Tweed Sand Bypassing Project

Reef Biota Monitoring 2021

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Executive Summary

The Tweed Sand Bypassing (TSB) project is a joint initiative of the New South Wales and Queensland State Governments, with the objectives to establish and maintain the entrance to the Tweed River, and to restore and maintain the coastal sand drift to the Southern Gold Coast. This report has been prepared by Ecological Service Professionals (ESP) to meet the environmental obligations of the TSB project to assess ecological changes in reef habitat, including changes in the composition, coverage, and diversity of benthic faunal and floral communities at Kirra and Cook Island reefs due to the TSB operations.

Changes in the extent of Kirra Reef were assessed using bathymetric survey data as well as aerial and satellite imagery, including a comparison of the historical changes in the areal extent. Field surveys were completed to assess differences in benthic communities (algae, sessile invertebrates and mobile invertebrates) and fish assemblages among reefs. Six reef locations were surveyed in May 2021: Kirra Reef (previously impacted reef); Cook Island West and South Reefs (potentially impacted reef); and Cook Island North Reef, Palm Beach Bait Reef, and Palm Beach Reef (comparative reefs). Differences in the composition of benthic communities among reefs were assessed over time using available historical data for the past six years.

Previous estimates of the areal extent of Kirra Reef indicate there have been substantial changes in area through time. The maximum extent of Kirra Reef was measured in 1995 (40,813 m^2), with the area declining following the commencement of the TSB project (as was predicted in the Project Environmental Impact Assessment) to be completely buried in 2007 and 2008, then uncovered and increasing in extent again from 2009 (1,009 m^2) onwards. There are three distinct reef areas at Kirra Reef, a shallow inner western reef, a shallow eastern reef near the Kirra groyne, and a northern reef in deeper water. In recent years, generally only the northern section located in deeper waters has been uncovered, with the eastern section also uncovered at times. In May 2021, the total areal extent of Kirra Reef was 4,930 m^2, inclusive of a recently exhumed section of eastern reef measuring 808 m^2. While this most recent estimate of the extent of Kirra Reef is the largest recorded since exhumation from complete burial in 2009, it is not substantially different to the relatively stable reef area that has been observed since 2012. Sand around Kirra Reef shifted between bathymetric surveys completed in 2020 and 2021, with depth increasing on the western side of the northern section of Kirra Reef. Depth also increased around the eastern section of Kirra Reef, which is consistent with the small increase in aerial extent measured in that area. The inner western and eastern sections of Kirra Reef have a low profile (or relief) and are naturally subject to increased frequency of disturbance, including sand burial. The combination of a low profile, and high frequency of physical disturbance associated with being in shallow water, close to the shoreline, is likely to limit the development of a diversity community of reef dwelling organisms on these reef sections.

In the past 6 years (since 2016), the composition of benthic communities on all reefs assessed has differed over time, which demonstrates the potential interannual variation. Differences in the composition of benthic communities also occurred among sites on each reef and among reefs in 2021. There continues to be a diverse benthic community on Kirra Reef dominated by macroalgae, although the coverage of longer-lived hard coral species recorded on the reefs around Cook Island, were limited on Kirra Reef. Benthic communities

around Cook Island differ in composition, including reefs separated by only a few hundred metres, indicating a diverse array of communities around the island and more generally in the region. Small-scale spatial variation among locations may be also be related to different physical conditions (e.g. nutrient availability and wave energy), disturbance regimes and ecological interactions around the island. These variations highlight the importance of sampling numerous comparative locations that are representative of the variety of reef habitats to provide confidence in attributing any changes detected to the TSB operations.

The algal assemblages on reefs were dominated by turf forming algae in May 2021, with other groups, such as foliose macroalgae (e.g. *Sargassum* spp. *Dictyota* sp. and *Padina* sp.), crustose coralline algae and articulate coralline algae (e.g. *Jania* sp.) also present. The algal assemblage on Cook Island reefs, typically had a high average coverage of turf forming species and coralline algae. The coverage of turf forming algae on Kirra Reef was lower than at the other reefs. However, the coverage of foliose macroalgae (dominated by *Sargassum* spp.), was higher at Kirra Reef. Differences in the composition of algal assemblages are likely the result of variation in physical conditions among sites and reef locations (e.g. depth and exposure to wave energy), the timing and magnitude of physical disturbance, availability of spores at the time of disturbance or exhumation, and other more complex ecological interactions with herbivorous species, which are likely to differ among the reefs.

In May 2021, the sessile invertebrate assemblages on Kirra Reef were more similar in diversity both in terms of the overall coverage and average number of species present, than in the previous 2020 survey, and most similar in composition to the other nearshore reefs at Palm Beach. Ascidians and sponges remained the dominant sessile invertebrates on Kirra Reef. There was a lack of hard coral species on Kirra Reef in May 2021 (which have consistently been absent or covered a small area on the reef), and a small decline in the coverage of soft corals relative to 2020. Low coverage of hard and soft corals at Kirra Reef may be related to ongoing physical factors (e.g. wave energy and sand scouring due to the position of the reef), but is also likely to be related to the relatively recent disturbance history (i.e. Kirra Reef was completely buried in 2007 and 2008) and the prolonged period of time required for coral communities to become established. Cook Island reefs generally had a high cover of long-lived hard corals (such as those from the genus *Paragoniastrea, Turbinaria* and encrusting *Porites*) compared with other reefs in the region, with the highest coverage recorded on horizontal surfaces at Cook Island North and Cook Island South.

A variety of echinoderms dominated the mobile invertebrates observed on the reefs in May 2021, with feather stars (particularly *Cenolia* spp.) having the highest density on Kirra Reef. Several sea star, urchin, and sea cucumber species were also present at some reefs in lower densities.

A total of 129 bony and cartilaginous fish species from 44 families were recorded across all reefs in May 2021. Most fish species recorded were common to the region; however, 22 species were observed among the reefs that had not been recorded in previous surveys, potentially relating to the timing of surveys. The fish assemblage at Kirra Reef was not significantly different to any of the other reefs in 2021. In contrast the fish assemblage at Cook Island South, differed from the other reefs primarily due to the absence of yellowtail scad. The highest abundance of fish was recorded at Kirra Reef due to dense schools of yellowtail scad. However, the average species richness was comparable to all other reefs except for Cook Island South, which was lower than at Kirra Reef. The fish assemblage at

Kirra Reef was dominated by reef-associated, carnivorous fish species, with omnivores being the second most diverse group.

The benthic communities around Cook Island were in good condition with a diverse assemblage of sessile invertebrates, including abundant hard and soft corals, and a diverse fish assemblage representative of reef communities in the region. Despite remaining dissimilar, the benthic communities at Kirra Reef are considered to be representative of a mature assemblage of both algae and sessile invertebrates. This reflects the ecology of the reef community, which is comparable to that found on other reefs with similar exposure and depth characteristics (i.e. Palm Beach and Palm Beach Bait reefs). The benthic community occurring on Kirra Reef should be considered unique to the region, with the differences among reefs, including between other comparative reef locations, providing an understanding of the natural variability over a range of spatial scales within the region. Understanding the natural variability among reefs not exposed to disturbance from TSB is essential when assessing changes in these communities due to sand burial and other factors of disturbance. At Kirra Reef, the differences in the composition of reef communities reflect the subtle differences in ecological and abiotic conditions (particularly recruitment, nutrient availability, wave climate and local sand dispersal), as well as potential differences in anthropogenic pressures (e.g. recreational fishing) among reefs.

Recommendations

The TSB monitoring program has provided evidence of the recovery in reef communities through time in response to almost complete burial of Kirra Reef in 2007 and 2008. Since becoming uncovered, there has generally been an increase in the coverage and diversity of algal and sessile invertebrate assemblages growing on the reef and an increase in the diversity of the fish assemblage indicative of the variety of ecological niches available on Kirra Reef. Unless there is a substantial change in the sand delivery planned to manage coastal erosion due to storm and wave activity, annual ecological monitoring of Kirra Reef is likely to only provide an understanding of the processes contributing to community succession over the coming years. It is therefore recommended that monitoring of the response in benthic communities is completed before and after any planned changes to the program, such as the development of thresholds for changes in the monthly or annual volume of sand delivered. The environmental monitoring components could also be reviewed to better reflect a leading indicator of potential changes to the environment, such as hydrographic surveys and a comparison of the change in bottom depth year to year allowing for a degree of natural variability due to normal wave action and long-shore sand transport. An event or trigger-based monitoring program with the proposed triggers including operational changes in TSB (relative to those between 2012 and 2021), and/or indicators directly related to sand deposition such as sedimentation above a set threshold (as measured using hydrographic survey) or a substantial change in the accretion / erosion of sand around the reef measured through changes in reef area from aerial photos or hydrographic survey would be suitable for future ecological assessments.

To assess potential impacts at Cook Island reef due to sand placement activities, ongoing monitoring at both Cook Island and nearby comparative locations is recommended during and after planned disposal activities. It is recommended that the monitoring program focus on key indicator species that are known to be impacted by sedimentation changes in the coverage of hard and soft corals, ascidians and seagrass. Seagrass has only been recorded at one area around Cook Island, therefore good baseline data on the extent and condition of seagrass over time will provide a baseline against which direct impact can be measured, as suitable comparative areas may be difficult to identify. Monitoring the impacts of sand deposition including a direct measure of sedimentation at comparative areas adjacent to sensitive ecological receptor communities (i.e. coral reefs and seagrass areas that could be smothered) would provide a leading indicator of the potential for any negative impact and could also be used as a trigger for additional assessment of the reef communities, where background sedimentation is exceeded.

1 Introduction

1.1 Background

The Tweed Sand Bypassing (TSB) project is a joint initiative of the New South Wales and Queensland State Governments, with the objectives to establish and maintain the entrance to the Tweed River, and to restore and maintain coastal sand drift to the Southern Gold Coast beaches.

As part of the TSB, the fixed sand bypass system commenced operation in 2001 and comprises a sand collection jetty on the southern side of the Tweed River entrance at Letitia Spit. Sand is pumped under the river through a series of buried pipelines to four outlets on the northern side of the River (Figure 1.1). The majority of sand collected is delivered to Snapper Rocks East, but discharge outlets have also been established at Duranbah Beach, Snapper Rocks West and Kirra Point to allow for flexibility in sand delivery. Sand discharged from the outlets is predominantly transported northwards by waves and currents to nourish southern Gold Coast beaches. Supplementary dredging to clear the Tweed River entrance is also commissioned by TSB when required. Dredging is generally carried out using a trailer suction hopper dredge, which typically removes 50,000 to 200,000 m^3 of sand per dredge event.

During a period (2001 to 2008) of Supplementary Increment, quantities of sand greater than the natural littoral drift were transported via the fixed sand bypass system and dredging to replenish eroded beaches. Since 2009, the system has been transporting quantities closer to the natural movement of sand northwards along the coast (i.e. 500,000 m^3 per year).

Figure 1.1 Fixed sand bypassing system (TSB, 2021)

Kirra Reef is a rocky reef outcrop, located approximately 500 m offshore of Kirra Beach on the Southern Gold Coast. The nearshore location of the reef makes it subject to naturally shifting sand movements that cover and expose parts of the reef, and makes the reef susceptible to physical disturbance from sand scour, storms and wave action. The extent of reef exposed at Kirra Reef has also varied due to anthropogenic changes to the coastal environment, including an increase in areal extent following extension of the Tweed River training walls (in 1965) and almost complete burial by sand following the period of Supplementary Increment by TSB (in 2007 and 2008). Indeed, a reduction in the exposed extent of Kirra Reef as a consequence of the recovery of the offshore bathymetry of Kirra Beach was predicted the Environmental Impact Statement / Impact Assessment Study (EIS / IAS) (Hyder Consulting et al. 1997). Since 2009, Kirra Reef has been partly uncovered and the extent of reef exposed has been relatively stable since 2012 (Ecosure 2016; frc environmental 2019; ESP 2020). The TSB operates under several environmental and planning approvals covering different project elements. As part of approval requirements from the EIS / IAS (Hyder Consulting et al. 1997; DoE 1998), ongoing monitoring of the marine biota at Kirra Reef has been completed for over 20 years. Most recently the monitoring has been completed as part of the Environmental Management System (EMS) Operations Sub-Plan B.14 Kirra Reef Management Plan (Revision 2; TRESBP 2010), which is currently under review.

When dredging occurs, the dredge deposits sand in approved placement areas along the Tweed Coast and Southern Gold Coast (Figure 1.2). In 2019, additional placement areas at Fingal and Dreamtime were approved to provide greater flexibility in the operations. Sand was placed at Fingal in 2019 and 2020 but no sand has been placed at Dreamtime to date. Sand placed in these areas (annual placement of less than 50,000 m^3 across both areas) is predicted to move predominantly in a northerly direction. Any sand placed at Dreamtime (up to 20,000 m^3) is likely to move with the natural transport pathway around Fingal Head to the west of Cook Island in water depths less than 4 m (Jacobs 2017). The movement of sand around the headland is expected to occur during suitable conditions in episodic ‘slugs’ or sand waves of relatively large quantities of sand over a short period of time (Jacobs 2017). The Review of Environmental Factors (REF) for the back-passing placement areas (Fingal and Dreamtime) specified a monitoring program was required to detect any impacts to reef habitat within potential impact areas of Fingal Head and Cook Island Aquatic Reserve, inclusive of a mix of biotic and abiotic variables and collection of sufficient baselines dataset to account for temporal variability (APP 2019).

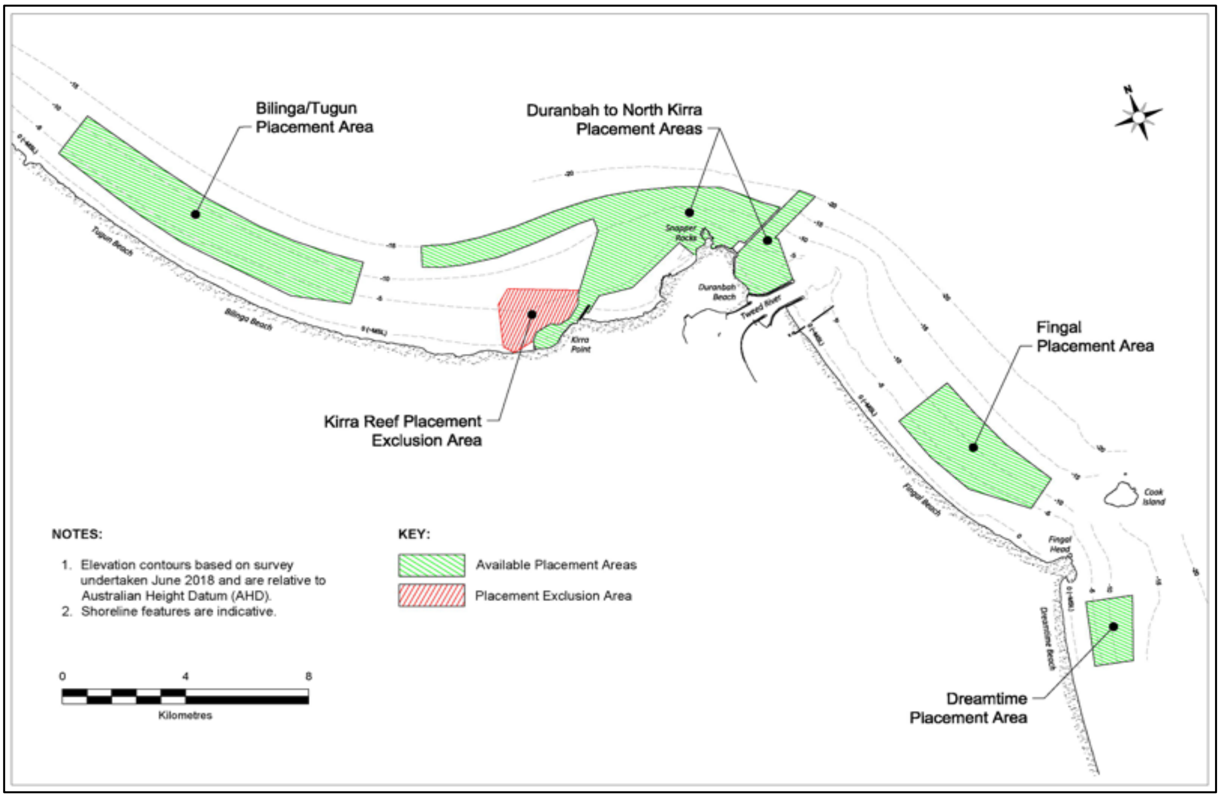

Figure 1.2 Current approved placement areas for disposing dredged sand (TSB, 2021)

1.2 Scope of Works

The overall objective of the reef biota monitoring program in 2021 was to investigate changes in reef habitat, including changes in the composition, coverage, and diversity of benthic faunal and floral communities at Kirra and Cook Island reefs due to the TSB operations.

2 Methods

2.1 Reef Extent

2.1.1 Aerial Imagery

Image analysis of the current areal extent of exposed reef at Kirra Reef was completed using imagery obtained from the Queensland Government 2021b for June 2021 in ESRI ArcGIS and compared with previous assessments of reef area obtained from past assessments. The total areal area exposed was calculated in square metres (m^2).

2.1.2 Bathymetric Surveys

Annual bathymetric survey data for Kirra Reef was obtained by TSB for 2020 and 2021. The depth and coordinate data were converted to the same datum (GDA2020) prior to converting to a digital elevation model in ESRI ArcGIS using interpolation among the point cloud. The Kriging method was used by averaging among the nearest 12 points. Differences in the depth of subsequent digital elevation models for each year were then subtracted to assess the increase or decrease in depth around Kirra Reef. The digital elevation models and change in depth were then mapped relative to the 2020 and 2021 reef extent.

2.2 Field Survey

2.2.1 Reef Locations

Six reef locations were surveyed in 2021 (Figure 2.1) based on a review of reefs previously surveyed (ESP 2020), including:

- Kirra Reef (KR) – previously impacted (Figure 2.2)
- Cook Island West Reef (CIW) and Cook Island South Reef (CIS) – potentially impacted (Figure 2.3), and
- Cook Island North Reef (CIN), Palm Beach Bait Reef (PBBR) and Palm Beach Reef (PB) – comparative (Figure 2.3 & Figure 2.4).

Ideally the comparative reefs would be standardised for reef depth and distance from the shore so that they are exposed to relatively similar physical disturbance vectors; however, there are limited reefs along the coast that experience conditions similar to Kirra Reef. Therefore, the reefs selected provide a broad range of ambient environmental conditions occurring on reefs in the southern Gold Coast.

2.2.2 Timing

The reefs were surveyed over three days between the 17 – 19 May 2021. This aligned with previous surveys, which have historically occurred between April and July. Sea conditions were favourable with low to moderate swell (0.5–2 m) and southwest to south-easterly winds (12–15 knots). Water clarity was good (approximately 6–8 m).

Figure 2.1 Reef locations for Biota Monitoring in 2021

2.2.3 Benthic Communities

Benthic communities (including algal, sessile invertebrate and conspicuous mobile invertebrate assemblages) were quantified at each reef location using 15 photo quadrats each separated by at least 1 metre and taken from both horizontal and vertical surfaces along three 25 m long transects (i.e. a total of 45 horizontal quadrats and 45 vertical quadrats were collected at each reef location). The position of the start and end points of each transect were recorded using a handheld GPS (accuracy ± 4 m) attached to a surface buoy led by SCUBA divers (Table 2.1; Figure 2.2 to Figure 2.4). Photo quadrats were taken using a pole camera to maintain consistent depth above the bottom. In-situ remotely operated underwater vehicle (ROV) searches were also complete to targeting taxonomic identification, as well as cryptic, invasive and threatened species were completed at Kirra Reef and Cook Island West reef (Figure 2.5a).

Table 2.1 Location of transects (sites) at each reef location

Reef Location	Transect (Sites)	Transect Start *		Transect End *	
		Easting	Northing	Easting	Northing
Kirra Reef (KR)	KRN1	552092.0	6884632.0	552103.0	6884662.0
	KRN2	552126.5	6884662.5	552114.2	6884684.0
	KRN3	552156.5	6884677.8	552147.5	6884706.2
Palm Beach Reef (PB)	PB1	546824.7	6890769.6	546801.5	6890783.1
	PB2	546821.4	6890786.4	546807.6	6890815.9
	PB3	546839.8	6890770.0	546822.6	6890778.5
Palm Beach Bait Reef (PBBR)	PBB1	546660.6	6890130.9	546665.6	6890113.4
	PBB2	546669.0	6890103.6	546673.1	6890076.3
	PBB3	546667.6	6890129.4	546675.3	6890094.9
Cook Island North Reef (CIN)	CIN1	556636.0	6881188.7	556654.6	6881205.5
	CIN2	556613.8	6881172.3	556595.5	6881156.8
	CIN3	556588.5	6881142.1	556568.7	6881124.3
Cook Island South Reef (CIS)	CIS1	556584.3	6880905.3	556556.7	6880899.6
	CIS2	556629.2	6880889.9	556606.0	6880900.7
	CIS3	556637.7	6880880.5	556657.6	6880858.2
Cook Island West Reef (CIW)	CIW1	556495.6	6881041.2	556515.5	6881057.7
	CIW2	556486.2	6881041.1	556461.5	6881033.1
	CIW3	556453.4	6881026.9	556426.1	6881017.0

*Datum: GDA2020 UTM Zone 56J

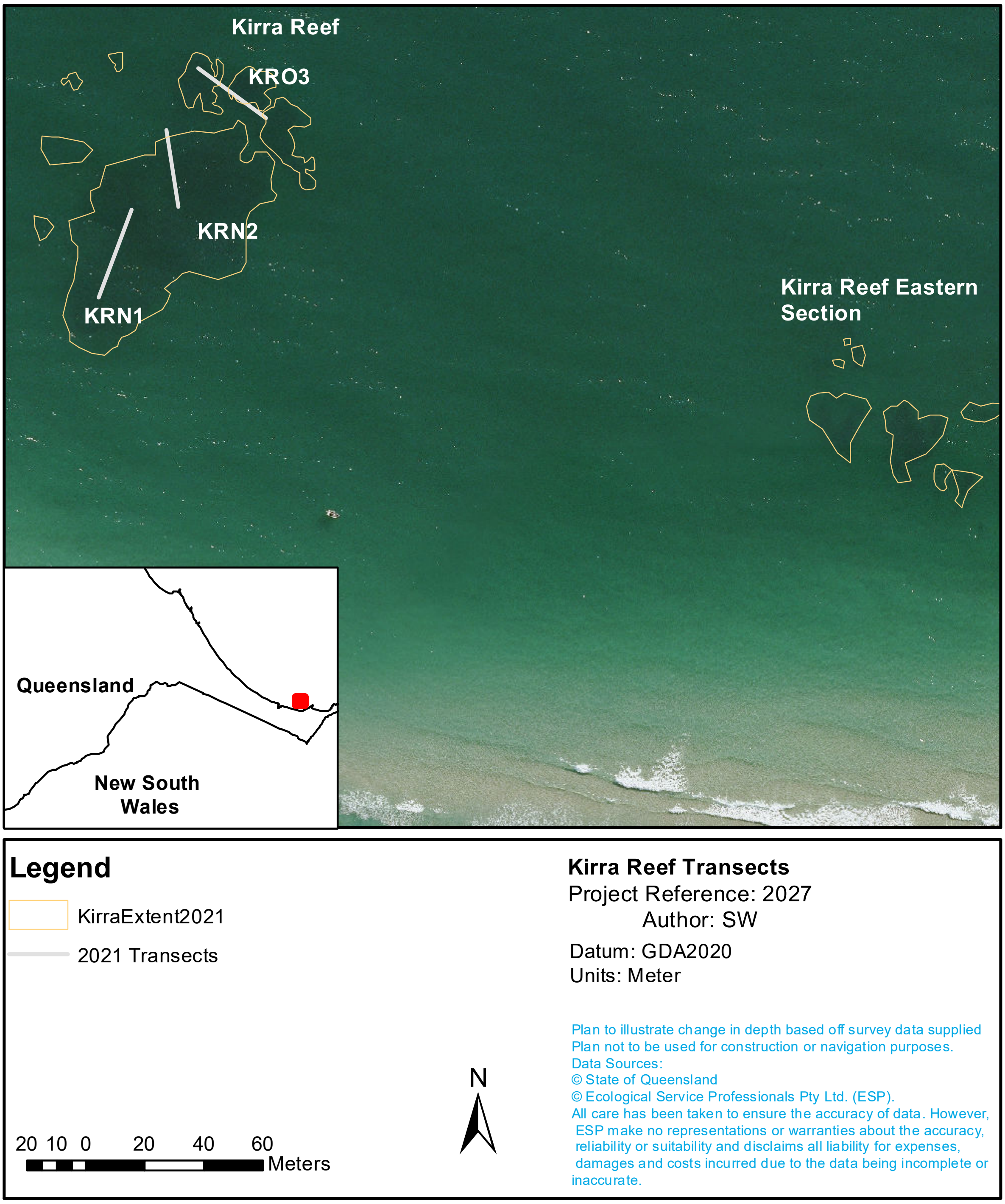

Figure 2.2 Location of transects surveyed in 2021 at Kirra Reef

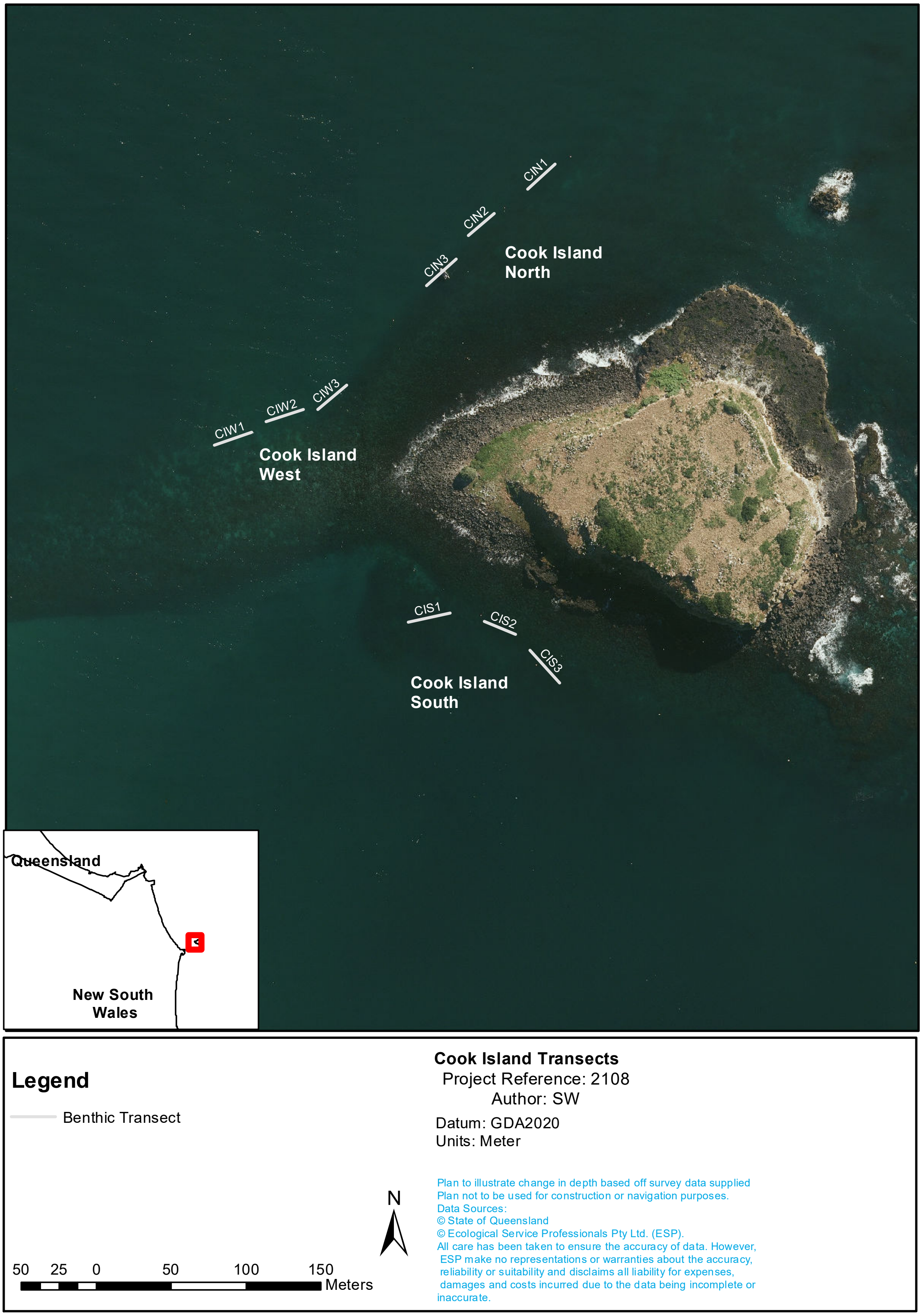

Figure 2.3 Location of transects surveyed in 2021 at the three reef locations around Cook Island

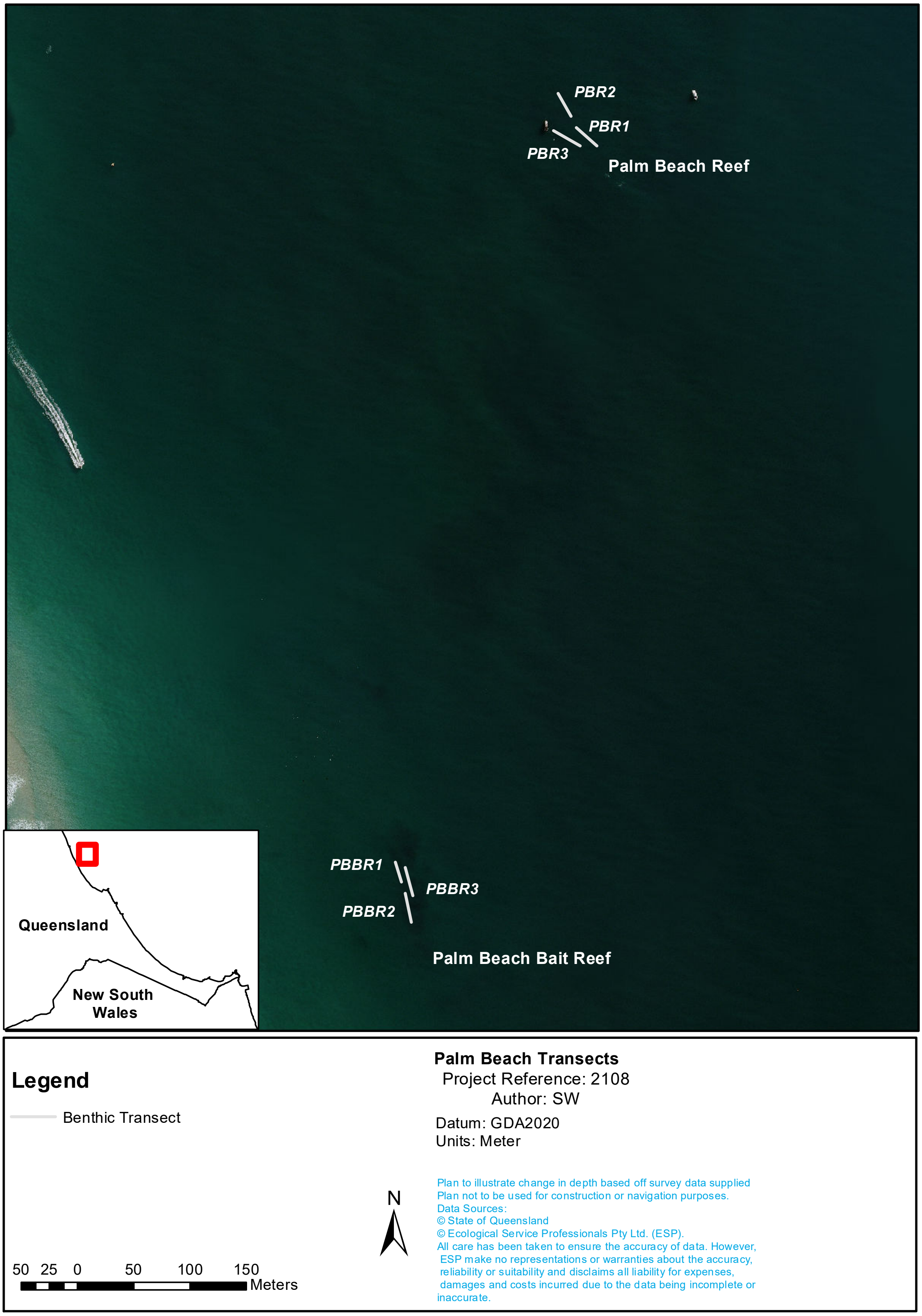

Figure 2.4 Location of transects surveyed in 2021 at Palm Beach Reef and Palm Beach Bait Reef

2.2.3.1 Data Management and Analysis

Processing of photo-quadrats was completed using standard image processing techniques (Kohler & Gill 2006; Walker et al. 2007) to determine composition and coverage of benthic communities (algal and sessile invertebrate assemblages). Up to 50 stratified random points were overlayed on each of the photo-quadrats based on standard approaches modified where appropriate and using Coral Point Count (CPCe) software (Kohler & Gill 2006), adapted where required to characterise the composition of benthic temperate rocky and artificial reefs in region (Schlacher-Hoenlinger et al. 2009; Walker et al. 2007; Walker and Schlacher 2014). The benthic communities (including hard and soft corals, hydrozoans, zoanthids, sponges, ascidians, bryozoans, bivalves, barnacles, macroalgae, turf forming algae and coralline algae) were identified to lowest taxonomic level possible (sites and taxa were aggregated to a taxonomic resolution comparable to previous monitoring to allow temporal comparisons among previous surveys). Voucher specimens were used to identify sessile species present where required (e.g. many species of sponges in Australia remain undescribed and are commonly identified to Operational Taxonomic Units or morphospecies; Walker et al. 2008).

