0.99     1.21      2.46  82.98
Lobophora             0.56            0.00     0.92     0.96      2.28  85.26
Lobophytum            1.35            0.98     0.89     1.16      2.22  87.48
Padina                0.31            0.35     0.78     1.11      1.94  89.42
Stylophora          0.48             0.00     0.76     0.91       1.89  91.31
```

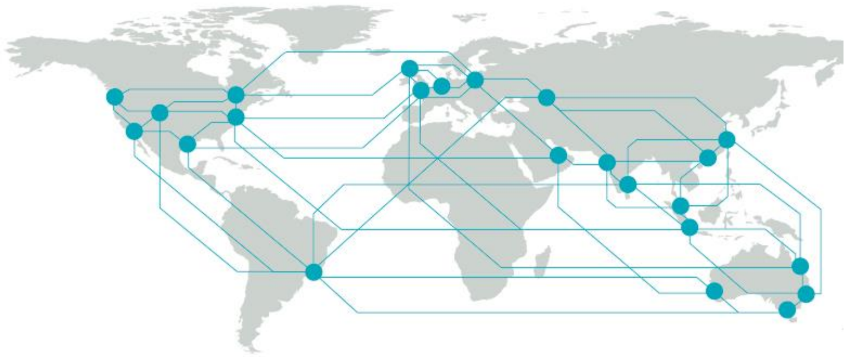
*Groups **2018 RUN3 & 2023 RUN3***
Average dissimilarity = 42.21

```
            Group 2018RUN3  Group 2023RUN3
Species           Av.Abund        Av.Abund  Av.Diss  Diss/SD  Contrib%  Cum.%
Acropora              5.26            6.80     7.42     1.48     17.58  17.58
Turf algae            7.11            5.07     6.68     1.34     15.83  33.41
Montipora             1.00            2.31     4.18     1.16      9.91  43.32
Padina                0.00            1.55     3.63     1.35      8.59  51.91
Porites               1.41            0.00     3.39     1.22      8.04  59.95
Sand                  0.89            1.29     2.86     1.62      6.78  66.73
Lobophora             1.00            1.59     2.72     1.46      6.45  73.17
Dictyota              0.00            1.00     2.45     2.81      5.80  78.98
Pocillopora           0.25            0.68     1.88     0.75      4.46  83.44
Stylophora            0.57            0.00     1.38     0.84      3.27  86.70
Fungia                0.66            0.48     1.36     1.20      3.23  89.94
Cladiella             0.00            0.56     1.35     0.56      3.21  93.14
```

*Groups **2018 SCR & 2023 SCR***
Average dissimilarity = 40.49

```
            Group 2018SCR  Group 2023SCR
Species          Av.Abund       Av.Abund  Av.Diss  Diss/SD  Contrib%  Cum.%
```

```
Padina               0.00          1.67    3.54    3.37     8.73  8.73
Acropora             6.53          6.40    3.24    1.52     8.01 16.74
Cladiella            0.00          1.52    3.23    3.45     7.98 24.72
Sand                 1.31          0.66    3.13    0.91     7.73 32.45
Turf algae           5.92          6.08    3.07    1.45     7.58 40.03
Montipora            2.08          1.65    2.32    1.35     5.72 45.75
Sarcophyton          0.88          0.59    2.19    1.28     5.40 51.15
Pocillopora          1.06          1.39    2.18    1.49     5.39 56.55
Goniastrea           0.96          0.00    1.97    1.64     4.87 61.42
Porites              0.91          0.00    1.96    3.31     4.83 66.25
Goniopora            0.75          0.00    1.53    1.37     3.78 70.03
CCA                  0.85          0.18    1.45    1.90     3.57 73.60
Sinularia            0.48          0.40    1.37    1.06     3.38 76.98
Hydnophora           0.00          0.56    1.18    0.56     2.92 79.89
Sponge               0.48          0.25    1.11    1.00     2.74 82.63
Hypnea               0.00          0.50    1.07    0.96     2.64 85.27
Favites              0.43          0.18    0.91    0.99     2.24 87.51
Lobophora            0.35          0.00    0.76    0.97     1.89 89.40
Halimeda             0.00          0.31    0.65    0.56     1.60 91.00
```



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