Tweed Sand Bypassing Project

Reef Biota Monitoring 2024

Prepared for: Tweed Sand Bypassing

Prepared by Ecological Service Professionals Pty Ltd

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Acknowledgement of Country: In the spirit of reconciliation, Ecological Service Professionals acknowledges the Yugambeh language peoples, Traditional Custodians of the part of Bundjalung Country where we have worked, and we recognise their connection to land, sea and community. We pay our respect to their Elders, past and present, and extend that respect to all Aboriginal and Torres Strait Islander peoples through our scientific work on country.

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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 objective of establishing and maintaining the entrance to the Tweed River, and restoring and maintaining northward 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 TSB operations.

Changes in the extent of Kirra Reef were assessed using bathymetric survey data as well as aerial imagery and compared with historical changes in the areal extent. Field surveys were completed to assess changes in the composition of benthic communities (algae, sessile invertebrates and mobile invertebrates) and fish assemblages among reefs. In July 2024, six reef locations were surveyed: Kirra Reef (previously and potentially impacted reef); Cook Island West and South reefs (potentially impacted reefs); 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 collected over the past nine years since 2016.

The areal extent of Kirra Reef has varied through time, with the maximum extent of Kirra Reef of 40,813 m^2 measured in 1995. The reef extent declined following the commencement of the TSB project (as was predicted in the Project Environmental Impact Assessment). The reef was completely buried in 2007 and 2008, then uncovered and has generally increased in extent since 2009 from 1,009 m^2 to the current extent. Historically there have been 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 remained uncovered, with the eastern section periodically uncovered. The areal extent of Kirra Reef decreased over the past year from 3,492 m^2 in April 2023 to 2365 m^2 in June 2024; however, remains within the relatively stable reef extent observed since 2012. The inner western and eastern sections of Kirra Reef were not uncovered in June or July 2024. These inner reef sections have a very low profile (or relief) and are normally subject to increased frequency of physical disturbance, including sand burial following the normal migration of the offshore bar along the beach. 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 diverse community of reef dwelling organisms on these inner reef sections.

Following exhumation in 2009, the benthic faunal and floral communities on Kirra Reef have shown signs of ecological succession, with the recruitment of pioneer species such as foliose macroalgae and turf forming algae, and gradually becoming more similar in composition to other reef communities in the Gold Coast and Tweed Coast Region. In the past nine years (since 2016), the composition of benthic communities on all reefs assessed has differed. However, in recent years the monitoring program has shown succession slowing, generally demonstrating consistent differences in the composition of benthic assemblages on Kirra Reef relative to those at other reef locations. In 2024, the biodiversity of benthic assemblages living on Kirra Reef was consistent with that occurring on several of the other reefs in the area, although the benthic assemblages on Kirra Reef were dominated by foliose macroalgae and did not have longer-lived hard coral species that are found on the reefs

around Cook Island. Many of these species require a long period of suitable stable physical conditions to establish and grow to a point where they dominate the benthic assemblages. It is not uncommon for benthic communities to differ on a range of spatial scales with the communities around Cook Island differing in composition despite the close proximity (i.e. hundreds of metres). This small-scale spatial variation among reef locations may be related to different physical conditions (e.g. nutrient availability and wave energy), disturbance regimes and other ecological interactions occurring around the island. This degree of variability highlights the importance of sampling numerous comparative locations to build a comprehensive and representative understanding of the variety of reef habitats and variation in benthic assemblages in the local region, which provides confidence in attributing any changes detected to TSB operations.

In 2024, the average cover of foliose macroalgae (predominantly *Sargassum* spp.) had continued to increase at Kirra Reef and was a primary driver in the dissimilarity among reefs. Of note was the presence of an increasing coverage of kelp (*Ecklonia radiata*), which was recorded at Kirra Reef in 2023 and 2024, and has not been present for many years. Turf forming algae continues to dominate the benthic assemblages on vertical surfaces at Kirra Reef and elsewhere, accounting for 25 to 33% of the total coverage at Kirra Reef and 54 to 72% of the total coverage on all other reefs. Other groups, such as foliose macroalgae (e.g. *Dictyota* sp. and *Padina* sp.), crustose coralline algae and articulate coralline algae (e.g. *Jania* sp.) were also present at the reefs. Foliose macroalgae dominated horizontal surfaces at Kirra Reef, with a coverage of 43%, which was much higher than other reefs, which had a coverage of <7%.

In 2024, the sessile invertebrate assemblages on Kirra Reef remain dissimilar to those on other reefs in the region; however, were more similar to surrounding reefs both in terms of the overall coverage and average number of species. In 2024, ascidians and sponges remain the dominant sessile invertebrates on Kirra Reef, with the highest coverage of ascidians recorded on vertical surfaces on Kirra Reef. There continues to be a lack of abundant hard coral species on Kirra Reef, and the coverage of soft corals has remained relatively low. 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. In contrast, the reefs around Cook Island generally had a good coverage of long-lived hard corals (such as those from the genus *Paragoniastrea, Turbinaria* and encrusting *Porites*), particularly at Cook Island North and Cook Island South reefs.

A variety of sea urchins and feather stars dominated the mobile invertebrate assemblages observed on the reefs in 2024, with Cook Island West having the highest density, primarily due to the abundance of *Tripneustes* urchins. The highest diversity of mobile invertebrates was also recorded at Cook Island West. Several sea star, sea cucumber, snail, nudibranch, octopus, squid, cuttlefish, crayfish and crab species were also observed at the reefs.

A total of 138 bony and cartilaginous fish species from 45 families were recorded across all reefs in 2024. Most fish species recorded were common to the region; however, 13 species were observed among the reefs that had not been recorded in previous surveys. Fish communities at Palm Beach Reef were more diverse and abundant than all other reef locations in 2024; although, the overall composition of the community was generally similar among most reefs. The trophic composition of fish communities did not differ substantially among most reefs, with carnivores and omnivores dominating the assemblages.

Despite differences in the composition, the benthic community at Kirra Reef is considered to be representative of a mature assemblage of both algae and sessile invertebrates as well as mobile invertebrates and fish, reflective of the ecology of the reef community, and comparable in diversity to that found on other reefs with similar exposure and depth characteristics. Understanding the natural variability among reefs not exposed to disturbance from TSB is essential when assessing the impact and attributing 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 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 among reefs (e.g. recreational fishing through the conservation reserve around Cook Island).

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 2009, 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 and / or variability in communities over the coming years.

It is recommended that ongoing monitoring at Kirra Reef and Cook Island Aquatic Reserve be completed at adequate spatial and temporal scales to determine any potential impacts of TSB operations. Where possible monitoring of reef biota should be completed around June to allow for comparisons with existing data sets. Additional monitoring of the seagrass around Cook Island during November (when seagrass distribution is likely highest) should also be completed. Given the relatively stable reef area and differences among reefs, the annual monitoring program could shift to an event-based monitoring program using suitably derived environmental and operational based triggers for ecological monitoring components. Triggers for monitoring could include operational changes in TSB and / or indicators directly related to sand deposition, such as sedimentation or a substantial change in the accretion / erosion of sand around the reef measured through changes in reef area from aerial photos or hydrographic surveys.

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, 2024)

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 2023). 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. The monitoring is currently completed in accordance with Environmental Management Plan (EMP) Sub-Plan PLN.ENV.009 Flora and Fauna Management Plan (Revision 1; TSB 2024).

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 TSB operations. Sand was placed at Fingal in 2019, 2020, 2021, 2023 and 2024, and sand was placed at Dreamtime in 2022 and 2023. 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).

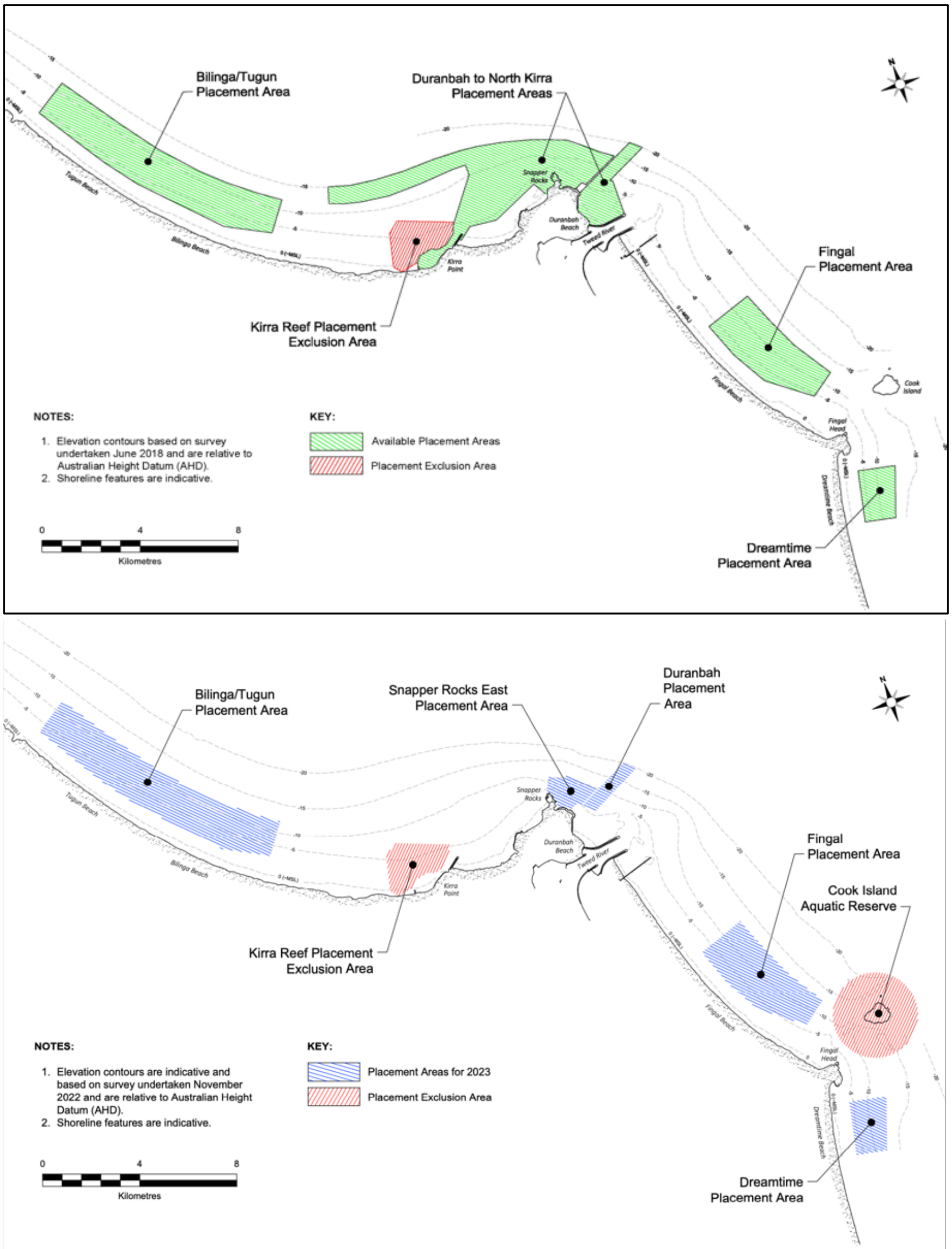


Figure 1.2 Current approved placement areas for disposing dredged sand (top) and nominated placement areas for the 2023 dredging campaign (bottom) (TSB 2023)

1.2 Scope of Works

The overall objective of the reef biota monitoring program in 2024 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 NearMap for June 2024 (NearMap 2024), 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 were obtained by TSB for 2021, 2022, 2023 and 2024. 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 model for 2024 and change in depth were then mapped and compared between 2022 and 2023, and 2023 and 2024.

2.2 Field Survey

2.2.1 Reef Locations

Six reef locations were surveyed in 2024 (Figure 2.1) based on a review of reefs previously surveyed (ESP 2024), including:

- Kirra Reef (KR) – previously impacted and potentially 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 (PBR) – comparative (Figure 2.3 & Figure 2.4).

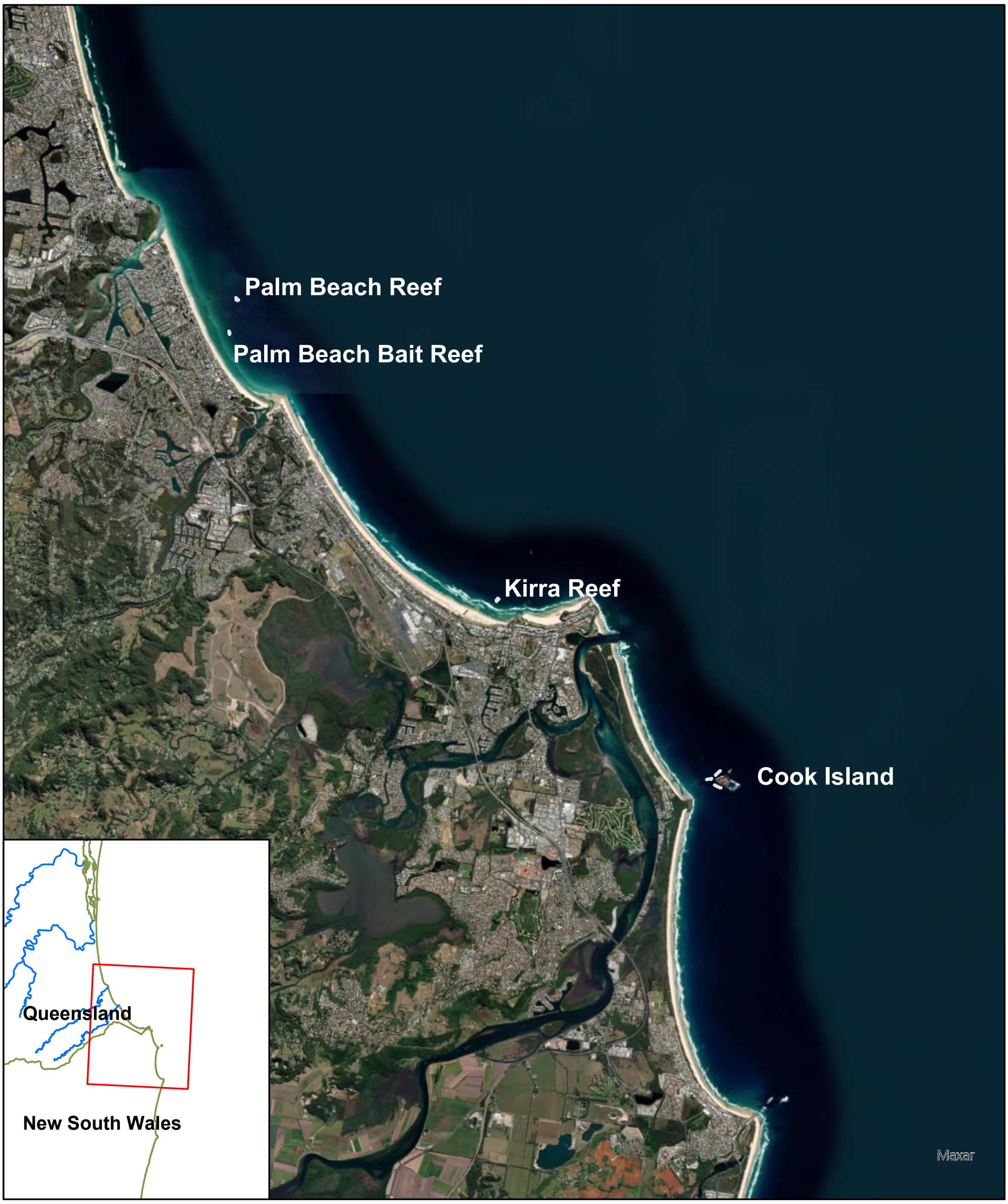
Ideally the comparative reefs would be standardised for reef depth and distance from the shore so that they are exposed to relatively similar physical disturbance vectors; however, there are limited reefs along the coast that experience conditions similar to the previously and potentially impacted reefs. 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 two days on 19 and 20 July 2024, aligning with previous surveys, which have historically occurred between April and July.

During the July 2024 survey, sea conditions were good, with small, easterly swell. Winds were north-easterly to north-westerly (approximately 8 to 10 knots) and water clarity was good, with the sea floor visible from the surface at all sites. Swells were low to moderate (<1 to 2 m) in the few weeks leading up to the survey. Rainfall leading up to the survey was above average, with 105.6 mm recorded in early July 2024 (monthly average for July is 73.7 mm), though no rain fell in the week prior to the survey (Coolangatta station 40717; BOM 2024).

Significant wave heights were up to 1 m at Tweed Heads, 0.7 m at Bilinga and 0.6 m at Palm Beach wave rider buoys, and maximum wave heights were 1.8 m at Tweed Heads, and 1.3 m at Bilinga and Palm Beach wave rider buoys between 19 and 20 July 2024. In the two weeks prior to this, significant wave heights were up to 2.5 m at Tweed Heads, 1.8 m at Bilinga and 2.0 m at Palm Beach wave rider buoys, and maximum wave heights were 5.0 m at Tweed Heads, 3.3 m at Bilinga and 3.7 m at Palm Beach wave rider buoys (Queensland Government 2024).



Legend

Transect 2024

Kirra Reef Transects

Project Reference: 2440 Author: SW
Datum: GDA2020

0 0.75 1.5 3 4.5
Kilometres

N

Figure 2.1 Reef locations for Biota Monitoring in 2024

2.2.3 Benthic Communities

Benthic communities (including algal, sessile invertebrate and conspicuous mobile invertebrate assemblages) were quantified at each reef location using up to 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 up to 45 horizontal quadrats and 45 vertical quadrats were collected at each reef location (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 diver searches were also completed at all reefs to aid taxonomic identification, as well as targeting cryptic, invasive and threatened species.

Table 2.1 Location of transects (sites) at each reef location (Datum: GDA2020 UTM Zone 56J)

Reef Location	Transect (Sites)	Transect Start		Transect End	
		Easting	Northing	Easting	Northing
Kirra Reef (KR)	KRN1	552104.0	6884649.0	552100.0	6884671.0
	KRN2	552126.5	6884662.5	552114.2	6884684.0
	KRN3	552156.5	6884677.8	552147.5	6884706.2
Palm Beach Reef (PBR)	PB1	546853.2	6890777.0	546827.5	6890789.4
	PB2	546817.1	6890803.0	546798.1	6890823.4
	PB3	546829.1	6890764.7	546803.4	6890783.2
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	6881190.2	556656.6	6881205.7
	CIN2	556616.9	6881173.8	556597.2	6881154.7
	CIN3	556580.9	6881138.9	556560.7	6881115.0
Cook Island South reef (CIS)	CIS1	556568.2	6880901.9	556549.0	6880915.3
	CIS2	556588.5	6880891.8	556612.2	6880879.3
	CIS3	556635.8	6880866.6	556670.8	6880858.5
Cook Island West reef (CIW)	CIW1	556381.7	6881027.2	556406.4	6881035.7
	CIW2	556423.8	6881038.7	556444.3	6881032.3
	CIW3	556460.2	6881032.3	556478.1	6881046.0

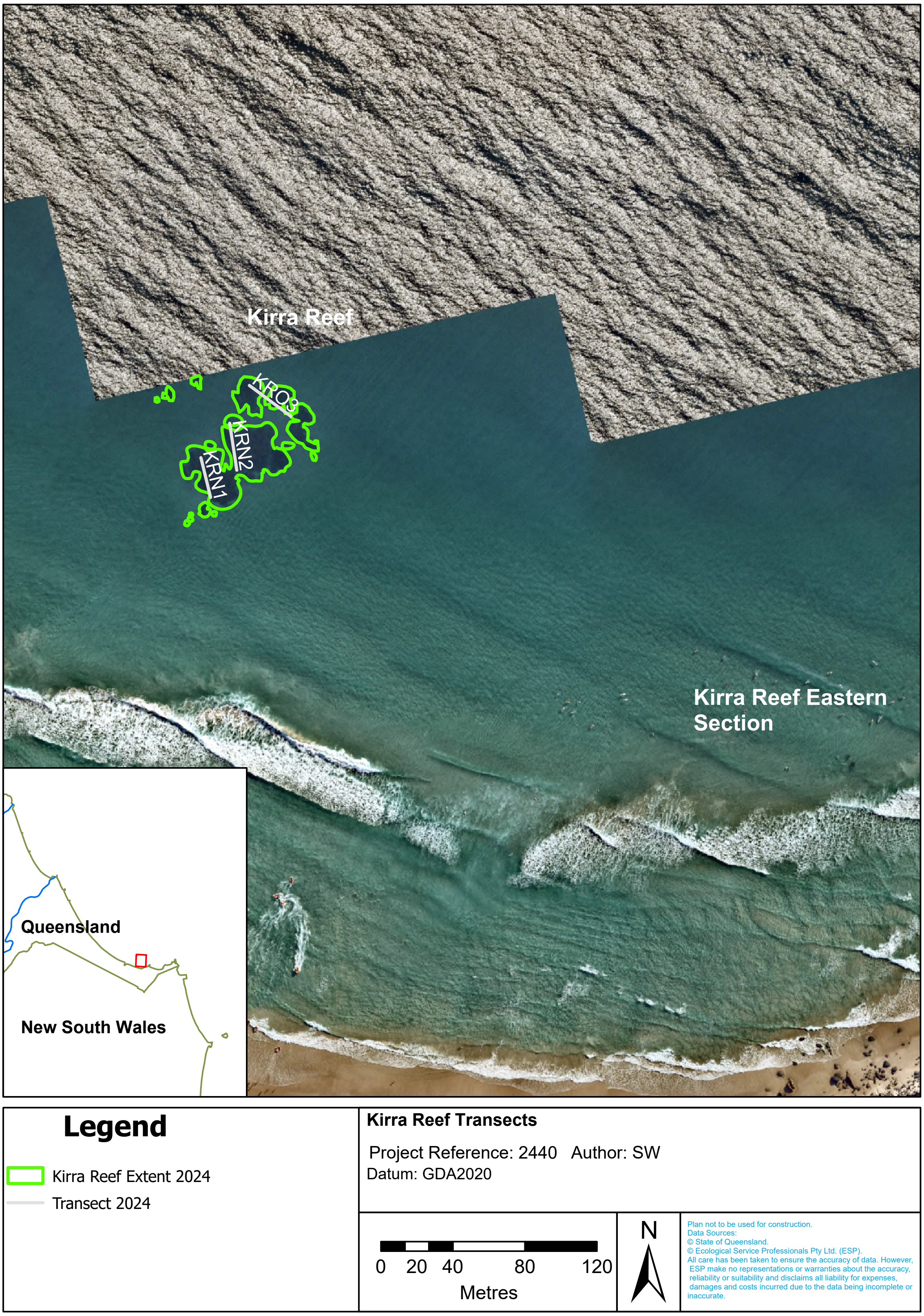


Figure 2.2 Location of transects surveyed in 2024 at Kirra Reef

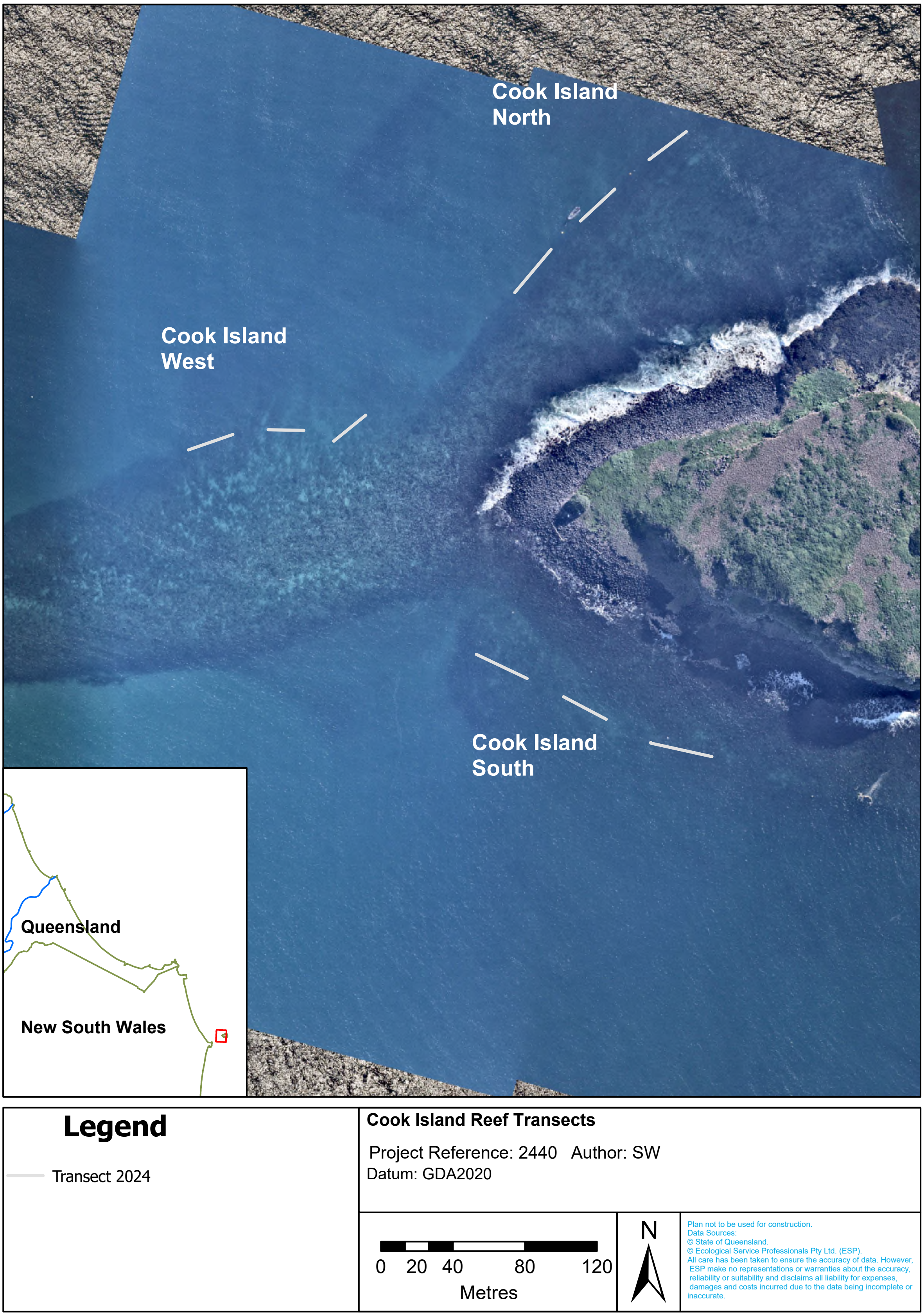


Figure 2.3 Location of transects surveyed in 2024 at the three reef locations around Cook Island

Figure 2.4 Location of transects surveyed in 2024 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). Fifty 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 2024, 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 and 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

[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.

benthic assemblages were 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. A species accumulation curves for the number of sessile invertebrate taxa among reefs on vertical and horizontal surfaces was also completed.