In 2021, differences in the composition and coverage of benthic communities and assemblages (i.e. algal and sessile invertebrates) among reef locations were compared using a three factor permutational multivariate analysis of variance (PERMANOVA[1]; Anderson 2001) on untransformed data, with orientation (vertical surface and horizontal surface) and reef location (Cook Island South, Cook Island North, Cook Island West, Kirra Reef, Palm Beach Reef & Palm Beach Bait Reef) as fixed factors, and site (transects nested in reef location) included as a random factor. Differences between vertical and horizonal surfaces within each reef location were assessed specifically in the first instance, as a potential impact to horizontal but not vertical surfaces provides a direct test of the potential impacts of smothering at each reef. It was expected that if there was a substantial impact of smothering that the magnitude of any impact would be greater on horizontal than vertical surfaces at Kirra Reef relative to comparative reefs. The degree of multivariate dispersion was assessed using the PERMDISP[2] routine to determine the degree of within and between site variation (Anderson 2001). Taxonomic groups contributing to the differences among sites and locations were identified using the SIMilarity PERcentages (SIMPER) routine[3] (Clarke & Warwick 1994). Spatial differences in the composition of the benthic assemblages were

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[1] Permutational Multivariate Analysis of Variance (PERMANOVA) is used to test the response of one of more variables to a priori derived structured factors, using a random permutation of the existing data to test significance. This non-parametric test of significance is similar to the generalised linear models completed using ANOVA; however, allows for the testing of significance without the need to meet a strict set of assumptions required in ANOVA.
[2] The Permutational Dispersion (PERMDISP) routine allows for an assessment of the degree of multivariate dispersion among different factors relative to a centroid or median value. This is similar to tests for homogeneity of variance used in parametric tests. Where there is significant differences in the dispersion of data, caution in interpretation of significance in PERMANOVA results should be used.
[3] The SIMilarity PERcentages (SIMPER) routine allows for a test of the rank order contribution of the variables to the measure of dissimilarity between pairs of groups being assessed. Therefore it can allow for an assessment of the magnitude at which different taxa contribute to the differences between pairwise groups of interest.

visualised using non-metric multidimensional scaling (nMDS[4]) ordinations (Clarke & Warwick 1994).

A range of biodiversity indices such as taxonomic richness, abundance (% cover for sessile organisms and density for mobile species) were calculated, where appropriate. Differences in the diversity of benthic communities and dominant species were assessed among reefs using PERMANOVA; however, data were converted to a Euclidean distance matrix prior to analyses to account for the univariate nature of each index. The mean taxonomic richness and coverage (± standard error (SE)) for each variable were graphed.

To compare differences among reef locations (location) over the previous six years (between 2016 and 2021), the data for benthic assemblages on vertical and horizontal surfaces were aggregated to an appropriate taxonomic level to match previous assessments (usually basic benthic cover categories such as hard corals, ascidians, sponges, coralline algae and macroalgae). Spatial and temporal differences were then assessed with a 2-factor PERMANOVA based on untransformed data, with survey year and location as the fixed factors. Differences in the composition of the benthic assemblages among locations through time were visualised using non-metric multidimensional scaling ordinations. Sites were aggregated within each reef locations as there was no differentiation provided for sites within reefs in 2018 and 2019.

Conspicuous mobile invertebrates (> 50 mm) were quantified from photo quadrats collected along georeferenced transects (refer to Section 2.2.3). In addition, taxa observed using other survey methods (for fish communities; refer to Section 2.2.4) were also recorded to compile a species inventory for each reef. The abundance and type of large benthic invertebrates, including echinoderms (e.g. urchins, sea stars, holothurians), crustaceans (e.g crabs, stomatopods and lobsters), and molluscs (e.g. octopus, clams, oysters and nudibranchs) were recorded. The density of conspicuous mobile invertebrates was compiled from photo quadrat data and compared among reefs.

2.2.4 Fish Communities

The established method of analysis of video from multiple unbaited remote underwater video stations (UBRUVS; Figure 2.5a) was used to assess the abundance and diversity of fish assemblages among reefs (Cappo et al. 2003). Three UBRUVS, separated by more than 25 m, were deployed at each reef location for a minimum of one hour (only 60 minutes of footage per UBRUVS unit was viewed). In addition, active searches for rare and threatened fish species were completed using an ROV (reducing behavioural bias caused by diver-fish interactions) at Kirra Reef and Cook Island (Figure 2.5a). Targeted searches by divers in both open water and specific habitat types (overhangs, caves and in structurally complex habitat like macroalgae) were completed for species of conservation significance, cryptic and invasive species. Additional species filmed by divers (not already observed on UBRUVS and ROV footage) were also incorporated into fish assemblage records for all sites.

[4] Non-metric multi-dimensional scaling (nMDS) ordinations provide a two-dimensional map so that the rank order distance between samples match the rank order similarity from a matrix. The placement represents the similarity or difference in the composition of assemblages (presence and abundance of each taxon) among samples, so that samples that appear closer on the ordination are more similar in composition, and those further apart more dissimilar or share fewer traits.

a) b)

Figure 2.5 Survey methods used included b) UBRUVS; and a) ROV deployed at each reef location

2.2.4.1 Data Management and Analysis

Fish assemblages and other marine vertebrates were determined for each reef from UBRUVS, SCUBA diver and ROV video imagery, and were used to collate a species inventory for each reef. Biotic indices including species richness, abundance (based on a measure of Max N) and taxonomic distinctness were calculated for each reef. Abundance and taxonomic richness were compared among reef locations from UBRUVS data only, to ensure standardised comparisons among reefs. In some instances, identification of fish to species level was not possible due poor visibility (e.g., distance from camera, light and turbidity). These fish were identified to the lowest possible taxonomic level for the species inventory for each reef but were excluded from further analyses.

Differences in the composition of assemblages from each UBRUVS (species and relative abundance as measured by Max N) were transformed by dispersion weighting (due to the overabundance of some schooling species) and transformed to a Bray Curtis Similarity matrix. Differences were compared among reefs using a one-factor PERMANOVA and where there were differences, Monte Carlo pairwise tests were used to determine which reefs differed. The degree of multivariate dispersion was assessed using the PERMDISP routine and there was no significant variation within each reef (Anderson 2001). Taxonomic groups contributing to the differences among sites and locations were identified using the SIMPER routine (Clarke & Warwick 1994). Centroids of assemblages for each reef were visualised using nMDS (Clarke & Warwick 1994). The total number of species (taxonomic richness) recorded on each UBRUVS was calculated, transformed using Euclidean similarity matrix and compared among reefs using a one-factor PERMANOVA. Where there were differences, Monte Carlo pairwise tests were used to determine which reefs differed.

2.2.5 Quality Assurance and Control

Suitable Quality Control & Assurance (QAQC) measures, including use of suitably qualified ecologists, were included in the monitoring program. The methods were generally consistent with previous monitoring and repeatable to allow for temporal comparisons. Observer bias was reduced or removed using suitable repeatable methods such as UBRUVS and photo-quadrats. A minimum of 10% of images and video footage were reanalysed by another suitably qualified ecologist for quality control.

2.3 Threatened and Invasive Species

A desktop assessment of threatened and invasive species that may occur at each reef was done using database searches and available literature and data, including the Commonwealth Department of Agriculture, Water and Environment (DAWE) Protected Matters Search Tool (PMST) for a 2 km buffer of the coastline between Cook Island and Palm Beach (DAWE 2020) and National Introduced Marine Pest Information System (NIMPIS 2020). Additional timed searches for species of significance for conservation and invasive species were completed using ROV and divers as outlined in Sections 2.2.3 and 2.2.4.

2.4 Abiotic Conditions

2.4.1 Water Quality

Duplicate water quality profiles were taken at each site using a calibrated YSI ProDSS hand-held water quality meter from the surface to the bottom to measure salinity, conductivity, temperature, dissolved oxygen, pH, salinity and turbidity. Each parameter was logged continuously at 5 second intervals to collect at least three sample points per metre, vertically through the water column. Photosynthetic Active Radiation (PAR: available light spectrum used by coral and algae for photosynthesis) was also measured at the surface and bottom at Cook Island South, Cook Island West and Kirra Reef using PME miniPAR meter calibrated for use in marine water. Light attenuation coefficient (Kd) using Beer-Lambert's Law ($Kd = \ln(Iz_0/Iz)/(z)$, where Iz_0 was the surface PAR and Iz was the PAR at a depth of z) and % change with depth were calculated.

Water quality data was used to assist interpretation of spatial and temporal changes in benthic assemblages but was not used for a detailed water quality assessment (which would require much greater spatial and temporal sampling).

2.4.2 Wave Conditions

Wave height and wave direction data were sourced from the coastal data systems database (Queensland Government 2021a) for the Tweed Heads wave rider buoy, located approximately 1.6 km offshore in 22 m water depth (refer to Figure 2.1). Data were graphed to provide a record of physical conditions preceding monitoring and compared to previous assessments of abiotic conditions of the region.

3 Results

3.1 Kirra Reef Extent

3.1.1 Aerial Imagery

Kirra Reef consists of three sections defined as the northern (referred to in some reports as the outer western section), inner western (referred to in some reports as the western or southern section) and eastern sections (Figure 3.3b). The inner western and eastern sections of Kirra Reef are naturally more prone to fluctuation in their exposed area compared with the northern section given their closer proximity to shore (and to Kirra Point) and shallower depth, making them more susceptible to the effects of expanding and retreating beach width, sand shoal movement, wave action, sand scour, nearshore bar formation and longshore sand flow (TRESBP 2009).

In May 2021, Kirra Reef had an estimated total aerial extent of 4,930 m^2 recorded from visual interpretation of aerial and satellite imagery, which comprised 808 m^2 of recently exhumed reef in the eastern section and 4,122 m^2 of reef in the northern section. This is the largest area of reef recorded since exhumation from complete burial in 2009, although it has not changed substantially during this time, particularly considering the potential margin of error associated with calculating the area from aerial images (Figure 3.1). Likewise, the areal extent of Cook Island and Palm Beach Reef have not changed substantially during this time (Appendix A, Table A.5.1).

Previous estimates of the extent of Kirra Reef from aerial photographs and satellite imagery indicate vast changes in the aerial extent through time (Appendix A, Table A.5.1). Prior to 1965, during a time of no major artificial changes to sand movements, the northern section of Kirra Reef had an estimated reef area ranging between 1,800 and 7,800 m^2 (Appendix A, Table A.5.1). The maximum area of the northern section of reef exposed from aerial photograph estimates was 10,200 m^2 in 1989 following a period of sand depletion in the area. The area of reef exposed decreased following the commencement of TSB project, with the northern section of reef almost completely covered by 2006 and an estimated area of reef <1000 m^2 estimated in 2009 and 2010. Storm and cyclone activities were also relatively low during this period, which may have reduced the frequency of large volumes of sand being displaced from the area. Since Kirra Reef emerged from complete burial in 2009, the estimated reef area of the northern section of Kirra Reef has remained relatively stable, ranging between 2,659 and 4,122 m^2 (Appendix A, Table A.5.1), despite cyclonic wave events in 2017 and 2019 which caused relatively minor changes to area of Kirra Reef (frc environmental 2019). The exposed area of the northern section of reef has been relatively stable since 2012, which has supported the development of a diverse reef community.

The inner western and eastern sections of Kirra Reef are naturally subject to ongoing sand burial and exhumation. Prior to 1965 (and the artificial changes to sand movements in the region), the estimated areal extent for the inner western section of reef is 0 to 4,900 m^2, and for the eastern section of the reef is 0 to 2,150 m^2 (Appendix A, Table A.5.1). The extent of these sections reached a maximum in 1989, with 65,400 m^2 of reef estimated for the inner western section and 22,500 m^2 estimated for the eastern section. The inner western section of the reef has been buried for the last 20 years, which corresponds to the commencement of the TSB (in 2001). The eastern section of reef has only occasionally had small areas exposed during this time, with the maximum of 808 m^2 in 2021. These inner western and eastern sections of Kirra Reef both have a low reef profile (or relief) and are naturally subject to increased frequency of disturbance including sand burial. For example, in May 2021, the vertical relief of the eastern section was approximately 30 cm above the bottom, while the northern section was approximately 1.5 to 2 m above the bottom. The low relief combined with greater potential for disturbance associated with being closer to the shoreline, is likely to limit the development of a biodiverse community of reef dwelling organisms on these reefs (refer to Section 3.2.2 for community composition of the eastern section of reef).

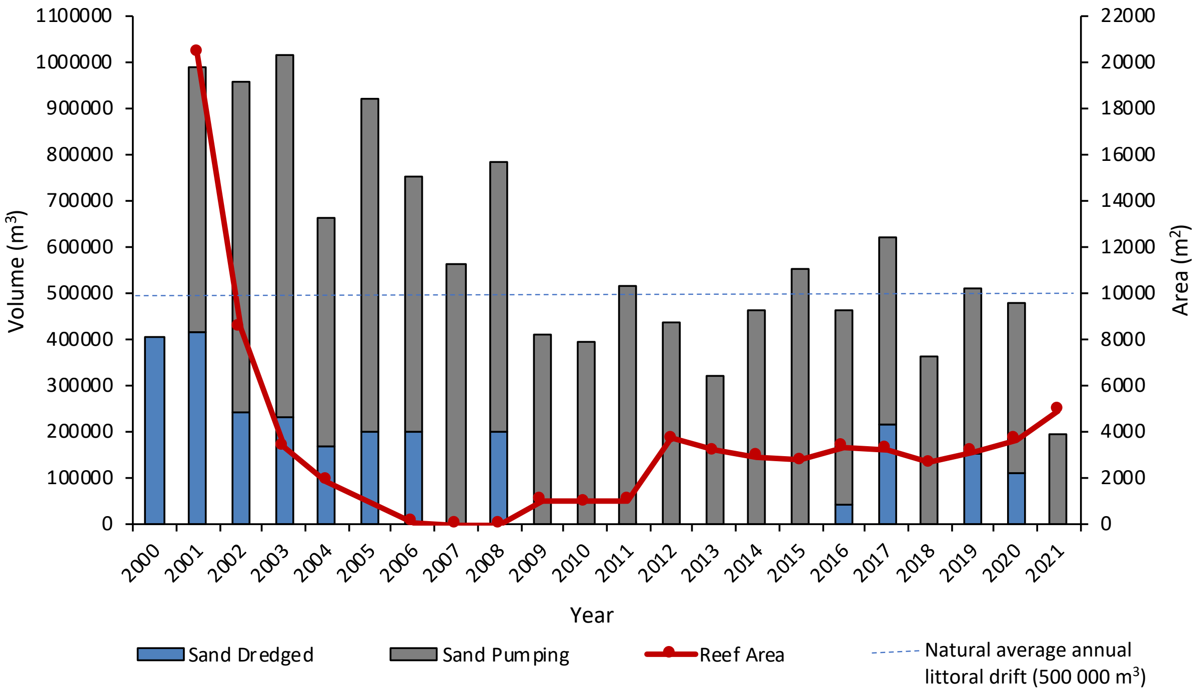


Figure 3.1 Estimated surface area (m^2) at Kirra Reef and total annual and dredging and pumping volumes (m^3) between 2000 and 2021 (data for 2021 includes sand volumes up to August)

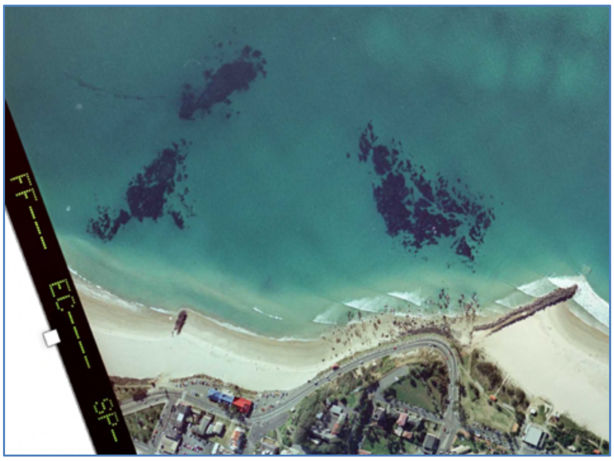
a)

Source: Queensland Government 2021b

b)

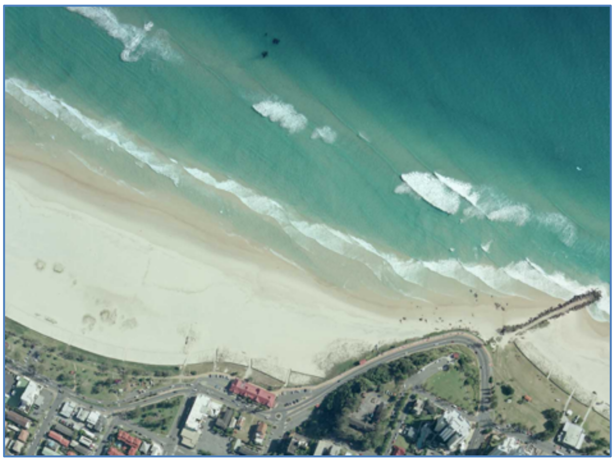
Source: WorleyParsons 2009

c)



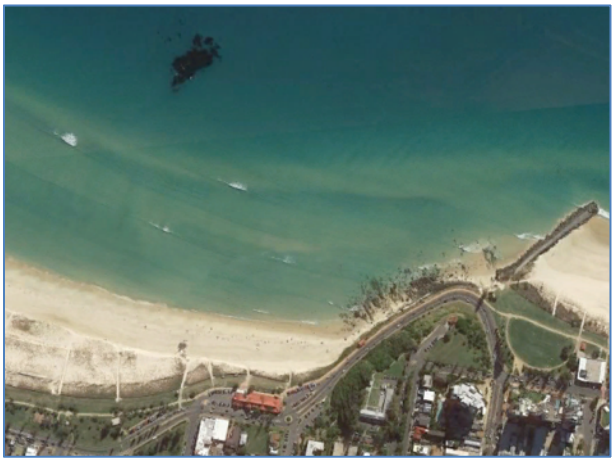
Source: Queensland Government 2021b

d)



Source: Queensland Government 2021c

e)



Source: Queensland Government 2021c

f)

Source: Queensland Government 2021c

Figure 3.2 Photographs indicating major changes at Kirra Reef in (a) 1956 during a time with no major artificial changes to sand movements; (b) 1982 following sand depletion between the 1960s and 1980s; (c) 1995 at the measured maximum extent; (d) 2007 following an oversupply of sand during the early years of the TSB sand bypassing system; (e) 2018; and, (f) March 2021 with sand delivery of the TSB now matching natural longshore drift of sand.

3.1.2 Bathymetric Surveys

There were some increases in depth around Kirra Reef between May 2020 and May 2021 from bathymetric survey results, with a 20 to 60 cm decrease in sand height along the western edge and approximately 1 m around the north-eastern edge (between outcrops) of the northern section of reef (Figure 3.3). Some small outcrops of reef on the western side of the northern section of reef were exposed during this time (refer to Section 2.1.1). The change in depth between May 2020 and May 2021 was more substantial than changes observed between July 2019 and May 2020, where depth around much of the reef stayed relatively similar (± 20 cm change represented by the white sections surrounding the reef in Figure 3.3). The depth around the recently exhumed eastern section of reef increased by approximately 20 to 60 cm between May 2020 and May 2021 (Figure 3.4). In comparison, the offshore bar running along Kirra Beach built up by a 1 to 1.6 m in height within the same time period, likely a result of the offshore bar shifting further seawards (Figure 3.4). It is common for an offshore bar to form and migrate on dynamic sandy beaches to dissipate wave energy (Short 2019).

There was some variance in the surveyed depth above Kirra Reef between years (± 1.4 m in sections), particularly between July 2019 and May 2020, which may correspond to changes in the coverage of macroalgae (such as the dense fronds of *Sargassum* spp. macroalgae observed on the horizontal surfaces in the middle of the reef; ESP 2020). Depth over much of the reef remained relatively consistent between May 2020 and May 2021 (as seen by white sections on the reef in Figure 3.3) as the macroalgae cover remained relatively consistent over the past year (refer to Section 3.2).

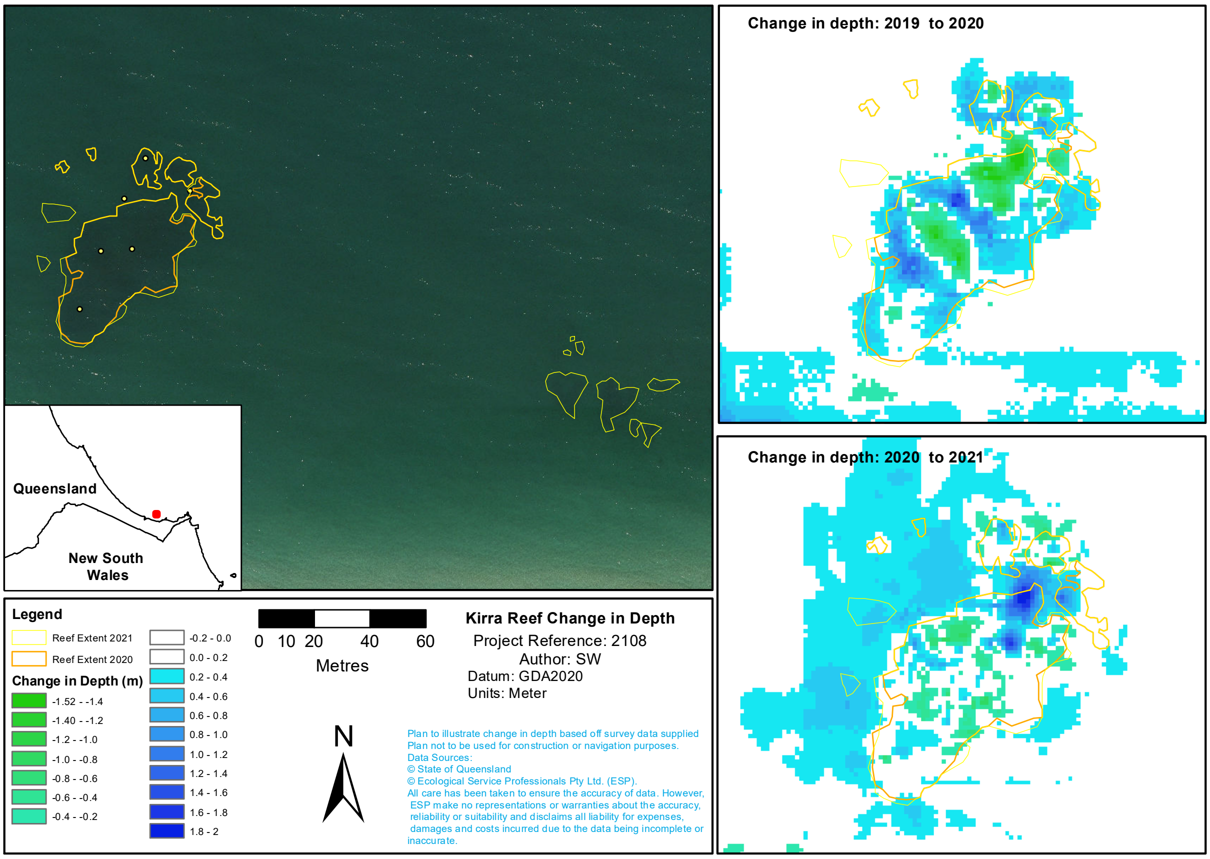


Figure 3.3 Areal extent (left) and changes in depth (green indicating shallower and blue indicating deeper water) from July 2019 to May 2020 (top right); and May 2020 to May 2021 (bottom right)

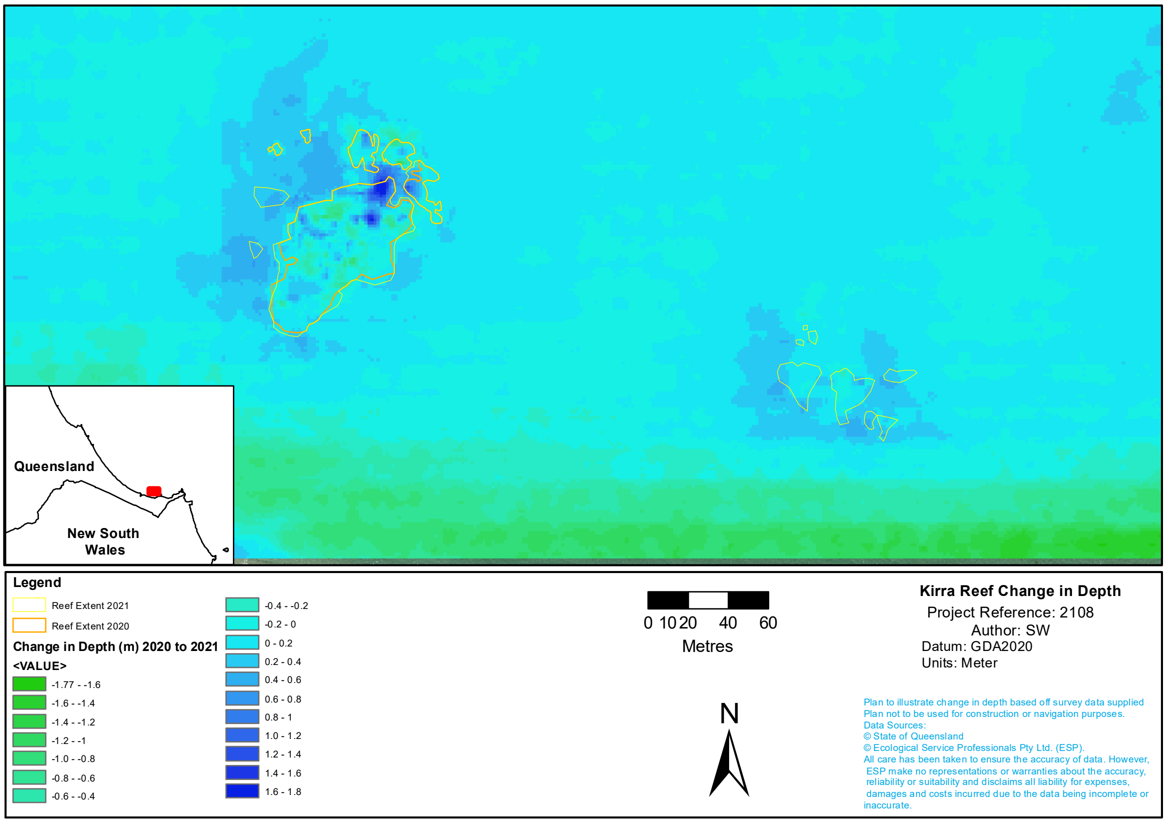


Figure 3.4 Broad scale changes in depth (green indicating shallower and blue indicating deeper water) around Kirra Reef between 2020 and 2021 from bathymetric survey data (top) and oblique aerial photograph of Kirra Reef taken in April 2021 (bottom) (image provided by TSB)

3.2 Benthic Communities

3.2.1 Composition of Benthic Communities

The composition of benthic communities (including both algal and sessile invertebrate assemblages) on the reefs in the region differed at a range of spatial scales, including between Kirra and the other reefs, on both horizontal and vertical surfaces [5] (Figure 3.6, Figure 3.7 and Figure 3.5a; PERMANOVA, Appendix B, Table B.5.2). There were also differences in the composition of benthic communities among reef locations including those separated by only a few hundred metres at Cook Island (Appendix B, Table B.5.2). The differences in benthic communities between Kirra and the other reefs in the area was typically due to a lower coverage of turfing algae and higher coverage of *Sargassum* sp. (refer to Section 3.2.2). The differences in the composition of benthic communities among reefs were likely due to a range of site-specific factors including differences in the disturbance regime and the length of time since sand burial (as Kirra Reef was almost completely buried in 2007 and 2008), abiotic factors (such as wave action), settlement and recruitment of sessile species, water quality (including nutrient availability), and / or variation in the abundance of herbivorous fauna between reefs.

On Kirra reef, the differences in the composition of benthic communities between horizontal and vertical surfaces were less pronounced in 2021 than in previous years (Appendix B, Table B.5.2). In 2021, there was no difference in the overall composition of the benthic community between horizontal and vertical surfaces (SIMPER Appendix B, Table B.5.3). The coverage of ascidians *Polycarpa procera, Pyura stolonifera* and *Herdmania momus* typically differed between surface orientations on Kirra Reef in previous surveys (ESP 2020); however, in 2021, the coverage of these dominant species was more similar with a combined 15% of the area on vertical surfaces and 12% on horizontal surfaces (SIMPER Appendix B, Table B.5.3). This provides a good indicator that there have not been any substantial impacts to the benthic community from sand burial or sand scour on horizontal surfaces on the reef.

The moderately dense patch of seagrass recorded in 2020 at Cook Island West adjacent to Cook Island was still present in 2021. The seagrass community occurred between macroalgae, rock and rubble on sand and was dominated by *Halophila ovalis*, covering approximately 32% to 52% of the space where it was recorded (Figure 3.8). Despite previous anecdotal evidence seagrass was first recorded as part of the TSB in the 2020. Marine vegetation, including seagrass, are protected under the *NSW Fisheries Management Act 1995*.

Bare sand and rubble habitat covered the most area of horizontal surfaces at Cook Island West (20%), Kirra (18%) and Palm Beach Bait reefs (15%) (Figure 3.9). Elsewhere the coverage of sand and rubble was more similar among surface orientations and reef locations covering less than 7% of the surface area (Figure 3.9).