To compare differences among reef locations (location) over the previous nine years (between 2016 and 2024), 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 two-factor PERMANOVA based on untransformed data, with survey year and location as the fixed factors separately for vertical and horizontal surfaces. Differences in the composition of the benthic assemblages among locations through time were visualised using nMDS ordinations. Sites were aggregated within each reef locations as in 2018 and 2019 there was no differentiation provided for sites within reefs.

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. feather stars, urchins, sea stars, sea cucumbers), crustaceans (e.g. crabs and lobsters), and mobile molluscs (e.g. octopus, snails, nudibranchs) were recorded. The density of conspicuous mobile invertebrates was compiled from photo quadrat data and compared among reefs. Data were pooled among each of the photos for different surface orientations.

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). 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 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.

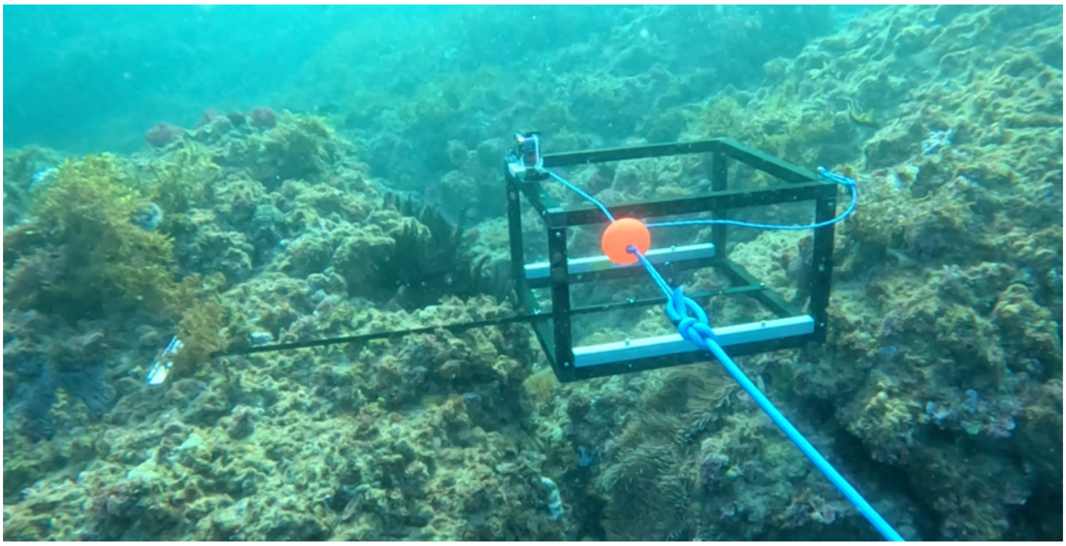


Figure 2.5 UBRUVS were the primary survey method for fish communities at each reef location

2.2.4.1 Data Management and Analysis

Fish assemblages and other marine vertebrates were determined for each reef from UBRUVS and SCUBA diver 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.

One UBRUVS at Palm Beach Bait Reef was excluded from analyses, as it was positioned downward, facing sand for the entire recording. The number of species for each transect from UBRUVS were transformed by fourth root transformation (due to the overabundance of some schooling species) and transformed to a Bray Curtis similarity matrix. Differences in fish assemblages were compared among reefs using a one-factor PERMANOVA and where there were differences, Monte Carlo pairwise tests were used to determine which reef differed. Taxonomic groups contributing to the differences among sites and locations were identified using the SIMPER routine (Clarke & Warwick 1994). Assemblages for each UBRUVS on each reef were visualised using nMDS (Clarke & Warwick 1994). The total number of species (taxonomic richness) recorded on each UBRUVS was also 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 Assurance and Quality Control (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 subset 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 Climate Change, Energy, the Environment and Water (DCCEEW) Protected Matters Search Tool (PMST) for a 2 km buffer of the coastline between Cook Island and Palm Beach (DCCEEW 2024) and National Introduced Marine Pest Information System (NIMPIS 2024). Additional searches for species of significance for conservation and invasive species were completed using 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, temperature, dissolved oxygen, pH and turbidity. Each parameter was logged continuously at 5 second intervals to collect approximately 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 all sites using a PME mini PAR meter calibrated for use in marine water. The light attenuation coefficient (Kd) using Beer-Lambert's Law ($Kd = \ln(Iz0/Iz)/(z)$, where Iz0 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 2024) for the Tweed Heads (representative of conditions at Cook Island reefs), Bilinga (representative of conditions at Kirra Reef) and Palm Beach (representative of conditions at Palm Beach and Palm Beach Bait reefs) wave rider buoys (Table 2.2). Data available for the year prior to the survey (21 July 2023 to 20 July 2024) were graphed to provide a record of physical conditions preceding monitoring.

Table 2.2 Wave rider buoys water depth (m) and location (Datum: GDA2020 UTM Zone 56J) (Queensland Government 2024)

Wave Rider Buoy	Depth (m)	Location	
		Easting	Northing
Tweed Heads	22	556596.8	6882991.1
Bilinga	18	550154.9	6886848.1
Palm Beach	23	547676.0	6893147.9

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 historic reports as the outer western section), inner western (referred to in some historic reports as the western or southern section) and eastern sections (Figure 3.2b). The inner western and eastern sections of Kirra Reef are naturally more prone to fluctuation in the area of reef exposed 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 June 2024, Kirra Reef had an estimated total aerial extent of 2,365 m^2, which only comprised of reef in the northern section, with no inner or eastern sections of reef. This was approximately 32% smaller than the total extent measured in April 2023 (total area of 3,492 m^2; ESP 2023). While there is a margin of error in the estimation of aerial extent, there are some obvious changes visible in the aerial images between 2022 and 2023 as well as between 2023 and 2024. This is likely due to the movement of the offshore sandbar, rather than TSB given sand pumping has remained relatively consistent over the last year. Despite this recent changes, the total area of Kirra Reef has remained relatively stable since 2012 compared to the extreme changes previously recorded (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 (Figure 3.1). 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 2,365 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). While there were some clear areas of change (burial) in 2024, the exposed area of the northern section of reef has still been relatively stable since 2012 (Figure 3.1), 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 was 0 to 4,900 m^2, and for the eastern section of the reef was 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, which reduced to 204 m^2 in 2022, and was not present in 2023 or 2024. 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 June 2022, the vertical relief of the eastern section was approximately 30 cm above the bottom, while the northern section was approximately 1.5 to 3 m above the bottom (ESP 2022). 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 the eastern section of the reef.

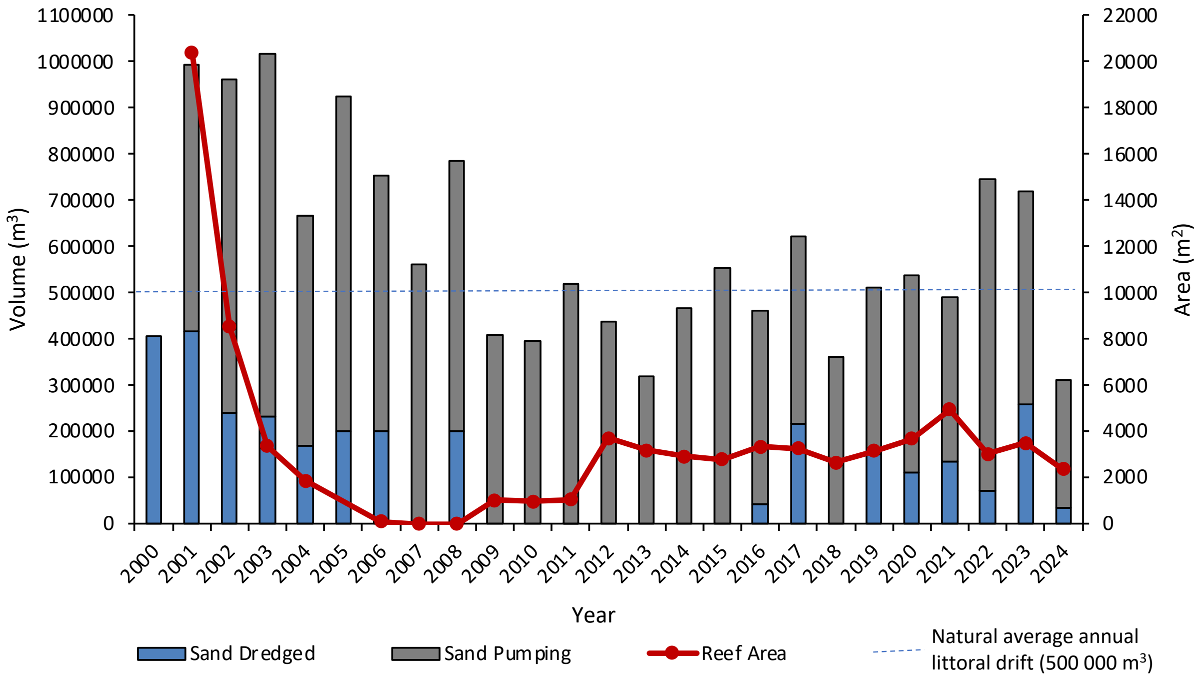
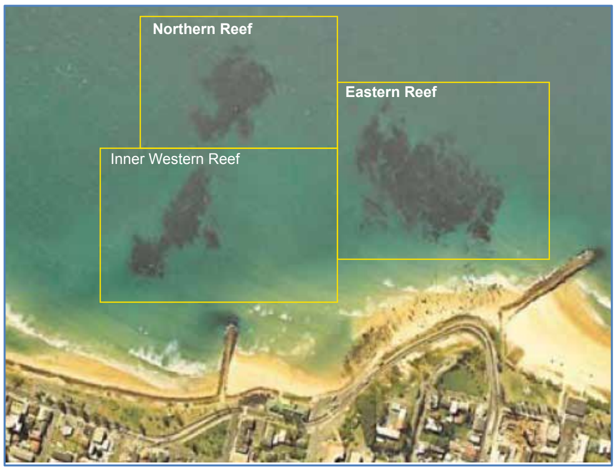


Figure 3.1 Estimated surface area (m^2) at Kirra Reef and total annual and dredging and pumping volumes (m^3) between 2000 and 2024 (data for 2024 includes sand volumes up to end of July) (pumping and dredging volumes sourced from TSB 2024)

a) 1956

Source: Queensland Government 2021a

b) 1982

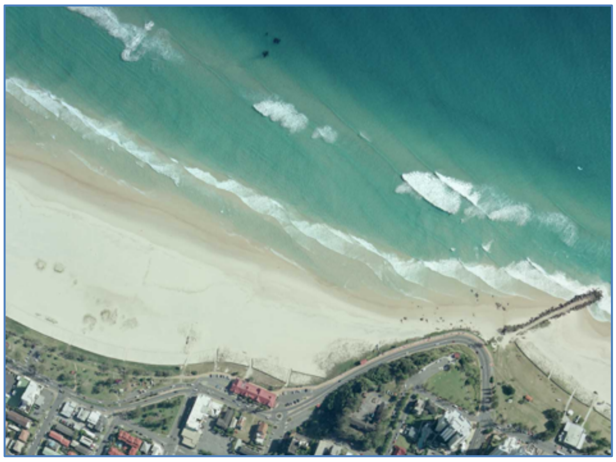


Source: WorleyParsons 2009

c) 1995

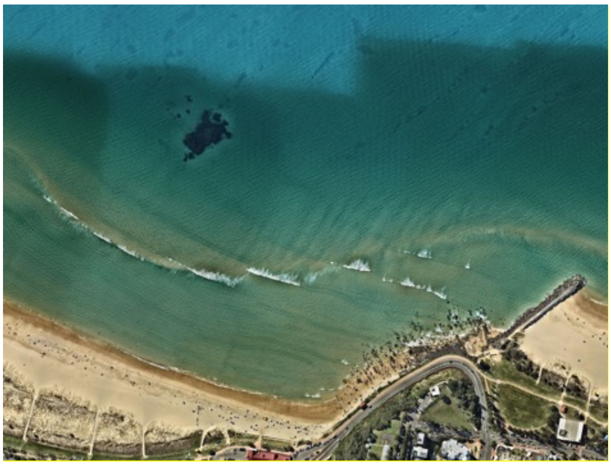
Source: Queensland Government 2021a

d) 2007



Source: Queensland Government 2021b

e) 2023



Source: NearMap 2023

f) 2024

Source: Nearmap 2024

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) 2023; and, (f) 2024.

3.1.2 Bathymetric Surveys

The depth around Kirra Reef decreased between April 2023 and May 2024 based on bathymetric survey results, with a 0.8 to 1.2 m increase in sand height along the south-eastern edge of the northern reef section (Figure 3.3; as shown by the light green colours). This has coincided with the migration of a large sand bar further offshore. In contrast, between June 2022 and April 2023, there was generally an increase in depth around Kirra Reef of up to 0.8 and 1.7 m (Figure 3.3; as shown by the darker blue colours). There were small outcrops of eastern reef exposed in 2021 (ESP 2021), and a smaller area of rock outcrop exposed to the southeast, and landwards the offshore sandbar in 2022 (ESP 2022). This small rock outcrop was covered by the shoreward migration of the offshore sandbar between 2022 and 2023 (as shown by the dark blue colour in Figure 3.3). These eastern outcrops were not present in during the 2023 and 2024 surveys, However, aerial photographs taken in August 2024 (following the surveys) show a small area of the eastern outcrops potentially exposed, although this may also be a build-up of macroalgae that is visible in the aerial photographs (Figure 3.4). The migration of the sandbar further offshore between 2023 and 2024 has decreased the extent of reef around the main northern reef section, resulting in a reduction in the extent of reef area. It is common for an offshore bar to form and migrate inshore and offshore on dynamic sandy beaches to dissipate wave energy (Short 2019). The decrease and increase in depth between May 2021 and May 2024 have been more substantial than observed in recent years (i.e. ± 0.2 m change between July 2019 and May 2020 and ± 0.2 to 1.0 m change between May 2020 and May 2021), when depth around much of the reef had either increased or stayed relatively similar (ESP 2020; ESP 2021).

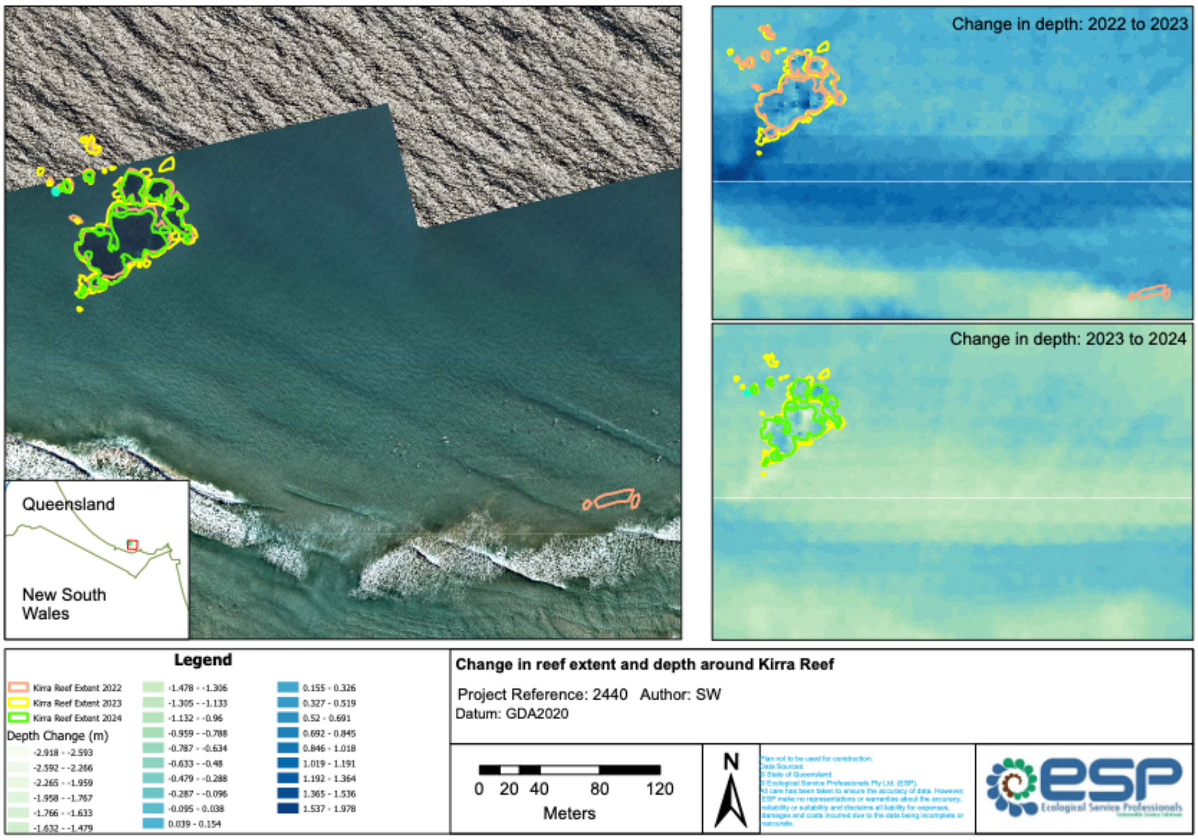


Figure 3.3 Areal extent (left) and changes in depth (light green indicating shallower and blue indicating deeper water) from June 2022 to April 2023 (top right); and April 2023 to May 2024 (bottom right)

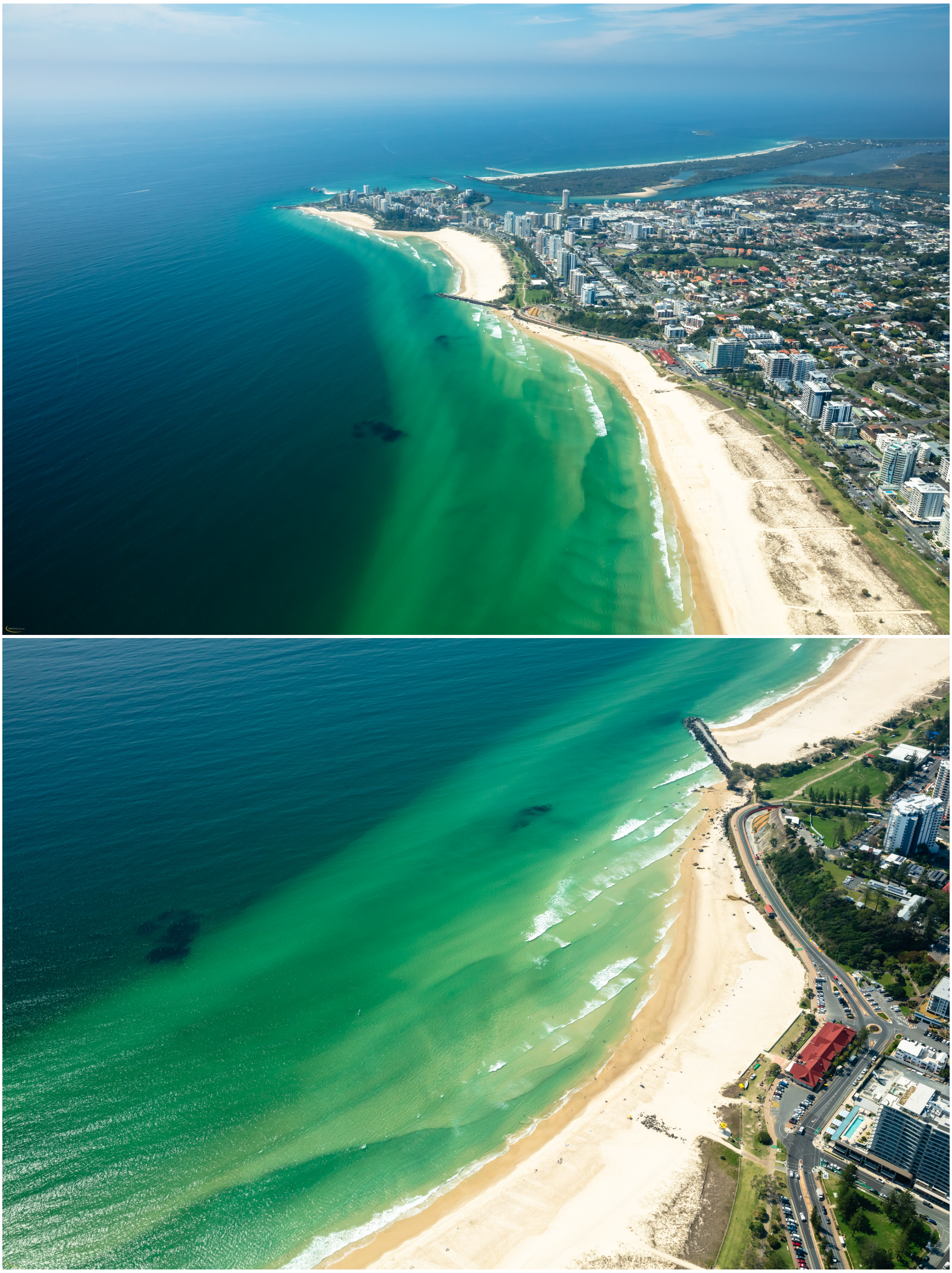


Figure 3.4 Oblique aerial photographs of Kirra Reef taken in August 2024 (images provided by TSB)

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. The assemblages on Kirra Reef differed from those on comparative 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). The assemblages on reefs around Cook Island on vertical surface and those at Cook Island South and Cook Island North on horizontal surfaces were most similar among the reefs surveyed.

The differences in benthic communities between Kirra and the other reefs in the area was typically due to the lower coverage of turf forming algae and higher coverage of foliose macroalgae (Sargassum) at Kirra Reef, which contributed to more than 33% of the dissimilarity among reefs (SIMPER; refer to Section 3.2.2 & 3.2.3). 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), position of the off-shore sandbar, abiotic factors (such as wave action), settlement and recruitment of sessile species, water quality (including nutrient availability and high rainfall), and / or possible variation in the abundance of herbivorous fauna among reefs.

In July 2024, the differences in the composition of benthic communities between horizontal and vertical surfaces were less pronounced in each reef location than in previous years; however there was a significant difference in the composition of assemblages among reefs (Appendix B, Table B.5.2). At Kirra Reef, there was a difference in the overall composition of the benthic communities between horizontal and vertical surfaces, with the differences primarily due to a lower coverage of Sargassum and a higher coverage of sessile invertebrates on vertical compared horizontal surfaces (SIMPER Appendix B, Table B.5.3).

[5] Benthic communities PERMANOVA Orientation vs Site interaction MS = 78 pseudo-$F_{4,10}$ = 3.88, p = 0.032; Pairwise tests for differences among reefs for horizontal surfaces: KR≠PBR≠CIS=CIN≠CIW and vertical surfaces: CIS≠KR≠PBR≠CIS=CIN=CIW ≠PBNR *p(MC)* < 0.05

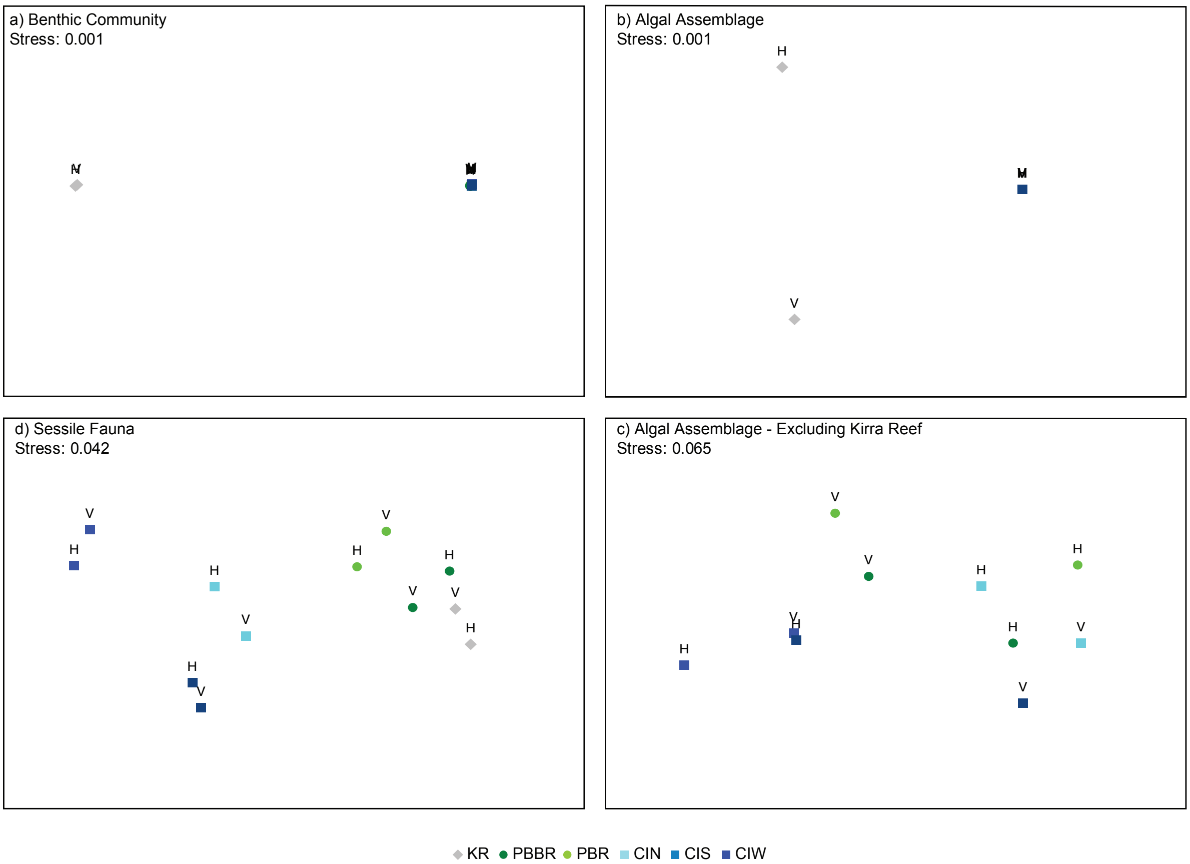
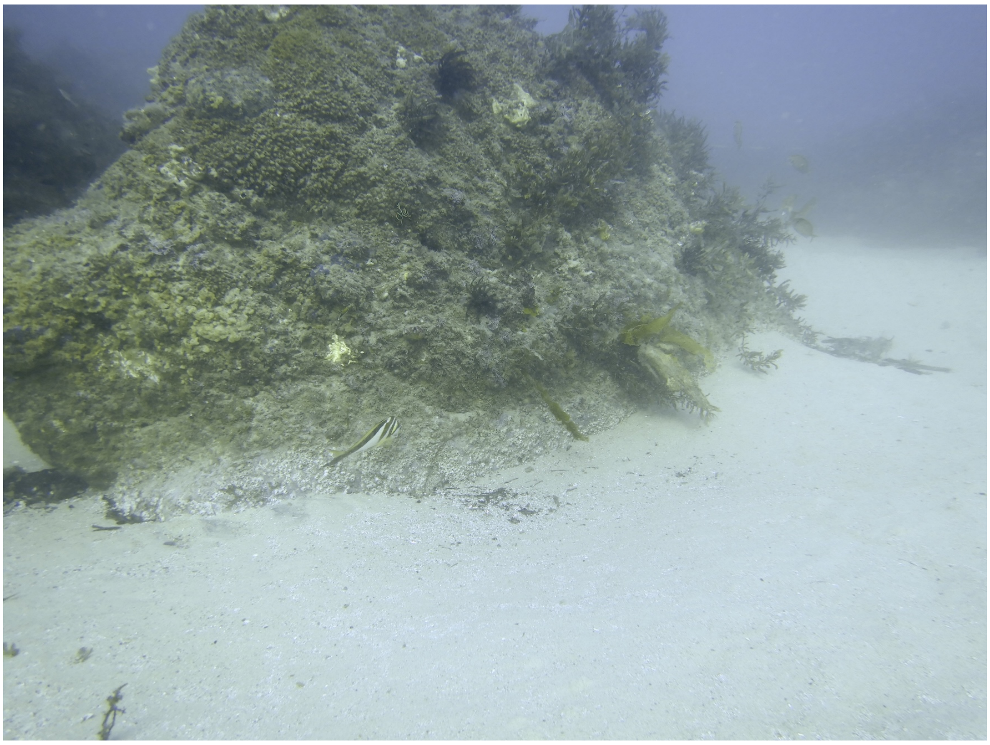


Figure 3.5 nMDS ordination showing difference in the composition of benthic assemblages between surface orientations and reefs for (a) the sessile community, (b) algal assemblages including Kirra reef assemblages, (c) algal assemblages excluding Kirra reef assemblages, and (d) sessile invertebrate assemblages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

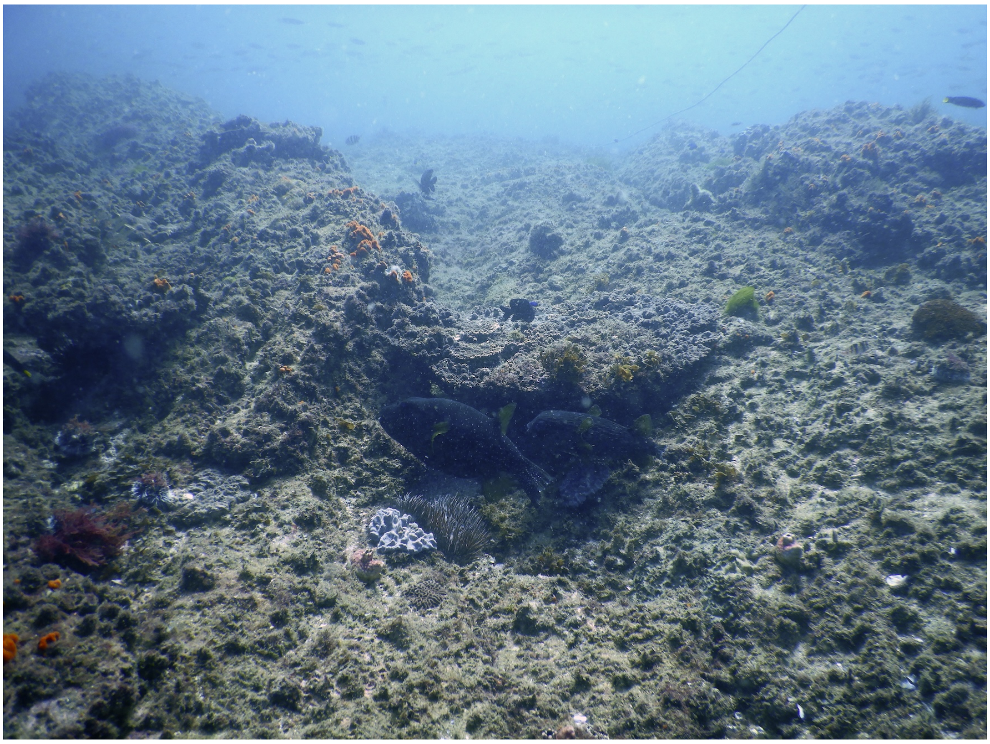
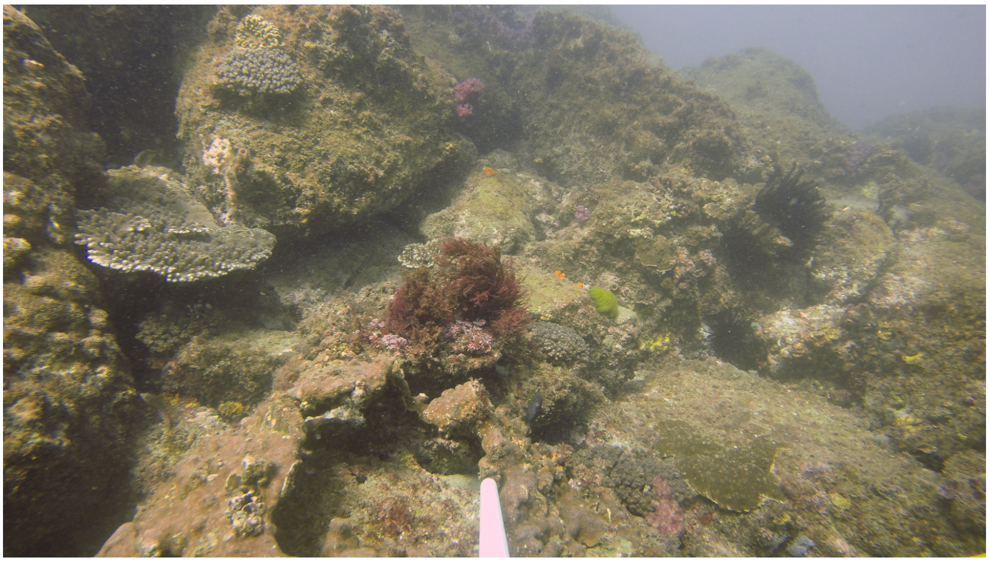


Figure 3.6 Example benthic assemblages at a) Kirra Reef and b) Palm Beach Reef

a)

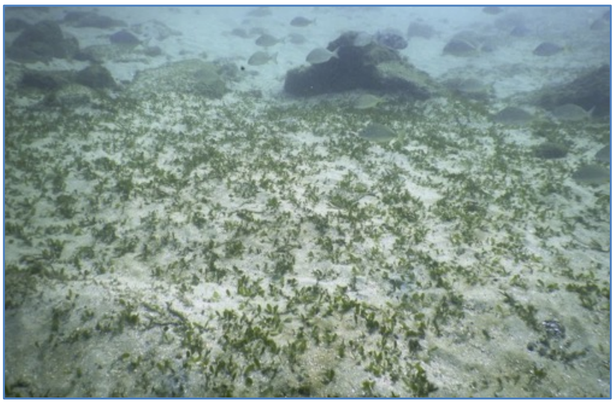


b)

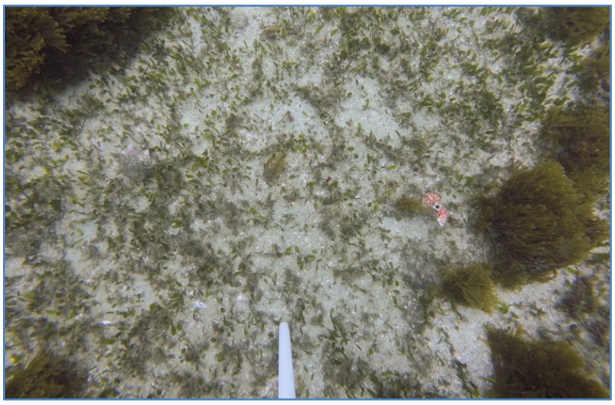
Figure 3.7 Example benthic assemblages at a) Cook Island North and b) Cook Island West

A survey of seagrass distribution in November 2023 recorded seagrass on the north-western and south-western sides of Cook Island, which covered a total area of 958 m^2 (ESP 2024). On the north-western side of Cook Island, seagrass had a discontinuous extent, recorded in patches between macroalgae, rock and rubble on sand habitats. The community was dominated by *Halophia ovalis*, with coverage of patches ranging between approximately 15% and 50%. On the south-western side of Cook Island, seagrass was more continuous and had a much greater extent. The community was typically dominated by *H. ovalis* often growing amongst various foliose macroalgae, with a patch of mixed seagrass (*H. ovalis* and *Zostera muelleri*) also present. Coverage of seagrass on the south-western side of Cook Island was dense (>60% coverage) on the fringe of the rocky reef and decreased as the patches extended out over bare sand (ESP 2024). The extent and coverage of seagrass around Cook Island varies over time. Opportunistic observations in July 2020 and May 2021, indicated the seagrass patch on the north-western side of Cook Island had a cover of approximately 30% to 50% (ESP 2020; ESP 2021), whereas in June 2022 and May 2023, it covered approximately 10% to <10% of the space where it was present (ESP 2022; ESP 2023; Figure 3.8). The coverage and distribution of seagrass previously recorded around Cook Island will be assessed and mapped in November 2024. Marine vegetation, including seagrass, are protected under the *NSW Fisheries Management Act 1995*.

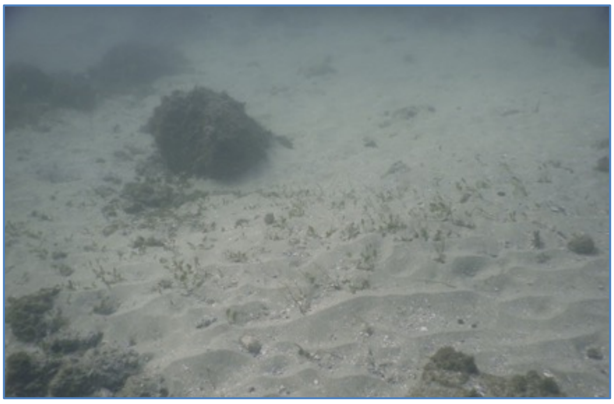
a)



b)



c)



d)

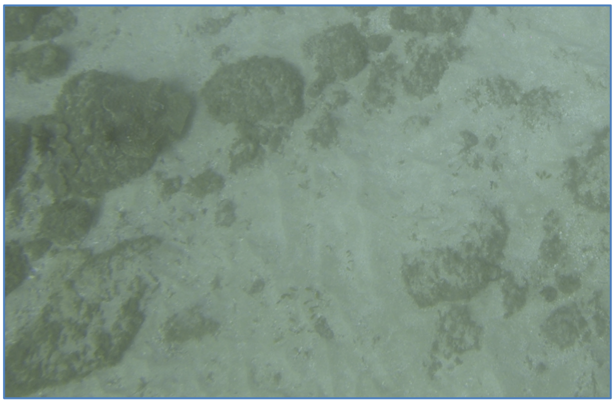


Figure 3.8 Seagrass at Cook Island West in a) 2020 b) 2021 c) 2022 and d) 2023

The coverage of bare sand and rubble habitat was higher on horizontal than vertical surfaces at all reefs in 2023 and 2024, except at Palm Beach Bait Reef in 2024. There was a decrease in the coverage of bare sand and rubble on Kirra Reef between 2023 and 2024 surveys (Figure 3.9). However, bare sand and rubble habitat coverage also increased between 2023 and 2024 at Cook Island West Reef (Figure 3.9).

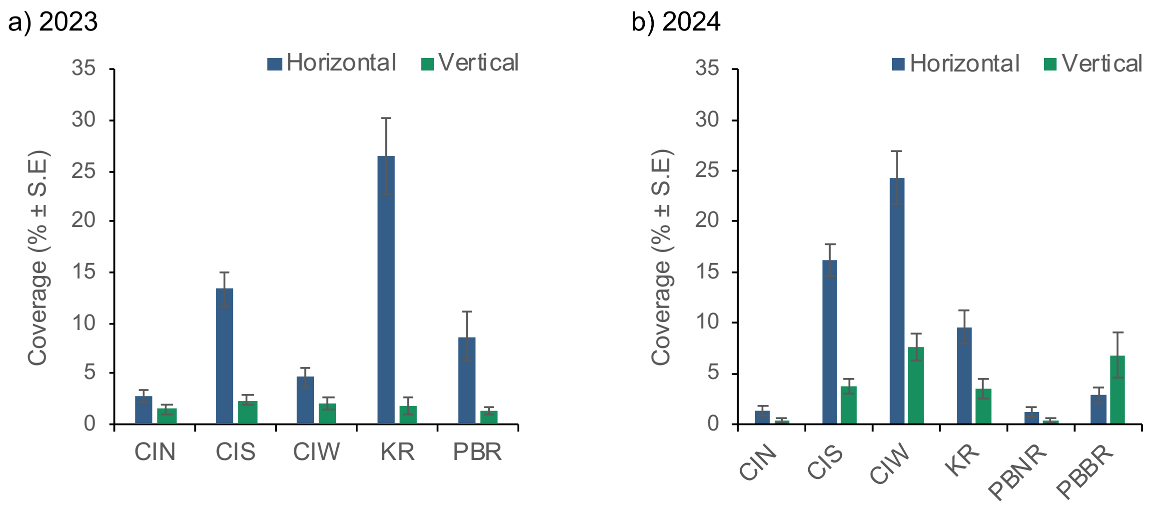


Figure 3.9 Average coverage (% ± S.E.) of bare (sand & rubble) habitat between surface orientations, among reefs in (a) 2023 and (b) 2024

3.2.2 Algal Assemblages

The algal assemblage on most reefs was dominated by turf forming algae on both horizontal and vertical surfaces. The exception was the algal assemblage on horizontal surfaces at Kirra Reef, which was dominated by foliose macroalgae (43% of the reef area), with turf algae covering 25% of the reef area. Turf forming algae covered on average more than 33% of the reef areas on vertical surfaces at all reefs and more than 54% of the reef areas on horizontal surfaces at all reefs excluding Kirra Reef. 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.) were also present. The composition of algal assemblages differed among reefs on both horizontal and vertical surfaces [7] (Figure 3.5b; Figure 3.11; PERMANOVA, Appendix B, Table B.5.4). The algal assemblages on Kirra Reef differed most from those on the other reefs, largely due to the higher coverage of Sargassum at Kirra Reef relative to other reefs.

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 foliose macroalgae was highest at Kirra Reef (24 – 43%) and lowest at Palm Beach Bait Reef (<0.1%) (Figure 3.10a). The coverage of macroalgae on Kirra Reef was dominated by *Sargassum* spp. and was relatively high compared with that recorded on most of the other reefs (Figure 3.10a). The coverage of foliose macroalgae on Kirra Reef was higher in 2024

[7] Algal assemblages PERMANOVA Reef main effect $MS_{5,12}$ = 69797, pseudo-F = 10.13, p = 0.003; Pairwise tests for differences among reefs: Table B.5.4

relative to that recorded between 2021 and 2023, (Figure 3.10a; ESP 2021; ESP 2022; ESP 2023). Foliose macroalgae covered on average 43% of horizontal and 24% of vertical surfaces at Kirra Reef in 2024 (Figure 3.10a; Figure 3.11), 10 – 16% in 2021, 2 – 6% in 2022 and 18 – 29% in 2023 on both horizontal and vertical surfaces (ESP 2021; ESP 2022; ESP 2023). Foliose macroalgae cover in 2020, was more similar to 2024 and covered an average of 18 – 38% of surfaces at Kirra Reef. *Sargassum* spp. was largely absent at the other reefs surveyed in 2024, with differences among reefs often largely due to variation in the coverage of turf forming algae (SIMPER; Appendix B, Table B.5.6).

The eastern section of Kirra Reef was buried by sand in 2023 and 2024. When this low relief reef section of Kirra Reef was exhumed in 2022 (while not quantitatively assessed), the rock surface was dominated by a moderate coverage of foliose macroalgae, in particular *Sargassum, Padina* and *Ulva*. These macroalgal species colonise rocky reefs quickly, particularly where reef surfaces are available for colonisation during winter months when algae are known to spawn (Kennelly 1987). Foliose macroalgae including kelp (*Ecklonia radiata*) has also established on recently exhumed rock on the northern section of Kirra Reef (Figure 3.11).

The coverage of turf forming algae was highest on both vertical and horizontal surfaces at Cook Island North and Palm Beach reefs (>60%) and was lowest on vertical and horizontal surfaces at Kirra Reef (<33%) (Figure 3.10b; PERMANOVA Appendix B Table B.5.5b). Differences in the coverage of turf forming algae at Kirra Reef relative to that measured on the other reefs contributed more than 44% of the difference in algal assemblages among reefs (SIMPER Appendix B, Table B.5.6).

The coverage of articulate and crustose coralline algae has remained relatively consisted through time, typically remaining less that 13%; however, in 2024 crustose coralline algae covered less than 4% of the surface area on any one reef (Figure 3.10c). In 2024, the coverage of coralline algae was similar among reefs, except on horizontal and vertical surfaces at Palm Beach Reef, which were higher than at the other reefs (Figure 3.10c; PERMANOVA Appendix B Table B.5.5c). Crustose coralline algae was largely absent from the areas surveyed on Palm Beach Bait Reef (Figure 3.10c).

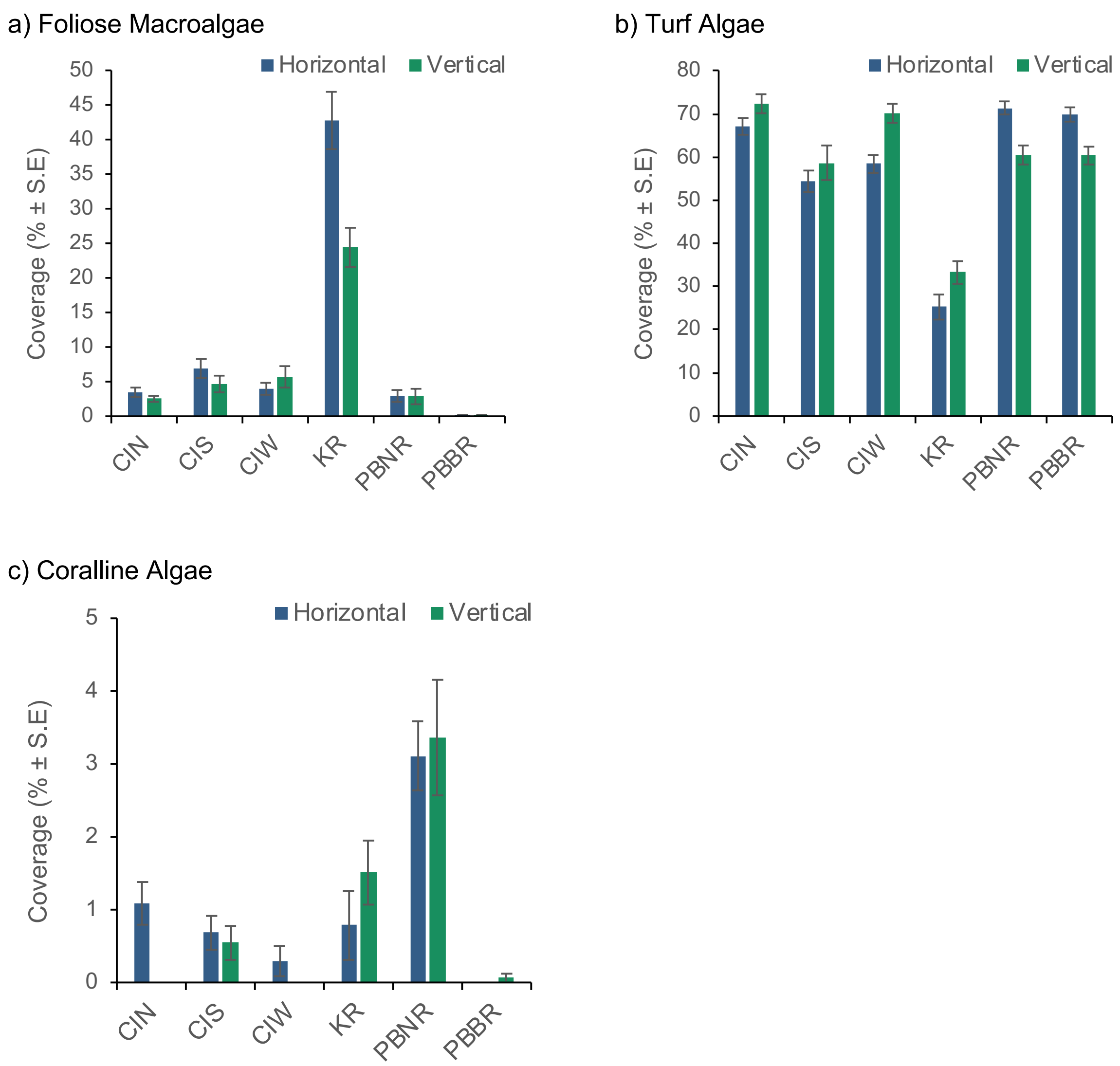


Figure 3.10 Average coverage (% ± SE) of foliose macroalgae, turf algae and coralline algae on vertical and horizontal surfaces, among reefs in 2024

a)

b)

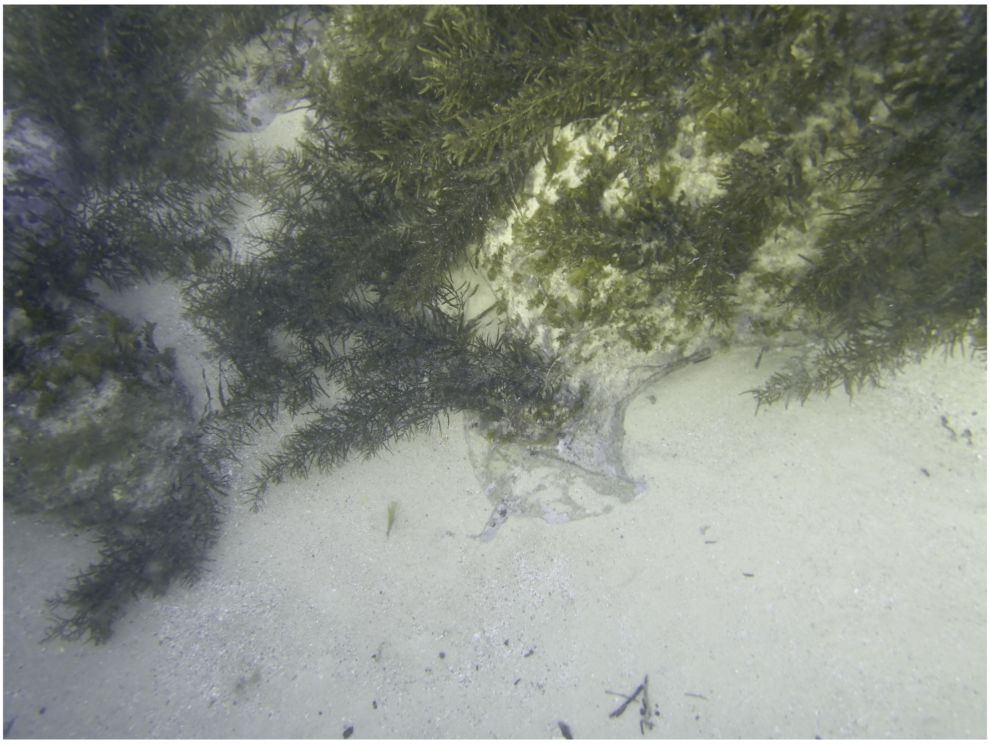


Figure 3.11 Algal communities at a) Kirra Reef northern section and b) a band of recently exhumed reef section rapidly colonised by foliose macroalgae

3.2.3 Sessile Invertebrate Assemblages

In 2024, a total of 105 taxa were recorded across all vertical surfaces and 108 taxa recorded across all horizontal surfaces across all reefs. The fewest taxa were recorded on horizontal surfaces at Cook Island West Reef (25 taxa) (Figure 3.12). The greatest number of taxa were recorded on horizontal surfaces at Palm Beach Reef (49 taxa). A total of 47 taxa were recorded on vertical surfaces and 32 taxa on horizontal surfaces at Kirra Reef (Figure 3.12). Generally, there has been similar number of taxa recorded on both horizontal and vertical surfaces at Kirra Reef since 2021.

In 2024, 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 ascidian *Polycarpa procera*, was typically higher on horizontal surfaces at Kirra Reef than at the other reefs and contributed to 10 – 19 % of the difference in assemblage composition (SIMPER Appendix B, Table B.5.8). The lack of hard corals (i.e. from genus Paragoniastrea, Turbinaria and encrusting *Porites*) and low coverage of soft corals (Sclerophytum) at Kirra Reef also contributed to differences in the composition of assemblages among reefs, particular with those assemblages surrounding Cook Island (SIMPER Appendix B, Table B.5.8 & Table B.5.9). On vertical surfaces, the higher coverage of ascidians *Polycarpa procera*, *Pyura stolonifera* and *Herdmania momus,* and differences in the coverage of several sponges contributed most to the difference among assemblages on Kirra Reef and the other reefs (SIMPER Appendix B, Table B.5.9).