[5] Benthic communities PERMANOVA Orientation vs Reef interaction MS = 3415 pseudo-$F_{5,12}$ = 1.75, $p = 0.022$; Pairwise tests for differences among reefs for horizontal and vertical surfaces: KR≠CIW≠CIS≠CIN≠PB≠PBBR $p(MC) < 0.05$;

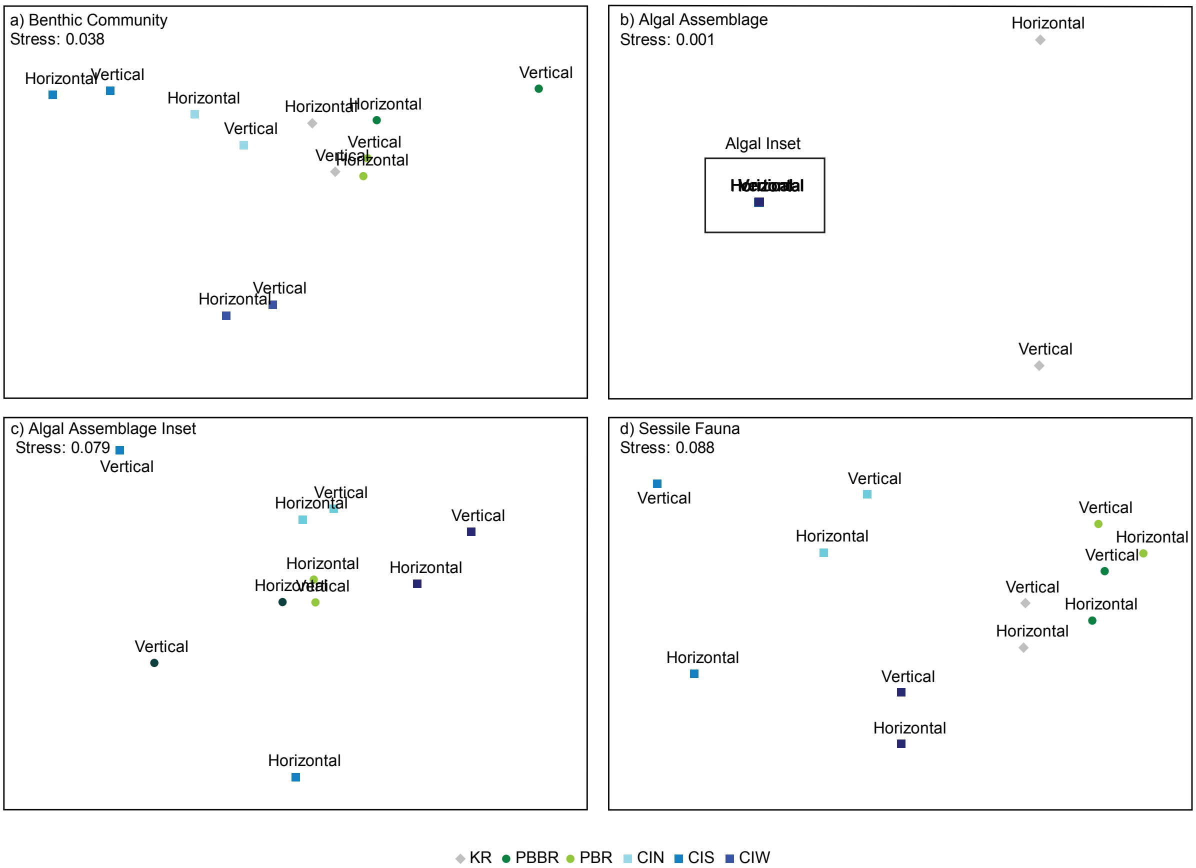


Figure 3.5 nMDS ordination showing difference in the composition of benthic assemblages between surface orientations and reefs for (a) the sessile community, (b-c) algal assemblages, and (d) sessile invertebrate assemblages [6]

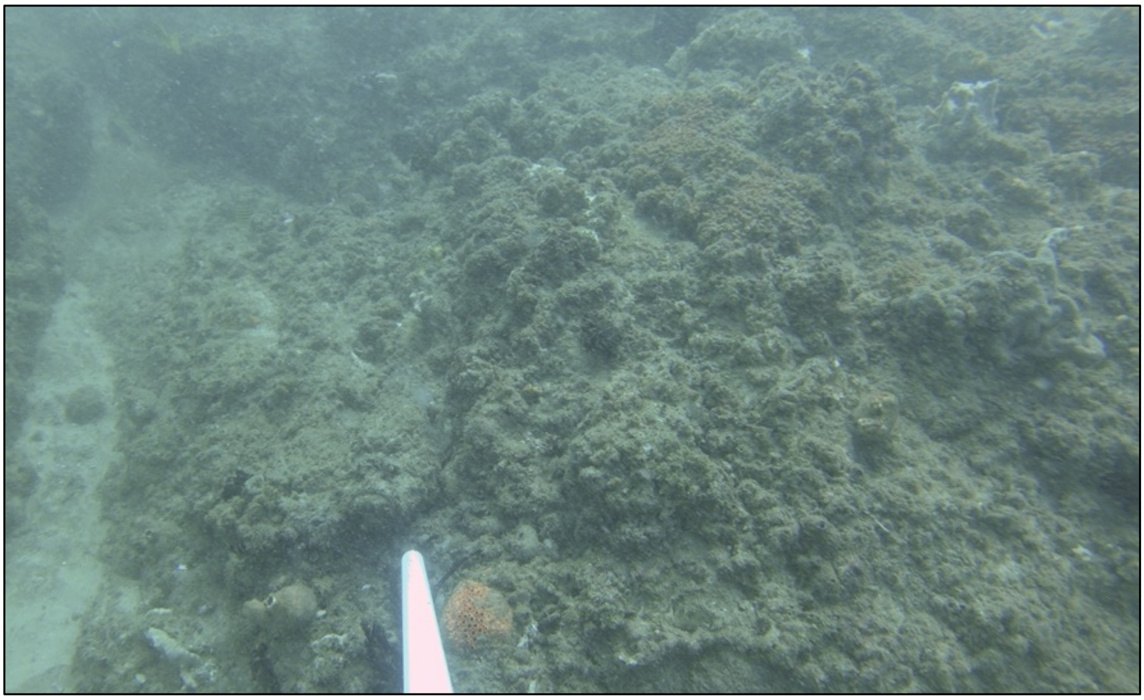
[6] nMDS ordination plot provides a two-dimensional map so that the rank order distance between samples match the rank order similarity from a matrix of sample pairs. The placement of points represents the similarity or difference among samples (in this case in the composition of assemblages - presence and abundance of each taxon). Samples that appear closer on the ordination are more similar in composition, and those further apart are more dissimilar or share fewer traits.

a)

b)

Figure 3.6 Example benthic assemblages at a) Kirra Reef and b) Palm Beach Reef

a)



b)

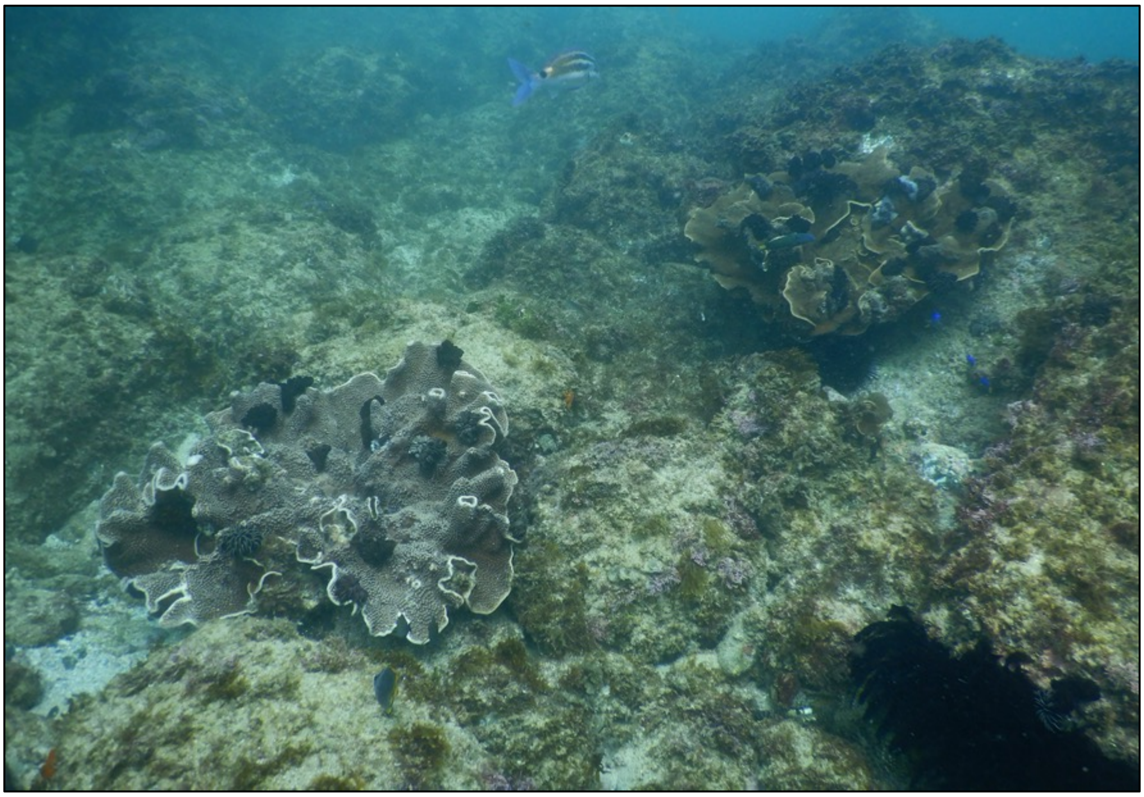


Figure 3.7 Example benthic assemblages at a) Palm Beach Bait Reef and b) Cook Island West

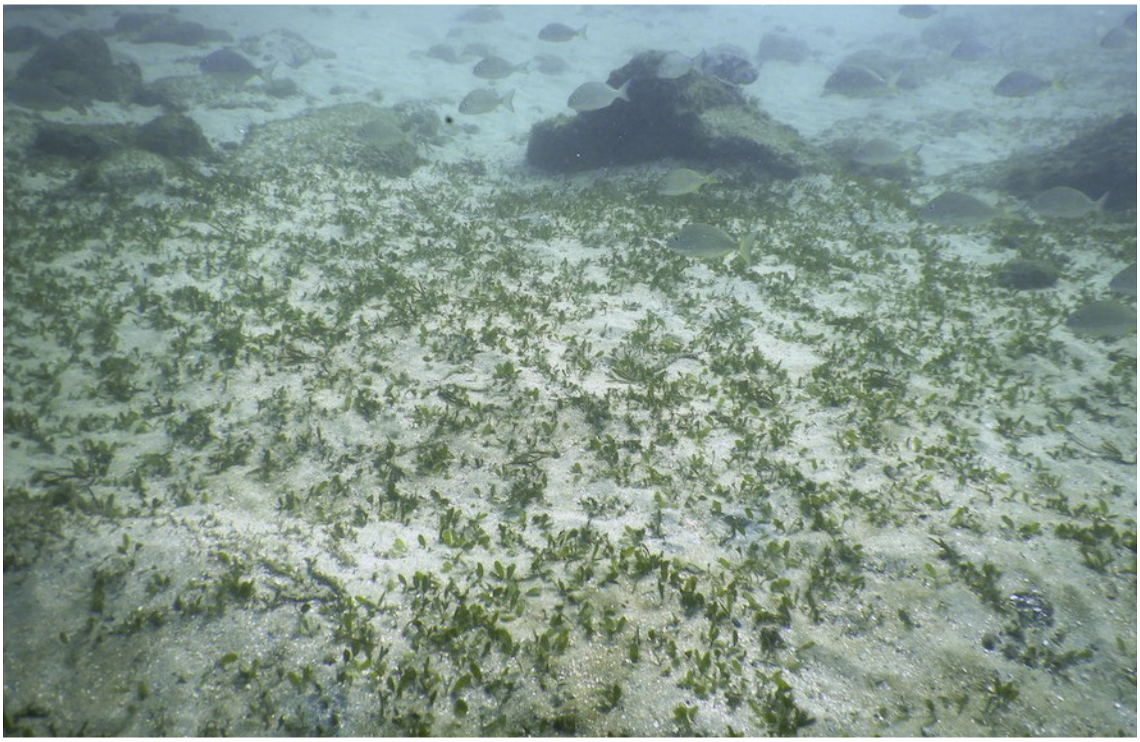


Figure 3.8 Seagrass *Halophila ovalis* at Cook Island West

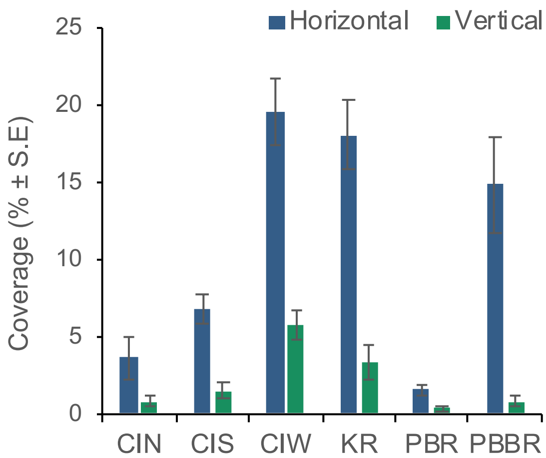


Figure 3.9 Coverage of bare (sand & rubble) habitat between surface orientations, among reefs

3.2.2 Algal Assemblages

The algal assemblages on all reefs were dominated by turf forming algae, with other groups such as foliose macroalgae (including *Sargassum* sp., *Dictyota* sp. and *Padina* sp.), crustose coralline algae and articulate coralline algae (e.g. *Jania* sp.) also present. The composition of algal assemblages differed at a range of spatial scales, with differences in the coverage of algae occurring among reefs on both horizontal and vertical surfaces[7] (Figure 3.5b & c; Figure 3.11; PERMANOVA, Appendix B, Table B.5.4). On horizontal and vertical surfaces, there were often differences in the composition of algal assemblages among the reefs, particularly between Kirra and other reefs (Figure 3.5b & c; PERMANOVA pairwise comparisons, Appendix B, Table B.5.4; Table B.5.5; SIMPER Table B.5.6).

The average coverage of foliose macroalgae was similar between the surface orientations on each reef (Figure 3.10a; PERMANOVA Appendix B Table B.5.5a). The coverage of macroalgae on Kirra and Cook Island West reefs was generally higher than on the other reefs (Figure 3.10a). *Sargassum* spp. covered on average 14% of horizontal surfaces and 12% on vertical surfaces on Kirra Reef (Figure 3.11). *Sargassum* spp. was largely absent at all other reefs surveyed, with this difference accounting for more than 27% of the difference in algal assemblages between Kirra Reef and the other reefs (SIMPER; Appendix B, Table B.5.6).

The coverage of turf forming algae was highest on both vertical and horizontal surfaces at Cook Island West Reef (65%) and was lowest on Kirra Reef on horizontal (37%) and vertical (43%) surfaces (Figure 3.10b; Figure 3.11; PERMANOVA Appendix B Table B.5.5b). Differences in the coverage of turf forming algae between Kirra and the other reefs contributed 53 to 58% of the difference in algal assemblages among those reefs (Figure 3.10b; SIMPER Appendix B, Table B.5.6).

Articulate and crustose coralline algae typically covered less than 9% of the surface area on any one reef, and was highest on horizontal surfaces at Cook Island North (Figure 3.10c; PERMANOVA Appendix B Table B.5.5c). In 2021, the coverage of coralline algae did not contribute substantially to the differences among reefs (SIMPER Appendix B, Table B.5.6)

While the coverage of algae on the recently exhumed section of Kirra Reef (part of the eastern section) was not specifically assessed, the low relief reef was dominated by a moderate coverage of foliose macroalgae, in particular *Sargassum* and *Ulva* (Figure 3.11). These species are an early coloniser of reefs in the area, particularly where reef surfaces are available for colonisation during winter months when algae are known to spawn (Kennelly 1987), as was the case here.

[7] Algal assemblages PERMANOVA Orientation x Reef interaction $MS_{5,12}$ = 1341, pseudo-F = 2.39, $p = 0.03$; Pairwise tests for differences among reefs for horizontal and vertical surfaces: KR≠CIW,CIS,CIN,PBR,PBBR *p(MC)* < 0.05

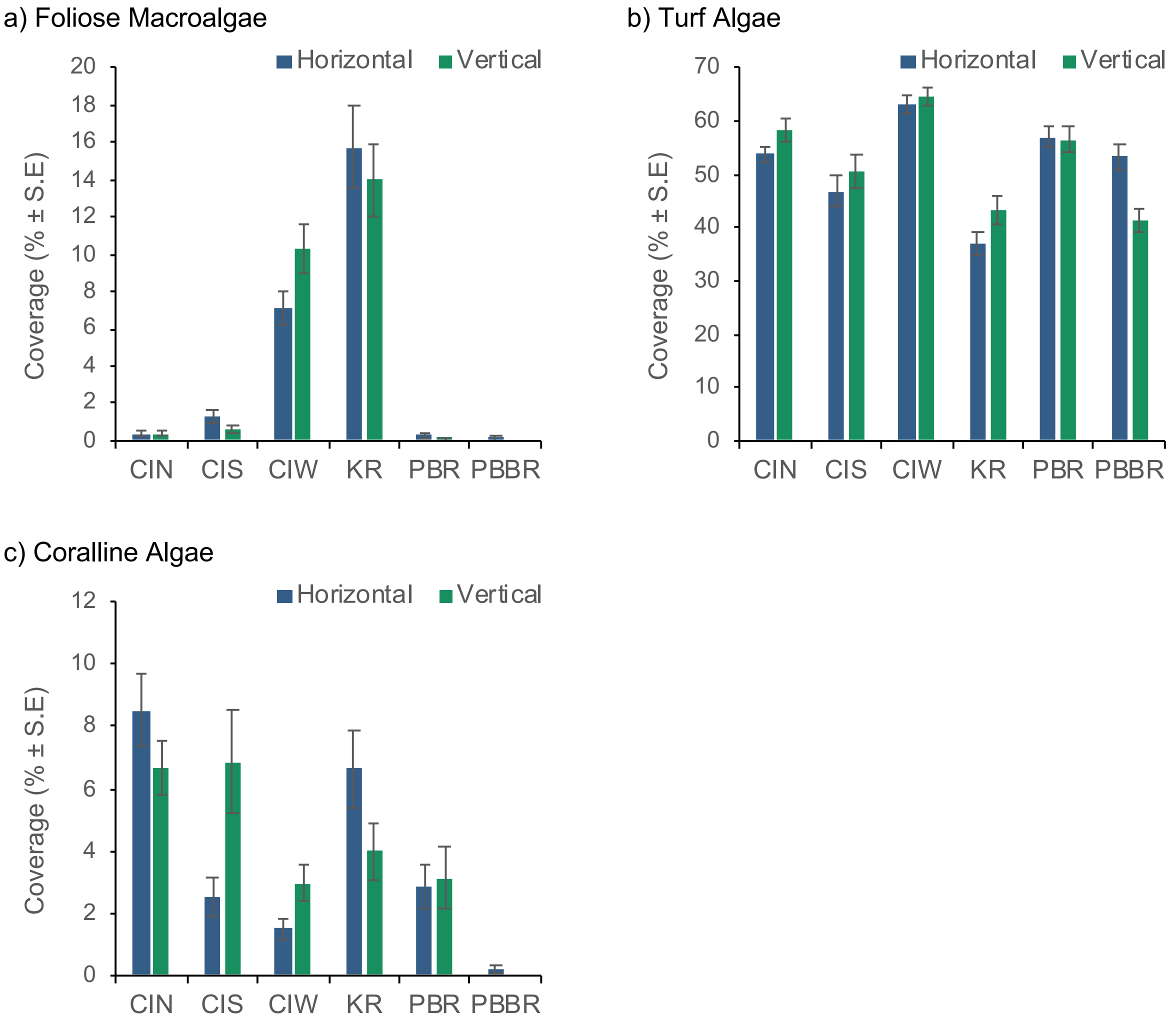
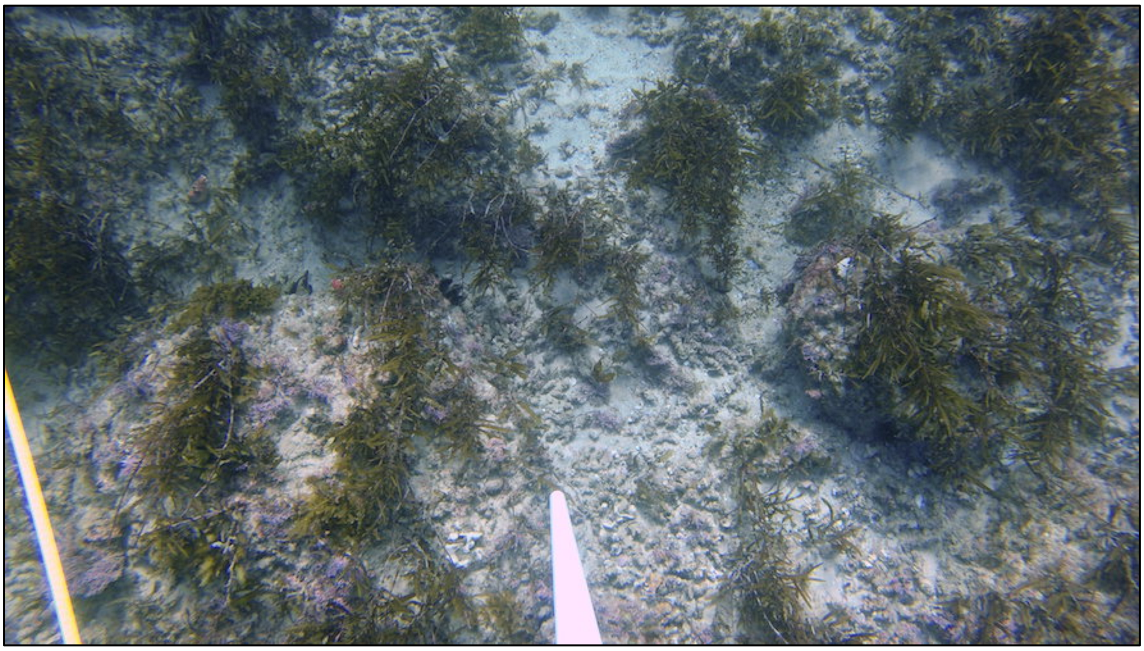


Figure 3.10 Average coverage (% ± SE) of foliose macroalgae, turf algae and coralline algae on vertical and horizontal surfaces, among reefs in 2021

a)



b)

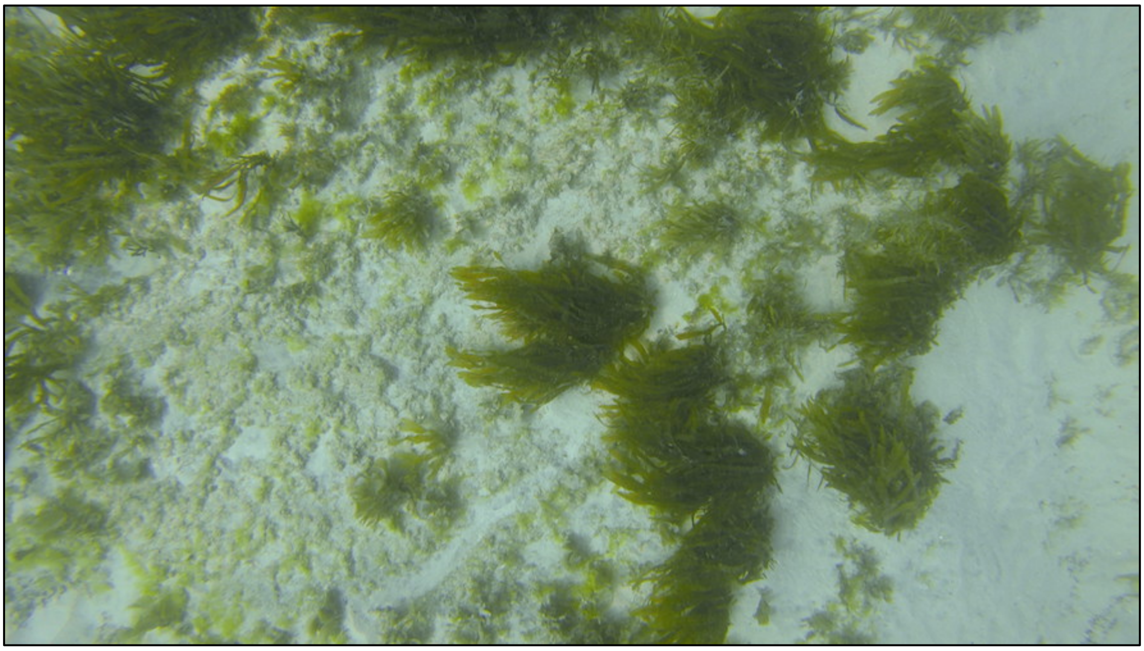


Figure 3.11 Algal communities at a) Kirra Reef northern section and b) recently exhumed eastern reef section

3.2.3 Sessile Invertebrate Assemblages

In 2021, a total of 90 taxa were recorded across all vertical surfaces and 98 taxa recorded across all horizontal surfaces on the reefs assessed. There were differences in the total number of taxa recorded between vertical and horizontal surfaces, with the fewest taxa recorded at Kirra Reef, with a total of 27 taxa recorded on vertical surfaces and only 23 taxa on horizontal surfaces of the reef.

The composition of sessile invertebrate assemblages (presence and % coverage of each taxonomic group) generally differed between Kirra Reef and the other reefs surveyed regardless of surface orientation[8] (Figure 3.5d; PERMANOVA Orientation x Reef pairwise comparisons Table B.5.7). The average coverage of the dominant ascidians *Polycarpa procera* and *Pyura stolonifera*, was typically higher on horizontal surfaces at Kirra Reef than on other reefs and contributed 16 to 36% of the difference in assemblage composition (SIMPER Appendix B, Table B.5.8b,c). The lack of hard corals (i.e. from genus *Paragoniastrea, Turbinaria* and encrusting *Porites*) and lower coverage of soft corals on Kirra Reef also contributed to differences in assemblage composition among reefs, particular those surrounding Cook Island (SIMPER Appendix B, Table B.5.8). On vertical surfaces, the lower coverage of bivalves and ascidian *Pyura stolonifera* contributed most to the difference among assemblages on Kirra Reef and Palm Beach or Palm Beach Bait reefs (SIMPER Appendix B, Table B.5.9). In comparison, the lack of hard corals and greater coverage of the dominant ascidians *Polycarpa procera* and *Pyura stolonifera* on Kirra Reef contributed most to the differences in assemblages between Kirra and Cook Island reefs (SIMPER Appendix B, Table B.5.8 & Table B.5.9).

On Kirra Reef, the average taxonomic richness was similar between horizontal and vertical surfaces (Figure 3.12a; PERMANOVA Appendix B, Table B.5.10a). In contrast, the average coverage of sessile fauna was higher on vertical than horizontal surfaces[9] (Figure 3.12b; PERMANOVA Appendix B, Table B.5.10b). This was to be expected as horizontal surfaces on Kirra Reef have typically had a greater coverage of foliose macroalgae and turf algae (Figure 3.10), which can out compete sessile invertebrates and cause physical disturbance preventing settlement. There was also a higher coverage of bare sand on horizontal than vertical surfaces, which can increase physical disturbance from sand scour and burial creating conditions that are unsuitable for sessile invertebrate recruitment and growth (Figure 3.9).

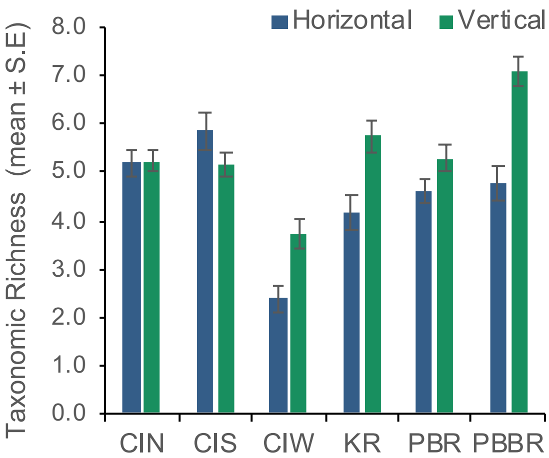
The average coverage of sessile invertebrates was higher on vertical than horizontal surfaces at Palm Beach Bait and Cook Island West reefs (Figure 3.12b). Although, the average coverage of sessile assemblages remained similar between vertical and horizontal surfaces at Cook Island North, Cook Island South and Palm Beach reefs (Figure 3.12b; PERMANOVA Appendix B, Table B.5.10b). At Cook Island North and Cook Island South reefs this similarity in coverage between surface orientations was typically due to the

[8] Sessile Invertebrates - PERMANOVA Orientation vs Reef interaction $MS_{5,12}$ = 10214, pseudo-F = 1.71, p = 0.008; Pairwise tests for differences among reefs for horizontal and vertical surfaces: CIW≠CIS≠CIN≠KR≠PBR *p(MC)* < 0.05; horizontal surfaces: CIN = CIS *p(MC)* = 0.07; Coverage on horizontal ≠ vertical at CIW, CIN and PBBR *p(MC)* < 0.05

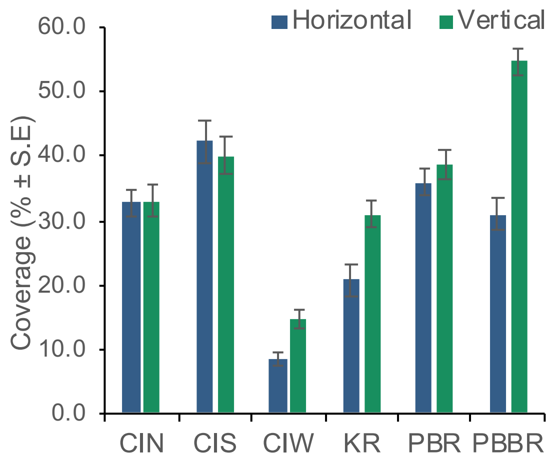
[9] Coverage of Sessile Invertebrates PERMANOVA Orientation vs Reef interaction $MS_{5,12}$ = 2050, pseudo-F = 3.92, p = 0.028; Pairwise tests for differences in coverage: among reefs for horizontal surfaces: CIW≠CIS,CIN,PBBR,PBR *p(MC)* < 0.05; horizontal ≠ vertical surfaces at CIW, *p(MC)* < 0.05; among reefs for horizontal surfaces: CIW≠CIS,CIN,PBBR,PBR,KR *p(MC)* < 0.05

dominance of longer lived hard and soft corals covering a large proportion of the surface area on both vertical and horizontal surfaces (Figure 3.12c,d and Figure 3.13), despite having a similar average taxonomic richness to that recorded on the other reefs (Figure 3.12a).