The average taxonomic richness and coverage of sessile invertebrates often did not differ significantly between Kirra Reef and the comparative reefs surveyed in 2024, except on vertical surfaces at Cook Island West, which had significantly lower taxonomic richness than recorded at Kirra Reef [9] (Figure 3.13a,b; PERMANOVA Appendix B, Table B.5.10a,b). On most reefs (except Cook Island North), the average coverage of sessile fauna was higher on vertical than horizontal surfaces[10] (Figure 3.13a,b; PERMANOVA Appendix B, Table B.5.10b). This was expected as horizontal surfaces such as those on Kirra Reef typically had a greater coverage of foliose and turf forming algae (Figure 3.10), which can outcompete sessile invertebrates and cause physical disturbance preventing settlement. There was also a higher coverage of sand and rubble on horizontal than vertical surfaces (Figure 3.9), which can increase physical disturbance from sand scour and burial creating conditions that are unsuitable for sessile invertebrate recruitment and growth.

At both Cook Island and Palm Beach reefs, longer lived species such as hard and soft corals covered a greater proportion of both vertical and horizontal surfaces than on Kirra Reef or

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[8] Sessile Invertebrates - PERMANOVA Orientation vs Reef interaction $MS_{5,12}$ = 5643, pseudo-F = 1.35, p = 0.041; Pairwise tests for differences among reefs for horizontal surfaces: CIW≠CIS≠CIN≠KR≠PBR≠PBBR *p(MC)* < 0.05; on vertical surfaces, CIW≠CIS≠CIN≠KR≠PBR KR=PBBR *p(MC)* < 0.05

[9] Richness of Sessile Invertebrates PERMANOVA Orientation x Reef Interaction $MS_{5,12}$ = 27, pseudo-F = 6.49, p = 0.007, Pairwise tests for differences among reefs: CIW<KR=CIS=CIN=PBBR=PBNR *p(MC)* < 0.05; Coverage of Sessile Invertebrates PERMANOVA Orientation Main effect $MS_{1,12}$ = 5294, pseudo-F = 20.30, p = 0.004 Pairwise tests Vertical>Horizontal *p(MC)* < 0.05.

[10] Coverage of Sessile Invertebrates PERMANOVA Orientation Main effect $MS_{1,12}$ = 5294, pseudo-F = 20.30, p = 0.004 Pairwise tests Vertical>Horizontal *p(MC)* < 0.05.

Palm Beach Bait Reef (Figure 3.13c,d and Figure 3.14). In 2024, there was no evidence of the higher incidence of diseased corals recorded on reefs around Cook Island and Palm Beach reefs in 2022; although several hard coral colonies had died and were covered in turfing algae.

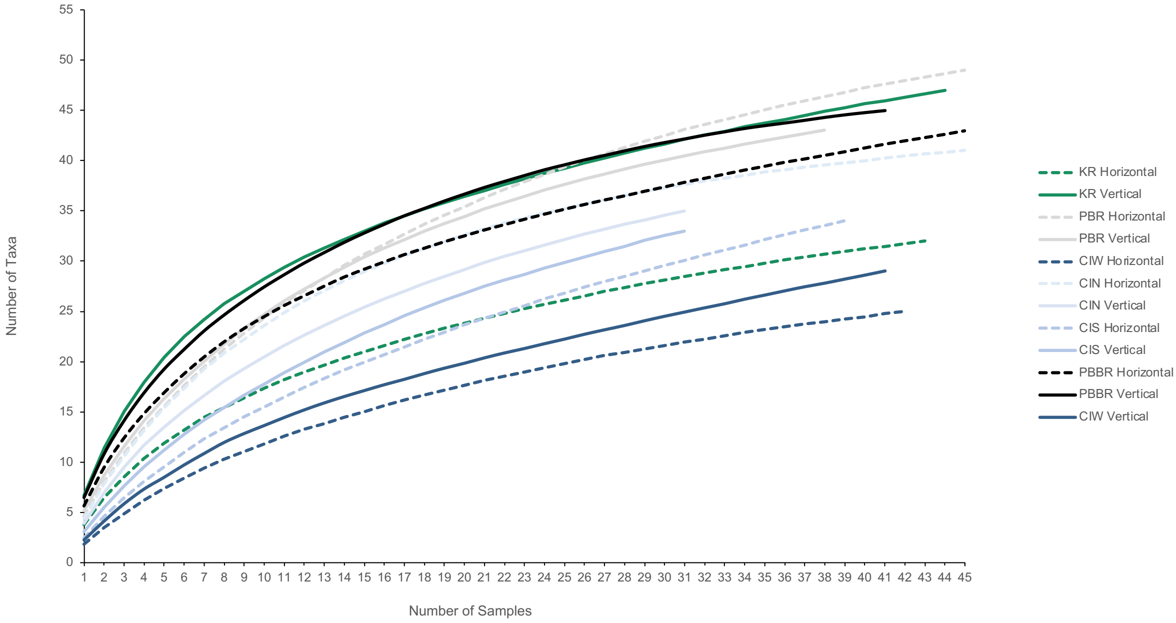


Figure 3.12 Species accumulation curves for the number of sessile invertebrate taxa among reefs on vertical and horizontal surfaces

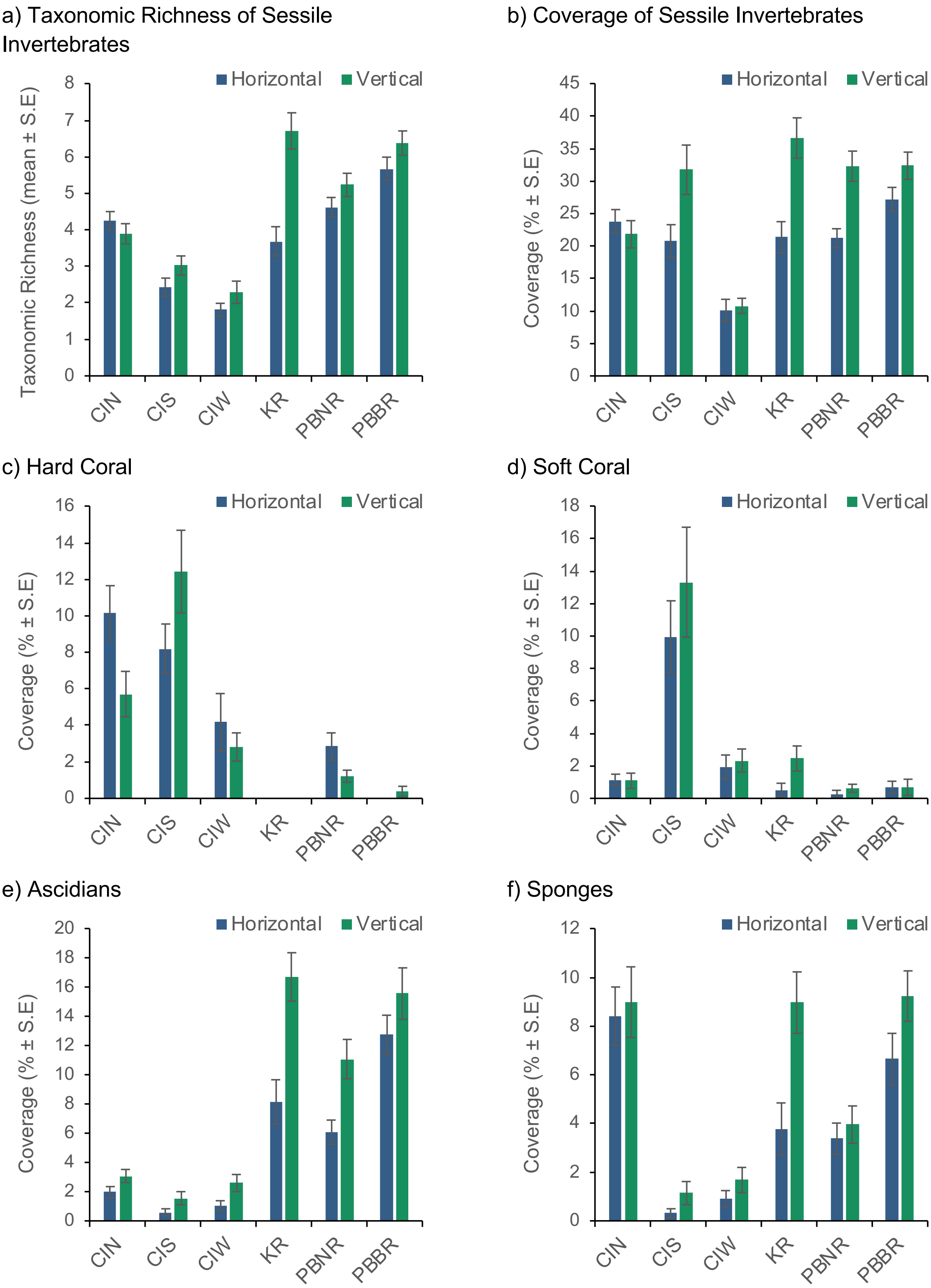
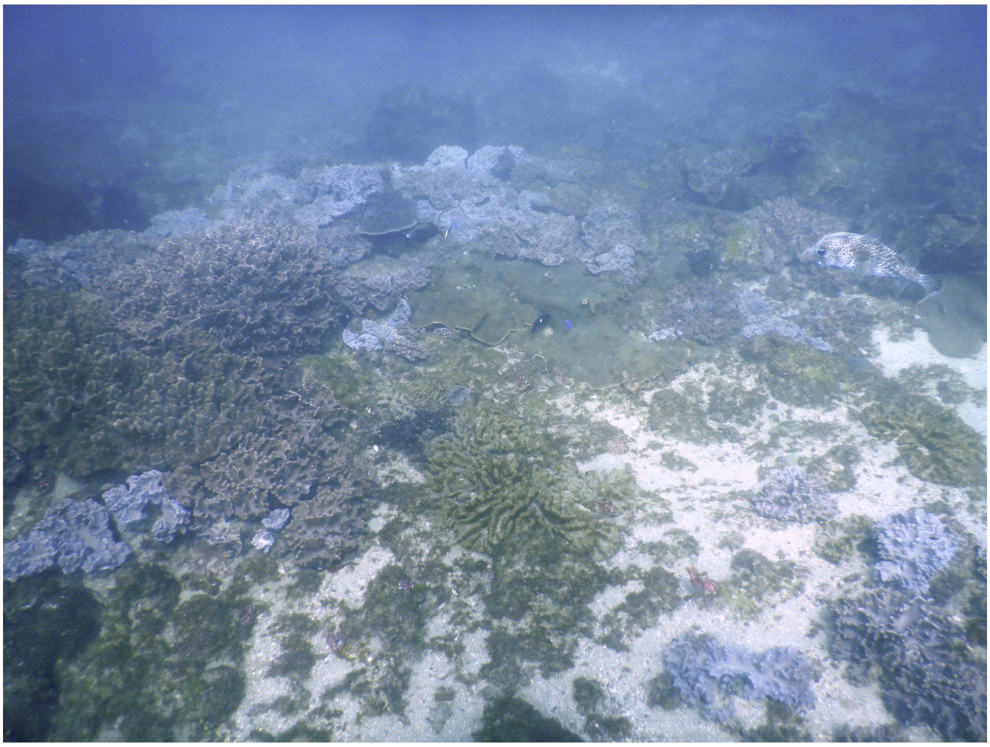


Figure 3.13 Average taxonomic richness and coverage (% ± SE) of all sessile invertebrates and average coverage of dominant sessile invertebrates categories on vertical and horizontal surfaces, among reefs in 2024 (Blue – Horizontal; Green – Vertical)

a)



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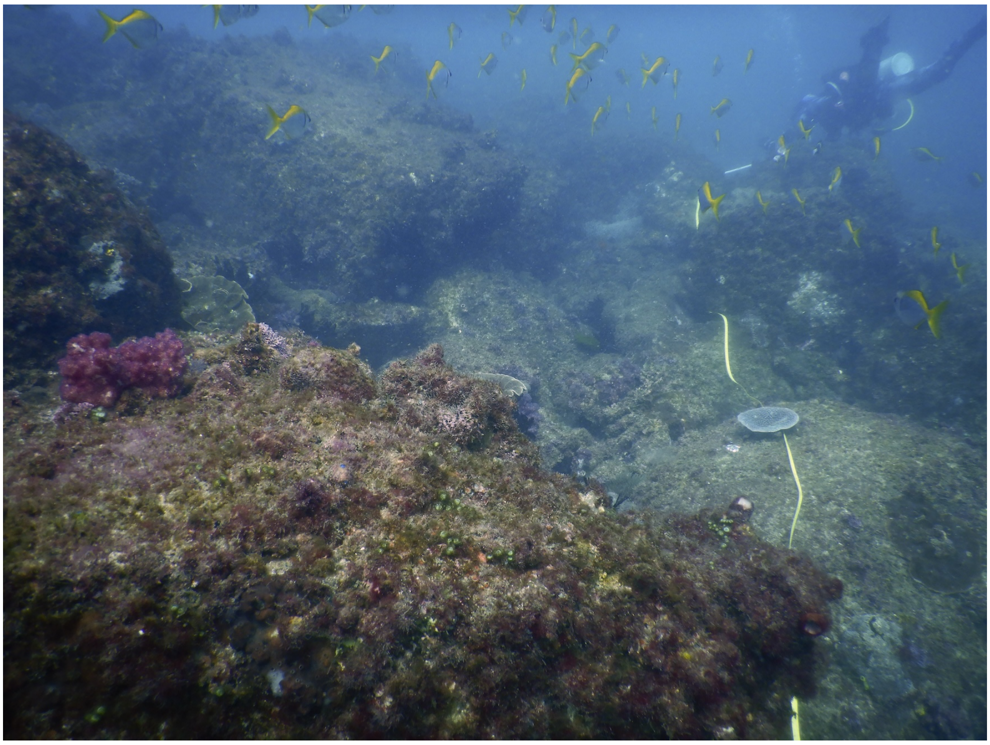


Figure 3.14 Hard and soft coral at a) Cook Island South and b) Cook Island North

3.2.4 Historic Comparison of Benthic Communities

The composition of benthic communities (algae and sessile invertebrates identified to a broad taxonomic level) continue to differ between Kirra and Palm Beach reefs (most commonly surveyed) and among the other reefs assessed over time[11] (Figure 3.15; PERMANOVA Survey x Reef Interaction for both horizontal and vertical surfaces; pairwise comparisons Appendix B, Table B.5.11). In the past nine years (since 2016), the composition of benthic communities on all reefs assessed has differed between successive years (where surveys were completed), with the interannual variation in the composition of benthic communities largely driven by changes in the coverage of macroalgae and turf forming algae relative to the coverage of sessile invertebrates such hard corals, which have remained more stable (PERMANOVA pairwise comparisons, SIMPER Table B.5.11g). Although, there have been some differences in the methods of data collection among surveys, particularly between 2017 and 2019, which may limit the interpretation of temporal changes. Despite these methodological differences, the composition of benthic assemblages at Kirra Reef in 2024 were more similar to that recorded in the 2016 and 2023 surveys (Figure 3.15), likely due to the recent increases in the coverage of foliose and turf forming macroalgae.

On Kirra Reef, the differences in composition between successive surveys were due primarily to changes in the average coverage of foliose macroalgae, turf forming algae and ascidians, which combined accounted 71% to 84% of the difference surveys (SIMPER Table B.5.13). Between 2023 and 2024, there was an increase in the coverage of macroalgae and turf forming algae, which contributed 30% of the difference between successive years (Table B.5.13). In comparison, the coverage of sessile fauna such as ascidians and sponges decreased in coverage over that time, which contributed 30% of the difference (Table B.5.13). Hard corals were also not recorded in the benthic community on Kirra Reef in 2024, despite covering 2% of the area in 2020. An increase in the coverage of hard and soft corals would increase the similarity with those benthic assemblages found on surrounding reefs, but many of these species are slow growing so may take considerable time to become established and cover a large area on Kirra Reef (Walker & Schlacher 2014).

On reefs around Cook Island, differences in the composition of benthic communities between successive surveys at each reef were due primarily to changes in the average coverage of macroalgae, coralline, hard corals and turf forming algae, which combined contributed more than 49% of the dissimilarity between successive surveys at each reef (SIMPER Table B.5.14 to Table B.5.17). In 2024, the coverage of hard coral at locations around Cook Island remained similar to the previous survey (SIMPER Table B.5.14 to Table B.5.16).

At Palm Beach Reef there was a large increase in the coverage of turf forming algae from an average of 44% in 2023 to 66% in 2024 (SIMPER Table B.5.17). In contrast, the coverage of soft corals and ascidians decreased, while other sessile organisms remained relatively consistent over time (SIMPER Table B.5.17).

[11] Benthic Communities over time - PERMANOVA **Horizontal Surfaces** - Survey x Reef interaction $MS_{24,1698}$ = 12897 pseudo-F = 13.3, p = 0.001; **Vertical Surfaces** - Survey x Reef interaction $MS_{14,1136}$ = 11623 pseudo-F = 16.3, p = 0.001; Pairwise tests for differences among reefs over time are provided in Appendix B Table B.5.11.

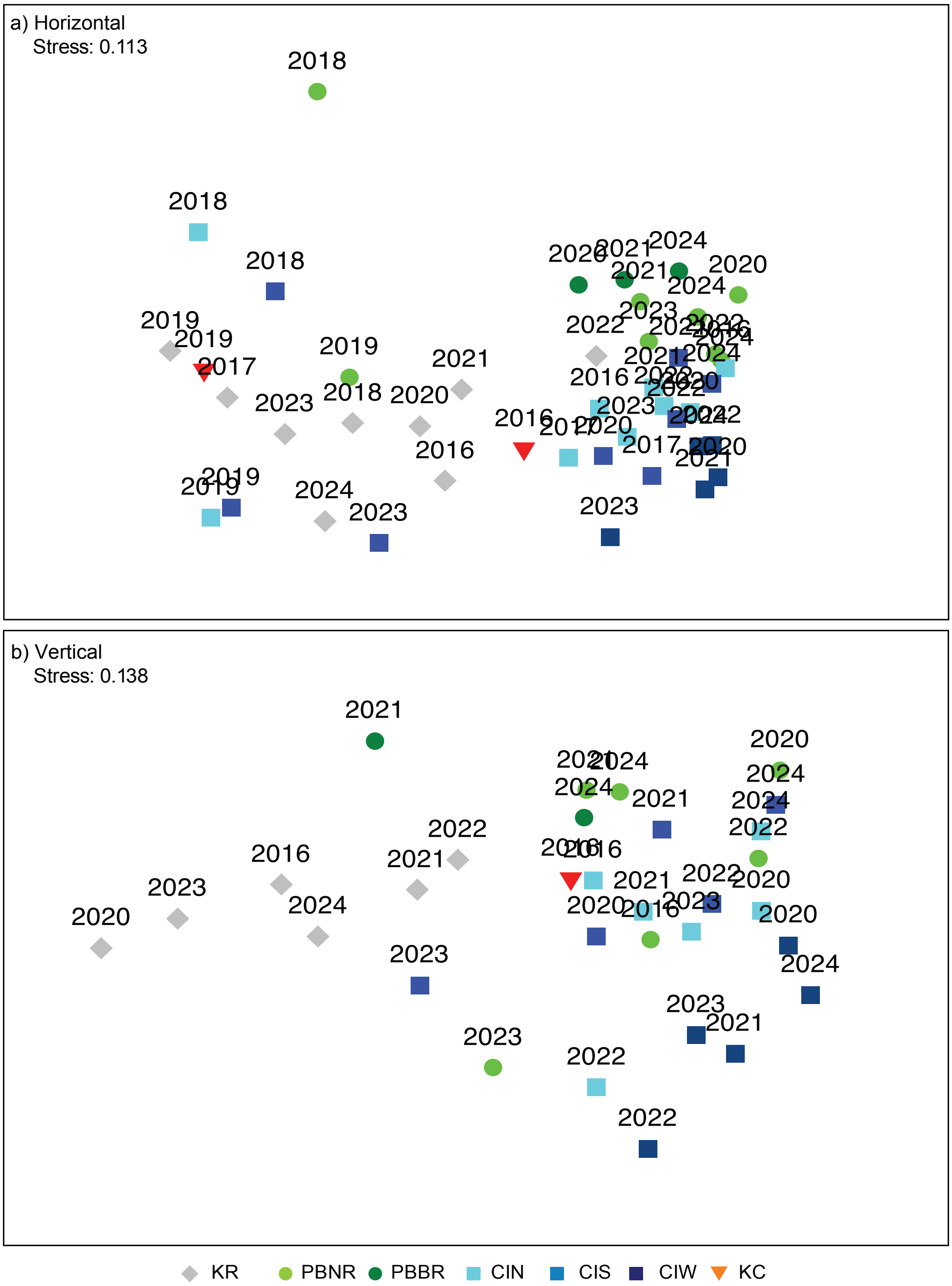


Figure 3.15 nMDS ordination of the difference in the composition of benthic assemblages on horizontal surfaces between Kirra and Palm Beach Reefs between 2016 and 2024 (KC = Kingscliff Reef – only surveyed in 2016 & 2019) [12]

[12] 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.

3.2.5 Mobile Invertebrate Assemblages

In 2024, mobile invertebrate diversity was highest at Cook Island West Reef, with 14 species recorded from photo quadrats (Appendix C). The average density of mobile invertebrate assemblages was also highest at Cook Island West, primarily due to an increase in abundance of sea urchins (average of 3.4 individuals per photo quadrat in 2024; Appendix C) compared to recent years (average of ≤0.06 individuals per photo quadrat; ESP 2021; ESP 2022; ESP 2023). Urchins have been shown to exhibit short-term booms in abundance in Australia but they generally are a natural and stable component of rocky reef habitats in NSW (Glasby and Gibson 2020; McLaren et al 2024; Przeslawski et al. 2023). Two species of *Tripneustes* urchins, the lamington urchin (*T. australiae*) and the collector urchin (*T. gratilla*), were identified from images collected by divers during the survey (Figure 3.17d).

As in previous years, echinoderms dominated mobile invertebrate assemblages at all reefs (ESP 2020; ESP 2021; ESP 2022; ESP 2023). Sea urchins had the highest average density of mobile invertebrates at Palm Beach and Cook Island West reefs, whereas feather stars (particularly the black feather star, *Cenolia glebosus*) had the highest density at Kirra, Palm Beach Bait and Cook Island North reefs. Sea urchins and feather stars had a similar average density at Cook Island South (Figure 3.16; Appendix C).

In addition to mobile invertebrates recorded from photo quadrats, several species were also observed on UBRUVS or SCUBA diver footage and images in July 2024. Specifically:

- black feather star at all reefs
- sea stars, including luzon sea star (*Echinaster luzonicus*; Figure 3.17a) at all reefs except Kirra Reef and Palm Beach Bait Reef; blue sea star (*Linckia laevigata;* Figure 3.17b) and tamaria sea star (*Tamari* sp.; Figure 3.17c) at Cook Island South and Palm Beach reefs; and many-spotted sea star (*Fromia polypora*) and dusky sea star (*Pseudonepanthia nigrobrunnea*) at Cook Island South Reef
- sea urchins, including lamington and collector urchins (Figure 3.17d), long-spined sea urchin (*Diadema savignyi;* Figure 3.17b) and slate pencil urchin (*Phyllacanthus parvispinus*) at all reefs except Palm Beach Bait Reef; spiny sea urchin (*Centrostephanus rodgersii*) at Cook Island South and Palm Beach reefs; banded sea urchin (*Echinothrix calamaris*) at Cook Island North, Cook Island South, Kirra and Palm Beach reesf; and rock-boring sea urchin (*Echinometra mathaei*) at Kirra Reef
- blackfish sea cucumber (*Actinopyga miliaris*) at Cook Island South and Cook Island West reefs; and lollyfish sea cucumber (*Holothuria atra*) at Cook Island North and Cook Island South reefs
- molluscs, including captain's cone snail (*Conus capitaneus*) at Kirra Reef; obscure nudibranch (*Hypselodoris obscura*; Figure 3.17a) at Palm Beach Reef; White's nudibranch (*Hypselodoris whitei*) at Palm Beach Bait Reef; common Sydney octopus (*Octopus tetricus*; Figure 3.17e) at all reefs except Cook Island South and Cook Island West reefs; big-fin reef squid at Cook Island North, Cook Island West, and Kirra reefs; and cuttlefish (*Sepia sp.*) at Palm Beach Bait Reef, and
- painted crayfish (*Panulirus versicolor*) at Cook Island South and Kirra reefs; and striped agile shore crab (*Percnon planissimum*; Figure 3.17f) at Cook Island West.

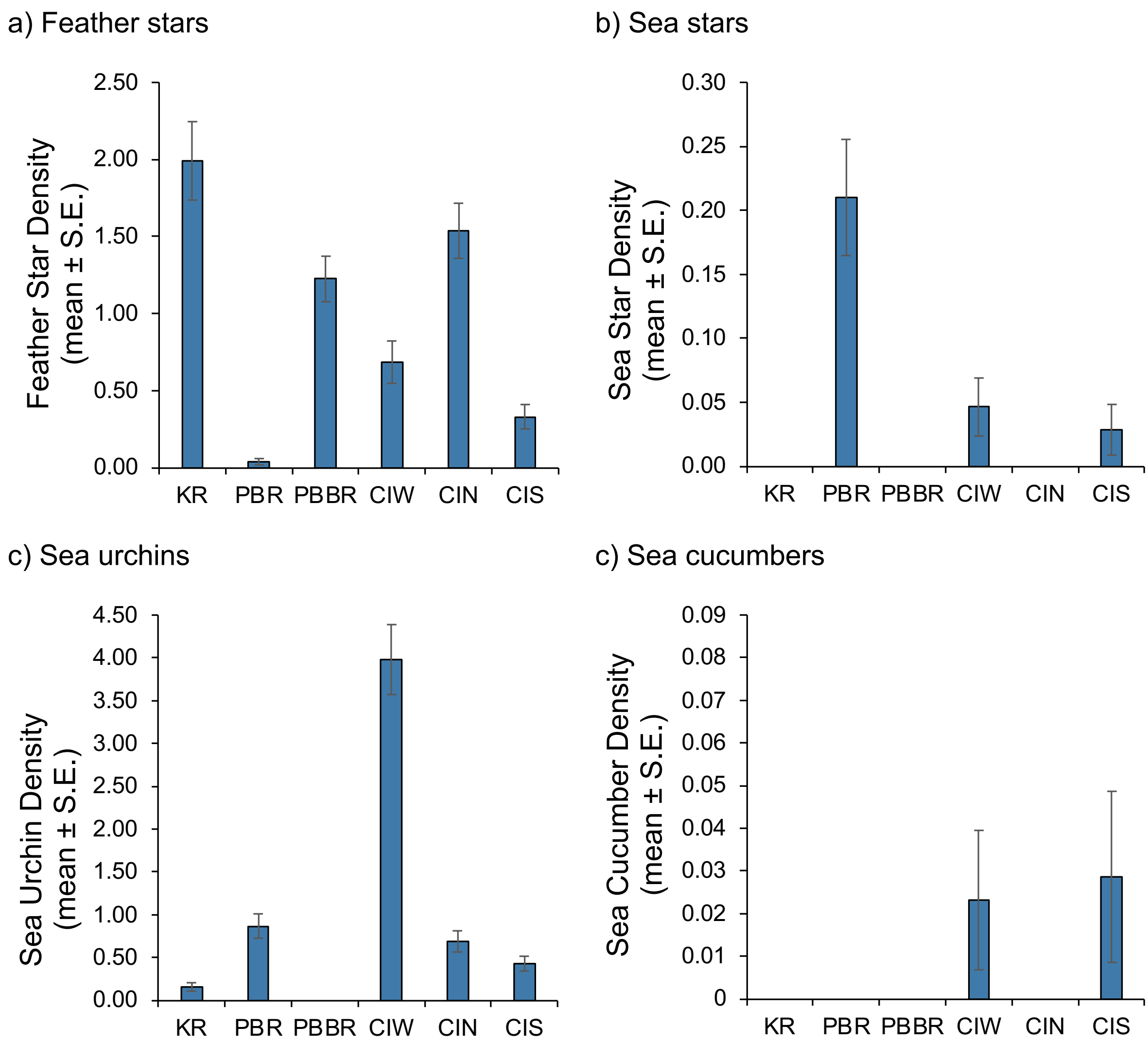


Figure 3.16 Density (number of individuals per photo quadrat; mean ± SE) of a) feather stars, b) sea stars c) sea urchins and d) sea cucumbers at each reef in 2024

a)

b)

c)

d)

e)

f)

Figure 3.17 Mobile invertebrates recorded on reefs in 2024 including a) luzon sea star and obscure nudibranch, b) blue sea star and long-spined sea urchin, c) tamaria sea star, d) lamington (left) and collector (right) sea urchins, e) common Sydney octopus, and f) striped agile shore crab

3.3 Fish Assemblages

A total of 138 bony and cartilaginous fish species, from 45 families were recorded across all reefs in the July 2024 survey (Appendix D), which is higher than recent years. Higher fish diversity in 2024 was likely influenced by clear conditions during sampling, compared to poor visibility during some previous sampling events, especially May 2023. Consistent with previous years, Labridae (wrasses) and Pomacentridae (damselfishes) were the most diverse families (ESP 2020; ESP 2021; ESP 2022; ESP 2023). These families had 22 and 20 species recorded, respectively, in July 2024. An additional 13 fish species were observed that have not been recorded in previous surveys (Appendix D).

Table 3.1 Annual fish diversity

Year	Families	Species
2020	34	116
2021	44	129
2022	40	126
2023	38	91
2024	45	138

Cartilaginous fish recorded in July 2024 included:

- banded wobbegong (*Orectolobus ornatus*) at all reefs except Cook Island South
- spotted wobbegong (*Orectolobus maculatus*; Figure 3.19a) at all reefs except Palm Beach Bait Reef
- grey carpet shark (*Chiloscyllium punctatum*) at Cook Island South
- whitespotted eagle ray (*Aetobatus ocellatus*) at Kirra Reef, and
- bluespotted maskray (*Neotrygon australiae*) at Kirra Reef.

The composition of fish assemblages differed among reefs [13], specifically between assemblages at Cook Island South and Kirra Reef, and between Cook Island West and Kirra Reef, with no significant difference in composition among the other reefs (Figure 3.18; PERMANOVA Appendix B, Table B.5.18). Differences in fish assemblages at Kirra Reef compared to Cook Island South and Cook Island West were attributed to variation in the abundance of a broad range of species. Yellowtail scad (*Trachurus novaezelandiae*) were present in high abundances at Kirra Reef, but were absent from Cook Island South and Cook Island West, contributing 9.1% and 7.4% of the dissimilarity, respectively. No other individual species contributed more than 3.3% of the dissimilarity among reefs (SIMPER Appendix B, Table B.5.19). Differences in the habitat complexity, benthic composition (refer to Section 3.2), availability of prey or other ecological interactions (e.g. predator abundance) likely contributed to differences in fish assemblages at these reefs.

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

[13] PERMANOVA for differences in fish assemblages among reefs $F_{5,11} = 2.90$, $p = 0.001$; Pairwise comparisons among reefs CIS≠KR; CIW≠KR; CIN=KR=PBBR=PBR; CIS=CIW=CIN=PBBR=PBR at $p < 0.05$.

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 Cook Island reefs and Palm Beach Reef (Figure 3.19b). No invasive fish species were recorded.

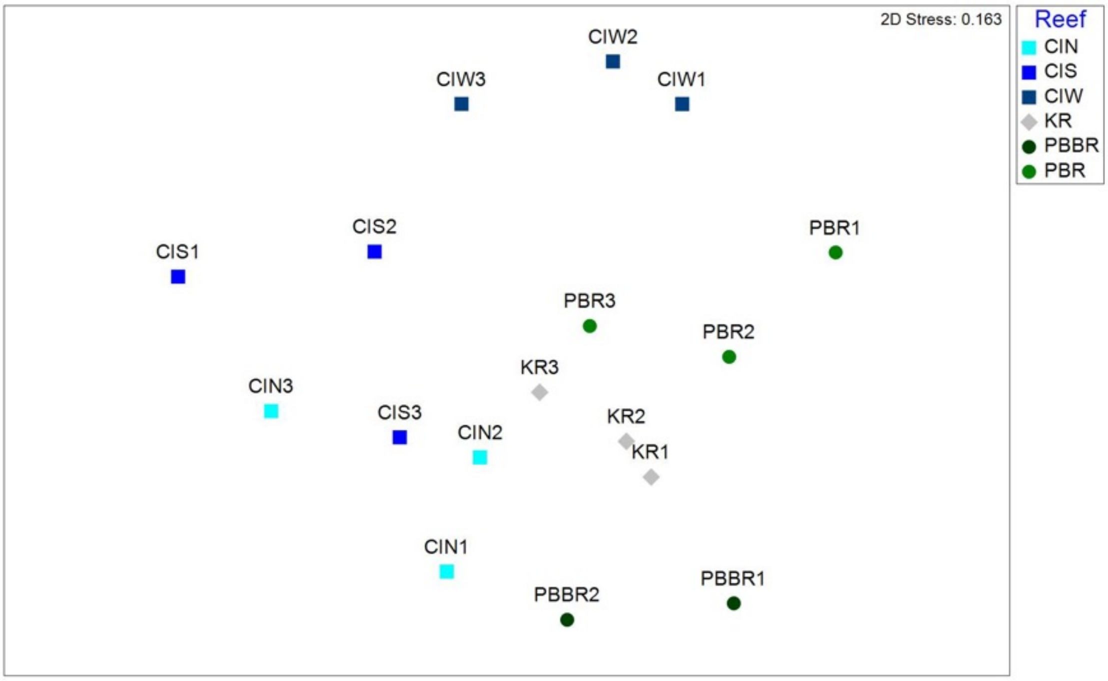
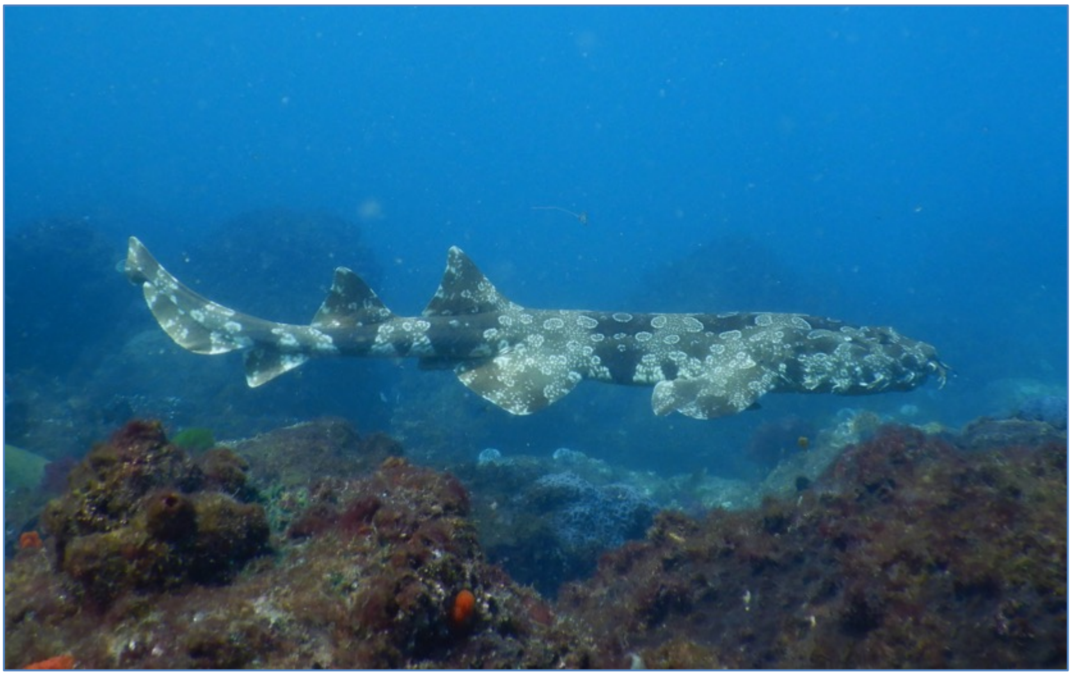


Figure 3.18 nMDS ordination of the differences in the composition of fish assemblage among reefs in July 2024 [14]

[14] 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 3.19 a) spotted wobbegong, and b) Eastern blue grouper recorded in July 2024

3.3.1 Species Richness of Fish Assemblages

In July 2024, the total species richness varied among reefs, with the highest number of species recorded at Palm Beach Reef (81 species) and the fewest species recorded at Palm

Beach Bait Reef (39 species) (Table 3.2; Appendix D). Conversely, in May 2023, the highest number of species was recorded at Cook Island North (70 species), though the fewest species were also recorded at Palm Beach Bait Reef (9 species; ESP 2023). Temporal differences in the species richness during this period may be related to differences in sampling techniques, conditions while sampling (e.g. water clarity) and the timing of monitoring events.

In July 2024, the average species richness did not differ significantly among reefs[15] (PERMANOVA Appendix B, Table B.5.20). The lowest average species richness was recorded at Palm Beach Bait Reef and the highest average richness recorded at Palm Beach Reef and Cook Island West (Figure 3.20).

Table 3.2 Total species richness and abundance among the reefs in 2024

	Total Species Richness*	Total Abundance (Pooled Max N)^
Kirra Reef	68	1221
Palm Beach Reef	81	2072
Palm Beach Bait Reef	39	1601
Cook Island West	75	921
Cook Island North	62	102
Cook Island South	68	443

* Total Species Richness collated from UBRUVS and diver recordings

^ Total Abundance calculated from UBRUVS recordings only

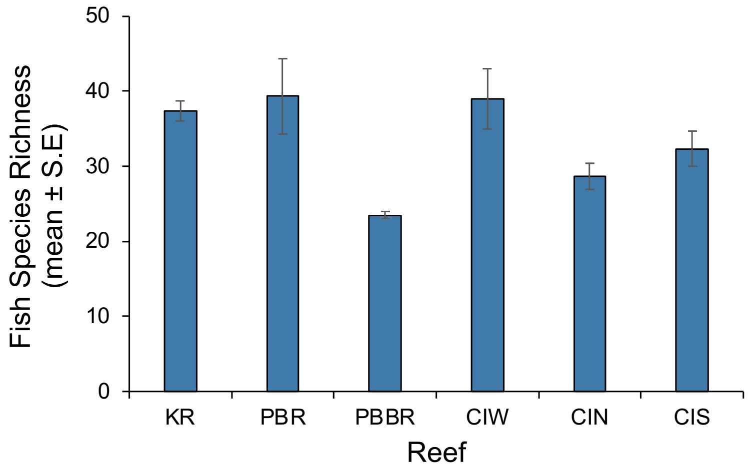


Figure 3.20 Average species richness (± SE) of fish assemblages among reefs

3.3.2 Relative Abundance of Fish Assemblages

The total abundance of fish, measured as the pooled Max N from UBRUVS, was highest at Palm Beach Reef (2,072 individuals) and the lowest at Cook Island North (102 individuals) in July 2024 (Table 3.2). Kirra Reef often has the highest total abundance of fish with 1,206 individuals recorded in 2022, 1,132 individuals in 2021, and 496 individuals in 2020 (ESP

[15] PERMANOVA for differences in species richness among reefs $F_{5,11} = 3.61$, $p = 0.053$.

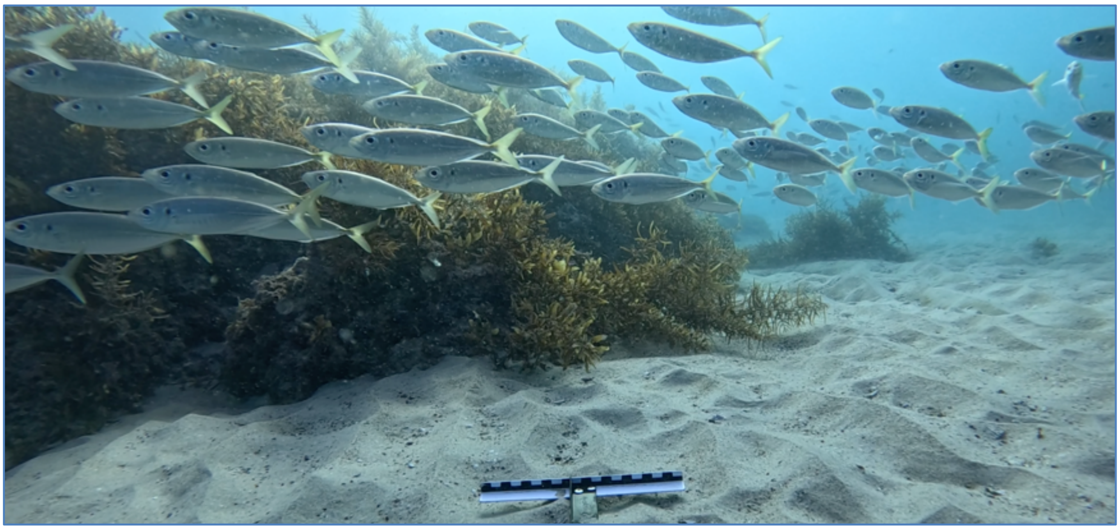
2021; ESP 2022). In July 2024, total abundance at Kirra Reef (1,221 individuals) was comparable to the relatively high abundances recorded in 2022 and 2021.

High abundance is primarily driven by schooling fish at some reefs. In July 2024, dense schools (approximately 1,000 to 1,500 individuals) of yellowtail scad dominated fish assemblages at Kirra Reef (Figure 3.21a), Palm Beach Reef, and Palm Beach Bait Reef. Less dense schools of eastern pomfred (*Schuettea scalaripinnis*; approximately 200 to 300 individuals) were recorded at Cook Island South and Cook Island West (Figure 3.21b), silver moony (*Monodactylus argenteus*; approximately 60 to 250 individuals) at Cook Island West and Palm Beach Reef, Indo-Pacific sergeant (*Abudefduf vaigiensis*; approximately 100 individuals) at Palm Beach Reef, Whitley's sergeant (*Abudefduf whitleyi*; approximately 140 individuals) and silver trevally (*Pseudocaranx georgianus*; approximately 60 individuals) at Cook Island West. Additional schooling species were recorded at some reefs (Appendix D, Table D.5.22), though schools were always < 40 individuals. With exception of Whitley's sergeant (only 9 individuals), no schooling fish were detected on UBRUVS at Cook Island North in July 2024.

Species that commonly occurred among all reefs included:

- several wrasse species (such as Günther's wrasse, *Pseudolabrus guentheri*; moon wrasse, *Thalassoma lunare*; green moon wrasse, *Thalassoma lutescens*; crimsonband wrasse, *Notolabrus gymnogenis*; diamond wrasse, *Anampses caeruleopunctatus*; brokenline wrasse, *Stethojulis interrupta*; and common cleaner fish, *Labroides dimidiatus*)
- several damselfish species (such as neon damsel, *Pomacentrus coelestis*; bigscale scalyfin, *Parma oligolepis*; and Pacific Gregory, *Plectroglyphidodon fasciolatus*)
- eye-stripe triggerfish (*Sufflamen chrysopterum*)
- goldspotted sweetlips (*Plectorhinchus flavomaculatus*)
- crested morwong (*Goniistius vestitus*)
- black rabbitfish (*Siganus fuscescens*)
- blacksaddle goatfish (*Parupeneus spilurus*)
- yellowfin bream or tarwhine (Acanthopagrus australis or Rhabdosargus sarba)
- , and silver sweep (*Scorpis lineolata*) (Figure 3.22; Appendix D).

a)



b)

Figure 3.21 Schools of a) yellowtail scad at Kirra Reef, and b) eastern pomfred at Cook Island West in July 2024

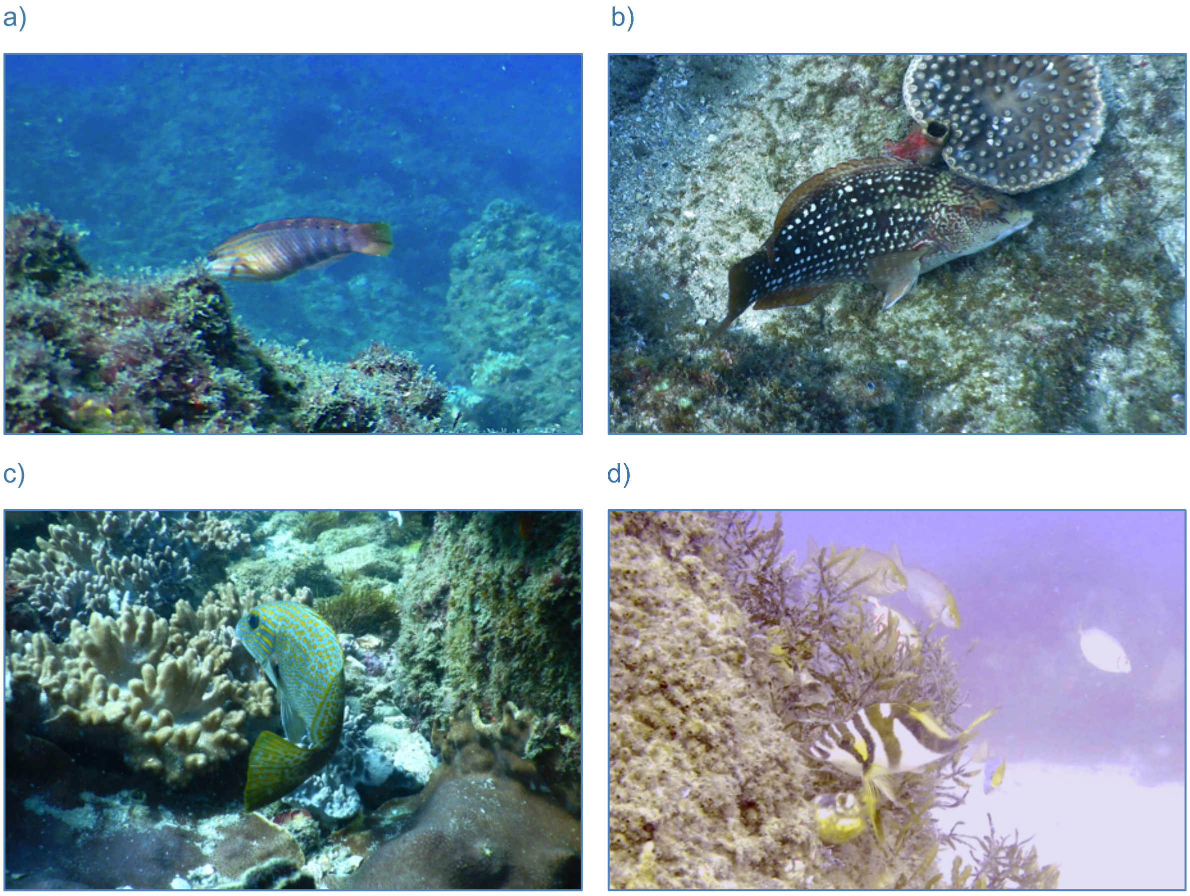


Figure 3.22 Fish species commonly seen at most reefs in 2024 included a) Günther's wrasse, b) crimsonband wrasse, c) goldspotted sweetlips, and d) crested morwong and black rabbitfish.

3.3.3 Trophic Composition and Habitat Preference

The contribution of different trophic levels to the diversity of fish assemblages (trophic composition) did not differ substantially among most reefs in July 2024 (Figure 3.23). Carnivorous species were the most diverse group at all reefs (36 to 51% of species), and omnivores with and without herbivorous tendencies were generally the next most diverse groups (13 to 16%, and 13 to 25% of species, respectively). While there was some variation in the proportion of herbivores and planktivores among reefs, these groups each contributed ≤ 13% to the trophic composition of fish assemblages at each reef. Consistent with previous years (ESP 2022; ESP 2023), corallivores were generally the least diverse group and were absent from the fish assemblage recorded at Palm Beach Bait Reef and Cook Island South (Figure 3.23).

In the July 2024 survey, 86 to 92% of species recorded at each reef were reef-associated species, which was expected given the dominance of rocky reef habitat surveyed (Appendix D).

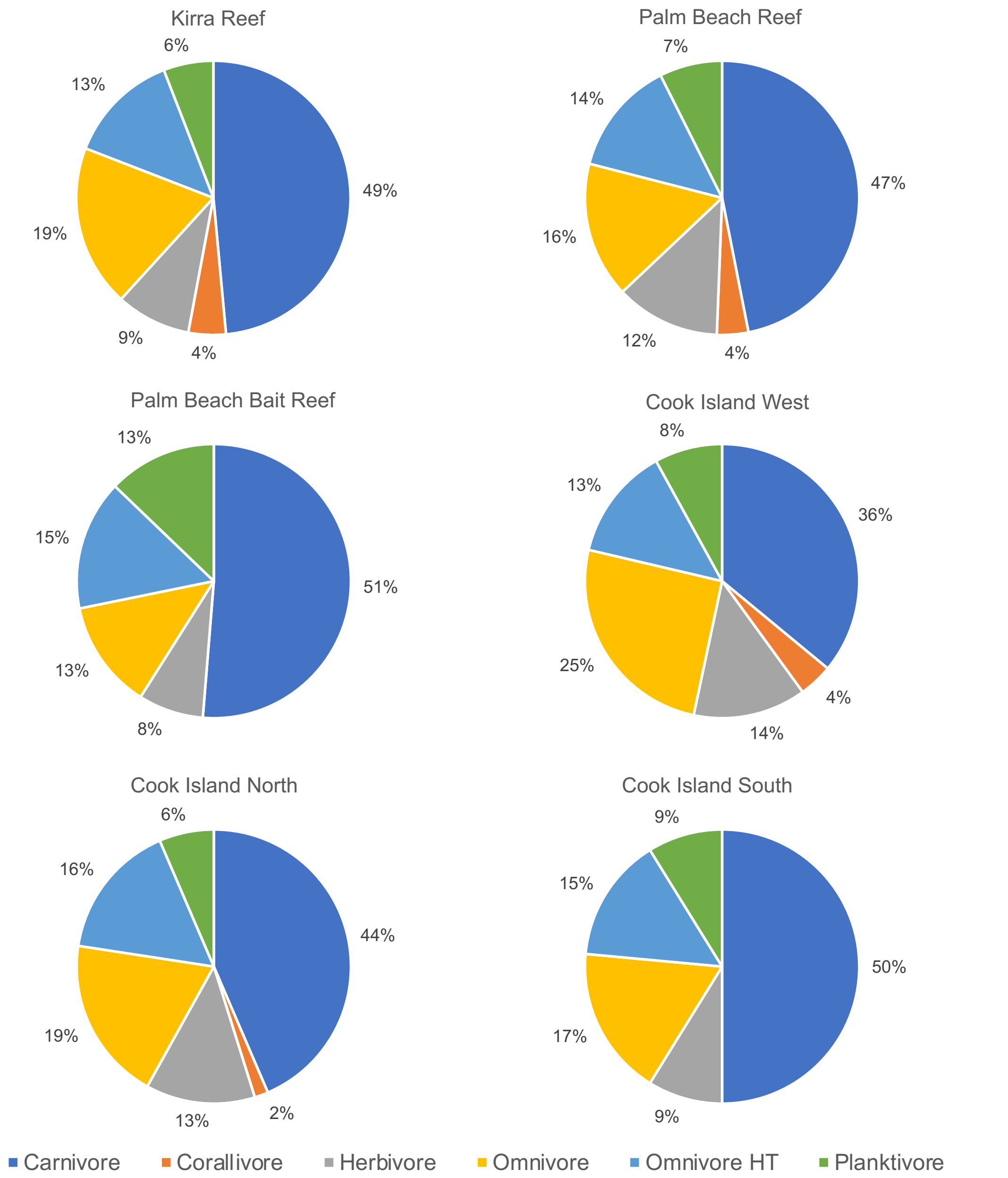


Figure 3.23 Trophic level composition of fish communities (% of species) recorded at each reef (based on UBRUVS and diver recordings)

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 (DCCEEW 2024), several species of conservation significance are known or likely to occur around the reefs, including:

- blue warehou (*Seriolella brama*) listed as conservation dependent
- White's seahorse (*Hippocampus whitei*) listed as endangered
- humpback whale (*Megaptera novaeangliae*) listed as 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 and migratory
- olive ridley turtle (*Lepidochelys olivacea*) listed as endangered and migratory
- grey nurse shark (*Carcharias taurus*) listed as critically endangered
- great white shark (*Carcharodon carcharias*) listed as vulnerable and migratory
- scalloped hammerhead (*Sphyrna lewini*) listed as conservation dependent
- Australian humpback dolphin (*Sousa sahulensis*) listed as migratory, and
- southern right whale (*Eubalaena australis*), listed as endangered and migratory.