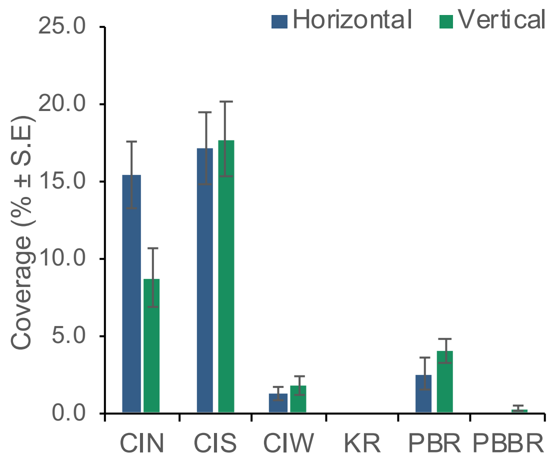
a) Taxonomic Richness of Sessile Invertebrates



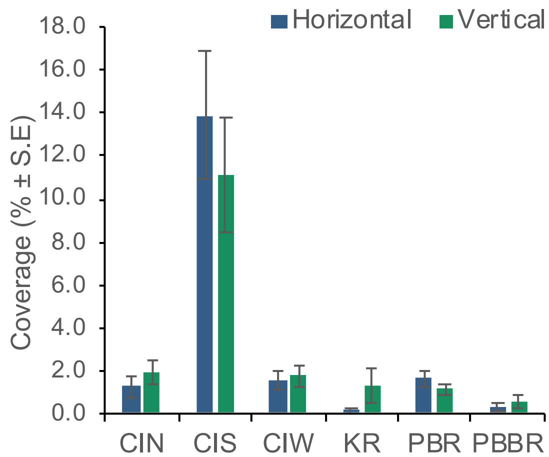
b) Coverage of Sessile Invertebrates



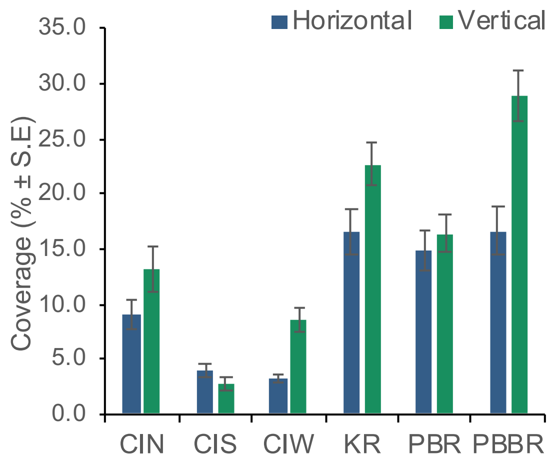
c) Hard Coral



d) Soft Coral



e) Ascidians



f) Sponges

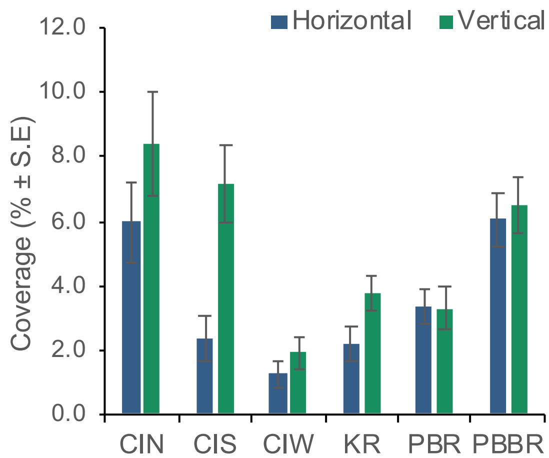
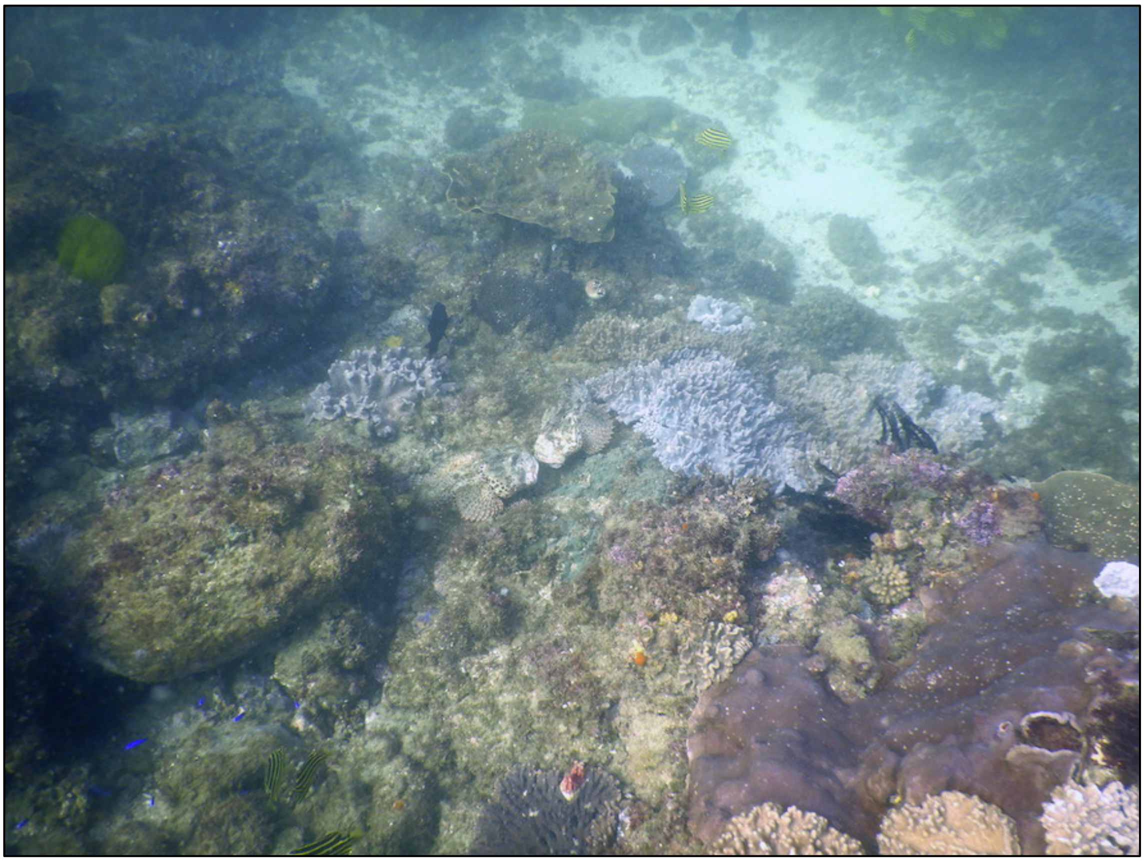


Figure 3.12 Average taxonomic richness and coverage (% ± SE) of all sessile invertebrates and average coverage of dominant sessile invertebrates categories on vertical and horizontal surfaces, among reefs in 2021 (Blue – Horizontal; Green – Vertical)

a)



b)

Figure 3.13 Hard and soft coral at a) Cook Island South and b) Cook Island North

3.2.4 Historic Comparison of Benthic Communities

The composition of benthic communities (algae and sessile invertebrates identified to a broad taxonomic level) continued to differ between Kirra and Palm Beach Reefs (most commonly surveyed) and the various other reefs assessed over time[10] (Figure 3.14; PERMANOVA Survey x Reef Interaction; pairwise comparisons Appendix B, Table B.5.11). In the past 6 years (since 2016), the composition of benthic communities on all reefs assessed have differed between successive years where surveys have been completed which demonstrates the potential interannual variation in the composition of benthic communities (PERMANOVA pairwise comparisons, Table B.5.11, Table 5.11g). Although, there have been some differences in the methods of data collection among surveys, particularly between 2017 and 2019.

On Kirra Reef, the differences in composition between successive surveys were due to changes in the average coverage of macroalgae, turf algae and ascidians, which combined accounted for up to 84% of the difference between the surveys on that reef (SIMPER Table B.5.12). In particular, increased coverage of turf forming algae and decreased coverage of macroalgae, ascidians and sponges contributed 82% of the difference in the composition of the benthic community on Kirra Reef between 2020 and 2021 (Table B.5.12). Hard corals were also not recorded in the benthic community on Kirra Reef in 2021, despite covering 2% of the area in 2020. An increase in the coverage of hard and soft corals would likely result in more similar composition of benthic communities with those found on surrounding reefs, but many of these species are slow growing so may take considerable time to become established and cover more than 5% on Kirra Reef (Walker & Schlacher 2014).

[10] Benthic Communities over time - PERMANOVA Survey x Reef interaction $MS_{16,1970}$ = 19000 pseudo-F = 21.35, p = 0.01; Pairwise tests for differences among reefs over time are provided in Appendix B Table B.5.11.

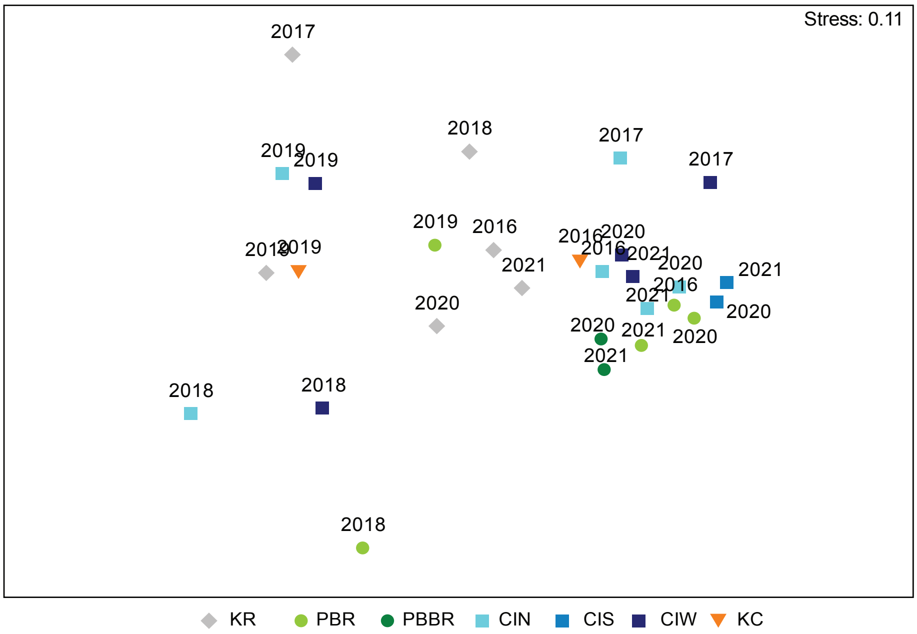


Figure 3.14 nMDS ordination of the difference in the composition of benthic assemblages on horizontal surfaces between Kirra and Palm Beach Reefs between 2016 and 2021 (KC = Kingscliff Reef – not surveyed in 2020 or 2021) [11]

3.2.5 Mobile Invertebrate Assemblages

The total density of mobile invertebrate assemblages was highest at Kirra Reef and assemblages were most diverse at Cook Island West than recorded on other reefs (Appendix C). Echinoderms dominated the mobile invertebrate assemblages at all reefs in 2021, which is consistent with findings in 2020 (ESP 2020) (Figure 3.15; Appendix C). Feather stars (primarily *Cenolia* spp.; Figure 3.16a) had the highest densities at all reefs, except for Cook Island South and Palm Beach Reef, where sea urchins had higher densities (e.g. Figure 3.16b; Figure 3.15). Sea cucumbers and sea snails (e.g. Figure 3.16c) occurred in low densities at some reefs and several octopus (Figure 3.16d) and a hermit crab were also observed in photo quadrats from Cook Island West and Palm Beach Reef, respectively (Appendix C). Additional to those mobile invertebrates recorded from photo quadrats, several other species were observed on ROV, UBRUVS or SCUBA diver footage, including:

- nudibranchs such as *Hypselodoris tryoni* (observed at CIN) and *Doriprismatica atromarginata* (observed at CIS)
- spanish dancer (*Hexabranchus sanguineus*) observed at Cook Island South (Figure 3.16e)

[11] nMDS ordination plot provides a two-dimensional map so that the rank order distance between samples match the rank order similarity from a matrix of sample pairs. The placement of points represents the similarity or difference among samples (in this case in the composition of assemblages - presence and abundance of each taxon). Samples that appear closer on the ordination are more similar in composition, and those further apart are more dissimilar or share fewer traits.

- bigfin reef squid (*Sepioteuthis lessoniana*) observed at Cook Island West, Cook Island North and Kirra Reef
- cuttlefish (*Sepia* sp.) observed at Cook Island West and Palm Beach Natural Reef (Figure 3.16f)
- painted spiny lobster (*Panulirus versicolour*) observed at Cook Island West and an exoskeleton observed at Cook Island North
- hairy blackfish (*Actinopyga miliaris*) observed at Cook Island South
- blue linckia sea star (*Linckia laevigata*) observed at Cook Island South, and
- yellow-toothed cowrie (*Erronea xanthodon*) observed at Cook Island North.

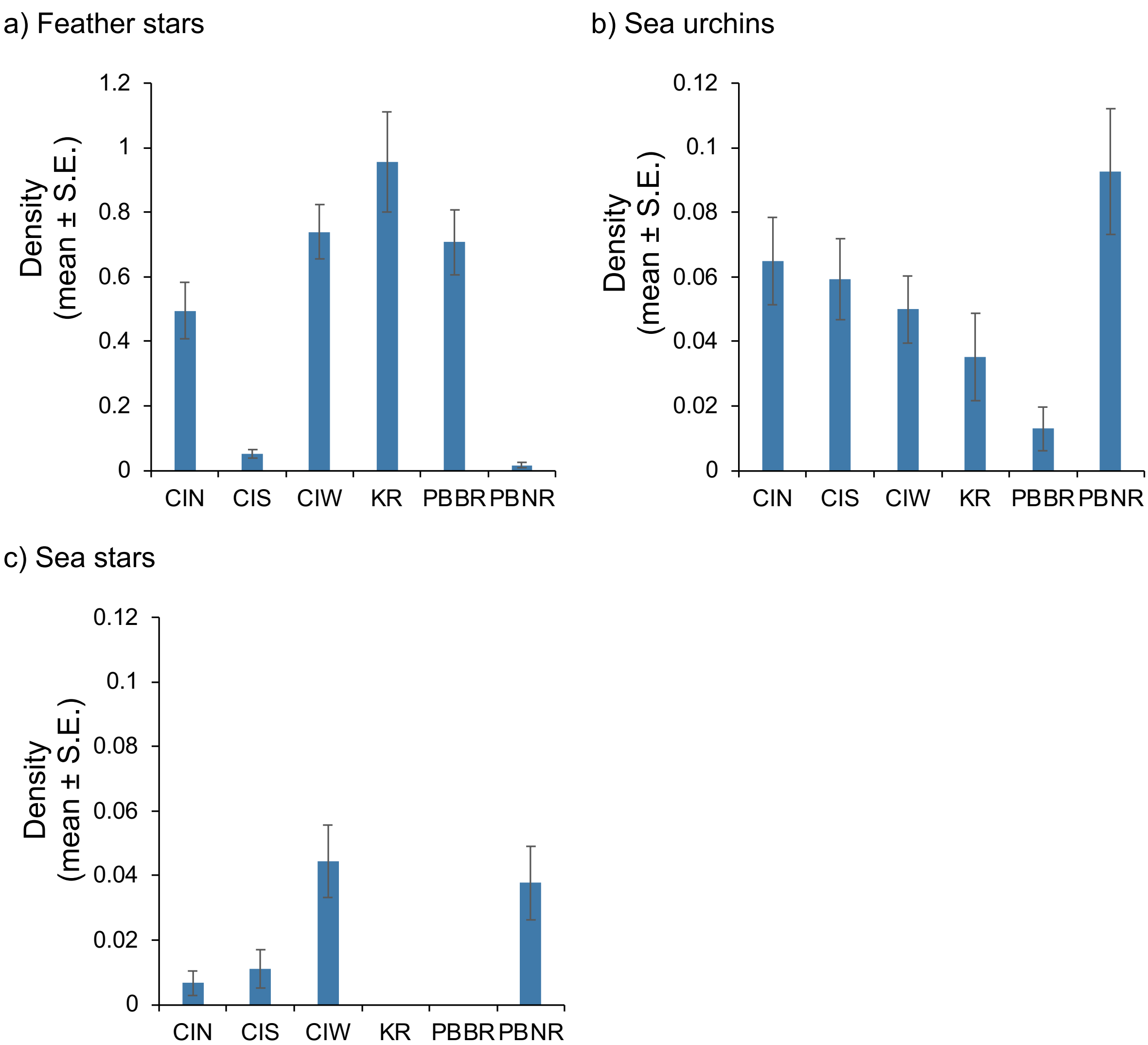


Figure 3.15 Density (number of individuals per photo quadrat; mean ± SE) of a) feather stars, b) sea urchins, and c) sea stars at each reef in 2021

a)

b)

c)

d)

e)

f)

Figure 3.16 Mobile invertebrates recorded on reefs in 2021 including a) *Cenolia* feather stars, b) slate pencil urchins, c) common egg cowrie, d) common Sydney octopus, e) Spanish dancer, and f) cuttlefish

3.3 Fish Assemblages

A total of 129 bony and cartilaginous fish species, from 44 families were recorded across all reefs in the May 2021 survey (Appendix D). Labridae (wrasses) and Pomacentridae (damselfishes) were the most diverse families, with 24 and 18 species, respectively. During the May 2021 survey, 22 fish species were observed that had not been recorded in previous surveys (Appendix D). Cartilaginous fish recorded in May 2021 included:

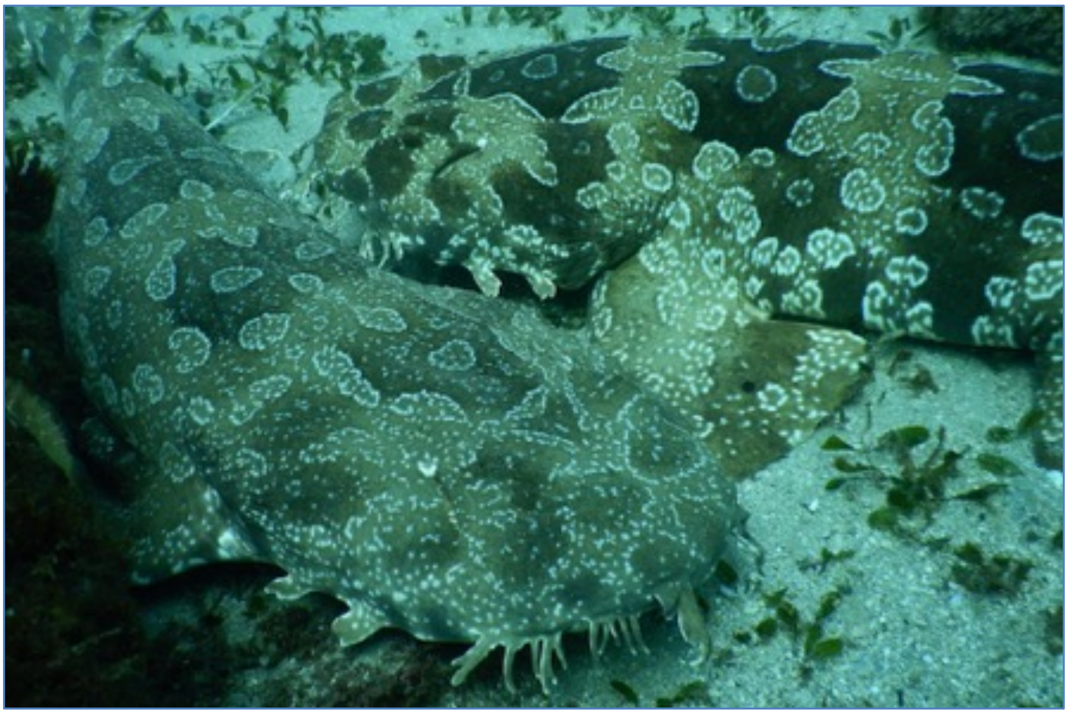
- spotted wobbegong (*Orectolobus maculatus*) at all reefs (Figure 3.17a);
- banded wobbegong (*Orectolobus ornatus*) at Palm Beach Reef, Palm Beach Bait Reef and Cook Island North;
- grey carpet shark (*Chiloscyllium punctatum*) at Kirra Reef;
- whitespotted guitarfish (*Rhynchobatus australiae*) at Palm Beach Reef;
- white-spotted eagle ray (*Aetobatus ocellatus*) at Kirra Reef, Palm Beach Reef and Palm Beach Bait Reef; and,
- bluespotted maskray (*Neotrygon kuhlii*) at Kirra Reef and Cook Island West.

The composition of fish assemblages differed among reefs [12], particularly between assemblages at Kirra Reef and Cook Island South, with no significant difference in composition among the other reefs (Figure 3.18). Differences in fish assemblages at Kirra Reef and Cook Island South were largely attributed to the absence of yellowtail scad (*Trachurus novaezelandiae*) at Cook Island South compared to high abundance of this species at Kirra Reef. This may be due to differences in the habitat complexity (e.g. yellowtail scad are known to have increased abundance on reefs with higher vertical relief; Holland et al 2021), benthic composition (refer to Section 3.2), availability of prey (e.g. abundant plankton) or other ecological interactions (e.g. predator abundance).

Most fish species recorded were common to the region. No threatened or protected fish species listed under the Queensland's *Nature Conservation Act 1992* or nationally under the Commonwealth's *Environmental Protection and Biodiversity Conservation Act 1999* were recorded. The eastern blue groper (*Achoerodus viridis*) is partly protected under the NSW Fisheries Management (General) Regulation 2019 (i.e. must not be fished by any method other than a rod and line or a handline) and was recorded at all three Cook Island sites (and Palm Beach Reef; Figure 3.17b). No invasive fish species were recorded.

[12] PERMANOVA for differences in fish assemblages among reefs $F_{5,12} = 2.08$, $p = 0.001$; Pairwise comparisons among reefs CIS≠KR; KR=CIN=CIW=PBR=PBBR; CIS=CIN=CIW=PBR=PBBR at $p=0.05$.

a)



b)

Figure 3.17 a) spotted wobbegong and b) Eastern blue grouper recorded in 2021

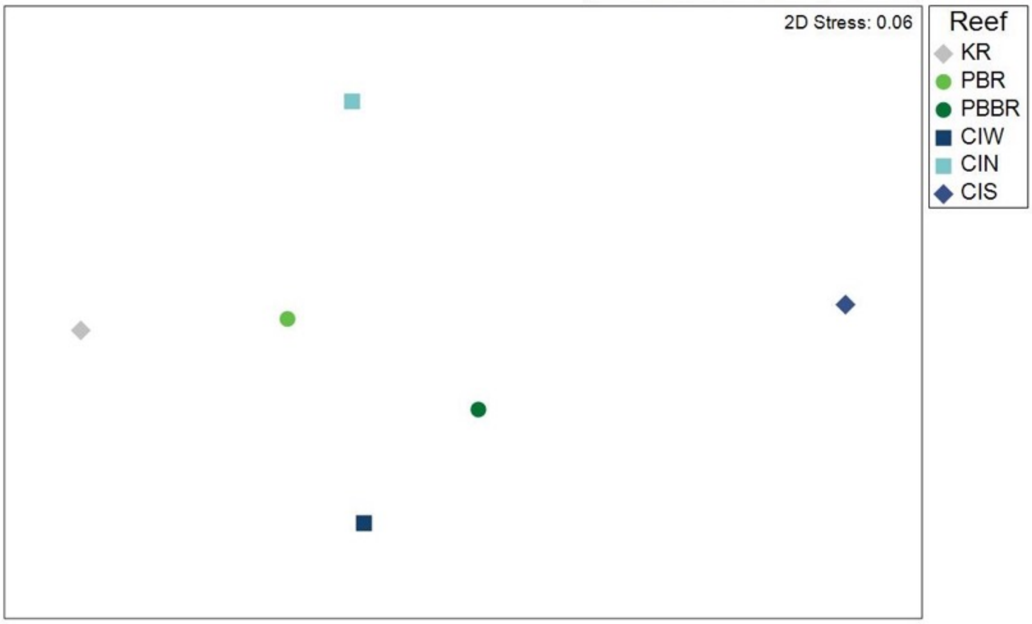


Figure 3.18 nMDS ordination of the differences in the composition of fish assemblage among reefs in 2021 [13]

3.3.1 Species Richness of Fish Assemblages

In 2021, total species richness varied among reefs, with the highest number of species recorded at Cook Island West (68 species) and the fewest species recorded at Cook Island South (39 species) (Table 3.1; Appendix D). The lowest average species richness was recorded at Cook Island South [14]. Species richness was also lower on Palm Beach Bait Reef, although did not differ significantly among the other reefs (Figure 3.19).

A variety of fish species have been recorded on the reefs during the various surveys between 1995 and 2021 and in the past few years, there has been little difference in the species richness between Kirra and the Palm Beach Reefs during any one survey (ESP 2020). This may be a result of these reefs having similar availability of primary food sources or providing relatively similar structural habitat in an otherwise featureless sandy bottom coastline. Temporal differences in the numbers of species identified may be related to differences in sampling techniques, personnel completing the surveys and monitoring events occurring during different times of the year (between February and July).

[13] nMDS ordination plot provides a two-dimensional map so that the rank order distance between samples match the rank order similarity from a matrix of sample pairs. The placement of points represents the similarity or difference among samples (in this case in the composition of assemblages - presence and abundance of each taxon). Samples that appear closer on the ordination are more similar in composition, and those further apart are more dissimilar or share fewer traits.
[14] PERMANOVA for differences in species richness among reefs $F_{5,12} = 3.33$, $p = 0.037$; Pairwise comparisons among reefs CIS≠CIN=KR=PBR; CIS=CIW=PBBR; CIN=KR=PBR=CIW=PBBR at p=0.05.

Table 3.1 Total species richness and abundance among the reefs in 2021

	Total Species Richness*	Total Abundance (Pooled Max N)^
Kirra Reef	57	1132
Palm Beach Reef	58	852
Palm Beach Bait Reef	42	163
Cook Island North	64	609
Cook Island West	68	142
Cook Island South	39	49

* Total Species Richness collated from UBUBRUVS, ROV and diver recordings

^ Total Abundance calculated from UBUBRUVS recordings only

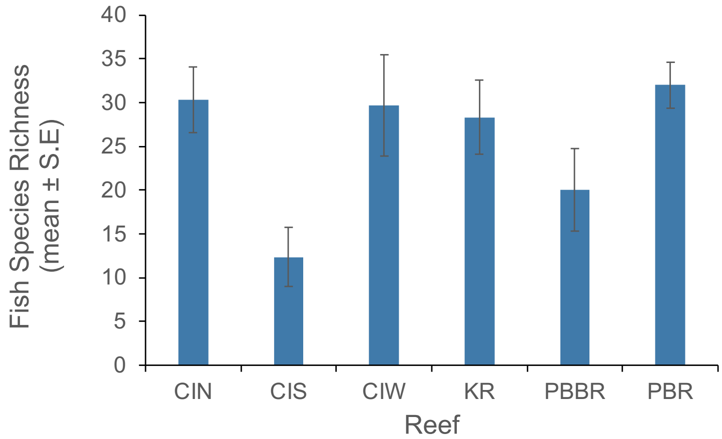


Figure 3.19 Average species richness (mean ± SE) of fish assemblages per reef

3.3.2 Relative Abundance of Fish Assemblages

The total abundance of fish, measured as the pooled Max N from UBRUVS, was highest at Kirra Reef (1132 individuals) and Palm Beach Reef (852 individuals) (Table 3.1). The lowest abundance was recorded at Cook Island South with only 49 individuals (Table 3.1). Differences in abundance among reefs were primarily driven by numbers of schooling fish. Abundant schools (approximately 550 to 1000 individuals) of yellowtail scad (*Trachurus novaezelandiae*) dominated fish assemblages at Kirra Reef (Figure 3.20a) and Palm Beach Reef and large schools (approximately 400 individuals) of eastern pomfred (*Schuettea scalaripinnis*) made up the majority of the total abundance at Cook Island North Reef (Figure 3.20b). Schooling species at Cook Island West Reef and Palm Beach Bait Reef included black rabbitfish (*Siganus fuscescens*), stripey (*Microcanthus strigatus*) and yellowtail scad (the latter only at PBBR), though individuals within schools were always ≤ 40. No schooling fish were detected on UBRUVS at Cook Island South during May 2021.

Several species of non-schooling fish were observed in similar abundances at all reefs including five wrasse species, dusky or greyhead surgeonfish (*Acanthurus nigrofuscus* or *A. nigroris*), bigscale scalyfin (*Parma oligolepis*) and yellowfin bream or tarwhine (*Acanthopagrus australis* or *Rhabdosargus sarba*). Excluding Cook Island South Reef, Inshore surgeonfish (*Acanthurus grammoptilus*), threadfin butterflyfish (*Chaetodon auriga*), threebar porcupinefish (*Dicotylichthys punctulatus*), stars-and-stripes pufferfish (*Arothron hispidus*) and blacksaddle goatfish (*Parupeneus spilurus*) also occurred in similar numbers at all reefs (Figure 3.21; Appendix D).

a)

b)

Figure 3.20 Schools of a) yellowtail scad at Kirra Reef and b) eastern pomfred at Cook Island North Reef

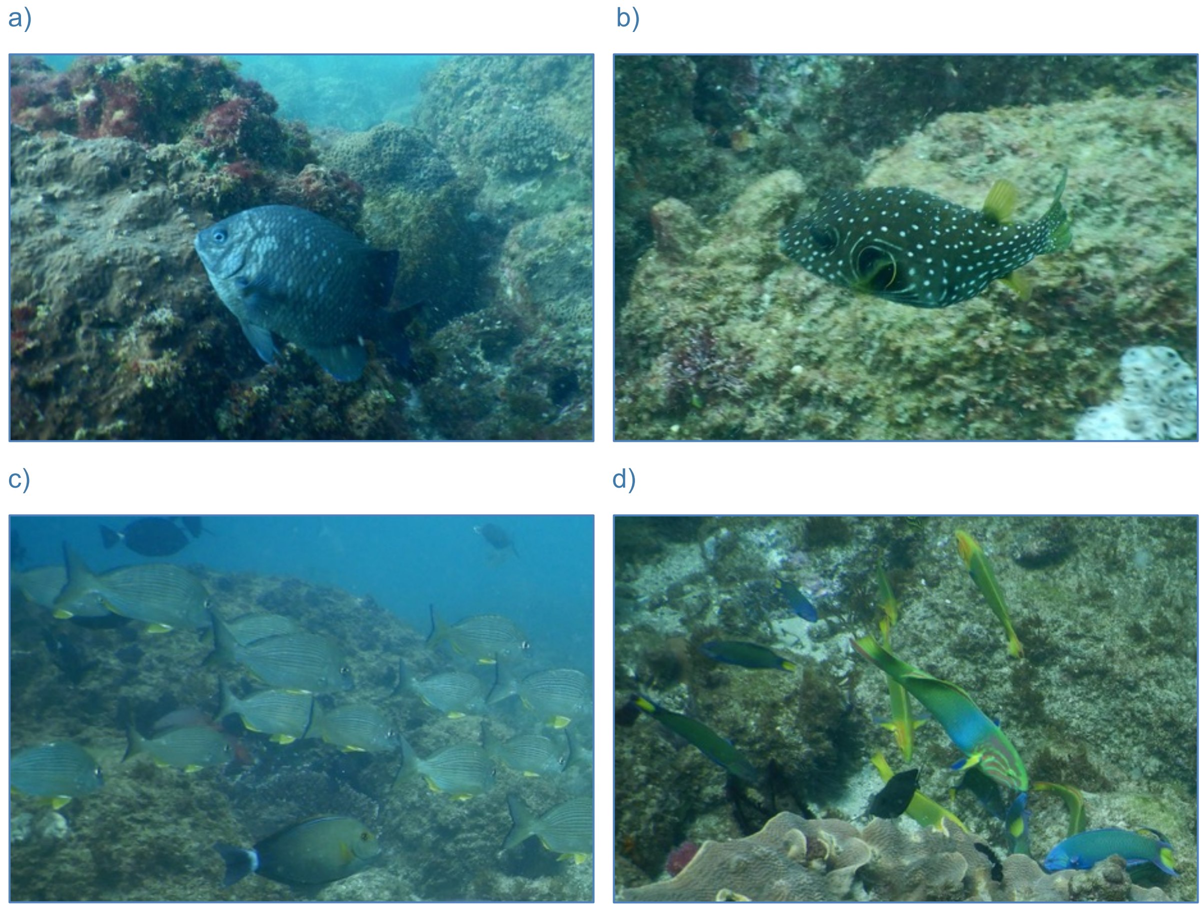


Figure 3.21 Fish species commonly seen at most reefs in 2021 including a) bigscale scalyfin, b) stars-and-stripes puffer, c) yellowfin bream and inshore surgeonfish, and d) moon wrasse and green moon wrasse

3.3.3 Trophic Level and Habitat Preferences of Fish

The contribution of different trophic levels to the diversity of fish assemblages (trophic composition) did not differ substantially among reefs (Figure 3.22). Carnivorous species were the most diverse group at all reefs (39 to 53% of species), with omnivores the next most diverse group (19 to 33% of species). While there was some variation in the proportion of herbivores, omnivores with herbivorous tendencies and planktivores among reefs, these groups each contributed ≤ 15% to the trophic composition at each reef. In May 2021, corallivores were generally the least diverse group and were absent from the fish assemblage recorded at Cook Island South (Figure 3.22).

In May 2021, 83 to 97% of species recorded at each reef were reef-associated species, which was expected given the dominance of rocky reef habitat surveyed (Appendix D). Pelagic species were slightly more diverse at Cook Island North and Palm Beach Reef than on the other reefs (5 and 4 species, respectively; Appendix D).

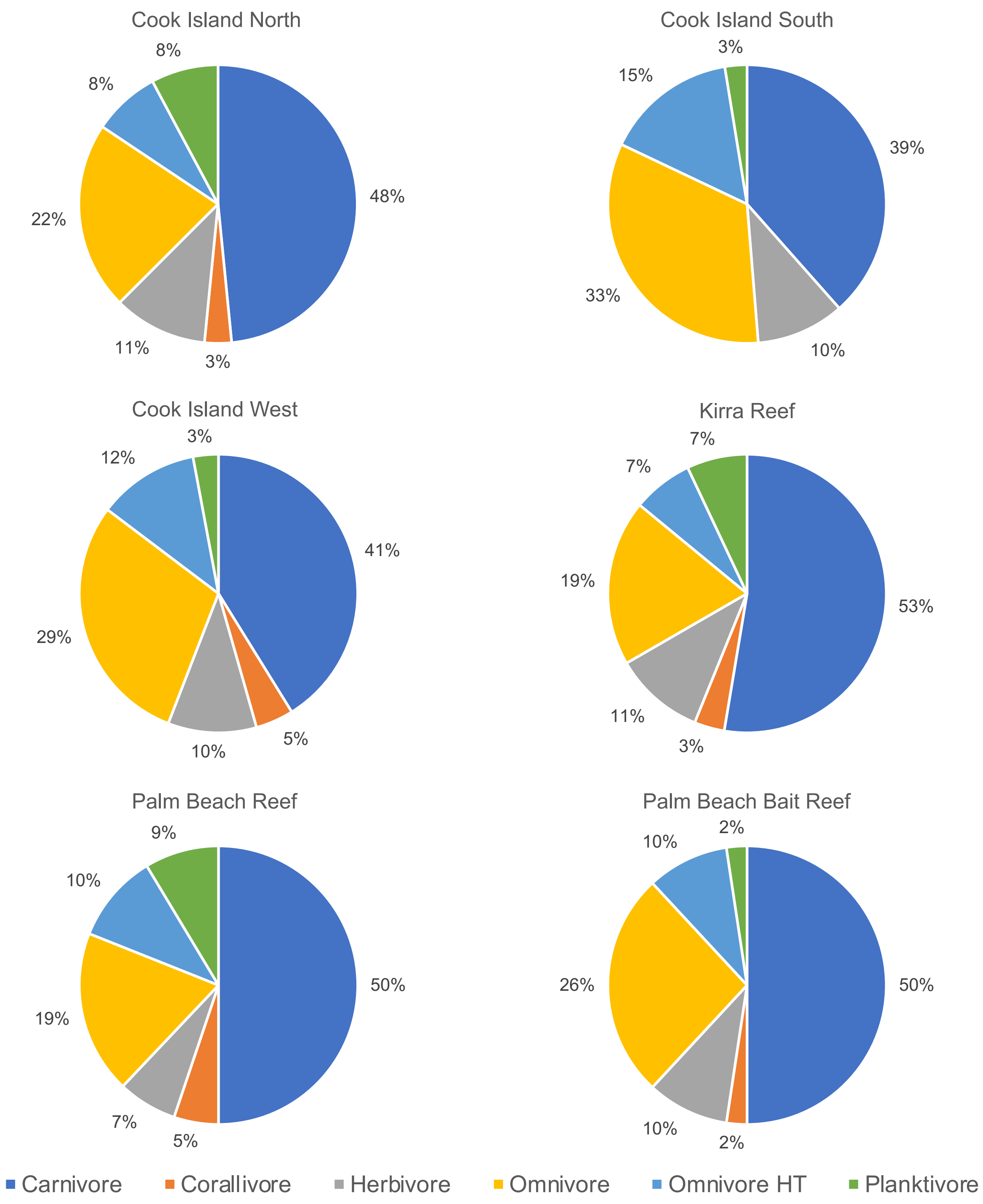


Figure 3.22 Trophic level composition of fish communities (% of species) recorded at each reef (based on UBRUVS, ROV and diver recordings)

3.4 Threatened and Invasive Species

3.4.1 Species of Conservation Significance

Of the species listed on the Protected Matters Search Tool as potentially occurring in the area, several species of conservation significance are known or likely to occur around the reefs, including:

- black rockcod (*Epinephelus daemelii*) listed as vulnerable
- white's seahorse (*Hippocampus whitei*) listed as endangered
- humpback whale (*Megaptera novaeangliae*) listed as vulnerable and migratory
- loggerhead turtle (*Caretta caretta*), listed as endangered and migratory
- green turtle (*Chelonia mydas*) listed as vulnerable and migratory
- leatherback turtle (*Dermochelys coriacea*) listed as endangered and migratory
- hawksbill turtle (*Eretmochelys imbricate*) listed as vulnerable and migratory
- flatback turtle (*Natator depressus*) listed as vulnerable
- grey nurse shark (*Carcharias taurus*) listed as critically endangered
- great white shark (*Carcharodon carcharias*) listed as vulnerable and migratory
- Indo-Pacific humpback dolphin (*Sousa chinensis*) listed as migratory, and
- manta ray (*Manta alfredi*) listed as migratory.

Several other species may occur or have suitable habitat recorded in the broader area, including:

- blue whale (*Balaenoptera musculus*) listed as endangered and migratory
- whale shark (*Rhincodon typus*) listed as vulnerable.
- olive southern right whale (*Eubalaena australis*), listed as endangered and migratory
- ridley turtle (*Lepidochelys olivacea*) listed as endangered and migratory

There are also several threatened and migratory bird species that are likely to use the reefs as feeding sites.

The only species of conservation significance (other than the blue grouper; refer to Section 3.3) recorded during the surveys was the green sea turtle (Figure 3.23), which were recorded at all reef locations.

Figure 3.23 Green turtle (*Chelonia mydas*) at Kirra Reef in 2021

3.4.2 Introduced Species

There are over 200 marine pests reported in Australian waters (DES 2020). Of these, the white colonial sea squirt (*Didemnum perlucidum*), which is listed as a prohibited marine animal under the *Biosecurity Act 2014,* has been recorded in the region (in Brisbane, > 50 km) (Queensland Government 2020c; NIMPIS 2021). Two other introduced marine species have been recorded from Brisbane, sea lettuce (*Ulva lactuca*) and isopod (*Sphaeroma walkeri*) (NIMPIS 2021).

No exotic or invasive species were recorded during surveys or during the analysis of photo-quadrats and video.

3.5 Abiotic Conditions

3.5.1 Water Quality

To assess the ambient water quality at each reef during the field survey, depth profiles for several physicochemical parameters were completed. In 2021, the temperature, concentration of dissolved oxygen, pH, turbidity and salinity were relatively consistent both with depth and among the reefs (Figure 3.24); although due to equipment failure, the turbidity was not recorded for Kirra Reef and Cook Island North. PAR was also measured at all sites, with benthic light attenuation ranging from 0.12 µmol/s^2 (at PBNR) to 1.07 µmol/s^2 (at CIS). Light was attenuated by between 51.9% (at CIS) and 84.7% (at PBBR) with depth relative to surface measurements. PAR can be influenced by a range of factors including the time when samples were collected and weather conditions (e.g. amount of incident sunlight due to cloud cover or season), which is more likely given that the turbidity remained low (<1 NTU) among all reefs.

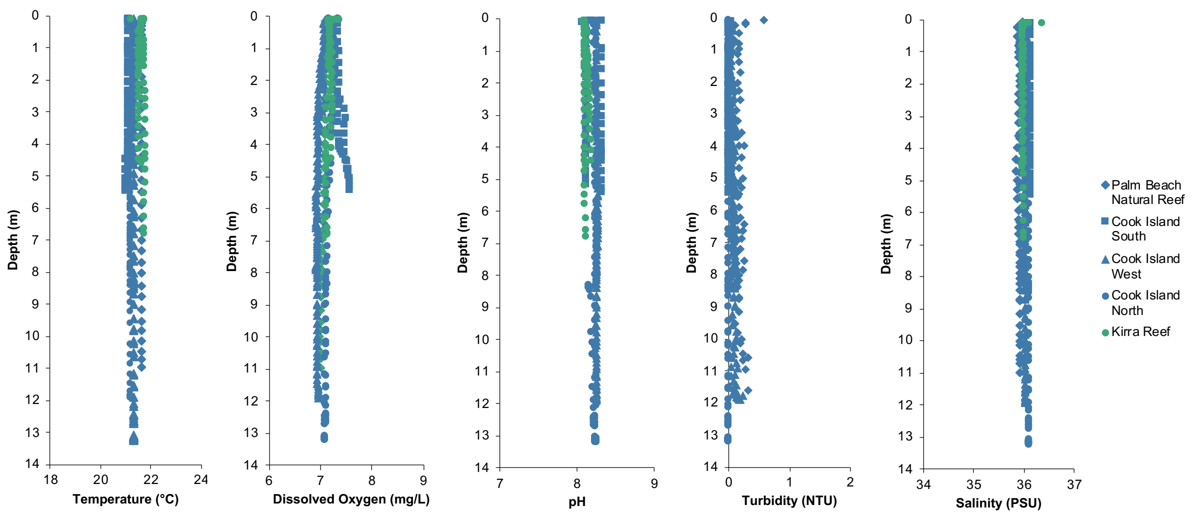


Figure 3.24 Vertical profiles of physicochemical water quality parameters among sites

3.5.2 Wave Conditions

The swell direction in the region typically ranges from a north-north-west to south-south-east direction (Ecosure 2016). Between 19 May 2020 and 19 May 2021, swell direction was predominantly from the east (47.7%) and northeast (47.3%), with most waves <1 m (30.9%) or 1 to 2 m (62.5%) (Figure 3.25). During the period assessed, significant wave heights (>3 m) were rare (<1%) and only occurred on 4 days (12, 13 and 14 December 2020 and 20 March 2021), predominantly from the east-north-east (Figure 3.25). Previous analyses of long-term (01/01/2000 to 31/05/2016) wave data for Tweed Heads indicates swell occurs predominately from an east (36%) or east-south-east (34%) direction and waves are generally < 1 m (26%) or 1 to 2 m (40%), with significant wave heights (>3 m) also rare (<1%) (Ecosure 2016). Overall, swell in the year prior to the survey (19 May 2020 to 19 May 2021) was typical of the region, with significant wave events unlikely to cause major changes to sand movements in the region.

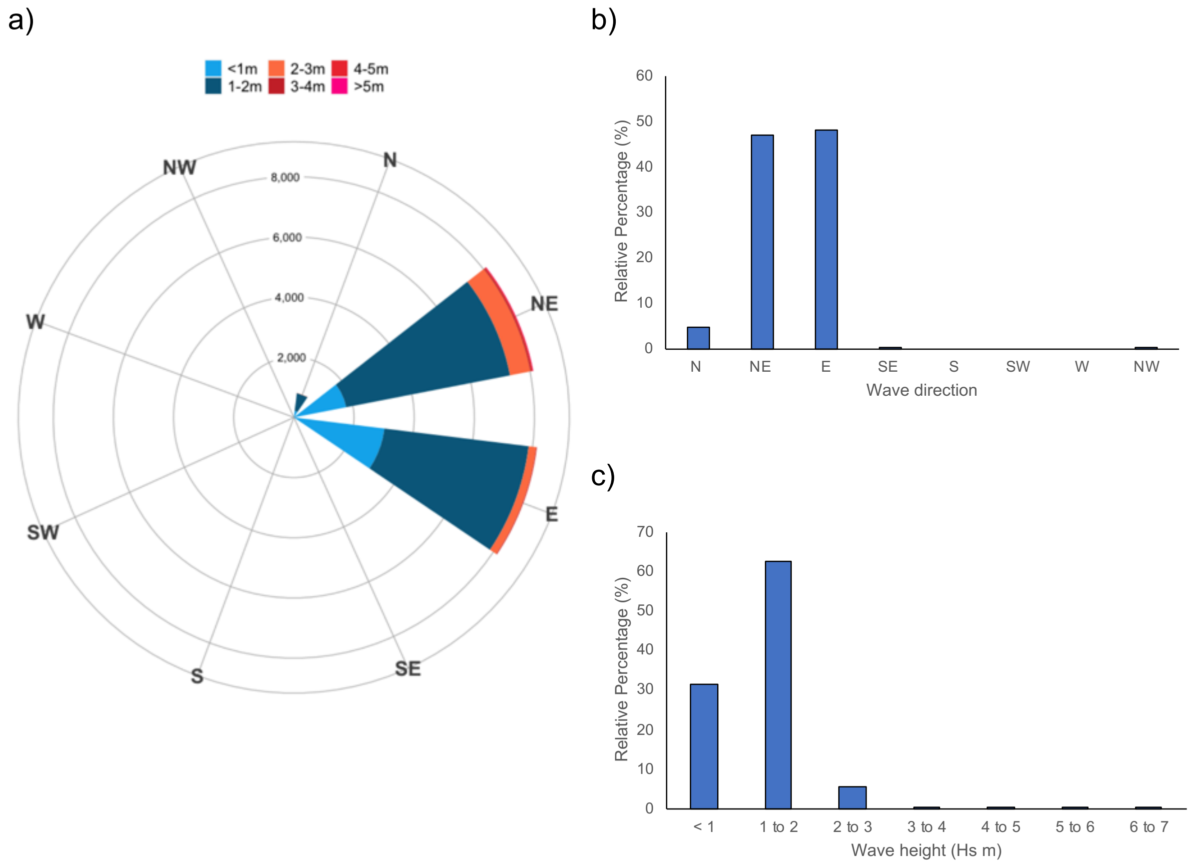


Figure 3.25 Wave data collected at Tweed Heads wave rider buoy between 19 May 2020 and 19 May 2021, showing a) wave heights and direction; b) relative percent frequency of wave direction and; c) relative precent frequency of wave height

4 Discussion and Conclusions

4.1 Changes in Reef Area at Kirra Reef

There have been large changes in the area of exposed rock at Kirra Reef through time, with periods of sand burial and exhumation, resulting in changes to the benthic communities growing on Kirra Reef. Prior to major artificial changes in sand movements (other than minor influences of the original Tweed River training walls built in 1891), Kirra Reef was partially covered by sand, which naturally varied as a result of longshore drift of sand and periods of storm activity. Between the 1960s to 1980s, sand supply to the area was depleted and large rocky reef areas to the south and east of the current extent of Kirra Reef were exposed, resulting from a range of factors including the extension of the Tweed River training walls completed 1965 and a series of successive high intensity east coast lows, including a cyclone in 1967. Beach nourishment works between the mid-1980s to 2001 (including stage 1 of the TSB project) resulted in sand accretion, with the extent of Kirra Reef decreasing (as predicted in the TSB EIS / IAS; Hyder Consulting 1997), but a relatively large area still remained uncovered. During the initial years of stage 2 of the TSB project, between 2001 to 2008, large quantities of sand were delivered to Southern Gold Coast beaches and as predicted in the EIS / IAS (Hyder Consulting 1997), the area of Kirra Reef decreased further. Between 2007 and 2008, Kirra Reef was almost completely covered with sand.

Sand delivery through the TSB project has been more consistent with natural longshore sand drift since 2009. In 2009, parts of Kirra Reef were uncovered, likely assisted by a series of storm events. The area of uncovered reef increased between 2009 and 2012 and has been relatively stable since 2012. The extent of Kirra Reef is unlikely to change substantially unless there are successive major storms in the region causing substantial changes to the position of the offshore bar along the beach (noting that cyclones in 2017 and 2019 caused relatively minor changes in total area of Kirra Reef) or major changes to sand delivery through the sand bypassing system.

The areal extent (based on aerial imagery provided by QLD Government) of Kirra Reef in June 2021, and changes in depth (based on 2019, 2020 and 2021 hydrographic surveys) were assessed. In May 2021, there had been an increase in reef areal extent and a corresponding increase in depth around some areas of the reef. The estimated areal extent of Kirra Reef was 4,930 m^2, which comprised 808 m^2 of recently exhumed reef in the eastern section and 4,122 m^2 of reef in the northern section. While this most recent estimate of Kirra Reef areal extent for the northern section of reef is the largest recorded since exhumation from complete burial in 2009, it is not substantially different to the relatively stable reef area that has been observed consistently since 2012 (particularly considering the potential margin of error associated with calculating the area from aerial images). This is indicative of balance in the sand transport budget as a result of past amendments to the TSB operation. The stability in the availability and extent of rock habitat has enabled the benthic community to increase in biodiversity, with an increase in the coverage of sessile invertebrates displacing foliose macroalgae and other early colonising species in some sections of the reef.

4.2 Benthic Communities

Following exhumation in 2009, the benthic faunal and floral communities on Kirra Reef have shown signs of ecological succession, starting with the recruitment of pioneer species such as foliose macroalgae and turf forming algae, and gradually becoming more similar in composition to reefs in the Gold Coast and Tweed Coast Region. However, in recent years the monitoring program has shown succession slowing with generally consistent differences in the composition of benthic communities on Kirra Reef and those at other reef locations. Benthic communities at Kirra Reef tend to be dominated foliose and / or turf forming macroalgae and ascidians, with a low coverage of soft and hard corals. In 2021, the benthic communities remained different to those on nearby reefs, although, they became more similar to nearby reefs than has been recorded in previous years (particularly in 2018 and 2019). Temporal variability among reefs has been attributed to natural variation (including physical disturbance from storm and ongoing disturbance from shifting sands and wave action) but may also be due to differences in the timing of when reef habitat became available, differences in the settlement and recruitment of benthic species and / or the survival due to differences in the assemblage of predators present at Kirra Reef relative to other reefs. Despite changes in the composition of benthic communities through time, it appears the overall coverage of sessile invertebrates on Kirra Reef has not changed substantially relative to other reefs. There continues to be a diverse sessile invertebrate assemblage on Kirra Reef that is consistent (relative to the degree of natural variability) with that occurring on several of the other reefs in the area, although benthic assemblages on Kirra Reef are not yet dominated by longer-lived hard coral species that are found on the reefs around Cook Island. Many of these species require a long period of suitable conditions to establish and grow to dominate the benthic assemblages.

4.2.1 Algal Assemblages

Fleshy macroalgae such as *Sargassum* can colonise bare substrata before other taxa such as sessile invertebrates, causing physical damage to sessile invertebrates that have recently settled, and preventing them from establishing on tropical coral reefs (Diaz-Pulido & McCook 2002). The high coverage of *Sargassum* on Kirra Reef in recent years is indicative of the more recent disturbance history at Kirra Reef, which may have been timed with a recruitment pulse enabling a high proportion of the area to be colonised by macroalgae (Kennelly 1987; McCook et al. 2001) or could reflect a reduced abundance of herbivorous fish and invertebrates such as sea urchins, which can be important in controlling fleshy macroalgae on reefs (McCook 1997; McCook et al. 2001). The recently exhumed eastern section of Kirra Reef is currently dominated by macroalgae including *Sargassum*. The exact mechanism for why the algal assemblages differ among the reefs has not been specifically assessed; however, it may be related to the timing of recruitment particularly given the dominance of macroalgae on sections of the recently exhumed eastern reef. Cook Island reefs and Palm Beach Reef are also likely to be more sheltered from wave action than Kirra Reef. While horizontal and vertical surfaces differed in terms of their coverage at Kirra reef (indicative of potential impacts from smothering by sand), sedimentation impacts on algal communities such as reduced crustose coralline algae (Fabricius and De'ath 2001) or reduced density and growth of young Sargassum (Umar et al. 1998) do not appear to be evident given the relatively similar or higher abundance of these species at Kirra Reef compared with that recorded on other reefs.

Of note, there was a moderate to dense patch of seagrass dominated by *Halophila ovalis* occurring on sand and boulder habitat adjacent to the Cook Island West location at Cook Island. Seagrass is protected under the NSW *Fisheries Management Act 1995.* Seagrass in this area appears healthy across the patch, with no substantial changes in the condition observed during the past two monitoring events, although a quantitative assessment of the distribution and density of seagrass habitat has not been completed.

4.2.2 Sessile Invertebrate Assemblages

Sessile invertebrate assemblages are often more diverse on vertical than horizontal surfaces due to a variety of factors such as the degree of competition or disturbance, availability of light, larval settlement preference and habitat complexity (Irving & Connell 2002; Walker & Schlacher 2014 and references cited within). Differences may also be due to variability in localised larval supply and recruitment processes. In 2021, the sessile invertebrate assemblages on Kirra Reef were more similar in diversity both in terms of the overall coverage and average number of species present between surface orientations and among reefs, than in the previous 2020 survey, and most similar in composition to the other nearshore reefs at Palm Beach and Palm Beach Bait reefs, which are not exposed to impacts associated with the TSB. While there was a lack of abundant hard coral species on Kirra Reef in 2021, and a small decline in the coverage of soft corals relative to 2020, ascidians and sponges remained the dominant invertebrates on Kirra Reef. The coverage of both hard and soft corals have typically been low in previous surveys and remain low on Kirra Reef relative to other more established reefs at Cook Island and Palm Beach. Generally, many of sessile invertebrates growing on Kirra Reef are susceptible to impacts from smothering and sand scouring, and the occurrence of a diverse group of sessile invertebrates on Kirra Reef, in 2021 is indicative of assemblages that are recovering from past impacts.

The reefs around Cook Island generally had a high coverage of long-lived hard corals (such as those from the genus *Paragoniastrea, Turbinaria* and encrusting *Porites*) compared with other reefs in the region. Particularly, Cook Island North and Cook Island South reef locations, which had a higher proportion of hard coral typically growing on horizontal surfaces. Despite the high coverage of hard corals at these sites, there were still differences in benthic communities among reef locations separated by only a few hundred metres, indicating a diverse array of communities around the island and the high degree of natural variability that exists among reefs in the region.

Due to the disturbance history of natural and artificial sand movement (e.g. almost complete burial between 2007 and 2008) and unique position (e.g. shallow, close to shore and subject to shifting sands and wave action), benthic communities at Kirra Reef are likely to always differ from those on surrounding reefs. This may be due to natural spatial variation in a range of factors, including larval supply and survival, density of predators and disturbance regime. For example, Palm Beach Reef is generally deeper, further offshore and less prone to wave action and Cook Island is likely to have greater nutrient availability due to the large bird colonies in the area fertilising the water from faeces. Ideally the comparative reefs would be standardised for reef depth and also distance from the shore so that they are exposed to relatively similar physical disturbance vectors; however, there are limited reefs along the coast that are representative of the range of conditions experienced at Kirra Reef. Maximising the number of reef locations provides the greatest opportunity to assess the relative change over time given the degree of natural variability that occurs among reef communities. Assessing the relative difference in assemblages among these comparative reefs therefore provides the degree of natural variation likely to occur due to other coastal processes operating in the local area. Based on the changes in reef communities over time, there is variability in the composition of benthic communities year to year; however, the overall community at Kirra Reef is becoming more similar to those at Palm Beach and Palm Beach Bait reefs.

4.2.3 Mobile Invertebrate Assemblages

In 2021, the mobile benthic invertebrate assemblages were consistent with that observed previously in 2020 (ESP 2020), with Kirra Reef having a slightly higher density than other sites, and being dominated by feather stars. Assemblages were most diverse at Cook Island West. Cook Island reefs had the highest diversity of mobile invertebrate assemblages compared with assemblages on the other reefs, including a variety of feather stars, sea urchins and sea stars, which is consistent with findings in 2020 (ESP 2020).

4.3 Fish Assemblages

Collectively, across reefs, a total of 129 bony and cartilaginous fish species from 44 families were recorded in May 2021. Similar to the 2020 survey (ESP 2020), Labridae (wrasses) and Pomacentridae (damselfishes) were the most diverse families. Fish species were generally common to the region, with most having been recorded during previous surveys; however, in the May 2021 survey, an additional 22 species were observed that had not been recorded in previous surveys.

Fish communities at Cook Island North and Cook Island West were more diverse than all other reef locations in 2020 (ESP 2020) and 2021; although, the overall composition of the community has generally been similar among reefs. The exception was the community composition of fish assemblages at Cook Island South in 2021, which differed from that recorded at Kirra Reef. The main difference in fish assemblages between reefs was the absence of yellowtail scad (*Trachurus novaezelandiae*) at Cook Island South, which was abundant at Kirra Reef.

No threatened or protected fish species listed under the Queensland's *Nature Conservation Act 1992* or nationally under the Commonwealth's *Environmental Protection and Biodiversity Conservation Act 1999* were recorded in the 2021 survey. The eastern blue grouper (*Achoerodus viridis*) was recorded at all Cook Island Reefs and Palm Beach Reef, and is partly protected under the NSW Fisheries Management (General) Regulation 2019 (i.e. must not be fished by any method other than a rod and line or a handline). No invasive fish species were recorded in 2021.

While total species richness recorded at Kirra Reef was moderate compared to other reefs, the average species richness was comparable to all other reefs except for Cook Island South, which had a lowest species richness of any reef surveyed. The assemblage at Kirra Reef had the highest abundance due to large schools of yellowtail scad. The trophic composition of the fish assemblage at Kirra Reef did not substantially differ compared with that surveyed at other reefs. Consistent with 2020 (ESP 2020), carnivorous species dominated the fish assemblage on Kirra Reef and omnivorous fish were also common in 2021. The fish assemblages were dominated by reef-associated species, which was expected given the dominance of rocky reef habitat surveyed.

4.3.1 Recommendations for Ongoing Monitoring

Sand delivery through the sand bypassing system has mimicked natural longshore movements since 2009, and in recent years (since 2016) benthic communities at Kirra Reef have been relatively stable (but subject to natural variation and ongoing disturbance from shifting sands and wave action). In recent years, results of the reef monitoring program have been relatively consistent, in that:

- The greatest temporal change at Kirra Reef has been in the area of exposed reef, which has remained relatively stable since 2012; with a large area of the northern reef exposed and small areas of the eastern section exhumed at times;
- Benthic communities at Kirra Reef have been dominated by macroalgae and ascidians, with generally low coverage of soft and hard corals relative to other reefs; and,
- Benthic communities at Kirra Reef have become more similar in composition over time to communities occurring on comparative reefs in the region, but still remain significantly different, most likely due to differences in the disturbance history. Despite the apparent differences, the community on Kirra Reef has a diverse community of sessile invertebrates, macroalgae and fish, which is generally representative of the region.

Given the consistent results over the past few years of monitoring, it is recommended that the program shifts from an annual monitoring program to an event-based monitoring program using suitably derived environmental and operational based triggers for ecological monitoring components (i.e. monitoring of benthic communities). The proposed triggers could include operational changes in TSB and/or indicators directly related to sand deposition such as sedimentation above a threshold (as measured using hydrographic survey) or abiotic changes to the accumulation of sand including a substantial change in the accretion / erosion of sand around the reef measured through changes in reef area from aerial photos or hydrographic survey.

It is recommended that ongoing monitoring at Cook Island Aquatic Reserve following any sand disposal activities be completed at adequate spatial and temporal scales to determine any potential impacts of future TSB operations adjacent to the Reserve. An ongoing monitoring program should focus on key indicator species that are known to be impacted by changes in sedimentation such as the coverage of hard and soft corals, ascidians and seagrass. Note that seagrass has only been recorded at one area around Cook Island, therefore a direct measure of impact before, during and after sand disposal would be necessary as suitable comparative areas may be difficult to identify.

Monitoring sedimentation would also provide a leading indicator of the potential for any impact to benthic communities and may also be used to trigger additional assessment of the benthic communities, where background rates of sedimentation are exceeded.

5 References

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Appendix A Areal Extent

Table A.5.1 Approximate areal extent of Kirra Reef, Palm Beach Reef and Cook Island Reef (data not available in all years)[1]

Date	Area (m^2)					
	Kirra Reef				Palm Beach Reef	Cook Island Reef
	Northern	Inner Western	Eastern	Total		
June 2021*	4,122	0	808	4,930	-	-
May 2020*	3,678	0	0	3,678	-	-
May-2019	3,161	0	0	3,161	-	-
May-2018	2,659	0	0	2,659	-	-
Feb-2017	3,263	0	0	3,263	-	-
May-2016	3,326	0	0	3,326	118,146	388,072
Mar-2015	2,672	0	116	2,788	-	-
Jun-2014	-	-	-	-	-	383,495
Apr-2014	2,920	0	0	2,920	117,960	-
Jun-2013	2,801	0	0	2,801	-	385,849
May-2013	3,589	0	0	3,539	-	-
Aug-2012	3,700	0	0	3,700	-	-
Nov-2011	1,044	0	0	1,044	-	-
Jul-2010	-	-	-	-	115,397	-
May-2010	965	0	0	965	-	-
Nov-2009	868	0	141	1,009	-	-
Apr-2004	1,578	0	273	1,851	-	-
Nov-2003	3,369	0	0	3,369	-	-
Aug-2002	8,442	0	73	8,515	-	-
Feb-2001	11,194	2,156	7,048	20,398	-	-
Oct-1996	3,700	3,600	9,200	16,500	-	-
Jan-1995	9,090	11,998	19,725	40,813	-	-
Nov-1989	10,200	65,400	22,500	38,100	-	-
Nov-1974	6,400	-	-	-	-	-
Feb-1972	6,800	100	17,800	24,700	-	-
1962 to 1965	4,850 to 7,800	0 to 4,900	600 to 2,150	7,000 to 13,300	-	-
Oct-1962	-	3,800	600	4,400	-	-
Nov-1935	1,800	-	1,600	3,400	-	-
Sep-1930	5,500	-	1,000	6,500	-	-

1 Data prior to 2020 sourced from Ecosure 2016 and frc environmental 2019, and references herein.
* Imagery based on 10 cm resolution imagery collected in May 2020 and June 2021 Datum: GDA2020
– Data not available
^ note that at this time there were three sections to the reef, an inner southern section, eastern section and the northern section of the reef, of which the present-day reef was part of, in deeper water. At this time the northern section of the reef was approximately 5900 m^2

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Appendix B Detailed Statistical Analyses

Table B.5.2 PERMANOVA of the difference in the composition of benthic communities among reefs in 2021

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	6460	3.32	**0.004**
Reef	5	36136	8.85	**0.001**
Site (Reef)	12	4085	4.74	**0.001**
Orientation x Reef	5	3415	1.75	**0.022**
Orientation x Site (Reef)	12	1948	2.26	**0.001**
Error	504	861		
Pairwise Comparisons	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
KR vs PBR	3.13	**0.001**	2.40	**0.004**
KR vs PBBR	2.88	**0.001**	2.54	**0.002**
KR vs CIW	3.87	**0.001**	2.63	**0.001**
KR vs CIS	2.54	**0.001**	2.58	**0.001**
KR vs CIN	3.25	**0.001**	2.96	**0.001**
CIW vs CIN	2.48	**0.001**	2.04	**0.003**
CIW vs CIS	1.99	**0.003**	2.08	**0.008**
CIW vs PBR	2.50	**0.001**	2.36	**0.005**
CIN vs CIS	1.53	**0.026**	1.98	**0.005**
CIN vs PBR	2.36	**0.001**	2.68	**0.002**
CIS vs PBR	2.03	**0.002**	2.18	**0.003**
CIS vs PBBR	1.99	**0.001**	3.15	**0.001**
CIW vs PBBR	2.41	**0.002**	4.00	**0.001**
CIN vs PBBR	2.51	**0.001**	4.78	**0.001**
PBR vs PBBR	1.63	**0.039**	1.93	**0.012**
d) Horizontal vs Vertical	t Value	P (MC)		
KR	1.15	0.328		
PBR	0.62	0.828		
PBBR	2.46	**0.004**		
CIW	1.24	0.244		
CIN	1.58	**0.046**		
CIS	1.46	**0.048**		

Significant tests at $p < 0.05$ are **bold**. P(Perm) are the p-values derived using the permutational method. P(MC) are p-values derived using the Monte Carlo method, used when there are low numbers of possible permutations (i.e. <100).