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

- Australian snubfin dolphin (*Orcaella heinsohni*) listed as migratory
- Bryde's whale (*Balaenoptera edeni*) listed as migratory
- orca (*Orcinus orca*) listed as migratory
- blue whale (*Balaenoptera musculus*) listed as endangered and migratory
- dugong (*Dugong dugon*) listed as migratory
- black rockcod (*Epinephelus daemelii*) listed as vulnerable
- whale shark (*Rhincodon typus*) listed as vulnerable and migratory
- oceanic whitetip shark (*Carcharhinus longimanus*) listed as migratory
- porbeagle shark (*Lamna nasus*) listed as migratory
- school shark (*Galeorhinus galeus*) listed as conservation dependent
- reef manta ray (*Mobula alfredi*) listed as migratory
- giant manta ray (*Mobula birostris*) listed as migratory, and

- green sawfish (*Pristis zijsron*) listed as vulnerable 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 survey were the green sea turtle (Figure 3.24a), recorded at all reefs, and the hawksbill turtle, recorded at Cook Island North reef.

While not a threatened species under the *Environment Protection and Biodiversity Conservation Act 1999*, one listed cetacean, the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) was recorded at Kirra Reef during the survey (Figure 3.24b).

a) b)

Figure 3.24 a) Green turtle (*Chelonia mydas*) at Cook Island North, and b) Indo-Pacific bottlenose dolphin at Kirra Reef in 2024

3.4.2 Introduced Species

There are over 200 marine pests reported in Australian waters (DES 2023). 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) (NIMPIS 2024).

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

All water quality parameters (temperature, pH, turbidity, salinity and the concentration of dissolved oxygen,) were generally consistent among sites and with increased depth, with the following exceptions (Figure 3.25):

- water temperature was slightly warmer at Cook Island North and Cook Island West than at other reefs
- the concentration of dissolved oxygen was slightly higher at Cook Island South compared to other reefs, and
- turbidity increased slightly within the deepest metre of the water column only at Kirra Reef and Cook Island South reef.

PAR was relatively similar among most sites, with the light attenuation coefficient ranging between 0.19 μmol/s^2 and 0.22 μmol/s^2 at Cook Island West, Kirra Reef, Palm Beach Reef, and Palm Beach Bait Reef. The light attenuation coefficient was lowest at Cook Island North (0.11 μmol/s^2; the shallowest site), and highest at Cook Island South (0.41 μmol/s^2; one of the two deepest sites). PAR can be influenced by a range of factors including the time when samples were collected and weather conditions (e.g. the influence of cloud cover). Light attenuation increased with the site water depth, and was attenuated by between 44% (at the shallowest site, Cook Island North) and 96% (at one of the two deepest sites, Cook Island South) with depth, relative to surface measurements.

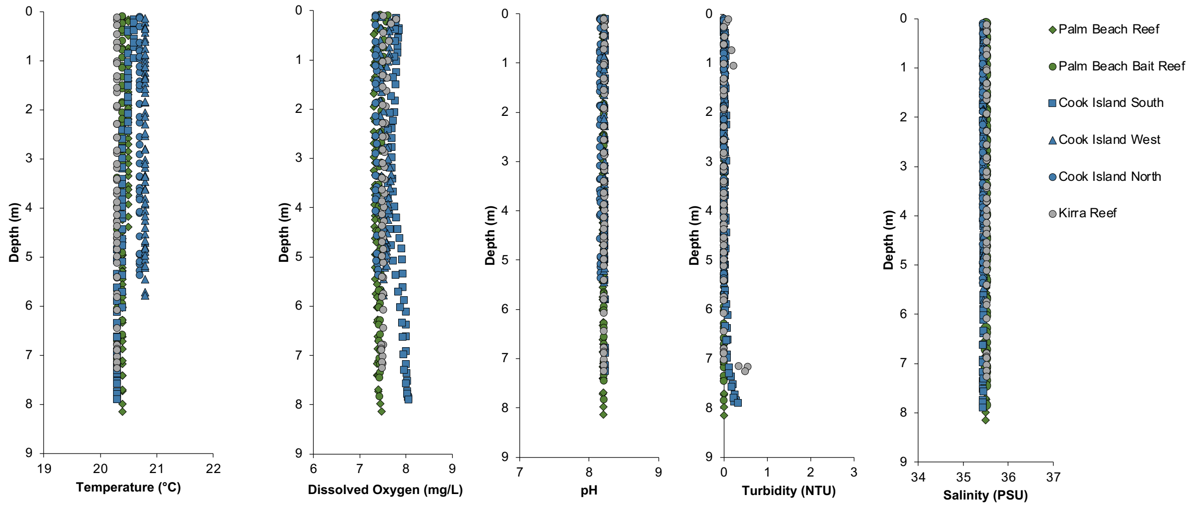
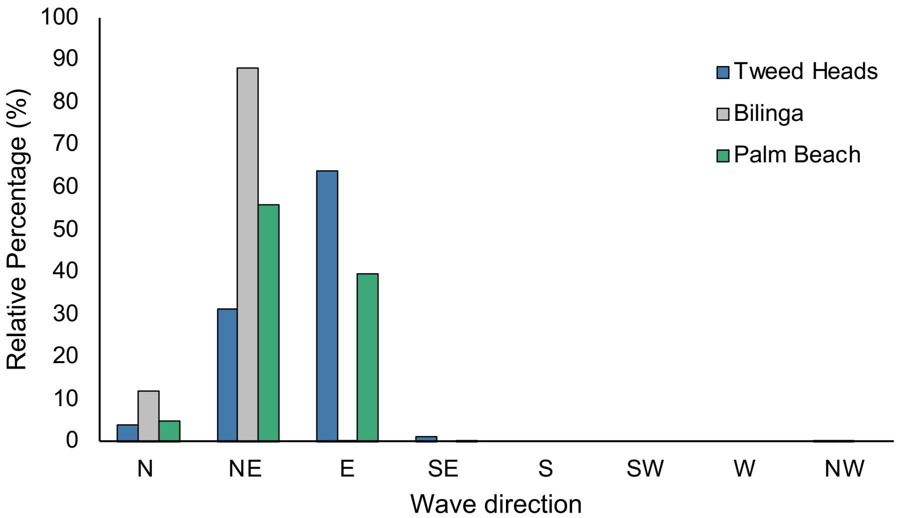


Figure 3.25 Vertical profiles of physicochemical water quality parameters among sites

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 21 July 2023 and 20 July 2024, swell direction was predominantly from the east at Tweed Heads and northeast at Bilinga and Palm Beach wave rider buoys (Figure 3.26 and Figure 3.27). Most waves were <1 m or 1 to 2 m, with <1 m waves most common at Bilinga and 1 to 2 m waves most common at Tweed Heads (Figure 3.26 and Figure 3.27Figure 3.27). During the period assessed, significant wave heights (>3 m) were rare (<0.5%), only recorded at Tweed Heads, and predominantly from the north-east (Figure 3.26 and Figure 3.27). Previous analyses of long-term (01/01/2000 to 31/05/2016) wave data for Tweed Heads indicated 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 (21 July 2023 and 20 July 2024) was typical of the region, with significant wave events unlikely to cause major changes to sand movements in the region.

a)



b)

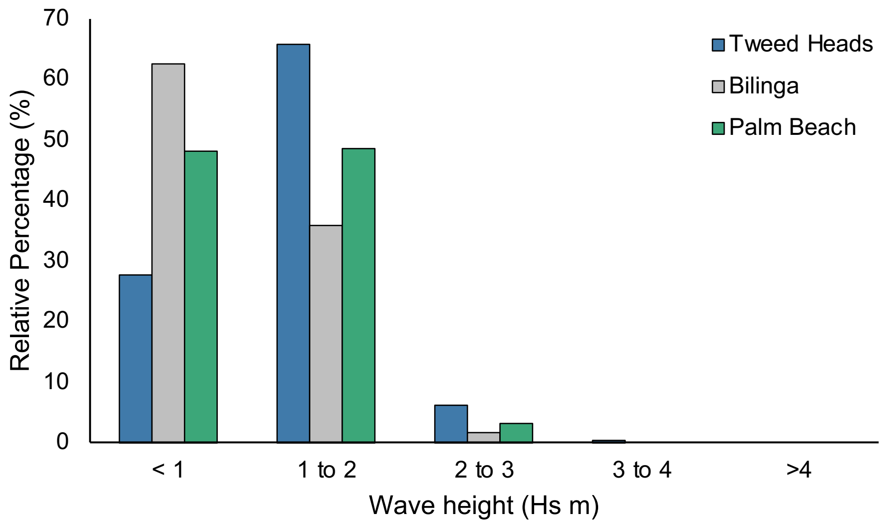


Figure 3.26 Wave data collected at Tweed Heads, Bilinga and Palm Beach wave rider buoys between 21 July 2023 and 20 July 2024, showing a) relative percent frequency of wave direction and; b) relative precent frequency of wave height

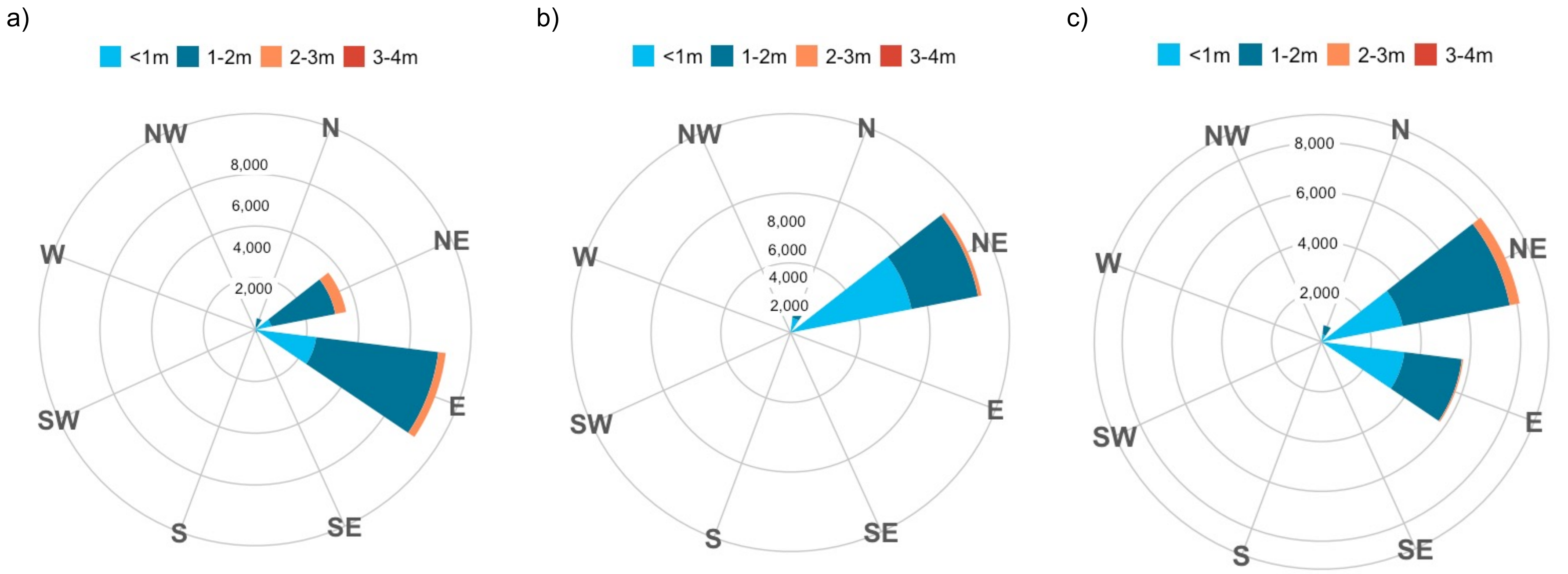


Figure 3.27 Wave height and direction between 21 July 2023 and 20 July 2024 at a) Tweed Heads wave rider buoy, b) Bilinga wave rider buoy, and c) Palm Beach wave rider buoy

4 Discussion and Conclusions

4.1 Changes in Reef Area at Kirra Reef

There have been large temporal changes in the area of exposed rock at Kirra Reef, with periods of sand burial and exhumation, resulting in changes to the benthic community growing on Kirra Reef. Prior to major artificial changes in sand movement (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 while there was a clear reduction in area in 2024 relative to that recorded in 2023, the reef extent has been relatively stable since 2012. The largest drive of change appears to be the migration of the offshore sand bar. 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 of Kirra Reef has varied through time, with the maximum extent of Kirra Reef of 40,813 m^2 measured in 1995. The reef extent declined following the commencement of the TSB project (as was predicted in the Project EIS). The reef was completely buried in 2007 and 2008, then uncovered and has been generally increasing in extent since 2009 from 1,009 m^2 to the current extent. Historically there have been 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 remained uncovered, with the eastern section periodically uncovered. The areal extent of Kirra Reef decreased over the past year from 3,492 m^2 in April 2023 to 2,365 m^2 in June 2024; however, remains within the relatively stable reef extent observed since 2012. The inner western and eastern sections of Kirra Reef were not uncovered in June or July 2024. These inner reef sections have a very low profile (or relief) and are normally subject to increased frequency of physical disturbance, including sand burial following the normal migration of the offshore bar along the beach. 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 diverse community of reef dwelling organisms on these inner reef sections.

4.2 Benthic Communities

The benthic faunal and floral assemblages on Kirra Reef have undergone a process of ecological succession following exhumation in 2009, starting with the recruitment of pioneer species such as turf forming algae and foliose macroalgae, and gradually becoming more similar in composition to other reef communities in the Gold Coast and Tweed Coast Region. In the past nine years (since 2016), the composition of benthic communities on all reefs assessed has differed. However, in recent years the monitoring program has shown succession slowing, generally demonstrating consistent differences in the composition of benthic assemblages on Kirra Reef relative to those at other reef locations. In 2024, the biodiversity of benthic assemblage living on Kirra Reef was consistent with that occurring on several of the other reefs in the area, although the benthic assemblages on Kirra Reef were dominated by foliose macroalgae (rather than turf algae at other reefs) and do not have longer-lived hard coral species that are found on the reefs around Cook Island. Many coral species require a long period of suitable stable physical conditions to establish and grow to a point where they dominate the benthic assemblages. It is not uncommon for benthic communities to differ on a range of spatial scales with the communities around Cook Island differing in composition despite the close proximity (i.e. hundreds of metres). This small-scale spatial variation among reef locations may be related to different physical conditions (e.g. nutrient availability and wave energy), disturbance regimes and other ecological interactions occurring around the island. This degree of variability highlights the importance of sampling numerous comparative locations to build a comprehensive and representative understanding of the variety of reef habitats and variation in benthic assemblages in the local region, which provides confidence in attributing any changes detected to TSB operations.

4.2.1 Algal Assemblages

In 2024, the average cover of foliose macroalgae (predominantly *Sargassum* spp.) had continued to increase at Kirra Reef and was a primary driver in the dissimilarity among reefs. Of note was the presence of an increasing coverage of kelp (*Ecklonia radiata*), which was recorded at Kirra Reef in 2023 and 2024, and has not been present for many years. Turf forming algae continues to dominate the benthic assemblages on vertical surface at Kirra Reef and elsewhere, accounting for 25% to 72% of the total coverage of the benthic assemblage on the reefs. Other groups, such as foliose macroalgae (e.g. *Dictyota* sp. and *Padina* sp.), crustose coralline algae and articulate coralline algae (e.g. *Jania* sp.) were also present at the reefs. Foliose macroalgae dominated horizontal surfaces at Kirra Reef, with a coverage of 43%, which was much higher than other reefs, which had a coverage of <7%.

Foliose 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 2024 may be indicative of the more recent disturbance history at Kirra Reef or other physical features. Where habitat availability is aligned with recruitment pulses, it can allow a high proportion of the area to be colonised relatively quickly by macroalgae (Kennelly 1987; McCook et al. 2001). The increase in macroalgal coverage could also 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).

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 among reefs. In 2024, the sessile invertebrate assemblages on Kirra Reef remain dissimilar to those on other reefs in the region; however, were more similar to surrounding reefs both in terms of the overall coverage and average number of species. In 2024, ascidians and sponges remain the dominant sessile invertebrates on Kirra Reef, with the highest coverage of ascidians recorded on vertical surfaces on Kirra Reef. There continues to be a lack of abundant hard coral species on Kirra Reef, and the coverage of soft corals has remained relatively low. 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. In contrast, the reefs around Cook Island generally had a good coverage of long-lived hard corals (such as those from the genus *Paragoniastrea, Turbinaria* and encrusting *Porites*), particularly at Cook Island North and Cook Island South reefs.

Assessing the relative difference in assemblages among these comparative reefs increases understanding of 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, which is often linked to the migration of an offshore bar; however, the overall community at Kirra Reef is becoming more diverse and more similar to reefs in the area since complete burial.

4.2.3 Mobile Invertebrate Assemblages

In 2024, the diversity and density of mobile invertebrates was highest at Cook Island West, which differed to recent years (ESP 2020; ESP 2021; ESP 2022; ESP 2023). Increased abundance of *Tripneustes* sea urchins was the largest contributor to higher mobile invertebrate densities at Cook Island West. As in previous years (2020, 2021, 2022, and 2023), echinoderms dominated the assemblages at all reefs; with urchins having the highest density at Palm Beach Reef and Cook Island West reefs, and feather stars having the highest density at Kirra Reef, Palm Beach Bait Reef and Cook Island North.

4.3 Fish Assemblages

A total of 138 bony and cartilaginous fish species from 45 families were recorded among all reefs in July 2024. Similar to recent surveys (ESP 2020; ESP 2021; ESP 2022; ESP 2023), Labridae (wrasses) and Pomacentridae (damselfishes) were the most diverse families. Fish species recorded were generally common to the region, with most having been recorded during previous surveys; however, in the July 2024 survey, an additional 13 species were observed that had not been recorded in previous surveys.

In July 2024, the average species richness of fish communities did not differ significantly among reef locations, though total species richness and abundance were highest at Palm Beach Reef. The overall composition of fish communities differed, primarily between Kirra Reef and the Cook Island West and Cook Island South reefs, due to variation in the abundance of a broad range of species. Differences in fish assemblages among the reef locations may be related to differences in the habitat complexity, benthic composition, availability of prey or other ecological interactions (e.g. predator abundance). There was no significant difference in fish community composition among the other reefs.

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 2024 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 2024.

The total species richness and total abundance of fish assemblages was highest at Palm Beach Reef, species richness was lowest at Palm Beach Bait Reef, and abundance was lowest at Cook Island North in July 2024. There were several schools of fish dominating assemblages, including schools of yellowtail scad at Kirra Reef, Palm Beach Reef, and Palm Beach Bait Reef, and eastern pomfred at Cook Island South and Cook Island West. Carnivorous species dominated the fish assemblage on all reefs, and omnivorous fish were also common at most reefs, which is consistent with past surveys (ESP 2020; ESP 2021; ESP 2022; ESP 2023). 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 outcrops of the eastern section exhumed periodically linked to the position of an offshore bar running along the beach.
- Benthic communities at Kirra Reef continue to be dominated by macroalgae and ascidians, with generally low coverage of soft and hard corals relative to other reefs. However, the benthic community on Kirra Reef displays good resilience to changes as evidenced by the increased coverage of macroalgae following exhumation of reef sections in previous years.
- 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 and availability of recruits to colonise the reef habitat. Despite the apparent differences,

the community on Kirra Reef has a diverse assemblage of sessile invertebrates, macroalgae and fish, which is generally representative of the region.

It is recommended that ongoing monitoring at Kirra Reef and Cook Island Aquatic Reserve be completed at adequate spatial and temporal scales to determine any potential impacts of TSB operations. Where possible monitoring of reef biota should be completed around June to allow for comparisons with existing data sets. Additional monitoring of the seagrass around Cook Island in November (when seagrass distribution is likely highest) should also be completed. Given the relatively stable reef area and differences among reefs, the annual monitoring program could shift to an event-based monitoring program using suitably derived environmental and operational based triggers for ecological monitoring components. Triggers for monitoring could include operational changes in TSB and / or indicators directly related to sand deposition, such as sedimentation or a substantial change in the accretion / erosion of sand around the reef measured through changes in reef area from aerial photos or hydrographic surveys.

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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		
July 2024	2,365	0	0	2,365	-	-
April 2023	3,492	0	0	3,492	-	-
June 2022	2,810	0	204	3,014	-	-
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

Appendix B Detailed Statistical Analyses

Table B.5.2 PERMANOVA of the difference in the composition of benthic communities among reefs in 2024

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	16350	3.92	0.001
Reef	5	70259	7.74	0.001
Site (Reef)	12	9106	3.05	0.001
Orientation x Reef	5	5643	1.35	0.041
Orientation x Site (Reef)	12	4183	1.40	0.001
Error	452	2987		
Pairwise Comparisons	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
PBNR vs KR	2.13	**0.001**	2.2567	**0.001**
PBBR vs KR	1.65	**0.017**	1.3229	0.074
CIN vs KR	2.39	**0.001**	3.037	**0.001**
CIS vs KR	2.23	**0.001**	2.7818	**0.001**
CIW vs KR	1.80	**0.003**	2.3616	**0.001**
CIN vs CIS	2.04	**0.001**	2.4181	**0.001**
CIN vs CIW	2.08	**0.001**	1.9954	**0.002**
CIS vs CIW	1.69	**0.005**	1.8253	**0.001**
PBNR vs CIN	2.72	**0.001**	2.6883	**0.001**
PBNR vs CIS	2.75	**0.001**	2.5116	**0.001**
PBNR vs CIW	2.50	**0.001**	2.3399	**0.001**
PBNR, PBBR	2.30	**0.001**	2.2153	**0.002**
CIN, PBBR	3.12	**0.001**	2.7794	**0.001**
CIS, PBBR	3.22	**0.001**	2.9145	**0.001**
PBBR, CIW	2.81	**0.001**	2.487	**0.001**
d) Horizontal vs Vertical	t Value	P (MC)		
KR	1.70	0.147		
PBNR	1.19	0.334		
PBBR	1.76	0.094		
CIN	0.92	0.464		
CIS	1.13	0.330		

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 in 2024

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Horizontal	Vertical	Average dissimilarity = 58.7		
Sargassum spp.	36.6	18.4	16.1	1.4	27.5
Turf forming algae	25.3	33.3	11.9	1.4	20.3
Polycarpa procera	4.1	8.0	4.7	1.0	8.0
Galaxaura sp.	4.6	3.2	2.6	1.1	4.5
Herdmania momus	1.8	2.7	1.9	0.8	3.3
Trichomya hirsuta	1.9	2.1	1.7	0.8	2.9
Heteractis sp.	2.4	0.6	1.4	0.7	2.4
Dendronephtya sp. 1	0.5	1.7	1.2	0.4	2.0

Table B.5.4 PERMANOVA of the difference in the composition of algal assemblages among reefs in 2024

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	1267	2.73	**0.046**
Reef	5	31756	20.14	**0.001**
Site (Reef)	12	1583	4.36	**0.001**
Orientation x Reef	5	2776	5.98	**0.001**
Orientation x Site (Reef)	12	465	1.28	0.107
Error	452	363		
Pairwise Tests	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
PBNR vs KR	6.24	**0.001**	3.35	**0.004**
PBBR vs KR	6.38	**0.001**	3.67	**0.003**
CIN vs KR	6.09	**0.002**	3.89	**0.003**
CIS vs KR	5.25	**0.001**	2.78	**0.007**
CIW vs KR	5.66	**0.001**	3.97	**0.002**
CIN vs CIS	3.04	**0.002**	1.72	0.097
CIN vs CIW	2.90	**0.013**	1.51	0.173
CIS vs CIW	1.13	0.329	1.32	0.211
PBNR vs CIN	2.50	**0.015**	2.05	**0.041**
PBNR vs CIS	3.80	**0.001**	0.94	0.468
PBNR vs CIW	3.52	**0.002**	1.62	0.109
PBNR, PBBR	1.99	0.063	0.96	0.433
CIN, PBBR	2.32	**0.033**	4.10	**0.006**
CIS, PBBR	3.71	**0.001**	0.98	0.443
PBBR, CIW	3.28	**0.009**	2.21	**0.045**

Table B.5.5 PERMANOVA of the difference in the coverage of algae among reefs in 2024

		a) Macroalgae			(d) Turfing Algae			(f) Coralline Algae		
Source	**df**	**MS**	**Pseudo-F**	**P (perm)**	**MS**	**Pseudo-F**	**P (perm)**	**MS**	**Pseudo-F**	**P (perm)**
Orientation	1	2834	1.44	0.224	338	1.13	0.314	3056	1.70	0.182
Reef	5	69797	10.13	**0.003**	18825	38.75	0.001	34431	9.64	0.002
Site (Reef)	12	6923	5.50	**0.001**	487	2.31	0.007	3588	4.03	0.001
Orientation x Reef	5	2319	1.18	0.287	1698	5.66	0.006	2515	1.40	0.250
Orientation x Site (Reef)	12	1974	1.57	**0.005**	300	1.43	0.146	1805	2.03	0.003
Error	452	1258			211			889		
Pairwise Tests	b) Reef				(e) Reef			(g) Reef		
	t-value	P(MC)			t-value	P(MC)		t-value	P(MC)	
PBNR vs KR	4.40	0.056			9.03	0.002		2.66	0.043	
PBBR vs KR	6.36	0.023			8.57	0.002		3.39	0.058	
CIN vs KR	5.23	0.045			8.32	0.003		1.30	0.340	
CIS vs KR	4.27	0.041			5.31	0.006		1.91	0.168	
CIW vs KR	3.23	0.023			6.66	0.004		3.28	0.083	
CIN vs CIS	2.27	0.028			4.16	0.009		1.68	0.099	
CIN vs CIW	1.62	0.337			3.97	0.013		5.11	0.027	
CIS vs CIW	0.80	0.690			1.40	0.217		4.36	0.036	
PBNR vs CIN	1.32	0.153			1.61	0.182		3.47	0.054	
PBNR vs CIS	1.48	0.106			5.32	0.005		3.07	0.061	
PBNR vs CIW	1.36	0.237			5.46	0.007		4.64	0.024	
PBNR, PBBR	1.85	0.072			0.54	0.624		4.90	0.015	
CIN, PBBR	3.77	0.030			0.91	0.395		5.37	0.020	
CIS, PBBR	4.12	0.029			4.51	0.009		4.70	0.032	
PBBR, CIW	2.17	0.010			4.26	0.015		0.81	0.665	