Table B.5.3 SIMPER of the difference in the composition of benthic communities between horizontal and vertical surfaces on Kirra Reef

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Horizontal	Vertical	Average dissimilarity = 46.64		
Turf forming algae	37.1	43.4	11.0	1.4	23.6
Sargassum sp	14.4	12.4	8.2	1.2	17.6
Polycarpa procera	4.9	7.0	4.9	0.8	10.6
Articulate coralline algae	6.5	3.8	4.1	0.9	8.7
Pyura stolonifera	5.6	5.7	3.5	1.1	7.5
Herdmania momus	1.5	2.7	2.0	0.7	4.3
Didemnum sp. *1*	1.9	2.8	1.7	1.0	3.7
Cnemidocarpa stolonifera	1.5	2.2	1.3	1.1	2.8
Trichomya hirsuta	0.4	2.1	1.3	0.6	2.7
Heteractis sp. 1	1.3	1.1	1.1	0.7	2.4
Polycarpa pigmentata	0.7	1.4	0.9	0.8	2.0
Dictyota spp	1.0	0.6	0.8	0.7	1.7
Padina spp	0.3	0.9	0.7	0.5	1.5
Haliclona sp. 1	0.5	0.8	0.7	0.7	1.4

Table B.5.4 PERMANOVA of the difference in the composition of algal assemblages among reefs in 2021

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	278	0.49	0.740
Reef	5	16568	8.23	**0.001**
Site (Reef)	12	2014	5.36	**0.001**
Orientation x Reef	5	1341	2.39	**0.030**
Orientation x Site (Reef)	12	562	1.50	0.030
Error	504	376		
Pairwise Tests	b) Horizontal Surfaces		c) Vertical Surfaces	
	t Value	P (MC)	t Value	P (MC)
KR vs PB	4.66	0.001	2.48	0.024
KR vs PBBR	4.18	0.001	2.57	0.018
KR vs CIW	4.58	0.001	2.61	0.022
KR vs CIS	2.87	0.003	2.11	0.023
KR vs CIN	4.19	0.004	2.61	0.020
CIW vs CIN	2.76	0.006	1.97	0.032
CIW vs CIS	2.33	0.021	2.10	0.020
CIW vs PB	2.15	0.031	1.74	0.067
CIN vs CIS	1.82	0.064	1.85	0.059
CIN vs PB	2.19	0.044	1.84	0.081
CIS vs PB	1.54	0.139	0.93	0.491
CIS vs PBBR	1.05	0.386	1.72	0.094
CIW vs PBBR	2.40	0.035	4.02	0.003
CIN vs PBBR	2.37	0.029	5.47	0.001
PB vs PBBR	1.27	0.266	2.67	0.024
d) Horizontal vs Vertical	t Value	P (MC)		
KR	1.10	0.379		
PBR	0.13	0.947		
PBBR	9.23	**0.004**		
CIW	1.63	0.149		
CIN	1.45	0.172		
CIS	0.81	0.615		

Table B.5.5 PERMANOVA of the difference in the coverage of algae among reefs in 2021

Source	df	a) Macroalgae MS	Pseudo-F	P (perm)	(b) Turfing Algae MS	Pseudo-F	P (perm)	(c) Coralline Algae MS	Pseudo -F	P (perm)
Orientation	1	0.4	0.01	0.922	54	0.23	0.650	8	0.09	0.755
Reef	5	3454.7	10.47	**0.007**	6322	5.34	**0.007**	619	4.43	**0.025**
Site (Reef)	12	330.0	9.41	**0.001**	1183	5.60	**0.001**	140	4.39	**0.001**
Orientation x Reef	5	60.4	1.81	0.174	994	4.30	**0.020**	138	1.56	0.262
Orientation x Site (Reef)	12	33.4	0.95	0.512	231	1.09	0.380	89	2.80	**0.001**
Error	504	35.1			211			32		

Pairwise Tests	d) Reef t	P (MC)	(e) Horizontal t	P(MC)	(f) Vertical t	P(MC)	(g) Reef t	P(MC)
KR vs PB	3.40	**0.021**	6.27	**0.007**	1.92	0.139	0.95	0.431
KR vs PBBR	3.41	**0.026**	4.29	**0.016**	0.36	0.727	2.26	0.103
KR vs CIW	1.33	0.250	11.46	**0.001**	3.26	**0.027**	1.17	0.303
KR vs CIS	3.20	**0.046**	1.48	0.221	0.81	0.465	0.26	0.791
KR vs CIN	3.35	**0.019**	5.45	**0.009**	2.69	0.050	0.88	0.434
CIW vs CIN	4.61	**0.015**	3.25	**0.029**	1.64	0.161	3.06	**0.046**
CIW vs CIS	4.25	**0.011**	2.48	0.066	1.82	0.117	1.80	0.121
CIW vs PB	4.73	**0.008**	2.02	0.109	1.48	0.201	0.52	0.646
CIN vs CIS	3.56	0.031	0.99	0.374	1.11	0.338	2.10	0.106
CIN vs PB	1.26	0.266	0.91	0.444	0.41	0.668	3.15	**0.046**
CIS vs PB	5.26	**0.006**	1.46	0.225	0.75	0.513	1.76	0.160
CIS vs PBBR	6.50	**0.004**	0.89	0.430	1.23	0.279	7.67	**0.003**
CIW vs PBBR	4.77	**0.007**	2.68	0.051	4.91	**0.013**	1.75	0.163
CIN vs PBBR	1.93	0.127	0.09	0.938	5.18	**0.010**	6.00	**0.003**
PB vs PBBR	0.61	0.610	0.86	0.430	2.97	**0.045**	3.82	**0.016**

Table B.5.6 SIMPER of the differences in the average coverage of algae among pairs of reefs

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Kirra	Palm Beach	Average dissimilarity = 35.37		
Turf	40.3	56.7	19.7	1.4	55.8
Sargassum sp	13.4	0.0	11.6	1.1	32.8
ACA	0.1	3.0	2.6	0.6	7.4
	Kirra	Palm Beach Bait	Average dissimilarity = 33.63		
Turf	40.3	47.2	18.9	1.4	56.2
Sargassum sp	13.4	0.1	13.1	1.1	38.9
	Kirra	Cook Is. West	Average dissimilarity = 37.77		
Turf	40.3	63.9	20.9	1.5	55.3
Sargassum sp	13.4	0.8	10.0	1.1	26.4
Dictyota sp	0.8	4.4	3.4	0.9	8.9
	Kirra	Cook Is. North	Average dissimilarity = 34.35		
Turf	40.3	56.0	19.5	1.4	56.6
Sargassum sp	13.4	0.0	11.8	1.1	34.3
	Kirra	Cook Is. South	Average dissimilarity = 38.39		
Turf	40.3	48.7	20.5	1.3	53.4
Sargassum sp	13.4	0.1	12.5	1.0	32.6
Coralline Algae	0.1	3.6	3.2	0.5	8.3
	Cook Is. West	Cook Is. North	Average dissimilarity = 20.50		
Turf	63.9	56.0	12.3	1.2	59.8
Dictyota sp	4.4	0.0	3.3	0.8	16.2
Coralline Algae	0.7	1.7	1.5	0.7	7.3
Padina sp	2.0	0.0	1.5	0.5	7.2
	Cook Is. West	Cook Is. South	Average dissimilarity = 29.90		
Turf	63.9	48.7	19.7	1.2	65.8
Dictyota sp	4.4	0.4	3.5	0.9	11.8
Coralline Algae	0.7	3.6	2.9	0.5	9.7
Padina sp	2.0	0.2	1.7	0.5	5.5
	Cook Is. North	Cook Is. South	Average dissimilarity = 25.05		
Turf	56.0	48.7	20.0	1.2	79.9
Coralline Algae	1.7	3.6	3.8	0.6	15.0
	Cook Is. West	Palm Beach	Average dissimilarity = 21.56		
Turf	63.9	56.7	12.6	1.2	58.6
Dictyota sp	4.4	0.0	3.3	0.8	15.2
Coralline Algae	0.7	3.0	2.4	0.6	11.1
Padina sp	2.0	0.0	1.5	0.5	6.8
	Cook Is. North	Palm Beach	Average dissimilarity = 17.51		
Turf	56.0	56.7	14.0	1.2	79.8

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Coralline Algae	1.7	3.0	3.1	0.7	17.7
	Cook Is. South	Palm Beach	Average dissimilarity = 25.89		
Turf	48.7	56.7	20.2	1.2	78.1
Coralline Algae	3.6	3.0	4.6	0.7	17.6
	Cook Is. West	Palm Beach Bait	Average dissimilarity = 26.58		
Turf	63.9	47.2	18.8	1.3	70.7
Dictyota sp	4.4	0.0	3.6	0.8	13.7
Padina sp	2.0	0.0	1.6	0.5	6.1
	Cook Is. North	Palm Beach Bait	Average dissimilarity = 20.35		
Turf	56.0	47.2	18.3	1.3	90.1
	Cook Is. South	Palm Beach Bait	Average dissimilarity = 26.37		
Turf	48.7	47.2	21.8	1.3	82.5
Coralline Algae	3.6	0.0	3.4	0.5	12.9
	Palm Beach	Palm Beach Bait	Average dissimilarity = 30.4		
Turf	56.7	47.2	18.8	1.3	86.2
Coralline Algae	3.0	0.0	2.8	0.6	12.8

ACA = Articulate Coralline Algae

Table B.5.7 PERMANOVA of the difference in the composition of sessile invertebrate assemblages among reefs in 2021

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	22284	3.72	**0.001**
Reef	5	86688	8.68	**0.001**
Site (Reef)	12	9981.6	3.69	**0.001**
Orientation x Reef	5	10214	1.71	**0.008**
Orientation x Site (Reef)	12	5983.8	2.21	**0.001**
Error	504	2704		
Pairwise Tests	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
KR vs PBR	2.17	**0.003**	2.56	**0.001**
KR vs PBBR	1.74	**0.021**	2.84	**0.001**
KR vs CIW	2.22	**0.002**	2.27	**0.001**
KR vs CIS	2.34	**0.001**	3.24	**0.001**
KR vs CIN	2.43	**0.001**	3.05	**0.001**
CIW vs CIN	2.36	**0.001**	1.88	**0.003**
CIW vs CIS	2.12	**0.001**	2.25	**0.001**
CIW vs PBR	2.86	**0.001**	2.92	**0.001**
CIN vs CIS	1.30	0.067	1.89	**0.001**
CIN vs PBR	2.42	**0.001**	2.87	**0.001**
CIS vs PBR	2.30	**0.001**	2.75	**0.001**
CIS vs PBBR	2.26	**0.001**	3.45	**0.001**
CIW vs PBBR	2.46	**0.001**	3.42	**0.001**
CIN vs PBBR	2.48	**0.001**	3.80	**0.001**
PBR vs PBBR	1.71	**0.018**	1.73	**0.008**
d) Horizontal vs Vertical	t Value	P (MC)		
KR	1.27	0.189		
PBR	1.03	0.408		
PBBR	1.71	**0.021**		
CIW	1.68	**0.015**		
CIN	1.49	**0.032**		
CIS	1.38	0.080		

Significant tests at $p < 0.05$ are **bold**. P(Perm) are the p-values derived using the permutational method. P(MC) are p-values derived using the Monte Carlo method, used when there are low numbers of possible permutations (i.e. <100).

Table B.5.8 SIMPER of the differences in the average coverage of sessile invertebrate taxonomic groups among pairs of reefs on horizontal surfaces

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Kirra Reef	Palm Beach	Average dissimilarity = 86.3		
Pyura stolonifera	5.6	13.8	22.2	1.1	25.8
Trichomya hirsuta	0.4	11.3	18.5	0.9	21.5
Polycarpa procera	4.9	0.2	7.0	0.7	8.1
Heteractis sp.	1.3	1.1	3.8	0.6	4.5
Amphibalanus spp.	0.0	1.9	3.7	0.5	4.3
Didemnum sp. 1	1.9	0.0	3.4	0.8	4.0
Cnemidocarpa stolonifera	1.5	0.1	2.6	0.7	3.0
Spheciospongia confoederata	0.3	1.0	2.3	0.5	2.6
Herdmania momus	1.5	0.2	2.2	0.5	2.6
Dendronephtya sp. 2	0.2	0.6	1.4	0.3	1.6
Polycarpa pigmentata	0.7	0.0	1.4	0.5	1.6
Turbinaria mesenterina	0.0	0.9	1.4	0.2	1.6
Haliclona sp. 2	0.0	0.6	1.1	0.4	1.3
encrusting porifera sp. 5	0.4	0.3	1.1	0.5	1.3
Pseudodistoma inflatum	0.0	0.5	1.0	0.4	1.1
Protopalythoa sp.	0.0	0.6	1.0	0.4	1.1
Zenia sp. 2	0.0	0.5	1.0	0.3	1.1
Chondrilla sp. 1	0.0	0.5	1.0	0.3	1.1
Acanthastrea bowerbanki	0.0	0.4	0.8	0.2	0.9
Didemnum membranaceum	0.4	0.0	0.7	0.4	0.8
Aplysilla sp. 3	0.3	0.1	0.7	0.3	0.8
	Kirra Reef	Bait Reef	Average dissimilarity = 83.8		
Polycarpa procera	4.9	9.1	17.9	1.0	21.4
Trichomya hirsuta	0.4	7.2	13.9	0.9	16.6
Pyura stolonifera	5.6	3.8	12.2	0.9	14.6
Cnemidocarpa stolonifera	1.5	1.3	5.3	0.6	6.4
Didemnum sp. 1	1.9	0.6	4.9	0.6	5.8
Spheciospongia confoederata	0.3	1.9	3.7	0.6	4.4
Polycarpa pigmentata	0.7	1.2	3.6	0.6	4.3
Haliclona sp. 2	0.0	1.9	3.6	0.7	4.3
Heteractis sp.1	1.3	0.0	2.6	0.4	3.1
Herdmania momus	1.5	0.2	2.4	0.5	2.9
Didemnum membranaceum	0.0	0.4	1.2	0.3	1.4
Spheciospongia sp. 4	0.4	0.1	1.1	0.3	1.3
Haliclona sp. 1	0.0	0.5	0.9	0.4	1.1
Tedania sp.1	0.5	0.1	0.9	0.3	1.1
	Kirra Reef	Cook Is. West	Average dissimilarity = 2.0		
Pyura stolonifera	5.6	0.2	16.1	1.2	17.5
Polycarpa procera	4.9	0.2	12.2	0.7	13.2
Cnemidocarpa stolonifera	1.5	1.8	10.5	0.7	11.4
Didemnum sp. 1	1.9	0.0	8.3	0.7	9.0
Heteractis sp.1	1.3	0.8	6.8	0.5	7.4
Polycarpa pigmentata	0.7	0.5	4.7	0.6	5.1
Herdmania momus	1.5	0.3	4.2	0.5	4.5
Turbinaria mesenterina	0.0	0.5	2.5	0.3	2.7
Spheciospongia confoederata	0.3	0.5	2.3	0.3	2.5
Trichomya hirsuta	0.4	0.0	2.2	0.3	2.4
Didemnum membranaceum	0.4	0.0	2.0	0.3	2.1
Cladiella sp. 2	0.0	0.5	1.8	0.3	2.0

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Cladiella sp. 3	0.0	0.4	1.4	0.2	1.5
Microcosmus exasperatus	0.0	0.2	1.3	0.2	1.4
encrusting porifera sp. 5	0.4	0.0	1.2	0.4	1.3
Lobophyton sp. 2	0.0	0.2	1.1	0.2	1.2
Haliclona sp. 1	0.5	0.0	1.1	0.4	1.1
Aplysilla sp. 3	0.3	0.0	0.8	0.4	0.9
Dendronephtya sp. 2	0.2	0.1	0.8	0.3	0.9
Clathria sp.	0.0	0.2	0.8	0.3	0.9
	Kirra Reef	Cook Is. North	Average dissimilarity = 94.0		
Herdmania momus	1.5	5.8	11.1	1.0	11.8
Pyura stolonifera	5.6	1.3	9.2	1.1	9.8
Turbinaria mesenterina	0.0	4.6	8.4	0.5	9.0
Polycarpa procera	4.9	0.0	7.5	0.7	8.0
Spheciospongia sp. 4	0.0	3.5	6.5	0.5	6.9
Acanthastrea bowerbanki	0.0	2.3	4.7	0.4	5.0
Didemnum sp. 1	1.9	0.0	4.0	0.7	4.3
Heteractis sp.1	1.3	0.5	3.4	0.5	3.6
Porites sp. 2	0.0	1.8	3.1	0.3	3.3
Cnemidocarpa stolonifera	1.5	0.2	3.1	0.6	3.3
Acropora hyacinthis	0.0	1.2	2.4	0.4	2.5
Polycarpa pigmentata	0.7	0.5	2.2	0.6	2.4
Pocillopora damicornis	0.0	1.1	2.2	0.4	2.3
Iotrochota sp. 1	0.0	0.6	1.8	0.4	1.9
Microcosmus exasperatus	0.0	0.7	1.4	0.4	1.5
Favites sp.	0.0	0.9	1.4	0.2	1.5
Dendronephtya sp. 1	0.0	0.6	1.2	0.2	1.3
Paragoniastrea australensis	0.0	0.6	1.1	0.2	1.2
encrusting porifera sp. 5	0.4	0.2	1.1	0.5	1.1
Spheciospongia confoederata	0.3	0.3	1.0	0.4	1.1
Aplysilla sp. 3	0.3	0.3	0.9	0.4	1.0
Trichomya hirsuta	0.4	0.0	0.9	0.3	1.0
Acropora solitaryensis	0.0	0.5	0.9	0.2	1.0
Platygyra lamellina	0.0	0.5	0.9	0.2	0.9
Lobophyllia sp. 1	0.0	0.5	0.9	0.2	0.9
Acanthastrea sp. 2	0.0	0.4	0.9	0.3	0.9
Didemnum membranaceum	0.4	0.0	0.9	0.3	0.9
Acropora sp. 1	0.0	0.3	0.8	0.2	0.9
Pocillopora aliciae	0.0	0.3	0.8	0.3	0.8
Astrea curta	0.0	0.3	0.7	0.3	0.8
	Kirra Reef	Cook Is. South	Average dissimilarity = 96.9		
Pyura stolonifera	5.6	0.5	8.3	1.0	8.6
Polycarpa procera	4.9	0.3	7.1	0.7	7.3
Cladiella sp. 2	0.0	4.1	5.9	0.4	6.1
Discosoma rhodostoma	0.0	4.1	5.9	0.4	6.1
Herdmania momus	1.5	1.9	5.6	0.6	5.8
Lobophyton sp. 1	0.0	3.8	4.2	0.3	4.4
Lobophyton sp. 2	0.0	1.9	3.7	0.4	3.9
Paragoniastrea australensis	0.0	2.7	3.7	0.4	3.8
Didemnum sp. 1	1.9	0.1	3.6	0.7	3.8
Porites sp. 2	0.0	2.2	3.5	0.3	3.6
Porites sp. 1	0.0	2.5	3.4	0.5	3.5
Pocillopora damicornis	0.0	1.8	3.2	0.5	3.3
Cladiella australis	0.0	1.8	2.7	0.4	2.8
Cnemidocarpa stolonifera	1.5	0.1	2.7	0.6	2.7
Spheciospongia sp. 4	0.0	1.7	2.6	0.4	2.7

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Turbinaria mesenterina	0.0	1.5	2.5	0.3	2.6
Acropora hyacinthis	0.0	1.5	2.3	0.3	2.4
Heteractis sp.1	1.3	0.1	2.2	0.4	2.3
Cladiella sp. 1	0.0	1.2	2.1	0.3	2.1
Porites lutea	0.0	1.3	2.0	0.2	2.0
Polycarpa pigmentata	0.7	0.4	1.8	0.6	1.9
Acanthastrea sp. 2	0.0	0.8	1.8	0.3	1.9
Sarcophyton sp. 2	0.0	0.8	1.3	0.2	1.4
Acanthastrea bowerbanki	0.0	0.8	1.1	0.4	1.2
Trichomya hirsuta	0.4	0.1	1.1	0.3	1.1
Acropora sp. 1	0.0	0.5	1.0	0.2	1.0
encrusting porifera sp. 5	0.4	0.0	0.8	0.4	0.8
Didemnum membranaceum	0.4	0.0	0.8	0.3	0.8
Microcosmus exasperatus	0.0	0.4	0.8	0.5	0.8
	Cook Is. West	Cook Is. North	Average dissimilarity = 95.7		
Herdmania momus	0.3	5.8	13.2	1.0	13.8
Turbinaria mesenterina	0.5	4.6	10.8	0.6	11.3
Spheciospongia sp. 4	0.1	3.5	7.9	0.5	8.3
Acanthastrea bowerbanki	0.3	2.3	6.3	0.5	6.6
Cnemidocarpa stolonifera	1.8	0.2	5.1	0.7	5.4
Porites sp. 2	0.0	1.8	3.7	0.3	3.9
Heteractis sp.1	0.8	0.5	3.4	0.4	3.5
Pyura stolonifera	0.2	1.3	3.3	0.6	3.4
Acropora hyacinthis	0.1	1.2	3.0	0.4	3.2
Pocillopora damicornis	0.2	1.1	2.9	0.4	3.0
Iotrochota sp. 1	0.1	0.6	2.4	0.4	2.5
Microcosmus exasperatus	0.2	0.7	2.2	0.5	2.3
Polycarpa pigmentata	0.5	0.5	2.2	0.6	2.3
Spheciospongia confoederata	0.5	0.3	1.8	0.4	1.9
Favites sp.	0.0	0.9	1.6	0.2	1.7
Dendronephtya sp. 1	0.0	0.6	1.5	0.3	1.6
Paragoniastrea australensis	0.0	0.6	1.3	0.2	1.4
Cladiella sp. 2	0.5	0.0	1.2	0.3	1.2
Acropora solitaryensis	0.0	0.5	1.1	0.2	1.1
Acanthastrea sp. 2	0.0	0.4	1.1	0.4	1.1
Acropora sp. 1	0.0	0.3	1.1	0.2	1.1
Platygyra lamellina	0.0	0.5	1.0	0.2	1.1
Lobophyllia sp. 1	0.0	0.5	1.0	0.2	1.1
Sarcophyton sp. 2	0.2	0.2	1.0	0.3	1.0
Pocillopora aliciae	0.0	0.3	1.0	0.3	1.0
Cladiella sp. 3	0.4	0.0	0.9	0.2	1.0
Astrea curta	0.0	0.3	0.9	0.3	0.9
Rhabdastrella globostellata	0.0	0.2	0.8	0.2	0.9
Entacmaea sp. 2	0.0	0.4	0.8	0.3	0.9
Lobophyton sp. 2	0.2	0.1	0.8	0.3	0.8
Aplysilla sp. 3	0.0	0.3	0.8	0.3	0.8
	Cook Is. West	Cook Is. South	Average dissimilarity = 96.9		
Cladiella sp. 2	0.5	4.1	7.7	0.5	7.9
Discosoma rhodostoma	0.1	4.1	7.1	0.4	7.3
Herdmania momus	0.3	1.9	6.2	0.5	6.4
Lobophyton sp. 2	0.2	1.9	4.9	0.4	5.1
Lobophyton sp. 1	0.0	3.8	4.8	0.3	5.0
Cnemidocarpa stolonifera	1.8	0.1	4.5	0.7	4.7

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Paragoniastrea australensis	0.0	2.7	4.3	0.4	4.4
Porites sp. 2	0.0	2.2	4.2	0.3	4.3
Porites sp. 1	0.0	2.5	3.9	0.5	4.1
Pocillopora damicornis	0.2	1.8	3.9	0.5	4.0
Turbinaria mesenterina	0.5	1.5	3.9	0.4	4.0
Spheciospongia sp. 4	0.1	1.7	3.3	0.4	3.4
Cladiella australis	0.0	1.8	3.2	0.4	3.3
Acropora hyacinthis	0.1	1.5	2.8	0.3	2.9
Porites lutea	0.1	1.3	2.5	0.3	2.6
Cladiella sp. 1	0.0	1.2	2.5	0.3	2.5
Acanthastrea sp. 2	0.0	0.8	2.3	0.3	2.4
Sarcophyton sp. 2	0.2	0.8	1.9	0.3	2.0
Heteractis sp.1	0.8	0.1	1.8	0.4	1.9
Acanthastrea bowerbanki	0.3	0.8	1.8	0.4	1.9
Polycarpa pigmentata	0.5	0.4	1.7	0.5	1.8
Microcosmus exasperatus	0.2	0.4	1.4	0.4	1.4
Pyura stolonifera	0.2	0.5	1.3	0.5	1.4
Spheciospongia confoederata	0.5	0.2	1.3	0.3	1.3
Acropora sp. 1	0.0	0.5	1.2	0.2	1.3
Polycarpa procera	0.2	0.3	1.1	0.4	1.1
Goniopora sp.1	0.0	0.4	0.9	0.3	0.9
Cladiella sp. 3	0.4	0.0	0.9	0.2	0.9
	Cook Is. North	Cook Is. South	Average dissimilarity = 91.9		
Herdmania momus	5.8	1.9	7.9	0.9	8.6
Turbinaria mesenterina	4.6	1.5	7.3	0.6	7.9
Spheciospongia sp. 4	3.5	1.7	6.0	0.6	6.6
Discosoma rhodostoma	0.0	4.1	4.9	0.4	5.3
Porites sp. 2	1.8	2.2	4.8	0.4	5.2
Cladiella sp. 2	0.0	4.1	4.8	0.4	5.2
Acanthastrea bowerbanki	2.3	0.8	3.8	0.5	4.2
Lobophyton sp. 1	0.2	3.8	3.8	0.3	4.2
Paragoniastrea australensis	0.6	2.7	3.7	0.5	4.0
Pocillopora damicornis	1.1	1.8	3.5	0.6	3.8
Acropora hyacinthis	1.2	1.5	3.4	0.4	3.7
Lobophyton sp. 2	0.1	1.9	3.0	0.4	3.2
Porites sp. 1	0.0	2.5	2.9	0.5	3.1
Cladiella australis	0.0	1.8	2.2	0.4	2.4
Pyura stolonifera	1.3	0.5	2.1	0.6	2.3
Acanthastrea sp. 2	0.4	0.8	1.7	0.4	1.9
Porites lutea	0.0	1.3	1.6	0.2	1.8
Cladiella sp. 1	0.0	1.2	1.6	0.3	1.8
Microcosmus exasperatus	0.7	0.4	1.4	0.6	1.5
Sarcophyton sp. 2	0.2	0.8	1.3	0.3	1.5
Acropora sp. 1	0.3	0.5	1.3	0.3	1.4
Favites sp.	0.9	0.2	1.3	0.2	1.4
Iotrochota sp. 1	0.6	0.2	1.2	0.4	1.3
Polycarpa pigmentata	0.5	0.4	1.1	0.6	1.2
Heteractis sp.	0.5	0.1	1.0	0.3	1.1
Pocillopora aliciae	0.3	0.4	0.9	0.4	1.0
Entacmaea sp. 2	0.4	0.3	0.9	0.3	1.0
Dendronephtya sp. 1	0.6	0.0	0.9	0.2	0.9
Acropora solitaryensis	0.5	0.0	0.7	0.2	0.7
Platygyra lamellina	0.5	0.0	0.6	0.2	0.7
Spheciospongia confoederata	0.3	0.2	0.6	0.4	0.7

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Lobophyllia sp. 1	0.5	0.0	0.6	0.2	0.7
Acanthastrea sp. 3	0.0	0.4	0.6	0.2	0.6
Herdmania momus	5.8	1.9	7.9	0.9	8.6
	Cook Is. West	Palm Beach	Average dissimilarity = 97.6		
Pyura stolonifera	0.2	13.8	29.9	1.2	30.7
Trichomya hirsuta	0.0	11.3	22.1	0.9	22.6
Amphibalanus sp.	0.0	1.9	4.5	0.5	4.7
Cnemidocarpa stolonifera	1.8	0.1	4.1	0.9	4.2
Heteractis sp.	0.8	1.1	4.0	0.6	4.1
Spheciospongia confoederata	0.5	1.0	3.2	0.5	3.2
Turbinaria mesenterina	0.5	0.9	2.7	0.3	2.7
Dendronephtya sp. 2	0.1	0.6	1.7	0.3	1.8
Cladiella sp. 2	0.5	0.2	1.6	0.4	1.6
Acanthastrea bowerbanki	0.3	0.4	1.4	0.3	1.5
Haliclona sp. 2	0.0	0.6	1.3	0.4	1.4
Zenia sp. 2	0.0	0.5	1.2	0.3	1.2
Pseudodistoma inflatum	0.0	0.5	1.2	0.5	1.2
Protopalythoa sp.	0.0	0.6	1.2	0.4	1.2
Chondrilla sp. 1	0.0	0.5	1.1	0.3	1.2
Polycarpa pigmentata	0.5	0.0	1.0	0.5	1.1
Herdmania momus	0.3	0.2	1.0	0.4	1.1
Polycarpa procera	0.2	0.2	0.9	0.3	0.9
Acropora hyacinthis	0.1	0.3	0.9	0.3	0.9
Cladiella sp. 3	0.4	0.0	0.8	0.2	0.8
encrusting porifera sp. 5	0.0	0.3	0.7	0.3	0.7
Pinctata maculata	0.0	0.4	0.6	0.3	0.7
Lobophyton sp. 2	0.2	0.1	0.6	0.3	0.6
Dysidea sp. 2	0.0	0.2	0.6	0.3	0.6
	Cook Is. North	Palm Beach	Average dissimilarity = 95.2		
Pyura stolonifera	1.3	13.8	19.0	1.1	20.0
Trichomya hirsuta	0.0	11.3	15.1	0.8	15.9
Herdmania momus	5.8	0.2	7.8	0.9	8.2
Turbinaria mesenterina	4.6	0.9	6.9	0.6	7.3
Spheciospongia sp. 4	3.5	0.1	4.7	0.5	5.0
Acanthastrea bowerbanki	2.3	0.4	3.6	0.5	3.8
Amphibalanus sp.	0.0	1.9	3.0	0.5	3.1
Heteractis sp.	0.5	1.1	2.5	0.5	2.6
Porites sp. 2	1.8	0.0	2.4	0.3	2.5
Acropora hyacinthis	1.2	0.3	2.1	0.4	2.2
Spheciospongia confoederata	0.3	1.0	1.8	0.6	1.9
Pocillopora damicornis	1.1	0.2	1.7	0.4	1.8
Paragoniastrea australensis	0.6	0.2	1.1	0.3	1.1
Favites sp.	0.9	0.0	1.1	0.2	1.1
Iotrochota sp. 1	0.6	0.0	1.0	0.4	1.1
Microcosmus exasperatus	0.7	0.0	1.0	0.5	1.1
Pseudodistoma inflatum	0.2	0.5	1.0	0.5	1.0
Dendronephtya sp. 2	0.0	0.6	1.0	0.3	1.0
Dendronephtya sp. 1	0.6	0.0	0.9	0.3	1.0
Haliclona sp. 2	0.0	0.6	0.9	0.4	0.9
Protopalythoa sp.	0.0	0.6	0.9	0.4	0.9
Acanthastrea sp. 2	0.4	0.2	0.8	0.4	0.9
Chondrilla sp. 1	0.0	0.5	0.8	0.3	0.8
Zenia sp. 2	0.0	0.5	0.7	0.3	0.8
Polycarpa pigmentata	0.5	0.0	0.7	0.4	0.8

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
encrusting porifera sp. 5	0.2	0.3	0.7	0.4	0.7
Acropora solitaryensis	0.5	0.0	0.7	0.2	0.7
Platygyra lamellina	0.5	0.0	0.7	0.2	0.7
Aplysilla sp. 3	0.3	0.1	0.7	0.3	0.7
Lobophyllia sp. 1	0.5	0.0	0.6	0.2	0.7
Pinctata maculata	0.1	0.4	0.6	0.4	0.6
Pyura stolonifera	1.3	13.8	19.0	1.1	20.0
	Cook Is. South	Palm Beach	Average dissimilarity = 97.5		
Pyura stolonifera	0.5	13.8	18.0	1.1	18.4
Trichomya hirsuta	0.1	11.3	13.9	0.8	14.2
Cladiella sp. 2	4.1	0.2	4.6	0.4	4.7
Discosoma rhodostoma	4.1	0.0	4.6	0.4	4.7
Lobophyton sp. 1	3.8	0.0	3.4	0.3	3.5
Paragoniastrea australensis	2.7	0.2	3.1	0.5	3.2
Herdmania momus	1.9	0.2	2.9	0.6	3.0
Turbinaria mesenterina	1.5	0.9	2.7	0.4	2.8
Porites sp. 1	2.5	0.0	2.7	0.5	2.8
Lobophyton sp. 2	1.9	0.1	2.7	0.4	2.8
Amphibalanus sp.	0.0	1.9	2.7	0.5	2.7
Porites sp. 2	2.2	0.0	2.6	0.3	2.6
Pocillopora damicornis	1.8	0.2	2.4	0.5	2.5
Acropora hyacinthis	1.5	0.3	2.2	0.3	2.2
Cladiella australis	1.8	0.0	2.1	0.4	2.1
Spheciospongia sp. 4	1.7	0.1	2.1	0.4	2.1
Heteractis sp.	0.1	1.1	1.8	0.5	1.8
Porites lutea	1.3	0.0	1.6	0.2	1.6
Spheciospongia confoederata	0.2	1.0	1.6	0.5	1.6
Cladiella sp. 1	1.2	0.0	1.5	0.3	1.6
Acanthastrea sp. 2	0.8	0.2	1.3	0.3	1.4
Acanthastrea bowerbanki	0.8	0.4	1.3	0.4	1.3
Sarcophyton sp. 2	0.8	0.0	1.0	0.2	1.0
Dendronephtya sp. 2	0.0	0.6	0.9	0.3	0.9
Zenia sp. 2	0.1	0.5	0.8	0.4	0.9
Pseudodistoma inflatum	0.1	0.5	0.8	0.5	0.8
Haliclona sp. 2	0.0	0.6	0.8	0.4	0.8
Protopalythoa sp.	0.0	0.6	0.8	0.4	0.8
Acropora sp. 1	0.5	0.0	0.7	0.2	0.7
Chondrilla sp. 1	0.0	0.5	0.7	0.3	0.7
	Cook Is. West	Palm Beach Bait Reef	Average dissimilarity = 94.2		
Polycarpa procera	0.2	9.1	18.3	0.9	19.5
Trichomya hirsuta	0.0	7.2	16.6	0.9	17.6
Pyura stolonifera	0.2	3.8	10.3	0.7	10.9
Cnemidocarpa stolonifera	1.8	1.3	8.0	0.6	8.5
Spheciospongia confoederata	0.5	1.9	5.0	0.6	5.4
Haliclona sp. 2	0.0	1.9	4.4	0.7	4.7
Polycarpa pigmentata	0.5	1.2	3.9	0.6	4.2
Heteractis sp.	0.8	0.0	2.5	0.3	2.7
Turbinaria mesenterina	0.5	0.0	1.8	0.2	2.0
Spheciospongia sp. 4	0.1	0.5	1.6	0.4	1.7
Cladiella sp. 2	0.5	0.0	1.5	0.3	1.5
Cladiella sp. 3	0.4	0.0	1.1	0.2	1.1
Herdmania momus	0.3	0.2	1.0	0.2	1.1
Didemnum sp. 1	0.0	0.6	1.0	0.4	1.1