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 = 56.4		
Turf	29.4	66.4	28.0	1.9	49.7
Sargassum	27.4	0.0	19.1	1.2	33.8
	Kirra	Palm Beach Bait	Average dissimilarity = 56.4		
Turf	69.2	66.2	11.1	1.2	80.2
	Kirra	Cook Is. West	Average dissimilarity = 55.8		
Turf	29.4	64.2	27.2	1.9	48.8
Sargassum	27.4	0.0	19.6	1.2	35.1
	Kirra	Cook Is. North	Average dissimilarity = 55.4		
Turf	29.4	69.2	29.6	2.0	53.5
Sargassum	27.4	0.0	19.0	1.2	34.3
	Kirra	Cook Is. South	Average dissimilarity = 55.4		
Turf	29.4	56.2	24.5	1.7	44.3
Sargassum	27.4	0.0	20.8	1.2	37.5
	Cook Is. North	Cook Is. West	Average dissimilarity = 17.56		
Turf	69.2	64.2	11.6	1.3	66.3
Dictyota sp.2	0.1	3.7	2.5	0.5	14.3
	Cook Is. South	Cook Is. West	Average dissimilarity = 24.04		
Turf	56.2	64.2	16.4	1.1	68.1
Dictyota dichotoma	1.5	3.7	3.3	0.6	13.9
	Cook Is. North	Cook Is. South	Average dissimilarity = 23.4		
Turf	69.2	56.2	16.6	1.1	70.9
	Cook Is. West	Palm Beach	Average dissimilarity = 19.1		
Turf	64.2	66.4	11.7	1.2	61.2
Dictyota dichotoma	3.7	0.0	2.5	0.5	13.1
	Cook Is. North	Palm Beach	Average dissimilarity = 16.8		
Turf	69.2	66.4	10.6	1.3	62.9
Crustose Coralline Algae	0.6	3.2	2.2	0.9	13.3
	Cook Is. South	Palm Beach	Average dissimilarity = 24.6		
Turf	56.2	66.4	16.1	1.1	65.5
Delisea pulchra	2.3	1.9	2.6	0.6	10.7
	Cook Is. West	Palm Beach Bait	Average dissimilarity = 52.8		
Turf	64.2	66.2	12.3	1.2	77.0
	Cook Is. North	Palm Beach Bait	Average dissimilarity = 13.9		
Turf	69.2	66.2	11.1	1.2	80.2
	Cook Is. South	Palm Beach Bait	Average dissimilarity = 34.6		
Turf	56.2	66.2	16.9	1.1	76.9
	Palm Beach	Palm Beach Bait	Average dissimilarity = 34.6		
Turf	66.4	66.2	11.4	1.2	72.1

Table B.5.7 PERMANOVA of the difference in the composition of sessile invertebrate assemblages among reefs in 2024

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	16350	3.92	**0.001**
Reef	5	70259	7.74	**0.001**
Site (Reef)	12	9106	3.05	**0.001**
Orientation x Reef	5	5643	1.35	**0.041**
Orientation x Site (Reef)	12	4183	1.40	**0.001**
Error	452	2987		
Pairwise Tests	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
PBNR vs KR	2.13	**0.001**	2.2567	**0.001**
PBBR vs KR	1.65	**0.017**	1.3229	0.074
CIN vs KR	2.39	**0.001**	3.037	**0.001**
CIS vs KR	2.23	**0.001**	2.7818	**0.001**
CIW vs KR	1.80	**0.003**	2.3616	**0.001**
CIN vs CIS	2.04	**0.001**	2.4181	**0.001**
CIN vs CIW	2.08	**0.001**	1.9954	**0.002**
CIS vs CIW	1.69	**0.005**	1.8253	**0.001**
PBNR vs CIN	2.72	**0.001**	2.6883	**0.001**
PBNR vs CIS	2.75	**0.001**	2.5116	**0.001**
PBNR vs CIW	2.50	**0.001**	2.3399	**0.001**
PBNR, PBBR	2.30	**0.001**	2.2153	**0.002**
CIN, PBBR	3.12	**0.001**	2.7794	**0.001**
CIS, PBBR	3.22	**0.001**	2.9145	**0.001**
PBBR, CIW	2.81	**0.001**	2.487	**0.001**
d) Horizontal vs Vertical	t Value	P (MC)		
KR	1.70	0.147		
PBNR	1.19	0.334		
PBBR	1.76	0.094		
CIN	0.92	0.464		
CIS	1.13	0.330		
CIW	1.26	0.235		

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%
a)	**Kirra Reef**	**Palm Beach**	**Average dissimilarity = 91.8**		
Trichomya hirsuta	1.9	6.6	18.1	1.0	19.7
Polycarpa procera	4.1	0.4	9.1	0.7	9.9
Heteractis sp.	2.4	1.0	6.8	0.7	7.5
Pseudodistoma inflatum	0.0	1.8	5.2	0.7	5.7
Herdmania momus	1.8	0.6	4.9	0.6	5.3
Pyura stolonifera	0.3	1.6	4.6	0.7	5.0
Cnemidocarpa stolonifera	1.5	0.4	4.6	0.7	5.0
Galeolaria caespitosa	1.4	0.0	4.5	0.4	4.9
Callyspongia sp. 3	1.4	0.0	2.6	0.4	2.8
Callyspongia sp. 1	0.0	0.9	2.4	0.4	2.6
Turbinaria mesenterina	0.0	0.8	2.1	0.3	2.3
b)	**Kirra Reef**	**Cook Is. West**	**Average dissimilarity = 96.6**		
Polycarpa procera	4.1	0.0	12.8	0.7	13.2
Cnemidocarpa stolonifera	1.5	0.7	10.2	0.6	10.6
Heteractis sp.	2.4	0.2	7.6	0.6	7.9
Galeolaria caespitosa	1.4	0.0	7.4	0.4	7.6
Turbinaria mesenterina	0.0	2.6	6.8	0.4	7.0
Herdmania momus	1.8	0.0	5.6	0.5	5.8
Trichomya hirsuta	1.9	0.0	5.2	0.5	5.4
Cladiella sp. 1	0.0	1.2	5.1	0.3	5.3
Callyspongia sp. 3	1.4	0.0	3.4	0.4	3.5
Acropora sp. 1	0.0	0.7	3.0	0.3	3.1
Oceanapia sp	0.0	0.4	2.9	0.3	3.0
c)	**Kirra Reef**	**Cook Is. North**	**Average dissimilarity = 97.9**		
Speciospongia sp. 4	0.0	5.8	14.4	0.8	14.7
Polycarpa procera	4.1	0.3	9.0	0.7	9.2
Turbinaria mesenterina	0.0	2.4	5.9	0.6	6.0
Heteractis sp.	2.4	0.1	5.0	0.6	5.1
Herdmania momus	1.8	0.8	5.0	0.7	5.1
Galeolaria caespitosa	1.4	0.0	4.2	0.3	4.3
Cnemidocarpa stolonifera	1.5	0.1	4.2	0.6	4.3
Acanthastrea sp. 2	0.0	1.9	4.0	0.3	4.1
Trichomya hirsuta	1.9	0.0	3.7	0.5	3.8
Spheciospongia confoederata	0.2	1.1	3.1	0.4	3.2
Acanthastrea bowerbanki	0.0	1.2	2.7	0.2	2.7
Porites sp. 1	0.0	1.2	2.6	0.3	2.6
Amphibalanus sp.	0.1	0.8	2.5	0.4	2.6
Callyspongia sp. 3	1.4	0.0	2.5	0.4	2.5
d)	**Kirra Reef**	**Cook Is. South**	**Average dissimilarity = 99.5**		
Sclerophytum sp. 1	0.0	7.4	16.3	0.6	16.3
Polycarpa procera	4.1	0.0	9.8	0.6	9.8
Porites sp. 1	0.0	2.8	6.7	0.4	6.8
Cnemidocarpa stolonifera	1.5	0.1	5.7	0.5	5.7
Heteractis sp.	2.4	0.2	5.6	0.6	5.6
Galeolaria caespitosa	1.4	0.0	5.3	0.3	5.3
Platygyra lamellina	0.0	1.8	5.3	0.4	5.3
Lobophytum sp. 2	0.0	1.8	4.5	0.3	4.5
Herdmania momus	1.8	0.0	4.3	0.5	4.3
Trichomya hirsuta	1.9	0.0	4.2	0.5	4.2
Callyspongia sp. 3	1.4	0.0	2.8	0.4	2.8
e)	**Cook Is. North**	**Cook Is. West**	**Average dissimilarity = 96.8**		
Speciospongia sp. 4	5.8	0.1	17.5	0.8	18.1
Turbinaria mesenterina	2.4	2.6	10.9	0.7	11.3
Acanthastrea sp. 2	1.9	0.0	4.8	0.4	4.9
Acropora sp. 1	0.6	0.7	4.4	0.4	4.5
Amphibalanus sp.	0.8	0.5	4.0	0.5	4.1

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Porites sp. 1	1.2	0.2	3.7	0.3	3.8
Cladiella sp. 1	0.0	1.2	3.6	0.3	3.7
Spheciospongia confoederata	1.1	0.0	3.4	0.3	3.5
Acanthastrea bowerbanki	1.2	0.0	3.2	0.3	3.3
Cnemidocarpa stolonifera	0.1	0.7	2.9	0.5	3.0
Paragoniastrea australensis	0.8	0.1	2.8	0.3	2.9
Herdmania momus	0.8	0.0	2.7	0.5	2.8
Platygyra lamellina	0.7	0.0	2.6	0.3	2.7
Sclerophytum sp. 1	0.5	0.1	1.9	0.4	2.0
f)	**Cook Is. South**	**Cook Is. West**	**Average dissimilarity = 97.9**		
Sclerophytum sp. 1	7.4	0.1	19.9	0.7	20.3
Porites sp. 1	2.8	0.2	9.0	0.5	9.2
Turbinaria mesenterina	0.8	2.6	8.7	0.5	8.9
Platygyra lamellina	1.8	0.0	6.5	0.4	6.7
Cladiella sp. 1	0.2	1.2	5.8	0.4	6.0
Lobophytum sp. 2	1.8	0.0	5.5	0.4	5.6
Cnemidocarpa stolonifera	0.1	0.7	4.6	0.4	4.7
Entacmaea sp. 2	0.5	0.7	3.7	0.3	3.7
Acropora sp. 1	0.1	0.7	3.6	0.3	3.7
Oceanapia sp	0.0	0.4	2.6	0.3	2.6
g)	**Cook Is. North**	**Cook Is. South**	**Average dissimilarity = 96.27**		
Sclerophytum sp. 1	0.5	7.4	14.1	0.7	14.6
Spheciospongia sp. 4	5.8	0.0	13.7	0.8	14.3
Porites sp. 1	1.2	2.8	7.3	0.5	7.6
Turbinaria mesenterina	2.4	0.8	6.8	0.6	7.0
Platygyra lamellina	0.7	1.8	5.8	0.5	6.0
Acanthastrea sp. 2	1.9	0.6	4.7	0.4	4.9
Lobophytum sp. 2	0.3	1.8	4.1	0.4	4.3
Acanthastrea bowerbanki	1.2	0.2	2.9	0.3	3.0
Paragoniastrea australensis	0.8	0.3	2.7	0.3	2.8
Spheciospongia confoederata	1.1	0.0	2.6	0.3	2.7
Amphibalanus sp.	0.8	0.0	2.3	0.4	2.4
Acropora sp. 1	0.6	0.1	2.2	0.3	2.2
h)	**Palm Beach**	**Cook Is. West**	**Average dissimilarity = 97.45**		
Trichomya hirsuta	6.6	0.0	22.2	1.0	22.8
Turbinaria mesenterina	0.8	2.6	7.7	0.5	7.9
Pseudodistoma inflatum	1.8	0.0	6.5	0.8	6.7
Pyura stolonifera	1.6	0.1	5.3	0.7	5.4
Heteractis sp.	1.0	0.2	4.5	0.5	4.6
Cladiella sp. 1	0.1	1.2	3.9	0.4	4.0
Cnemidocarpa stolonifera	0.4	0.7	3.7	0.6	3.8
Callyspongia sp. 1	0.9	0.0	3.0	0.4	3.0
Acropora sp. 1	0.1	0.7	2.8	0.4	2.9
Herdmania momus	0.6	0.0	2.0	0.4	2.1
Entacmaea sp. 2	0.0	0.7	2.0	0.3	2.0
Iotrochota sp. 1	0.2	0.4	1.9	0.3	2.0
Spheciospongia sp. 4	0.4	0.1	1.9	0.3	1.9
Paragoniastrea australensis	0.4	0.1	1.9	0.2	1.9
i)	**Palm Beach**	**Cook Is. North**	**Average dissimilarity = 96.2**		
Trichomya hirsuta	6.6	0.0	14.9	1.0	15.5
Spheciospongia sp. 4	0.4	5.8	12.7	0.8	13.2
Turbinaria mesenterina	0.8	2.4	6.3	0.7	6.6
Pseudodistoma inflatum	1.8	0.0	4.3	0.8	4.5
Pyura stolonifera	1.6	0.2	3.7	0.7	3.8
Acanthastrea sp. 2	0.0	1.9	3.6	0.3	3.8
Acanthastrea bowerbanki	0.6	1.2	3.3	0.3	3.5
Paragoniastrea australensis	0.4	0.8	2.9	0.4	3.0
Heteractis sp.	1.0	0.1	2.9	0.5	3.0
Spheciospongia confoederata	0.3	1.1	2.9	0.4	3.0
Herdmania momus	0.6	0.8	2.8	0.6	2.9
Porites sp. 1	0.2	1.2	2.6	0.4	2.7

Taxonomic Group	Average Abundance	Average Dissimilarity		Diss/SD	Contrib%
Amphibalanus sp.	0.1	0.8	2.2	0.5	2.3
Callyspongia sp. 1	0.9	0.0	2.0	0.4	2.1
Platygyra lamellina	0.0	0.7	1.9	0.3	2.0
j)	**Cook Is. South**	**Palm Beach**	**Average dissimilarity = 98.8**		
Trichomya hirsuta	0.0	6.6	17.1	0.9	17.3
Sclerophytum sp. 1	7.4	0.0	14.1	0.7	14.3
Porites sp. 1	2.8	0.2	6.1	0.5	6.1
Pseudodistoma inflatum	0.1	1.8	5.0	0.7	5.0
Platygyra lamellina	1.8	0.0	4.5	0.4	4.6
Pyura stolonifera	0.1	1.6	4.0	0.6	4.1
Lobophytum sp. 2	1.8	0.0	3.8	0.4	3.9
Turbinaria mesenterina	0.8	0.8	3.8	0.4	3.8
Heteractis sp.	0.2	1.0	3.3	0.5	3.3
Callyspongia sp. 1	0.0	0.9	2.3	0.4	2.3
Discosoma rhodostoma	1.0	0.1	2.1	0.3	2.1
Paragoniastrea australensis	0.3	0.4	2.0	0.3	2.1
Pocillopora aliciae	0.7	0.1	1.7	0.4	1.7
k)	**Kirra**	**Palm Beach Bait**	**Average dissimilarity = 93.4**		
Polycarpa procera	4.1	6.1	15.8	1.0	18.7
Trichomya hirsuta	1.9	3.5	9.7	0.9	11.4
Cnemidocarpa stolonifera	1.5	3.5	9.6	0.8	11.3
Heteractis sp.	2.4	1.0	5.8	0.7	6.8
Herdmania momus	1.8	1.0	4.8	0.7	5.6
Encrusting porifera sp. 2	0.2	2.0	4.5	0.4	5.4
Galeolaria caespitosa	1.4	0.0	4.0	0.3	4.7
Pseudodistoma inflatum	0.0	1.0	3.3	0.4	3.9
Callyspongia sp. 3	1.4	0.0	2.4	0.4	2.9
j)	**Palm Beach**	**Palm Beach Bait**	**Average dissimilarity = 84.9**		
Trichomya hirsuta	6.6	3.5	13.6	1.1	16.0
Polycarpa procera	0.4	6.1	11.6	0.8	13.7
Cnemidocarpa stolonifera	0.4	3.5	8.4	1.0	9.9
Pseudodistoma inflatum	1.8	1.0	5.0	0.8	5.9
Encrusting porifera sp. 2	0.4	2.0	4.6	0.5	5.4
Heteractis sp.	1.0	1.0	3.7	0.6	4.4
Pyura stolonifera	1.6	0.3	3.6	0.7	4.2
Herdmania momus	0.6	1.0	2.7	0.7	3.2
Spheciospongia confoederata	0.3	1.0	2.2	0.4	2.6
Callyspongia sp. 1	0.9	0.0	2.0	0.4	2.4
Turbinaria mesenterina	0.8	0.0	1.7	0.3	2.0
Spheciospongia sp. 4	0.4	0.4	1.7	0.4	2.0
l)	**Palm Beach Bait**	**Cook Is. North**	**Average dissimilarity = 96.5**		
Spheciospongia sp. 4	0.4	5.8	11.7	0.8	12.1
Polycarpa procera	6.1	0.3	11.3	0.8	11.7
Cnemidocarpa stolonifera	3.5	0.1	8.4	1.0	8.7
Trichomya hirsuta	3.5	0.0	7.3	0.9	7.6
Turbinaria mesenterina	0.0	2.4	4.8	0.6	5.0
Encrusting porifera sp. 2	2.0	0.0	3.8	0.4	3.9
Spheciospongia confoederata	1.0	1.1	3.7	0.5	3.8
Acanthastrea sp. 2	0.0	1.9	3.4	0.3	3.5
Herdmania momus	1.0	0.8	2.8	0.8	2.9
Pseudodistoma inflatum	1.0	0.0	2.6	0.5	2.7
Acanthastrea bowerbanki	0.0	1.2	2.2	0.2	2.3
Heteractis sp.	1.0	0.1	2.1	0.5	2.2
Porites sp. 1	0.0	1.2	2.1	0.3	2.2
Amphibalanus sp.	0.0	0.8	1.9	0.4	1.9
m)	**Palm Beach Bait**	**Cook Is. South**	**Average dissimilarity = 99.4**		
Sclerophytum sp. 1	0.0	7.4	13.0	0.6	13.1
Polycarpa procera	6.1	0.0	12.2	0.8	12.3
Cnemidocarpa stolonifera	3.5	0.1	10.0	0.8	10.1
Trichomya hirsuta	3.5	0.0	8.3	0.9	8.3
Porites sp. 1	0.0	2.8	5.3	0.5	5.3
Encrusting porifera sp. 2	2.0	0.0	4.1	0.4	4.2
Platygyra lamellina	0.0	1.8	4.1	0.4	4.1

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Lobophytum sp. 2	0.0	1.8	3.5	0.3	3.6
Pseudodistoma inflatum	1.0	0.1	3.1	0.4	3.1
Heteractis sp.	1.0	0.2	2.4	0.5	2.4
Herdmania momus	1.0	0.0	2.1	0.6	2.1
Spheciospongia confoederata	1.0	0.0	2.0	0.4	2.0
n)	**Palm Beach Bait**	**Cook Is. West**	**Average dissimilarity = 96.0**		
Polycarpa procera	6.1	0.0	15.1	0.8	15.7
Cnemidocarpa stolonifera	3.5	0.7	12.4	0.9	12.9
Trichomya hirsuta	3.5	0.0	10.6	0.9	11.0
Turbinaria mesenterina	0.0	2.6	5.2	0.4	5.4
Encrusting porifera sp. 2	2.0	0.0	5.1	0.4	5.3
Pseudodistoma inflatum	1.0	0.0	4.1	0.5	4.3
Cladiella sp. 1	0.0	1.2	3.3	0.3	3.5
Heteractis sp.	1.0	0.2	3.2	0.5	3.3
Herdmania momus	1.0	0.0	2.6	0.6	2.7
Spheciospongia confoederata	1.0	0.0	2.4	0.4	2.5
Acropora sp. 1	0.0	0.7	2.1	0.3	2.2
Entacmaea sp. 2	0.0	0.7	1.7	0.2	1.7

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	Contrib%
a)	**Kirra Reef**	**Palm Beach**	**Average dissimilarity = 88.5**		
Trichomya hirsuta	2.1	12.8	17.8	1.1	20.1
Polycarpa procera	8.0	1.8	11.8	1.0	13.3
Pyura stolonifera	1.4	3.9	6.7	0.8	7.5
Pseudodistoma inflatum	0.0	2.6	4.7	0.6	5.3
Herdmania momus	2.7	0.3	4.1	0.7	4.6
Cnemidocarpa stolonifera	1.6	0.8	3.3	0.8	3.7
Heteractis sp.	0.6	1.3	2.7	0.4	3.0
Dendronephtya sp. 1	1.7	0.0	2.2	0.4	2.5
Haliclona sp. 1	1.4	0.1	2.2	0.6	2.5
Amphibalanus sp.	0.7	0.7	2.1	0.4	2.4
Iotrochota sp. 1	0.2	1.1	1.9	0.6	2.1
Spheciospongia sp. 4	0.0	0.9	1.6	0.3	1.9
Cribrochalina sp. 3	0.9	0.1	1.6	0.6	1.8
b)	**Kirra Reef**	**Cook Is. West**	**Average dissimilarity = 89.5**		
Polycarpa procera	8.0	0.0	17.0	1.0	17.5
Amphibalanus sp.	0.7	2.2	6.0	0.5	6.2
Cnemidocarpa stolonifera	1.6	0.9	5.9	0.7	6.0
Herdmania momus	2.7	0.1	5.8	0.6	5.9
Trichomya hirsuta	2.1	0.0	4.7	0.6	4.8
Didemnum membranaceum	0.4	1.2	4.0	0.4	4.1
Cladiella sp. 1	0.0	1.6	3.6	0.4	3.7
Haliclona sp. 1	1.4	0.0	3.2	0.6	3.3
Dendronephtya sp. 1	1.7	0.0	3.0	0.4	3.1
Pyura stolonifera	1.4	0.0	3.0	0.6	3.1
Cribrochalina sp. 3	0.9	0.0	2.8	0.4	2.9
Turbinaria mesenterina	0.0	1.1	2.7	0.5	2.7
Oceanapia sp	0.1	0.8	2.4	0.3	2.4
Didemnum sp. 1	0.7	0.1	2.0	0.5	2.1
Cribrochalina sp. 1	0.8	0.0	1.7	0.4	1.8
Polycarpa pigmentata	0.6	0.0	1.7	0.4	1.7
c)	**Kirra Reef**	**Cook Is. North**	**Average dissimilarity = 95.7**		
Polycarpa procera	8.0	0.3	13.7	1.0	14.3
Spheciospongia sp. 4	0.0	6.6	13.2	0.9	13.7
Herdmania momus	2.7	1.6	6.3	0.9	6.6
Amphibalanus sp.	0.7	1.8	5.0	0.5	5.3

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Turbinaria mesenterina	0.0	1.9	3.9	0.4	4.0
Trichomya hirsuta	2.1	0.0	3.7	0.7	3.9
Cnemidocarpa stolonifera	1.6	0.0	3.6	0.7	3.7
Pyura stolonifera	1.4	0.2	2.7	0.6	2.8
Dendronephtya sp. 1	1.7	0.0	2.6	0.4	2.7
Haliclona sp. 1	1.4	0.0	2.6	0.6	2.7
Spheciospongia confoederata	0.4	0.9	2.2	0.6	2.3
Cribrochalina sp. 3	0.9	0.0	1.9	0.6	2.0
Acropora sp. 1	0.0	0.9	1.9	0.4	2.0
Didemnum sp. 1	0.7	0.3	1.8	0.6	1.9
Dendronephtya sp. 2	0.7	0.4	1.8	0.4	1.9
Acanthastrea sp. 2	0.0	0.8	1.7	0.4	1.8
d)	**Kirra Reef**	**Cook Is. South**	**Average dissimilarity = 99.1**		
Sclerophytum sp. 1	0.0	10.0	13.3	0.7	13.5
Polycarpa procera	8.0	0.0	12.4	0.9	12.6
Porites sp. 1	0.0	4.1	7.1	0.5	7.1
Herdmania momus	2.7	0.2	4.3	0.6	4.3
Pocillopora aliciae	0.0	1.9	3.9	0.5	4.0
Trichomya hirsuta	2.1	0.0	3.4	0.6	3.4
Platygyra lamellina	0.0	1.7	3.3	0.3	3.3
Cnemidocarpa stolonifera	1.6	0.0	3.2	0.7	3.2
Discosoma rhodostoma	0.0	2.5	3.0	0.3	3.0
Favites sp.	0.0	2.3	2.7	0.3	2.7
Cladiella sp. 1	0.0	1.9	2.5	0.3	2.6
Pyura stolonifera	1.4	0.3	2.5	0.6	2.6
Dendronephtya sp. 1	1.7	0.0	2.4	0.4	2.4
Haliclona sp. 1	1.4	0.0	2.3	0.6	2.3
Didemnum sp. 1	0.7	0.5	2.1	0.5	2.2
Cribrochalina sp. 3	0.9	0.0	1.8	0.5	1.8
e)	**Kirra Reef**	**Palm Beach Bait**	**Average dissimilarity = 80.8**		
Polycarpa procera	8.0	7.2	14.9	1.1	18.5
Herdmania momus	2.7	3.2	6.6	1.0	8.2
Trichomya hirsuta	2.1	2.7	5.6	0.9	6.9
Cnemidocarpa stolonifera	1.6	2.0	4.6	0.7	5.7
Cribrochalina sp. 3	0.9	1.5	3.2	0.8	3.9
Dysidea sp. 3	0.8	1.4	3.0	0.6	3.7
Pyura stolonifera	1.4	0.3	2.4	0.6	3.0
Haliclona sp. 1	1.4	0.3	2.4	0.7	2.9
Dendronephtya sp. 1	1.7	0.1	2.4	0.4	2.9
Spheciospongia sp. 4	0.0	1.4	2.2	0.5	2.8
Encrusting porifera sp. 2	0.3	1.2	2.2	0.6	2.8
Spheciospongia confoederata	0.4	0.7	1.8	0.5	2.2
Clavelina sp. 1	0.0	1.2	1.7	0.3	2.1
Amphibalanus sp.	0.7	0.3	1.7	0.3	2.1
Heteractis sp.	0.6	0.5	1.6	0.6	2.0
Polycarpa pigmentata	0.6	0.4	1.4	0.5	1.8
f)	**Cook Is. North**	**Cook Is. West**	**Average dissimilarity = 95.3**		
Spheciospongia sp. 4	6.6	0.2	20.1	1.0	21.1
Amphibalanus sp.	1.8	2.2	10.0	0.7	10.5
Turbinaria mesenterina	1.9	1.1	7.9	0.6	8.2
Herdmania momus	1.6	0.1	6.2	0.7	6.5
Acropora sp. 1	0.9	0.8	4.3	0.5	4.6
Cladiella sp. 1	0.0	1.6	4.2	0.4	4.4
Didemnum membranaceum	0.1	1.2	4.1	0.5	4.3
Cnemidocarpa stolonifera	0.0	0.9	3.1	0.4	3.3
Iotrochota sp. 1	0.5	0.5	2.8	0.4	3.0
Acanthastrea sp. 2	0.8	0.0	2.7	0.4	2.8
Spheciospongia confoederata	0.9	0.0	2.6	0.6	2.7
g)	**Cook Is. South**	**Cook Is. West**	**Average dissimilarity = 98.2**		
Sclerophytum sp. 1	10.0	0.2	18.2	0.7	18.5