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Microcosmus exasperatus	0.2	0.0	0.9	0.2	0.9
Sarcophyton sp. 2	0.2	0.2	0.9	0.3	0.9
Acanthella sp. 1	0.2	0.1	0.8	0.2	0.8
Lobophyton sp. 2	0.2	0.0	0.8	0.2	0.8
Chondrilla sp. 1	0.0	0.2	0.7	0.3	0.7
Tedania sp	0.0	0.2	0.7	0.2	0.7
Macrorhynchia sp. 2	0.0	0.3	0.7	0.2	0.7
	Cook Is. North	Palm Beach Bait Reef	Average dissimilarity = 96.6		
Polycarpa procera	0.0	9.1	12.2	0.8	12.6
Trichomya hirsuta	0.0	7.2	10.7	0.9	11.1
Herdmania momus	5.8	0.2	9.2	0.9	9.5
Turbinaria mesenterina	4.6	0.0	7.1	0.5	7.3
Pyura stolonifera	1.3	3.8	6.5	0.8	6.7
Spheciospongia sp. 4	3.5	0.5	5.8	0.5	6.0
Acanthastrea bowerbanki	2.3	0.0	3.9	0.4	4.1
Spheciospongia confoederata	0.3	1.9	3.0	0.6	3.1
Haliclona sp. 2	0.0	1.9	2.8	0.7	2.9
Cnemidocarpa stolonifera	0.2	1.3	2.7	0.6	2.8
Porites sp. 2	1.8	0.0	2.7	0.3	2.8
Polycarpa pigmentata	0.5	1.2	2.3	0.6	2.4
Acropora hyacinthis	1.2	0.0	2.0	0.4	2.1
Pocillopora damicornis	1.1	0.0	1.8	0.4	1.9
Iotrochota sp. 1	0.6	0.0	1.4	0.3	1.4
Microcosmus exasperatus	0.7	0.0	1.2	0.4	1.2
Favites sp.	0.9	0.0	1.2	0.2	1.2
Heteractis sp.	0.5	0.0	1.1	0.2	1.1
Dendronephtya sp. 1	0.6	0.0	1.0	0.2	1.1
Gastropod sp5 (GAS5)	0.0	0.4	1.0	0.2	1.0
Paragoniastrea australensis	0.6	0.0	0.9	0.2	1.0
Acropora solitaryensis	0.5	0.0	0.8	0.2	0.8
Platygyra lamellina	0.5	0.0	0.7	0.2	0.8
Lobophyllia sp. 1	0.5	0.0	0.7	0.2	0.8
Didemnum sp. 1	0.0	0.6	0.7	0.4	0.7
Acanthastrea sp. 2	0.4	0.0	0.7	0.3	0.7
Acropora sp. 1	0.3	0.0	0.7	0.2	0.7
Pocillopora aliciae	0.3	0.0	0.6	0.3	0.6
Entacmaea sp. 2	0.4	0.0	0.6	0.3	0.6
Astrea curta	0.3	0.0	0.6	0.3	0.6
Sarcophyton sp. 2	0.2	0.2	0.6	0.2	0.6
Polycarpa procera	0.0	9.1	12.2	0.8	12.6
	Cook Is. South	Palm Beach Bait Reef	Average dissimilarity = 97.7		
Polycarpa procera	0.3	9.1	11.2	0.8	11.5
Trichomya hirsuta	0.1	7.2	9.8	0.8	10.0
Pyura stolonifera	0.5	3.8	5.6	0.7	5.8
Discosoma rhodostoma	4.1	0.0	5.1	0.4	5.2
Cladiella sp. 2	4.1	0.0	5.1	0.4	5.2
Herdmania momus	1.9	0.2	3.8	0.5	3.9
Lobophyton sp. 1	3.8	0.0	3.8	0.3	3.9
Paragoniastrea australensis	2.7	0.0	3.3	0.4	3.3
Lobophyton sp. 2	1.9	0.0	3.1	0.4	3.2
Porites sp. 1	2.5	0.0	3.0	0.5	3.1
Porites sp. 2	2.2	0.0	3.0	0.3	3.0
Spheciospongia sp. 4	1.7	0.5	2.8	0.5	2.9

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Pocillopora damicornis	1.8	0.0	2.7	0.5	2.7
Spheciospongia confoederata	0.2	1.9	2.6	0.6	2.7
Haliclona sp. 2	0.0	1.9	2.6	0.7	2.7
Cnemidocarpa stolonifera	0.1	1.3	2.4	0.5	2.4
Cladiella australis	1.8	0.0	2.3	0.4	2.4
Turbinaria mesenterina	1.5	0.0	2.1	0.3	2.2
Polycarpa pigmentata	0.4	1.2	2.0	0.5	2.1
Acropora hyacinthis	1.5	0.0	2.0	0.3	2.0
Cladiella sp. 1	1.2	0.1	1.8	0.3	1.8
Porites lutea	1.3	0.0	1.7	0.2	1.8
Acanthastrea sp. 2	0.8	0.0	1.5	0.2	1.5
Sarcophyton sp. 2	0.8	0.2	1.3	0.3	1.4
Acanthastrea bowerbanki	0.8	0.0	1.0	0.3	1.0
Acropora sp. 1	0.5	0.0	0.8	0.2	0.9
Didemnum sp. 1	0.1	0.6	0.8	0.4	0.8
Microcosmus exasperatus	0.4	0.0	0.7	0.5	0.7
	Palm Beach	Palm Beach Bait Reef	Average dissimilarity = 82.1		
Pyura stolonifera	3.8	13.8	19.2	1.0	23.4
Trichomya hirsuta	7.2	11.3	17.5	1.0	21.3
Polycarpa procera	9.1	0.2	11.3	0.8	13.7
Spheciospongia confoederata	1.9	1.0	3.5	0.7	4.2
Amphibalanus sp.	0.2	1.9	3.2	0.5	3.9
Haliclona sp. 2	1.9	0.6	2.9	0.8	3.6
Cnemidocarpa stolonifera	1.3	0.1	2.3	0.6	2.8
Heteractis sp.	0.0	1.1	2.0	0.4	2.5
Polycarpa pigmentata	1.2	0.0	1.6	0.4	2.0
Turbinaria mesenterina	0.0	0.9	1.2	0.2	1.4
Chondrilla sp. 1	0.2	0.5	1.1	0.4	1.3
Dendronephtya sp. 2	0.0	0.6	1.0	0.3	1.2
Pseudodistoma inflatum	0.2	0.5	1.0	0.5	1.2
Protopalythoa sp.	0.0	0.6	0.8	0.4	1.0
Zenia sp. 2	0.0	0.5	0.8	0.3	1.0
Spheciospongia sp. 4	0.5	0.1	0.8	0.4	1.0
Didemnum sp. 1	0.6	0.0	0.7	0.4	0.8
Acanthastrea bowerbanki	0.0	0.4	0.6	0.2	0.8
Pinctata maculata	0.0	0.4	0.5	0.4	0.6
Herdmania momus	0.2	0.2	0.5	0.3	0.6
Acropora hyacinthis	0.0	0.3	0.5	0.2	0.6
encrusting porifera sp. 5	0.0	0.3	0.5	0.3	0.6
Pyura stolonifera	3.8	13.8	19.2	1.0	23.4

Table B.5.9 SIMPER of the differences in the average coverage of taxonomic groups among pairs of reefs on vertical surfaces

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
	Kirra Reef	Palm Beach Bait	Average dissimilarity = 75.1		
Trichomya hirsuta	2.1	15.9	17.4	1.2	23.2
Polycarpa procera	7.0	11.0	13.3	1.1	17.7
Pyura stolonifera	5.7	10.0	9.5	0.9	12.7
Didemnum sp. 1	2.8	2.2	4.3	0.9	5.7
Polycarpa pigmentata	1.4	2.8	3.5	0.8	4.7
Herdmania momus	2.7	0.1	3.0	0.6	4.0
Spheciospongia confoederata	0.7	1.9	2.6	0.6	3.5
Cnemidocarpa stolonifera	2.2	0.6	2.6	0.9	3.4
Pallusia julinea	0.6	1.6	2.1	0.9	2.8
Macrorhynchia sp. 2	0.1	1.5	1.8	0.3	2.4
Heteractis sp.	1.1	0.4	1.5	0.6	2.1
Spheciospongia sp. 3	0.0	1.2	1.5	0.5	2.0
Dendronephtya sp. 1	1.1	0.2	1.4	0.2	1.8
Haliclona sp. 1	0.8	0.0	1.0	0.5	1.3
Aplysilla sp. 3	0.7	0.1	0.9	0.5	1.2
Spheciospongia sp. 4	0.0	0.7	0.8	0.3	1.1
Clathria sp.	0.0	0.6	0.8	0.4	1.0
	Kirra Reef	Palm Beach	Average dissimilarity = 82.0		
Trichomya hirsuta	2.1	13.0	16.1	1.2	19.7
Pyura stolonifera	5.7	11.8	13.6	1.2	16.5
Polycarpa procera	7.0	0.4	9.1	0.8	11.1
Didemnum sp. 1	2.8	0.2	4.4	0.8	5.3
Herdmania momus	2.7	0.2	3.7	0.6	4.5
Cnemidocarpa stolonifera	2.2	0.1	3.3	0.9	4.0
Pallusia julinea	0.6	1.7	2.9	0.8	3.5
Polycarpa pigmentata	1.4	0.6	2.5	0.7	3.1
Spheciospongia confoederata	0.7	0.7	2.1	0.5	2.5
Pseudodistoma inflatum	0.1	1.3	2.0	0.7	2.5
Heteractis sp.	1.1	0.4	2.0	0.6	2.4
Dendronephtya sp. 1	1.1	0.1	1.6	0.2	1.9
Spheciospongia sp. 3	0.0	1.1	1.5	0.4	1.9
Paragoniastrea australensis	0.0	0.9	1.4	0.4	1.7
Iotrochota sp. 1	0.3	0.6	1.4	0.4	1.7
Acanthastrea sp. 2	0.0	0.9	1.3	0.4	1.6

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Porites sp. 2	0.0	0.7	1.3	0.3	1.6
Haliclona sp. 1	0.8	0.0	1.3	0.5	1.6
Aplysilla sp. 3	0.7	0.1	1.1	0.5	1.4
Acanthastrea bowerbanki	0.0	0.5	0.9	0.2	1.1
Zenia sp. 2	0.0	0.5	0.9	0.5	1.1
	Kirra Reef	Cook Island North	Average dissimilarity = 91.1		
Herdmania momus	2.7	7.8	12.2	0.8	13.4
Polycarpa procera	7.0	0.9	9.9	0.8	10.9
Pyura stolonifera	5.7	1.0	9.2	1.1	10.1
Spheciospongia sp. 4	0.0	4.9	6.8	0.5	7.5
Didemnum sp. 1	2.8	0.3	4.9	0.8	5.4
Cnemidocarpa stolonifera	2.2	0.4	3.6	0.9	3.9
Porites sp. 1	0.0	3.1	3.5	0.3	3.9
Trichomya hirsuta	2.1	0.0	3.2	0.6	3.5
Turbinaria mesenterina	0.0	1.4	2.5	0.3	2.7
Microcosmus exasperatus	0.0	1.4	2.4	0.6	2.7
Acropora sp. 1	0.0	1.3	2.4	0.4	2.6
Polycarpa pigmentata	1.4	0.2	2.4	0.7	2.6
Iotrochota sp. 1	0.3	1.0	2.1	0.4	2.3
Acanthastrea sp. 2	0.0	1.0	2.0	0.4	2.1
Dendronephtya sp. 1	1.1	0.2	1.9	0.2	2.0
Pallusia julinea	0.6	0.7	1.9	0.6	2.0
Spheciospongia sp. 3	0.0	1.1	1.8	0.5	2.0
Dendronephtya sp. 2	0.1	1.1	1.8	0.4	1.9
Heteractis sp.	1.1	0.0	1.7	0.5	1.9
Aplysilla sp. 3	0.7	0.4	1.7	0.5	1.9
Spheciospongia confoederata	0.7	0.3	1.6	0.4	1.8
Haliclona sp. 1	0.8	0.0	1.4	0.5	1.6
Paragoniastrea australensis	0.0	0.6	1.1	0.3	1.2
Pocillopora damicornis	0.0	0.7	1.1	0.4	1.2
	Kirra Reef	Cook Island South	Average dissimilarity = 97.8		
Polycarpa procera	7.0	0.3	9.1	0.7	9.3
Pyura stolonifera	5.7	0.3	8.4	1.1	8.6
Porites sp. 1	0.0	6.3	8.1	0.6	8.3
Capnella sp.	0.0	5.8	6.5	0.5	6.6
Spheciospongia sp. 4	0.0	4.1	6.3	0.6	6.5
Pocillopora damicornis	0.0	4.0	6.2	0.8	6.3

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Didemnum sp. 1	2.8	0.1	4.4	0.8	4.5
Herdmania momus	2.7	0.1	3.7	0.6	3.8
Cnemidocarpa stolonifera	2.2	0.0	3.4	0.9	3.5
Trichomya hirsuta	2.1	0.1	3.0	0.6	3.1
Acanthastrea bowerbanki	0.0	1.5	2.6	0.5	2.7
Spheciospongia confoederata	0.7	1.0	2.4	0.5	2.5
Cladiella sp. 1	0.0	1.4	2.1	0.3	2.2
Lobophyton sp. 1	0.0	1.6	2.0	0.5	2.1
Polycarpa pigmentata	1.4	0.1	2.0	0.7	2.0
Microcosmus exasperatus	0.0	1.1	1.8	0.4	1.8
Porites lutea	0.0	1.3	1.7	0.3	1.7
Heteractis sp.	1.1	0.1	1.6	0.5	1.7
Aplysilla sp. 3	0.7	0.4	1.5	0.4	1.5
Spheciospongia sp. 3	0.0	1.0	1.5	0.4	1.5
Dendronephtya sp. 1	1.1	0.0	1.4	0.2	1.5
Pallusia julinea	0.6	0.4	1.4	0.4	1.4
Haliclona sp. 1	0.8	0.0	1.3	0.5	1.3
Cladiella sp. 2	0.0	0.8	1.1	0.3	1.1
Discosoma rhodostoma	0.0	0.8	1.1	0.3	1.1
Porites sp. 2	0.0	0.6	0.9	0.2	1.0
Sarcophyton sp. 2	0.0	0.7	0.9	0.4	1.0
Acropora sp. 1	0.0	0.8	0.9	0.3	0.9
Paragoniastrea australensis	0.0	0.6	0.9	0.3	0.9
	Kirra Reef	Cook Island West	Average dissimilarity = 86.6		
Polycarpa procera	7.0	2.9	14.8	0.9	17.1
Pyura stolonifera	5.7	0.5	13.2	1.0	15.2
Didemnum sp. 1	2.8	0.2	7.1	0.8	8.2
Herdmania momus	2.7	1.6	6.8	0.8	7.9
Cnemidocarpa stolonifera	2.2	1.4	5.7	0.8	6.6
Trichomya hirsuta	2.1	0.0	4.4	0.6	5.1
Polycarpa pigmentata	1.4	0.5	3.5	0.7	4.0
Heteractis sp.	1.1	0.5	3.1	0.6	3.6
Haliclona sp. 1	0.8	0.4	2.7	0.5	3.2
Dendronephtya sp. 1	1.1	0.2	2.3	0.2	2.7
Iotrochota sp. 1	0.3	0.8	2.0	0.4	2.3
Spheciospongia confoederata	0.7	0.2	1.8	0.5	2.1

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Microcosmus exasperatus	0.0	0.8	1.8	0.4	2.0
Cladiella sp. 2	0.0	0.7	1.7	0.3	2.0
Acropora sp. 1	0.0	0.8	1.6	0.3	1.9
Aplysilla sp. 3	0.7	0.0	1.5	0.5	1.7
Pallusia julinea	0.6	0.0	1.3	0.5	1.5
Aplidium sp.1	0.0	0.5	1.1	0.2	1.3
Lobophyton sp. 3	0.0	0.4	0.9	0.3	1.1
Pocillopora damicornis	0.0	0.4	0.8	0.3	1.0
	Palm Beach	Palm Beach Bait	Average dissimilarity = 70.0		
Trichomya hirsuta	13.0	15.9	14.8	1.2	21.1
Polycarpa procera	0.4	11.0	11.6	1.1	16.6
Pyura stolonifera	11.8	10.0	11.4	1.1	16.2
Polycarpa pigmentata	0.6	2.8	3.1	0.7	4.4
Didemnum sp. 1	0.2	2.2	2.7	0.6	3.8
Spheciospongia confoederata	0.7	1.9	2.5	0.6	3.5
Pallusia julinea	1.7	1.6	2.3	1.0	3.3
Spheciospongia sp. 3	1.1	1.2	2.1	0.7	3.0
Macrorhynchia sp. 2	0.0	1.5	1.6	0.3	2.2
Pseudodistoma inflatum	1.3	0.1	1.5	0.7	2.1
Paragoniastrea australensis	0.9	0.0	1.0	0.4	1.4
Acanthastrea sp. 2	0.9	0.0	1.0	0.4	1.4
Iotrochota sp. 1	0.6	0.3	1.0	0.4	1.4
Porites sp. 2	0.7	0.0	0.9	0.3	1.3
Amphibalanus sp.	0.6	0.3	0.9	0.3	1.2
Heteractis sp.	0.4	0.4	0.8	0.4	1.2
Spheciospongia sp. 4	0.1	0.7	0.8	0.3	1.1
Clathria sp.	0.1	0.6	0.8	0.4	1.1
Cnemidocarpa stolonifera	0.1	0.6	0.7	0.5	0.9
Acanthastrea bowerbanki	0.5	0.0	0.6	0.3	0.9
Turbinaria mesenterina	0.5	0.0	0.6	0.2	0.9
Zenia sp. 2	0.5	0.0	0.6	0.5	0.9
Acanthella sp. 1	0.2	0.2	0.5	0.5	0.7
	Cook Island North	Palm Beach Bait	Average dissimilarity = 93.9		
Trichomya hirsuta	0.0	15.9	18.4	1.2	19.6
Polycarpa procera	0.9	11.0	12.2	1.1	13.0
Pyura stolonifera	1.0	10.0	10.9	0.9	11.6
Herdmania momus	7.8	0.1	8.1	0.7	8.7

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Spheciospongia sp. 4	4.9	0.7	5.3	0.6	5.7
Polycarpa pigmentata	0.2	2.8	3.1	0.7	3.3
Didemnum sp. 1	0.3	2.2	2.9	0.6	3.1
Porites sp. 1	3.1	0.0	2.7	0.3	2.9
Spheciospongia confoederata	0.3	1.9	2.4	0.6	2.5
Pallusia julinea	0.7	1.6	2.2	0.9	2.3
Spheciospongia sp. 3	1.1	1.2	2.2	0.7	2.3
Microcosmus exasperatus	1.4	0.0	1.7	0.6	1.8
Macrorhynchia sp. 2	0.0	1.5	1.7	0.3	1.8
Turbinaria mesenterina	1.4	0.0	1.7	0.3	1.8
Acropora sp. 1	1.3	0.0	1.6	0.4	1.7
Iotrochota sp. 1	1.0	0.3	1.4	0.4	1.5
Acanthastrea sp. 2	1.0	0.0	1.3	0.4	1.4
Dendronephtya sp. 2	1.1	0.0	1.2	0.4	1.3
Cnemidocarpa stolonifera	0.4	0.6	0.9	0.6	1.0
Pocillopora damicornis	0.7	0.0	0.8	0.4	0.8
Clathria sp.	0.0	0.6	0.8	0.4	0.8
Paragoniastrea australensis	0.6	0.0	0.7	0.3	0.8
Aplysilla sp. 3	0.4	0.1	0.6	0.3	0.6
	Cook Island North	Palm Beach	Average dissimilarity = 94.5		
Trichomya hirsuta	0.0	13.0	16.8	1.2	17.7
Pyura stolonifera	1.0	11.8	15.0	1.2	15.9
Herdmania momus	7.8	0.2	10.0	0.7	10.5
Spheciospongia sp. 4	4.9	0.1	6.1	0.5	6.4
Porites sp. 1	3.1	0.0	3.2	0.3	3.4
Pallusia julinea	0.7	1.7	2.9	0.9	3.0
Turbinaria mesenterina	1.4	0.5	2.8	0.4	2.9
Acanthastrea sp. 2	1.0	0.9	2.6	0.5	2.8
Spheciospongia sp. 3	1.1	1.1	2.6	0.6	2.7
Iotrochota sp. 1	1.0	0.6	2.3	0.5	2.4
Microcosmus exasperatus	1.4	0.0	2.1	0.6	2.2
Paragoniastrea australensis	0.6	0.9	2.1	0.5	2.2
Acropora sp. 1	1.3	0.0	2.0	0.4	2.1
Pseudodistoma inflatum	0.1	1.3	2.0	0.7	2.1
Spheciospongia confoederata	0.3	0.7	1.7	0.4	1.8
Polycarpa procera	0.9	0.4	1.5	0.5	1.6
Dendronephtya sp. 2	1.1	0.0	1.4	0.4	1.5

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Polycarpa pigmentata	0.2	0.6	1.3	0.4	1.4
Porites sp. 2	0.0	0.7	1.3	0.3	1.4
Acanthastrea bowerbanki	0.2	0.5	1.1	0.3	1.2
Pocillopora damicornis	0.7	0.1	1.0	0.4	1.1
Zenia sp. 2	0.1	0.5	0.9	0.5	0.9
Aplysilla sp. 3	0.4	0.1	0.8	0.3	0.8
Amphibalanus sp.	0.0	0.6	0.8	0.2	0.8
Cnemidocarpa stolonifera	0.4	0.1	0.7	0.5	0.7
Didemnum sp. 1	0.3	0.2	0.6	0.4	0.7
	Cook Island South	Palm Beach Bait	Average dissimilarity = 96.6		
Trichomya hirsuta	0.1	15.9	17.0	1.2	17.6
Polycarpa procera	0.3	11.0	11.6	1.1	12.0
Pyura stolonifera	0.3	10.0	10.4	0.9	10.8
Porites sp. 1	6.3	0.0	6.0	0.6	6.3
Capnella sp.	5.8	0.0	5.0	0.5	5.2
Spheciospongia sp. 4	4.1	0.7	4.7	0.7	4.9
Pocillopora damicornis	4.0	0.0	4.4	0.8	4.5
Polycarpa pigmentata	0.1	2.8	2.8	0.7	2.9
Didemnum sp. 1	0.1	2.2	2.7	0.6	2.8
Spheciospongia confoederata	1.0	1.9	2.7	0.7	2.8
Spheciospongia sp. 3	1.0	1.2	2.0	0.7	2.1
Pallusia julinea	0.4	1.6	2.0	0.8	2.1
Acanthastrea bowerbanki	1.5	0.0	1.7	0.6	1.8
Lobophyton sp. 1	1.6	0.2	1.7	0.5	1.7
Macrorhynchia sp. 2	0.0	1.5	1.6	0.3	1.6
Cladiella sp. 1	1.4	0.0	1.5	0.3	1.6
Microcosmus exasperatus	1.1	0.0	1.3	0.5	1.3
Porites lutea	1.3	0.0	1.2	0.3	1.3
Cladiella sp. 2	0.8	0.0	0.8	0.3	0.9
Discosoma rhodostoma	0.8	0.0	0.8	0.3	0.8
Sarcophyton sp. 2	0.7	0.0	0.7	0.4	0.7
Clathria sp.	0.0	0.6	0.7	0.4	0.7
Acropora sp. 1	0.8	0.0	0.7	0.3	0.7
Porites sp. 2	0.6	0.0	0.7	0.2	0.7
Paragoniastrea australensis	0.6	0.0	0.6	0.3	0.7
Cnemidocarpa stolonifera	0.0	0.6	0.6	0.5	0.6
Pocillopora aliciae	0.5	0.0	0.6	0.3	0.6

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Platygyra lamellina	0.7	0.0	0.5	0.2	0.6
	Cook Island South	Palm Beach	Average dissimilarity = 96.8		
Trichomya hirsuta	0.1	13.0	15.4	1.2	15.9
Pyura stolonifera	0.3	11.8	14.2	1.2	14.7
Porites sp. 1	6.3	0.0	7.2	0.6	7.5
Capnella sp.	5.8	0.0	5.9	0.5	6.1
Spheciospongia sp. 4	4.1	0.1	5.5	0.6	5.7
Pocillopora damicornis	4.0	0.1	5.4	0.8	5.6
Acanthastrea bowerbanki	1.5	0.5	2.7	0.6	2.8
Pallusia julinea	0.4	1.7	2.7	0.8	2.8
Spheciospongia sp. 3	1.0	1.1	2.3	0.6	2.4
Spheciospongia confoederata	1.0	0.7	2.3	0.6	2.4
Cladiella sp. 1	1.4	0.0	1.9	0.3	2.0
Porites sp. 2	0.6	0.7	1.9	0.4	1.9
Lobophyton sp. 1	1.6	0.0	1.8	0.5	1.9
Paragoniastrea australensis	0.6	0.9	1.8	0.5	1.9
Pseudodistoma inflatum	0.0	1.3	1.8	0.7	1.8
Microcosmus exasperatus	1.1	0.0	1.6	0.4	1.6
Porites lutea	1.3	0.0	1.5	0.3	1.5
Cladiella sp. 2	0.8	0.2	1.3	0.3	1.3
Acanthastrea sp. 2	0.1	0.9	1.3	0.4	1.3
Turbinaria mesenterina	0.4	0.5	1.1	0.3	1.2
Iotrochota sp. 1	0.2	0.6	1.1	0.4	1.2
Polycarpa pigmentata	0.1	0.6	1.0	0.4	1.0
Discosoma rhodostoma	0.8	0.0	1.0	0.3	1.0
Sarcophyton sp. 2	0.7	0.0	0.8	0.4	0.9
Acropora sp. 1	0.8	0.0	0.8	0.3	0.8
Polycarpa procera	0.3	0.4	0.8	0.3	0.8
Zenia sp. 2	0.0	0.5	0.8	0.5	0.8
Amphibalanus sp.	0.0	0.6	0.7	0.2	0.8
Pocillopora aliciae	0.5	0.0	0.7	0.3	0.7
Aplysilla sp. 3	0.4	0.1	0.7	0.2	0.7
	Cook Island South	Cook Island North	Average dissimilarity = 92.5		
Porites sp. 1	6.3	3.1	10.2	0.6	11.0
Herdmania momus	0.1	7.8	10.0	0.7	10.8
Spheciospongia sp. 4	4.1	4.9	9.5	0.8	10.3
Capnella sp.	5.8	0.0	6.3	0.5	6.8

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Pocillopora damicornis	4.0	0.7	6.1	0.8	6.5
Microcosmus exasperatus	1.1	1.4	3.1	0.7	3.4
Acropora sp. 1	0.8	1.3	2.7	0.5	2.9
Acanthastrea bowerbanki	1.5	0.2	2.6	0.5	2.8
Spheciospongia sp. 3	1.0	1.1	2.5		
Turbinaria mesenterina	0.4	1.4	2.5	0.4	2.7
Lobophyton sp. 1	1.6	0.2	2.1	0.5	2.3
Spheciospongia confoederata	1.0	0.3	2.1	0.5	2.2
Cladiella sp. 1	1.4	0.0	2.1	0.3	2.2
Porites lutea	1.3	0.3	2.0	0.4	2.2
Pyura stolonifera	0.3	1.0	1.8	0.5	1.9
Acanthastrea sp. 2	0.1	1.0	1.7	0.4	1.9
Iotrochota sp. 1	0.2	1.0	1.7	0.4	1.9
Paragoniastrea australensis	0.6	0.6	1.7	0.4	1.8
Pallusia julinea	0.4	0.7	1.6	0.5	1.8
Polycarpa procera	0.3	0.9	1.5	0.5	1.7
Dendronephtya sp. 2	0.0	1.1	1.5	0.4	1.6
Aplysilla sp. 3	0.4	0.4	1.2	0.3	1.3
Cladiella sp. 2	0.8	0.0	1.1	0.3	1.2
Discosoma rhodostoma	0.8	0.0	1.0	0.3	1.1
Sarcophyton sp. 2	0.7	0.0	0.9	0.4	1.0
Porites sp. 2	0.6	0.0	0.9	0.2	1.0
Pocillopora aliciae	0.5	0.1	0.9	0.3	0.9
Palythoa caesia	0.2	0.4	0.9	0.3	0.9
Stelletta sp.	0.1	0.3	0.7	0.4	0.7
Platygyra lamellina	0.7	0.0	0.7	0.2	0.7
	Cook Island West	Palm Beach Bait	Average dissimilarity = 91.9		
Trichomya hirsuta	0.0	15.9	22.9	1.3	24.9
Polycarpa procera	2.9	11.0	14.9	1.1	16.2
Pyura stolonifera	0.5	10.0	13.8	1.0	15.0
Polycarpa pigmentata	0.5	2.8	3.8	0.7	4.1
Didemnum sp. 1	0.2	2.2	3.7		
Spheciospongia confoederata	0.2	1.9	2.8	0.6	3.0
Pallusia julinea	0.0	1.6	2.5	0.8	2.7
Herdmania momus	1.6	0.1	2.3	0.7	2.5
Cnemidocarpa stolonifera	1.4	0.6	2.2	0.8	2.4
Macrorhynchia sp. 2	0.0	1.5	2.1	0.3	2.3

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contribution %
Spheciospongia sp. 3	0.0	1.2	1.9	0.5	2.0
Spheciospongia sp. 4	0.4	0.7	1.4	0.4	1.5
Iotrochota sp. 1	0.8	0.3	1.4	0.4	1.5
Heteractis sp.	0.5	0.4	1.2	0.5	1.3
Microcosmus exasperatus	0.8	0.0	1.1	0.5	1.2
Clathria sp.	0.1	0.6	1.1	0.4	1.2
Acropora sp. 1	0.8	0.0	1.0	0.3	1.1
Cladiella sp. 2	0.7	0.0	1.0	0.3	1.1
Aplidium sp.1	0.5	0.0	0.8	0.2	0.9
Amphibalanus sp.	0.3	0.3	0.7	0.3	0.8
Pocillopora damicornis	0.4	0.0	0.6	0.3	0.7
	Cook Island West	Palm Beach	Average dissimilarity = 96.8		
Trichomya hirsuta	0.0	13.0	21.6	1.3	22.4
Pyura stolonifera	0.5	11.8	20.0	1.3	20.7
Polycarpa procera	2.9	0.4	5.3	0.7	5.5
Pallusia julinea	0.0	1.7	3.6	0.8	3.8
Herdmania momus	1.6	0.2	3.0	0.7	3.1
Cnemidocarpa stolonifera	1.4	0.1	2.8	0.7	2.9
Pseudodistoma inflatum	0.0	1.3	2.6	0.7	2.7
Iotrochota sp. 1	0.8	0.6	2.5	0.5	2.6
Spheciospongia confoederata	0.2	0.7	2.2	0.4	2.3
Polycarpa pigmentata	0.5	0.6	2.1	0.5	2.2
Spheciospongia sp. 3	0.0	1.1	2.0	0.4	2.0
Porites sp. 2	0.0	0.7	1.9	0.3	1.9
Cladiella sp. 2	0.7	0.2	1.8	0.3	1.9
Paragoniastrea australensis	0.0	0.9	1.8	0.4	1.9
Acanthastrea sp. 2	0.0	0.9	1.7	0.4	1.8
Heteractis sp.	0.5	0.4	1.6	0.5	1.7
Microcosmus exasperatus	0.8	0.0	1.5	0.5	1.5
Amphibalanus sp.	0.3	0.6	1.4	0.3	1.5
Acropora sp. 1	0.8	0.0	1.3	0.3	1.4
Turbinaria mesenterina	0.1	0.5	1.3	0.2	1.4
Acanthastrea bowerbanki	0.0	0.5	1.3	0.2	1.3
Zenia sp. 2	0.0	0.5	1.2	0.5	1.2
Aplidium sp.1	0.5	0.0	1.0	0.2	1.0
Pocillopora damicornis	0.4	0.1	0.9	0.3	0.9
Astrea curta	0.0	0.4	0.8	0.3	0.9

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Didemnum sp. 1	0.2	0.2	0.8	0.4	0.8
	Cook Island West	Cook Island North	Average dissimilarity = 91.9		
Herdmania momus	1.6	7.8	14.8	0.8	16.1
Spheciospongia sp. 4	0.4	4.9	8.9	0.6	9.7
Polycarpa procera	2.9	0.9	6.5	0.7	7.0
Porites sp. 1	0.1	3.1	4.5	0.3	4.9
Acropora sp. 1	0.8	1.3	4.3	0.5	4.7
Microcosmus exasperatus	0.8	1.4	4.0	0.7	4.4
Iotrochota sp. 1	0.8	1.0	3.6	0.5	3.9
Turbinaria mesenterina	0.1	1.4	3.5	0.3	3.8
Cnemidocarpa stolonifera	1.4	0.4	3.3	0.8	3.6
Pyura stolonifera	0.5	1.0	3.0	0.5	3.2
Acanthastrea sp. 2	0.0	1.0	2.7	0.4	2.9
Spheciospongia sp. 3	0.0	1.1	2.4	0.5	2.6
Dendronephtya sp. 2	0.0	1.1	2.1	0.4	2.3
Pocillopora damicornis	0.4	0.7	2.1	0.5	2.2
Pallusia julinea	0.0	0.7	1.8	0.5	2.0
Polycarpa pigmentata	0.5	0.2	1.7	0.5	1.8
Cladiella sp. 2	0.7	0.0	1.6	0.3	1.7
Paragoniastrea australensis	0.0	0.6	1.5	0.3	1.7
Spheciospongia confoederata	0.2	0.3	1.5	0.3	1.7
Aplidium sp.1	0.5	0.1	1.2	0.2	1.3
Aplysilla sp. 3	0.0	0.4	1.2	0.3	1.3
Heteractis sp.	0.5	0.0	1.1	0.5	1.2
Porites lutea	0.1	0.3	1.0	0.3	1.1
Didemnum sp. 1	0.2	0.3	0.9	0.5	1.0
Palythoa caesia	0.0	0.4	0.9	0.2	1.0
Haliclona sp. 1	0.4	0.0	0.9		
Lobophyton sp. 3	0.4	0.0	0.8	0.3	0.9
Stelletta sp.	0.0	0.3	0.8	0.3	0.9
Dysidea sp. 2	0.1	0.2	0.8	0.3	0.9
	Cook Island West	Cook Island South	Average dissimilarity = 96.7		
Porites sp. 1	0.1	6.3	10.1	0.6	10.5
Spheciospongia sp. 4	0.4	4.1	8.5	0.6	8.7
Pocillopora damicornis	0.4	4.0	8.1	0.8	8.4
Capnella sp.	0.0	5.8	7.9	0.6	8.2
Polycarpa procera	2.9	0.3	5.5	0.7	5.7

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/ SD	Contribution %
Acanthastrea bowerbanki	0.0	1.5	3.8	0.4	3.9
Microcosmus exasperatus	0.8	1.1	3.3	0.6	3.4
Herdmania momus	1.6	0.1	3.0	0.7	3.1
Cnemidocarpa stolonifera	1.4	0.0	2.9	0.7	3.0
Cladiella sp. 1	0.0	1.4	2.7	0.3	2.8
Spheciospongia confoederata	0.2	1.0	2.6	0.5	2.7
Cladiella sp. 2	0.7	0.8	2.6	0.4	2.7
Lobophyton sp. 1	0.0	1.6	2.5	0.5	2.6
Acropora sp. 1	0.8	0.8	2.3	0.4	2.4
Porites lutea	0.1	1.3	2.2	0.4	2.2
Spheciospongia sp. 3	0.0	1.0	1.9	0.4	1.9
Sarcophyton sp. 2	0.3	0.7	1.7	0.4	1.7
Iotrochota sp. 1	0.8	0.2	1.6	0.4	1.7
Aplidium sp.1	0.5	0.4	1.4	0.3	1.5
Pyura stolonifera	0.5	0.3	1.4	0.4	1.5
Discosoma rhodostoma	0.0	0.8	1.4	0.3	1.4
Porites sp. 2	0.0	0.6	1.2	0.2	1.3
Pocillopora aliciae	0.1	0.5	1.2	0.3	1.3
Paragoniastrea australensis	0.0	0.6	1.2	0.3	1.2
Heteractis sp.1	0.5	0.1	1.1	0.5	1.2
Polycarpa pigmentata	0.5	0.1	1.1	0.4	1.1
Pallusia julinea	0.0	0.4	1.1	0.3	1.1
Lobophyton sp. 2	0.1	0.4	0.9	0.3	0.9
Lobophyton sp. 3	0.4	0.1	0.8	0.3	0.8
Turbinaria mesenterina	0.1	0.4	0.8	0.4	0.8
Platygyra lamellina	0.0	0.7	0.8	0.2	0.8

Table B.5.10 PERMANOVA of the difference in the taxonomic richness of sessile invertebrates among reefs in 2021

a) PERMANOVA Source		(a) Taxonomic Richness			**(b) % Coverage**			
	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)	
Orientation	1	103.14	18.18	**0.001**	5984	11.44	**0.002**	
Reef	5	90.15	3.34	**0.026**	12603	9.22	**0.002**	
Site (Reef)	12	27.02	7.37	**0.001**	1366	6.60	**0.001**	
Orientation x Reef	5	26.89	4.74	**0.016**	2050	3.92	**0.028**	
Orientation x Site (Reef)	12	5.67	1.55	0.115	523	2.53	**0.002**	
Error	504	3.67			207			
Pairwise Tests	Horizontal		Vertical		Horizontal		Vertical	
	t Value	P (MC)	t Value	P (MC)	t Value	P (MC)	t Value	P (MC)
KR vs PBR	0.5	0.62	0.4	0.68	2.5	0.08	1.1	0.29
KR vs PBBR	0.6	0.58	2.1	0.10	1.4	0.24	5.6	**0.01**
KR vs CIW	1.6	0.18	1.9	0.13	1.9	0.14	3.5	**0.03**
KR vs CIS	1.9	0.12	0.9	0.46	2.1	0.11	1.5	0.20
KR vs CIN	1.2	0.30	0.8	0.46	1.8	0.15	0.5	0.65
CIW vs CIN	3.4	**0.03**	1.7	0.16	6.8	**0.00**	4.2	**0.02**
CIW vs CIS	4.0	**0.02**	1.5	0.19	4.0	**0.02**	4.0	**0.02**
CIW vs PBR	2.4	0.06	1.3	0.28	7.7	**0.00**	3.3	**0.03**
CIN vs CIS	1.4	0.23	0.2	0.86	1.1	0.34	1.2	0.29
CIN vs PBR	1.1	0.35	0.0	0.97	1.2	0.30	0.9	0.43
CIS vs PBR	2.1	0.12	0.1	0.89	0.5	0.66	0.1	0.93
CIS vs PBBR	1.3	0.25	4.8	**0.01**	1.2	0.30	2.4	0.06
CIW vs PBBR	2.3	0.08	3.7	**0.02**	5.0	**0.01**	9.1	**0.00**
CIN vs PBBR	0.5	0.65	5.5	**0.00**	0.4	0.75	5.7	**0.01**
PBR vs PBBR	0.2	0.83	2.0	0.13	1.3	0.24	2.2	0.08
Horizontal vs Vertical	t Value	P (MC)			t Value	P (MC)		
KR	2.08	0.20			1.85	0.20		
PBR	1.48	0.26			0.22	0.87		
PBBR	4.24	0.07			3.62	0.08		
CIW	9.61	**0.02**			6.40	**0.03**		
CIN	0.08	0.95			0.02	0.99		
CIS	2.51	0.10			0.73	0.53		

Significant tests at $p < 0.05$ are **bold**. P(Perm) are the p-values derived using the permutational method. P(MC) are p-values derived using the Monte Carlo method, used when there are low numbers of possible permutations (i.e. <100).

Table B.5.11 Comparisons of sessile assemblages on horizontal surfaces among reefs and survey periods (2016 to 2021)

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)		
Survey	5	1.49E+05	167	**0.01**		
Reef	6	64222	72	**0.01**		
Survey x Reef	16	19000	21	**0.01**		
Error	1970	889.96				
Pairwise Tests	b) 2016	c) 2017	d) 2018	e) 2019	f) 2020	g)2021
	t Value	t Value	t Value	t Value	t Value	t Value
KR vs PBR	10.74**		6.2**	4.8**	8.6**	7.1**
KR vs PBBR					5.4**	6.5**
KR vs CIW		5.7**	3.5**	4.6**	8.2**	7.6**
KR vs CIS					10.5**	8.3**
KR vs CIN	6.96**	4.6**	4.6**	4.5**	10.6**	7.6**
CIW vs CIN		2.2**	1.7*	1.2	5.8**	6.3**
CIW vs CIS					6.2**	7.3**
CIW vs PBR			3.5**	5.3**	10.6**	6.9**
CIN vs CIS					3.2**	4.3**
CIN vs PBR			4.1**	5.7**	8.6**	5.1**
CIS vs PBR					9.2**	6.8**
KR vs KC	5.90**			2.0*		
PBR vs KC	6.16**			4.7**		
KC vs CIN	2.60**					
KC vs CIW				4.4**		
CIN vs PBBR					6.9**	7.3**
PBR vs PBBR					8.7**	3.5**
CIW vs PBBR					6.0**	9.4**
CIS vs PBBR					6.8**	8.4**
h) Pairwise comparison within reefs over time	Kirra	Palm Beach	Cook Island North	Cook Island West		
2016 vs 2017	**4.94****		**3.15****			
2017 vs 2018	**3.37****		**5.88****	**5.41****		
2018 vs 2019	**4.92****	**6.51****	**5.76****	**4.47****		
2019 vs 2020	**4.44****	**14.05****	**15.78****	**12.29****		
2020 vs 2021	**4.03****	**9.34****		**4.41****		

Significance level: * $p < 0.05$, ** $p < 0.01$

Table B.5.12 SIMPER differences in sessile assemblages at Kirra Reef among survey periods (2016 to 2021)

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	2016	2017	Average dissimilarity = 61.2		
Turf Algae	37.7	9.7	22.2	1.5	36.3
Macroalgae	29.7	22.3	15.8	1.3	25.8
Ascidian	16.4	16.6	13.6	1.1	22.2
Sponge	5.4	6.2	5.3	1.0	8.6
	2017	2018	Average dissimilarity = 67.4		
Turf Algae	9.7	28.6	19.1	1.1	28.3
Macroalgae	22.3	24.8	16.3	1.1	24.2
Ascidian	16.6	17.6	15.5	1.0	23.0
Coralline Algae	2.2	16.0	11.2	1.0	16.6
	2018	2019	Average dissimilarity = 59.5		
Ascidian	17.6	41.5	19.1	1.4	32.1
Macroalgae	24.8	35.7	14.2	1.4	24.0
Turf Algae	28.6	11.1	13.1	1.3	22.0
Coralline Algae	16.0	0.1	8.7	1.2	14.6
	2019	2020	Average dissimilarity = 53.4		
Ascidian	41.5	24.2	15.5	1.4	29.1
Macroalgae	35.7	20.5	14.9	1.5	27.96
Turf Algae	11.1	25.1	10.2	1.2	19.06
Sponge	2.8	8.6	4.2	1.0	7.91
Coralline Algae	0.1	7.6	4.0	1.1	7.47
	2020	2021	Average dissimilarity = 48.2		
Turf Algae	25.1	40.3	13.3	1.5	27.6
MACROALGAE	20.5	14.9	11.2	1.1	23.2
Ascidian	24.2	19.6	10.6	1.3	21.9
Sponge	8.6	3.0	4.3	1.0	9.0
Coralline Algae	7.6	5.3	4.3	1.1	9.0

Appendix C Mobile Invertebrate Densities

Table C.1 Mean (±SE) density (number per photo quadrat) of mobile invertebrates among reefs (horizontal and vertical surfaces combined)

Reef		CIN	CIS	CIW	KR	PBBR	PBR
Class Asteroidea (sea stars)							
Echinaster luzonicus	Mean	0.01	0.03	0.18	0.00	0.00	0.17
	S.E.	0.01	0.02	0.05	0.00	0.00	0.05
Linckia guildingi	Mean	0.00	0.00	0.01	0.00	0.00	0.00
	S.E.	0.00	0.00	0.01	0.00	0.00	0.00
Pentagonaster dubeni	Mean	0.02	0.01	0.03	0.00	0.00	0.01
	S.E.	0.02	0.01	0.02	0.00	0.00	0.01
Tamaria sp.	Mean	0.00	0.00	0.00	0.00	0.00	0.01
	S.E.	0.00	0.00	0.00	0.00	0.00	0.01
Asteroidea (unknown)	Mean	0.00	0.01	0.00	0.00	0.00	0.00
	S.E.	0.00	0.01	0.00	0.00	0.00	0.00
Class Crinoidea (feather stars)							
Cenolia glebosis	Mean	2.79	0.30	2.81	5.27	3.48	0.10
	S.E.	0.45	0.07	0.38	0.78	0.48	0.04
Cenolia sp.1	Mean	0.12	0.00	0.09	0.00	0.73	0.00
	S.E.	0.06	0.00	0.04	0.00	0.17	0.00
Cenolia sp.2	Mean	0.02	0.00	0.73	0.19	0.01	0.00
	S.E.	0.02	0.00	0.16	0.05	0.01	0.00
Cenolia sp.3	Mean	0.00	0.00	0.38	0.14	0.00	0.00
	S.E.	0.00	0.00	0.09	0.05	0.00	0.00
Cenolia sp.4	Mean	0.00	0.00	0.38	0.04	0.00	0.00
	S.E.	0.00	0.00	0.11	0.02	0.00	0.00
Oxycomanthus bennetti	Mean	0.03	0.01	0.04	0.09	0.02	0.00
	S.E.	0.02	0.01	0.03	0.05	0.02	0.00
Class Echinoidea (sea urchins)							
Diadema savignyi	Mean	0.28	0.29	0.12	0.10	0.00	0.42
	S.E.	0.07	0.07	0.04	0.05	0.00	0.10
Echinometra mathaei	Mean	0.00	0.00	0.00	0.00	0.00	0.02
	S.E.	0.00	0.00	0.00	0.00	0.00	0.02
Heliocidaris erythrogramma	Mean	0.01	0.00	0.01	0.00	0.00	0.00

Reef		CIN	CIS	CIW	KR	PBBR	PBR
	S.E.	0.01	0.00	0.01	0.00	0.00	0.00
Phyllacanthus parvispinus	Mean	0.00	0.00	0.00	0.07	0.00	0.00
	S.E.	0.00	0.00	0.00	0.06	0.00	0.00
Echinothrix calamaris	Mean	0.09	0.04	0.11	0.04	0.08	0.11
	S.E.	0.04	0.02	0.04	0.02	0.04	0.04
Tripneustes gratilla	Mean	0.01	0.02	0.06	0.00	0.00	0.00
	S.E.	0.01	0.02	0.02	0.00	0.00	0.00
Class Holothuroidea (sea cucumbers)							
Holothuria leucospilota	Mean	0.00	0.01	0.01	0.00	0.00	0.00
	S.E.	0.00	0.01	0.01	0.00	0.00	0.00
Holothuria whitmaei	Mean	0.00	0.00	0.01	0.00	0.00	0.00
	S.E.	0.00	0.00	0.01	0.00	0.00	0.00
Class Decapoda							
Dardanus sp.	Mean	0.00	0.00	0.00	0.00	0.00	0.01
	S.E.	0.00	0.00	0.00	0.00	0.00	0.01
Class Cephalopoda							
Octopus tetricus	Mean	0.00	0.00	0.01	0.00	0.00	0.00
	S.E.	0.00	0.00	0.01	0.00	0.00	0.00
Class Gastropoda							
Chomodoris kuiteri	Mean	0.01	0.00	0.00	0.00	0.00	0.00
	S.E.	0.01	0.00	0.00	0.00	0.00	0.00
Cypraeidae sp.	Mean	0.00	0.01	0.00	0.00	0.00	0.01
	S.E.	0.00	0.01	0.00	0.00	0.00	0.01
Ovula ovum	Mean	0.00	0.00	0.00	0.00	0.00	0.01
	S.E.	0.00	0.00	0.00	0.00	0.00	0.01

Appendix D July 2021 Fish Species List

Table D.5.13 Fish species recorded in July 2021 survey, not recorded in previous surveys

Scientific Name	Common name	Reef Recorded at
Acanthuridae		
Acanthurus dussumieri	pencil surgeonfish	Kirra Reef, Cook Island West
Carangidae		
Pseudocaranx georgianus	silver trevally	Cook Island North
Chaetodontidae		
Chaetodon vagabundus	vagabond butterflyfish	Cook Island West
Cirrhitidae		
Paracirrhites forsteri	freckled hawkfish	Cook Island West
Echeneidae		
Echeneis naucrates	Australian remora	Palm Beach Reef
Labridae		
Cheilinus chlorourus	floral Maori wrasse	Cook Island North
Halichoeres nebulosus	cloud wrasse	Kirra Reef, Palm Beach Reef, Palm Beach Bait Reef, Cook Island West
Labropsis australis	southern tubelip	Kirra Reef, Cook Island West
Scarus ghobban	bluebarred parrotfish	Palm Beach Bait Reef
Lutjanidae		
Lutjanus carponotatus	stripey snapper	Palm Beach Bait Reef
Lutjanus rivulatus	blubberlip snapper	Cook Island North
Mullidae		
Parupeneus cyclostomus	goldsaddle goatfish	Cook Island North
Muraenidae		
Gymnothorax undulatus	undulate moray	Kirra Reef
Pomacentridae		
Chromis weberi	Weber's chromis	Cook Island South
Dascyllus aruanus	banded humbug	Palm Beach Reef
Dascyllus reticulatus	headband humbug	Cook Island North, West and South
Pomacentrus moluccensis	lemon damsel	Cook Island West
Rhinidae		
Rhynchobatus australiae	whitespotted guitarfish	Palm Beach Reef

Scientific Name	Common name	Reef Recorded at
Scombridae		
Scomberomorus sp. 1 [15]	school or spotted mackerel	Palm Beach Reef, Palm Beach Bait Reef, Cook Island North
Scorpaenidae		
Scorpaena jacksoniensis	eastern red scorpionfish	Cook Island North and South
Sebastidae		
Helicolenus percoides	reef ocean perch	Cook Island North
Serranidae		
Epinephelus quoyanus	longfin grouper	Cook Island North and South

[15] This species is either *Scomberomorus queenslandicus* (Queensland school mackerel) or *Scomberomorus munroi* (Australian spotted mackerel) however, these two species are indistinguishable using the UBRUVS method.

Table D.5.14 Fish species and Max N values at Kirra Reef, Palm Beach Reef, Palm Beach Bait Reef and Cook Island Reef (West, North and South) recorded during the 2021 survey.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Acanthuridae									
Acanthurus dussumieri	pencil surgeonfish	H	R	2			2		1
Acanthurus grammoptilus	inshore surgeonfish	H	R	12	6	4	13	7	
Acanthurus sp. 1 [16]	dusky or greyhead surgeonfish	H	R	6	3	2	2	4	1
Naso unicornis	bluespine unicornfish	H	R					4	
Prionurus microlepidotus	Australian sawtail	H	R		1		4		
Zebrasoma velifer	sailfin tang	H	R					1	
Acanthuridae spp. (unidentified) [17]	surgeonfish	H	R		1			1	2
Apogonidae									
Ostorhinchus cookii	Cook's cardinalfish	CA	R			2			
Aulostomidae									
Aulostomus chinensis	Pacific trumpetfish	CA	R		1				
Balistidae									
Sufflamen chrysopterum	eye-stripe triggerfish	CA	R	1	1	2	1		
Sufflamen fraenatum	bridled triggerfish	CA	R				*		
Balistidae sp. (unidentified) [17]	triggerfish	CA	R				1		
Blenniidae									
Meiacanthus lineatus	lined fangblenny	CA	R	2	1				
Plagiotremus tapeinosoma	piano fangblenny	CA	R			1			

[16] This species is either *Acanthurus nigrofuscus* (dusky surgeonfish) or *Acanthurus nigroris* (greyhead surgeonfish) however, these two species are indistinguishable using the UBRUVS method.
[17] These records are of fish swimming in the distance, in conditions of low visibility so identification beyond family was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Caesionidae									
Caesionidae sp. 1	fusilier	P	P/R		3				
Carangidae									
Caranx melampygus	bluefin trevally	CA	P					13	2
Pseudocaranx georgianus	silver trevally	CA	P					10	
Trachurus novaezelandiae	yellowtail scad	P	P	1000	550	40			
Chaetodontidae									
Chaetodon auriga	threadfin butterflyfish	C	R	2	2	2	2	1	
Chaetodon citrinellus	citron butterflyfish	C	R		1		3		
Chaetodon flavirostris	dusky butterflyfish	C	R	2	2		1	2	
Chaetodon kleinii	Klein's butterflyfish	O	R	1			1		*
Chaetodon lunula	racoon butterflyfish	O	R	1					
Chaetodon vagabundus	vagabond butterflyfish	O	R				2		
Heniochus acuminatus	longfin bannerfish	P	R	1					
Cirrhitidae									
Cirrhitichthys aprinus	blotched hawkfish	CA	R	1	1	1		*	
Cirrhitichthys falco	dwarf hawkfish	CA	R				1		
Cirrhitichthys sp. (unidentified) [18]	hawkfish	CA	R					1	
Paracirrhites forsteri	freckled hawkfish	CA	R				*		
Dasyatidae									
Neotrygon kuhlii	bluespotted maskray	CA	R	*			1		
Diodontidae									

[18] This record is of a fish swimming in the distance, in conditions of low visibility so identification beyond genus was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Dicotylichthys punctulatus	threebar porcupinefish	CA	R	1	1	2	1	1	
Echeneidae									
Echeneis naucrates	Australian remora	CA	P/R		1				
Enoplosidae									
Enoplosus armatus	old wife	CA	R				*		
Fistulariidae									
Fistularia commersonii	smooth flutemouth	CA	R	2				2	
Gerreidae									
Gerres subfasciatus	common silver biddy	CA	P	1					
Haemulidae									
Diagramma pictum labiosum	painted sweetlips	CA	P/R		1	2		1	
Plectorhinchus flavomaculatus	goldspotted sweetlips	CA	P/R	2	1		2	1	
Plectorhinchus unicolor	sombre sweetlips	CA	R	1					
Hemiscylliidae									
Chiloscyllium punctatum	grey carpet shark	CA	R	*					
Kyphosidae									
Kyphosus bigibbus	grey drummer	H	R	1			1	1	1
Labridae									
Achoerodus viridis	eastern blue grouper	CA	R		1		2	4	1
Anampses neoguinaicus	blackback wrasse	CA	R				*		*
Bodianus axillaris	axilspot hogfish	CA	R					1	
Bodianus perditio	goldspot pigfish	CA	R				*	1	
Cheilinus chlorourus	floral Maori wrasse	CA	R					2	
Cheilio inermis	sharpnose wrasse	CA	R	1	1		1	1	
Choerodon graphicus	graphic tuskfish	CA	R					1	

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Halichoeres hortulanus	checkerboard wrasse	O	R		1			1	1
Halichoeres margaritaceus	pearly wrasse	CA	R	1					1
Halichoeres nebulosus	cloud wrasse	CA	R	1	1	2	2		
Halichoeres sp. (unidentified) [19]	wrasse		R						1
Hemigymnus fasciatus	fiveband wrasse	O	R					1	1
Labroides dimidiatus	common cleaner fish	CA	R	1	3	6	1	2	3
Labropsis australis	southern tubelip	CA	R	1			1		
Macropharyngodon meleagris	leopard wrasse	CA	R				2		
Notolabrus gymnogenis	crimsonband wrasse	CA	R	2	2		2	1	*
Pseudolabrus guentheri	Günther's wrasse	CA	R	3	2	4	3	2	2
Scarus ghobban	bluebarred parrotfish	H	R			5			
Stethojulis bandenensis	redspot wrasse	CA	R	1					
Stethojulis interrupta	brokenline wrasse	O	R	2	1	2	3	2	1
Thalassoma amblycephalum	bluntheaded wrasse	P	R	3				1	
Thalassoma hardwicke	sixbar wrasse	O	R						1
Thalassoma lunare	moon wrasse	CA	R	3	10	10	5	5	2
Thalassoma lutescens	green moon wrasse	CA	R	2	3	1	3	6	1
Thalassoma nigrofasciatum [20]	blackbarred wrasse	O	R	1	2	4		1	

[19] This record is of a fish swimming in the distance, in conditions of low visibility so identification beyond genus was not possible.
[20] There are few disguising features between *Thalassoma nigrofasciatum* and the closely related *Thalassoma jansenii*, however, based on the range, all were identified as *Thalassoma nigrofasciatum*.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Labridae (unidentified) [21]	wrasse		R		2			1	1
Latridae									
Goniistius vestitus	crested morwong	O	R			1	2		1
Morwong fuscus	red morwong	O	R				1	1	1
Lutjanidae									
Lutjanus carponotatus	stripey snapper	O	R			1			
Lutjanus fulviflamma	blackspot snapper	CA	R	3	1	2	1		
Lutjanus kasmira	bluestriped snapper	O	R				1		
Lutjanus rivulatus	blubberlip snapper	CA	R					17	
Lutjanus russellii	moses' snapper	CA	R	1			3	2	
Lutjanidae (unidentified) [21]	snapper		R		1				
Microcanthidae									
Atypichthys strigatus	mado	O	R				1		
Microcanthus strigatus	stripey	O	R	4	6	21	15	1	*
Monacanthidae									
Meuschenia sp. 1	leatherjacket 1	O	R		2	1			
Meuschenia sp. 2	leatherjacket 2	O	R				2		
Meuschenia trachylepis	yellowfin leatherjacket	O	R	1			1		
Monacanthus chinensis	fanbelly leatherjacket	O	R	1		1			
Paraluteres prionurus	blacksaddle filefish	O	R				1		
Monodactylidae									
Monodactylus argenteus	silver moony	P	P		70			1	
Schuettea scalaripinnis	eastern pomfred	P	P		80		*	400	
Mullidae									

[21] These records are of fish swimming in the distance, in conditions of low visibility so identification beyond family was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Mulloidichthys vanicolensis	goldstripe goatfish	CA	R		1			2	
Parupeneus cyclostomus	goldsaddle goatfish	CA	R					1	
Parupeneus multifasciatus	banded goatfish	CA	R	1	1	1	4		1
Parupeneus spilurus	blacksaddle goatfish	CA	R	2	2	4	3	2	
Muraenidae									
Gymnothorax favagineus	honeycomb moray	CA	R				*		
Gymnothorax undulatus	undulate moray	CA	R	1					
Myliobatidae									
Aetobatus ocellatus	whitespotted eagle ray	CA	P/R	2	3	1			
Orectolobidae									
Orectolobus maculatus	spotted wobbegong	CA	R	1	1	*	*	1	*
Orectolobus ornatus	banded wobbegong	CA	R		*	*		1	
Ostraciidae									
Ostracion sp. (unidentified) [22]	boxfish	O – HT	R		1				
Pempheridae									
Pempheris affinis	blacktip bullseye	P	R					2	
Pinguipedidae									
Parapercis stricticeps	whitestreak grubfish	O	R				*		
Pomacanthidae									
Centropyge tibicen	keyhole angelfish	O – HT	R				1		
Pomacanthus semicirculatus	semicircle angelfish	O – HT	R					*	
Pomacentridae									
Abudefduf bengalensis	bengal sergeant	O	R	1	1		1	1	

[22] This record is of a fish swimming in the distance, in conditions of low visibility so identification beyond genus was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Abudefduf vaigiensis	Indo-Pacific sergeant	O	R		11		2	22	
Abudefduf whitleyi	Whitley's sergeant	O	R				1	17	
Amphiprion akindynos	Barrier Reef anemonefish	O	R	*			*	*	*
Chromis margaritifer	whitetail puller	O	R		2			5	1
Chromis weberi	Weber's chromis	O	R						1
Dascyllus aruanus	banded humbug	O	R		1				
Dascyllus reticulatus	headband humbug	O	R				*	*	*
Dascyllus trimaculatus	threespot humbug	O	R	2			2	4	11
Parma oligolepis	bigscale scalyfin	O - HT	R	10	3	1	1	5	5
Parma polylepis	banded scalyfin	O - HT	R	1		*	1		*
Parma unifasciata	girdled scalyfin	O - HT	R				2	6	
Pomacentrus coelestis	neon damsel	O - HT	R			1	2		3
Pomacentrus moluccensis	lemon damsel	O - HT	R				*		
Pomacentrus nagasakiensis	blue-scribbled damsel	O - HT	R		1	3	1		
Pomacentrus wardi	Ward's damsel	H	R				2	3	2
Stegastes apicalis	yellowtip gregory	O - HT	R	3	2			4	1
Stegastes gascoynei	Coral Sea damsel	O - HT	R		1			2	1
Pomacentrus spp. (unidentified) [23]	damsel		R		2			1	5
Rhinidae									
Rhynchobatus australiae	whitespotted guitarfish	CA	R		1				
Scombridae									

[23] These records are of fish swimming in the distance, in conditions of low visibility so identification beyond genus was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Scomberomorus sp. 1 [24]	school or spotted mackerel	CA	P		22	*		16	
Scorpaenidae									
Dendrochirus zebra	zebra lionfish	CA	R			*			
Pterois volitans	common lionfish	CA	R	*			1		
Scorpaena jacksoniensis	eastern red scorpionfish	CA	R					1	*
Scorpaenopsis sp.	scorpionfish	CA	R						*
Scorpididae									
Scorpis lineolata	silver sweep	P	R	13	2		2	1	1
Sebastidae									
Helicolenus percoides	reef ocean perch	CA	R					*	
Serranidae									
Diploprion bifasciatum	barred soapfish	CA	R		1			1	
Epinephelus fasciatus	blacktip grouper	CA	R		1				
Epinephelus quoyanus	longfin grouper	CA	R					*	*
Siganidae									
Siganus fuscescens	black rabbitfish	H	R	9	19	19	22	7	
Sparidae									
Acanthopagrus australis [25]	yellowfin bream	CA	P/R	11	7	5	3	3	1
Sphyraenidae									
Sphyraena obtusata	striped barracuda	CA	P/R	3	3	4			
Tetraodontidae									

[24] This species is either *Scomberomorus queenslandicus* (Queensland school mackerel) or *Scomberomorus munroi* (Australian spotted mackerel) however, these two species are indistinguishable using the UBRUVS method.
[25] This species is either *Acanthopagrus australis* (yellowfin bream) or *Rhabdosargus sarba* (tarwhine). Using the UBRUVS method, confidently distinguishing between these two species is not possible.

Scientific Name	Common Name	Functional Group	Habitat	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South
Arothron hispidus	stars-and-stripes puffer	O	R	1	1	1	1	*	
Arothron nigropuncatus	blackspotted puffer	O	R		1	1			
Arothron stellatus	starry puffer	O	R			1	*		
Arothron spp. (unidentified)	puffer	O	R				1	1	
Canthigaster valentini	blacksaddle toby	O - HT	R		1		*		*
Tetrarogidae									
Centropogon australis	eastern fortescue	O	R			2			
Unidentified Species[26]					2	1			2

Key to Functional group abbreviations: Functional Group: H = herbivore, P = planktivore, CA = carnivore, C = corallivore, O = omnivore, O - HT = omnivore with herbivorous tendencies, D = Detritivore.

Key to Habitat abbreviations: P = Pelagic, R = Reef, P/R = Pelagic and Reef

* Species only observed on ROV or diver footage, not recorded on UBUBRUVS footage and, therefore, no comparable Max N value derived

[26] Individuals swimming in the distance, in conditions of low visibility or with only part of their body visible on camera so identification was not possible.