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Porites sp. 1	4.1	0.0	10.2	0.5	10.4
Cladiella sp. 1	1.9	1.6	6.6	0.5	6.7
Pocillopora aliciae	1.9	0.1	6.2	0.5	6.4
Platygyra lamellina	1.7	0.3	5.5	0.3	5.6
Amphibalanus sp.	0.0	2.2	4.6	0.4	4.7
Favites sp.	2.3	0.4	4.0	0.4	4.1
Discosoma rhodostoma	2.5	0.0	3.9	0.3	3.9
Turbinaria mesenterina	0.6	1.1	3.7	0.6	3.7
Didemnum membranaceum	0.0	1.2	3.6	0.4	3.6
Cnemidocarpa stolonifera	0.0	0.9	2.8	0.4	2.9
h)	**Cook Is. North**	**Cook Is. South**	**Average dissimilarity = 95.9**		
Sclerophytum sp. 1	0.0	10.0	15.0	0.7	15.7
Spheciospongia sp. 4	6.6	0.4	13.4	1.0	14.0
Porites sp. 1	0.5	4.1	8.5	0.6	8.9
Pocillopora aliciae	0.4	1.9	4.8	0.6	5.0
Turbinaria mesenterina	1.9	0.6	4.7	0.5	4.9
Platygyra lamellina	0.3	1.7	4.3	0.3	4.5
Amphibalanus sp.	1.8	0.0	4.2	0.5	4.3
Herdmania momus	1.6	0.2	3.9	0.7	4.1
Discosoma rhodostoma	0.0	2.5	3.4	0.3	3.5
Favites sp.	0.1	2.3	3.1	0.3	3.2
Cladiella sp. 1	0.0	1.9	2.8	0.3	3.0
i)	**Palm Beach**	**Cook Is. West**	**Average dissimilarity = 98.2**		
Trichomya hirsuta	12.8	0.0	26.3	1.3	26.8
Pyura stolonifera	3.9	0.0	9.3	0.8	9.5
Pseudodistoma inflatum	2.6	0.0	7.0	0.6	7.2
Amphibalanus sp.	0.7	2.2	5.1	0.5	5.2
Cladiella sp. 1	0.2	1.6	3.8	0.5	3.9
Polycarpa procera	1.8	0.0	3.5	0.5	3.6
Cnemidocarpa stolonifera	0.8	0.9	3.5	0.6	3.6
Iotrochota sp. 1	1.1	0.5	3.2	0.6	3.3
Didemnum membranaceum	0.1	1.2	3.1	0.4	3.1
Heteractis sp.	1.3	0.0	2.7	0.3	2.8
Spheciospongia sp. 4	0.9	0.2	2.7	0.4	2.8
j)	**Palm Beach**	**Cook Is. North**	**Average dissimilarity = 95.5**		
Trichomya hirsuta	12.8	0.0	21.6	1.2	22.6
Spheciospongia sp. 4	0.9	6.6	12.3	1.0	12.9
Pyura stolonifera	3.9	0.2	7.5	0.8	7.8
Pseudodistoma inflatum	2.6	0.1	5.4	0.7	5.7
Amphibalanus sp.	0.7	1.8	4.3	0.6	4.5
Turbinaria mesenterina	0.0	1.9	3.6	0.4	3.7
Herdmania momus	0.3	1.6	3.5	0.8	3.7
Polycarpa procera	1.8	0.3	3.3	0.5	3.5
Iotrochota sp. 1	1.1	0.5	2.5	0.7	2.6
Heteractis sp.	1.3	0.0	2.3	0.3	2.4
Acropora sp. 1	0.0	0.9	1.7	0.4	1.8
k)	**Palm Beach**	**Cook Is. South**	**Average dissimilarity = 98.8**		
Trichomya hirsuta	12.8	0.0	19.6	1.2	19.8
Sclerophytum sp. 1	0.0	10.0	12.8	0.7	13.0
Pyura stolonifera	3.9	0.3	6.8	0.8	6.9
Porites sp. 1	0.1	4.1	6.8	0.5	6.9
Pseudodistoma inflatum	2.6	0.1	4.9	0.6	4.9
Pocillopora aliciae	0.0	1.9	3.6	0.6	3.6
Platygyra lamellina	0.0	1.7	3.1	0.3	3.1
Discosoma rhodostoma	0.0	2.5	2.9	0.3	3.0
Cladiella sp. 1	0.2	1.9	2.8	0.3	2.9
Polycarpa procera	1.8	0.0	2.7	0.4	2.7
Favites sp.	0.0	2.3	2.6	0.3	2.6
Spheciospongia sp. 4	0.9	0.4	2.5	0.4	2.6
l)	**Palm Beach**	**Palm Beach Bait**	**Average dissimilarity = 87.06**		
Trichomya hirsuta	12.8	2.7	17.1	1.1	19.6
Polycarpa procera	1.8	7.2	11.1	0.9	12.8
Pyura stolonifera	3.9	0.3	6.4	0.8	7.3

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Herdmania momus	0.3	3.2	5.0	0.9	5.8
Pseudodistoma inflatum	2.6	0.6	4.8	0.7	5.6
Cnemidocarpa stolonifera	0.8	2.0	4.0	0.7	4.6
Spheciospongia sp. 4	0.9	1.4	3.3	0.6	3.8
Heteractis sp.	1.3	0.5	2.6	0.4	3.0
Dysidea sp. 3	0.3	1.4	2.5	0.5	2.9
Cribrochalina sp. 3	0.1	1.5	2.5	0.7	2.9
Iotrochota sp. 1	1.1	0.5	2.1	0.7	2.4
m)	**CIN**	**Palm Beach Bait**	**Average dissimilarity = 91.41**		
Polycarpa procera	0.3	7.2	12.8	0.9	14.0
Spheciospongia sp. 4	6.6	1.4	12.6	1.0	13.7
Herdmania momus	1.6	3.2	6.2	1.0	6.8
Trichomya hirsuta	0.0	2.7	5.3	0.8	5.8
Cnemidocarpa stolonifera	0.0	2.0	4.5	0.6	4.9
Amphibalanus sp.	1.8	0.3	4.2	0.5	4.6
Turbinaria mesenterina	1.9	0.4	4.2	0.5	4.6
Dysidea sp. 3	0.2	1.4	3.0	0.5	3.3
Cribrochalina sp. 3	0.0	1.5	3.0	0.7	3.3
Spheciospongia confoederata	0.9	0.7	2.7	0.7	3.0
Encrusting porifera sp. 2	0.0	1.2	2.3	0.5	2.5
Clavelina sp. 1	0.0	1.2	1.9	0.3	2.1
Iotrochota sp. 1	0.5	0.5	1.8	0.5	2.0
n)	**CIS**	**Palm Beach Bait**	**Average dissimilarity = 98.9**		
Sclerophytum sp. 1	10.0	0.0	13.2	0.7	13.4
Polycarpa procera	0.0	7.2	11.6	0.8	11.8
Porites sp. 1	4.1	0.0	6.9	0.5	7.0
Herdmania momus	0.2	3.2	5.3	0.9	5.4
Trichomya hirsuta	0.0	2.7	4.7	0.8	4.8
Cnemidocarpa stolonifera	0.0	2.0	4.1	0.6	4.1
Pocillopora aliciae	1.9	0.0	3.8	0.5	3.8
Platygyra lamellina	1.7	0.0	3.2	0.3	3.3
Spheciospongia sp. 4	0.4	1.4	3.1	0.5	3.1
Discosoma rhodostoma	2.5	0.0	3.0	0.3	3.0
Cribrochalina sp. 3	0.0	1.5	2.7	0.7	2.7
Favites sp.	2.3	0.0	2.7	0.3	2.7
Cladiella sp. 1	1.9	0.0	2.5	0.3	2.5
Dysidea sp. 3	0.0	1.4	2.5	0.5	2.5
o)	**CIW**	**Palm Beach Bait**	**Average dissimilarity = 97.0**		
Polycarpa procera	0.0	7.2	16.0	0.9	16.4
Herdmania momus	0.1	3.2	7.5	0.9	7.7
Cnemidocarpa stolonifera	0.9	2.0	7.0	0.6	7.2
Trichomya hirsuta	0.0	2.7	6.6	0.8	6.8
Amphibalanus sp.	2.2	0.3	4.8	0.5	5.0
Cribrochalina sp. 3	0.0	1.5	3.7	0.7	3.8
Dysidea sp. 3	0.0	1.4	3.5	0.5	3.6
Cladiella sp. 1	1.6	0.0	3.5	0.4	3.6
Spheciospongia sp. 4	0.2	1.4	3.5	0.5	3.6
Didemnum membranaceum	1.2	0.2	3.4	0.4	3.5
Turbinaria mesenterina	1.1	0.4	3.1	0.5	3.2
Encrusting porifera sp. 2	0.0	1.2	2.8	0.5	2.8
Oceanapia sp	0.8	0.2	2.6	0.4	2.7

Table B.5.10 PERMANOVA of the difference in the taxonomic richness of sessile invertebrates among reefs in 2024

a) PERMANOVA Source		(a) Taxonomic Richness			(b) % Coverage		
	df	MS	Pseudo-F	P(perm)	MS	Pseudo-F	P(perm)
Orientation	1	87	21.01	**0.001**	5294	20.30	**0.004**
Reef	5	186	9.48	**0.004**	3442	3.05	0.056
Site (Reef)	12	20	5.22	**0.001**	1135	7.01	**0.001**
Orientation x Reef	5	27	6.49	**0.007**	693	2.65	0.086
Orientation x Site (Reef)	12	4	1.10	0.356	262	1.62	0.088
Error	452	4			162		
	(c) Horizontal		(d) Vertical				
Pairwise Tests	t Value	P (MC)	t Value	P (MC)			
PBNR vs KR	1.10	0.311	1.50	0.170			
PBBR vs KR	2.44	0.065	0.36	0.951			
CIN vs KR	0.70	0.499	2.61	0.070			
CIS vs KR	1.52	0.176	3.45	0.063			
CIW vs KR	2.17	0.110	3.20	**0.008**			
CIN vs CIS	3.65	**0.014**	4.10	**0.044**			
CIN vs CIW	4.14	**0.017**	1.50	0.383			
CIS vs CIW	1.01	0.344	0.53	0.640			
PBNR vs CIN	0.72	0.515	2.94	0.058			
PBNR vs CIS	3.70	**0.023**	5.03	**0.045**			
PBNR vs CIW	4.21	**0.011**	2.69	0.064			
PBNR, PBBR	1.80	0.144	3.25	**0.015**			
CIN, PBBR	2.80	**0.040**	11.87	0.093			
CIS, PBBR	5.56	**0.005**	14.42	**0.044**			
PBBR, CIW	5.86	**0.004**	4.32	**0.010**			
d) Horizontal vs Vertical	t Value	P (MC)					
KR	8.63	0.084					
PBNR	0.65	0.588					
PBBR	1.61	0.263					
CIN	0.99	0.426					
CIS	2.34	0.165					
CIW	1.69	0.225					

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 2024)

PERMANOVA Source	df	(a) Horizontal MS	Pseudo-F	P(perm)					
Survey	6	74531	81.65	**0.001**					
Reef	8	100850	110.49	**0.001**					
Survey x Reef	29	12548	13.75	**0.001**					
Error	1957	913							
Pairwise Tests	b) 2016	c) 2017	d) 2018	e) 2019	f) 2020	g)2021	h)2022	i)2023	j) 2024
	t Values								
KR vs PBNR	10.4**		6.2**	4.8**	8.6**	7.1**	4.1**	7.7**	9.0**
KR vs PBBR					5.4**	6.5**			9.6**
KR vs CIW		5.7**	3.5**	4.6**	8.2**	7.6**	3.0**	3.2**	9.1**
KR vs CIS					10.5**	8.3**	4.0**	5.1**	7.3**
KR vs CIN	5.4**	4.6**	4.6**	4.5**	10.6**	7.6**	3.7**	6.8**	8.5**
CIW vs CIN		2.2**	1.7*	1.2	5.8**	6.3**	2.6**	6.5**	3.8**
CIW vs CIS					6.2**	7.3**	2.1**	5.1**	2.8**
CIW vs PBNR			3.5**	5.3**	10.6**	6.9**	2.9**	8.4**	4.7**
CIN vs CIS					3.2**	4.3**	3.0**	3.6**	3.9**
CIN vs PBNR			4.1**	5.7**	8.6**	5.1**	4.7**	5.5**	5.4**
CIS vs PBNR					9.2**	6.8**	4.0**	3.1**	5.4**
KR vs KC	4.2**			2.0*					
PBNR vs KC	8.0**			4.7**					
KC vs CIN	3.6**								
KC vs CIW				4.4**					
CIN vs PBBR					6.9**	7.3**			4.1**
PBNR vs PBBR					8.7**	3.5**			3.3**
CIW vs PBBR					6.0**	9.4**			5.7**
CIS vs PBBR					6.8**	8.4**			6.6**
h) Pairwise comparison within reefs over time	Kirra	Palm Beach	Cook Island North	Cook Island West	Cook Island South				
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****	**1.76***				
2021 vs 2022	**3.33****	**3.77****	**2.11****	**3.59****	**2.40****				
2022 vs 2023	**6.06****	**4.72****	**3.41****	**7.33****	**3.18****				
2023 vs 2024	**2.56****	**5.41****	**5.31****	**8.96****	**2.81****				

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

Table B.5.12 Comparisons of sessile assemblages on **Vertical** surfaces among reefs and survey periods (2016 to 2024)

		(a) Vertical				
PERMANOVA Source	**df**	**MS**	**Pseudo-F**	**P(perm)**		
Survey	6	61742	88.83	0.001		
Reef	5	19462	28.00	0.001		
Survey x Reef	19	10077	14.50	0.001		
Error	1356	695				
Pairwise Tests	b) 2016	c) 2020	d)2021	e)2022	f)2023	g) 2024
	t Values					
KR vs PBNR	7.0**	13.3**	4.9**	5.9**	6.1**	5.7**
KR vs CIW		9.7**	5.0**	4.3**	3.8**	7.7**
KR vs CIS		11.2**	6.2**	4.2**	6.7**	5.9**
KR vs CIN	5.8**	11.5**	5.1**	4.8**	7.9**	7.1**
CIW vs CIN		5.0**	3.9**	3.6**	4.4**	2.4**
CIW vs CIS		4.9**	5.3**	3.4**	3.6**	3.2**
CIW vs PBNR		9.1**	5.2**	3.0**	4.2**	4.6**
CIN vs CIS		1.6*	3.2**	2.5**	3.9**	3.4**
CIN vs PBNR	3.5**	6.1**	3.7**	6.3**	5.3**	4.6**
CIS vs PBNR		6.4**	5.1**	5.0**	4.2**	4.5**
KR vs KC	6.0**					
PBNR vs KC	3.2**					
KC vs CIN	1.6*					
KC vs CIW						
PBNR vs PBBR						2.8**
KR vs PBBR						6.1**
CIN vs PBBR						4.5**
CIS vs PBBR						5.1**
CIW vs PBBR						5.1**
g) Pairwise comparison within reefs over time	Kirra	Palm Beach	Cook Island North	Cook Island West	Cook Island South	
2016 vs 2020	**4.4****	**5.8****	**5.3****			
2020 vs 2021	**5.3****	**7.4****	**3.2****	**3.6****	**2.9****	
2021 vs 2022	**3.3****	**4.8****	**3.7****	**4.1****	**2.5****	
2022 vs 2023	**5.1****	**5.5****	**3.9****	**4.8****	**3.7****	
2023 vs 2024	**2.7****	**3.8****	**4.3****	**5.6****	**1.6***	

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

Table B.5.13 SIMPER differences in sessile assemblages at Kirra Reef among survey periods (2016 to 2024)

Taxonomic Group	Average Abundance		Average Dissimilarity	Dissimilarity/SD	Contribution%
	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
Ascidians	16.4	16.6	13.6	1.1	22.2
Sponges	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
Ascidians	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		
Ascidians	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		
Ascidians	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
Sponges	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
Ascidians	24.2	19.6	10.6	1.3	21.9
Sponges	8.6	3.0	4.3	1.0	9.0
Coralline Algae	7.6	5.3	4.3	1.1	9.0
	2021	2022	Average dissimilarity = 43.6		
Turf Algae	37.1	51.9	12.87	1.30	29.5
Ascidians	16.5	12.1	9.10	1.28	20.9
Macroalgae	15.7	5.6	9.04	1.19	20.8
Coralline Algae	6.6	4.4	3.90	0.95	9.0
Sponges	2.2	6.8	3.65	0.96	8.4
Anemone	1.3	3.4	2.30	0.69	5.3
	2022	2023	Average dissimilarity = 57.88		
Turf Algae	48.9	20.3	18.8	1.4	32.5
Macroalgae	3.8	26.0	14.0	1.2	24.2
Ascidian	17.5	22.6	11.6	1.2	20.0
Sponge	9.7	8.0	5.3	1.0	9.2
Coralline Algae	3.3	4.9	2.9	1.0	5.0
	2023	2024	Average dissimilarity = 51.25		
Macroalgae	26.0	33.5	15.8	1.3	30.8
Turf Algae	20.3	29.3	12.0	1.2	23.5
Ascidian	22.6	12.5	10.8	1.3	21.1
Sponge	8.0	6.4	4.8	1.0	9.4
Coralline Algae	4.9	1.2	2.8	1.0	5.4

Table B.5.14 SIMPER differences in sessile assemblages at Cook Island North reef among survey periods (2016 to 2024)

Taxonomic Group	Average Abundance		Average Dissimilarity	Dissimilarity/SD	Contribution%
	2016	2017	Average dissimilarity = 46.8		
Turf Algae	58.3	42.8	15.0	1.1	32.1
Macroalgae	14.4	17.4	10.4	1.1	22.2
Hard coral	4.0	10.9	6.7	0.7	14.4
Sponges	8.2	6.9	5.2	1.0	11.0
Coralline algae	3.7	5.7	3.9	0.7	8.3
Ascidians	6.4	1.8	3.3	0.9	7.1
	2017	2018	Average dissimilarity = 79.5		
Turf Algae	42.8	3.9	21.3	1.7	26.7
Ascidians	1.8	35.5	19.1	1.2	24.0
Macroalgae	17.4	22.1	13.6	1.0	17.1
Hard coral	10.9	20.7	11.9	1.0	15.0
Coralline algae	5.7	10.0	6.7	0.7	8.4
	2018	2019	Average dissimilarity = 67.1		
Macroalgae	22.1	59.8	22.8	1.7	34.0
Ascidians	35.5	15.2	15.8	1.3	23.6
Hard coral	20.7	1.4	10.4	1.0	15.6
Turf Algae	3.9	13.8	6.8	1.2	10.1
Coralline algae	10.0	0.0	5.1	0.6	7.6
	2019	2020	Average dissimilarity = 80.4		
Macroalgae	59.8	1.5	30.7	2.4	38.1
Turf Algae	13.8	60.8	24.8	2.9	30.8
Ascidians	15.2	2.7	7.5	0.9	9.3
Coralline algae	0.0	11.0	5.7	1.4	7.1
Hard coral	1.4	9.3	4.9	0.9	6.1
	2020	2021	Average dissimilarity = 32.6		
Turf Algae	60.8	56.0	7.8	1.3	24.1
Hard coral	9.3	12.1	6.8	1.0	20.9
Ascidians	2.7	11.1	5.2	0.9	15.9
Coralline algae	11.0	7.6	4.5	1.2	13.8
Sponges	2.9	7.2	3.8	0.8	11.6
Soft coral	2.3	1.6	1.8	0.4	5.5
	2021	2022	Average dissimilarity = 36.8		
Turf Algae	56.0	45.8	9.2	1.4	25.1
Hard coral	12.1	13.3	7.3	1.1	19.7
Coralline algae	7.6	14.6	6.0	1.1	16.4
Sponges	7.2	11.2	5.4	1.1	14.8
Ascidians	11.1	7.8	5.2	1.0	14.0
	2022	2023	Average dissimilarity = 38.9		
Turf Algae	45.8	54.4	9.2	1.4	23.7
Coralline Algae	14.6	12.1	6.1	1.2	15.8
Hard coral	13.3	9.1	5.9	1.1	15.2
Sponge	11.2	2.8	5.0	1.0	13.0
Ascidian	7.8	4.9	4.0	1.0	10.3
Macroalgae	0.0	7.2	3.7	0.9	9.6
Barnacle	2.3	2.3	1.8	0.8	4.6
	2023	2024	Average dissimilarity = 35.61		
Turf Algae	54.4	69.2	10.2	1.4	28.5
Coralline Algae	12.1	0.6	6.0	1.2	16.8
Hard coral	9.1	8.3	4.7	1.1	13.2
Sponge	2.8	8.6	4.0	1.1	11.3
Macroalgae	7.2	3.1	3.6	1.0	10.0
Ascidian	4.9	2.4	2.6	0.9	7.4
Barnacle	2.3	1.2	1.4	0.8	4.0

Table B.5.15 SIMPER differences in sessile assemblages at Cook Island South Reef among survey periods (2020 to 2024)

Taxonomic Group	Average Abundance		Average Dissimilarity	Dissimilarity/SD	Contribution%
	2020	2021	Average dissimilarity = 41.3		
Turf Algae	55.1	48.7	11.7	1.4	28.4
Hard coral	16.0	17.4	8.5	1.1	20.7
Soft coral	4.1	12.5	6.8	0.7	16.4
Coralline algae	8.5	4.7	4.8	0.9	11.6
Zoanthid	4.5	2.7	3.3	0.5	8.1
Sponges	2.2	4.8	2.9	0.8	7.0
	2021	2022	Average dissimilarity = 46.4		
Turf Algae	48.7	45.5	11.5	1.4	24.8
Soft coral	12.5	13.2	9.8	0.9	21.0
Hard coral	17.4	9.4	8.5	1.1	18.3
Sponges	4.8	10.4	5.9	0.8	12.8
Coralline algae	4.7	11.1	5.8	1.0	12.5
Ascidians	3.3	3.5	2.3	1.0	4.9
	2022	2023	Average dissimilarity = 52.0		
Turf Algae	45.5	44.6	11.9	1.3	22.9
Soft Coral	13.2	13.6	10.1	1.0	19.4
Macroalgae	0.1	11.6	6.3	0.6	12.2
Hard coral	9.4	7.7	6.1	0.9	11.7
Sponge	10.4	4.5	6.1	0.8	11.6
Coralline Algae	11.1	1.7	5.6	1.0	10.7
Zoanthid	0.2	3.9	2.1	0.3	4.1
	2023	2024	Average dissimilarity = 45.8		
Turf Algae	44.6	56.2	13.8	1.4	30.2
Soft Coral	13.6	11.4	9.3	1.0	20.2
Macroalgae	11.6	5.9	7.0	0.8	15.3
Hard coral	7.7	10.1	6.1	1.1	13.4
Zoanthid	3.9	1.7	2.9	0.4	6.3
Sponge	4.5	0.7	2.5	0.6	5.5

Table B.5.16 SIMPER differences in sessile assemblages at Cook Island West Reef among survey periods (2017 to 2024)

Taxonomic Group	Average Abundance		Average Dissimilarity	Dissimilarity/SD	Contribution%
	2017	2018	Average dissimilarity = 75.7		
Ascidians	3.4	34.7	22.0	1.1	29.1
Turf algae	40.5	16.9	20.7	1.6	27.3
Macroalgae	3.7	21.6	14.0	0.9	18.5
Hard coral	10.6	13.0	10.7	0.9	14.2
Coralline algae	3.1	3.4	3.3	0.7	4.4
	2018	2019	Average dissimilarity = 59.4		
Macroalgae	21.6	53.7	18.8	1.8	31.6
Ascidians	34.7	16.0	15.0	1.2	25.3
Turf algae	16.9	15.0	10.0	1.2	16.8
Hard coral	13.0	5.7	7.7	0.9	13.0
Soft coral	3.4	3.3	2.7	0.8	4.6
	2019	2020	Average dissimilarity = 67.3		
Macroalgae	53.7	10.9	24.8	2.4	36.8
Turf algae	15.0	49.7	20.2	2.3	30.0
Ascidians	16.0	3.3	8.4	1.0	12.4
Coralline algae	0.0	7.1	4.0	1.0	6.0
Hard coral	5.7	1.3	3.7	0.5	5.5
	2020	2021	Average dissimilarity = 31.8		
Turf algae	49.7	63.9	11.8	1.3	36.9
Macroalgae	10.9	8.7	5.8	1.2	18.1
Coralline algae	7.1	2.2	3.9	1.0	12.3
Ascidians	3.3	5.9	3.6	1.1	11.3
Seagrass	1.7	1.1	1.7	0.3	5.3
Hard coral	1.3	1.5	1.5	0.6	4.7
Sponges	1.5	1.6	1.5	0.7	4.6
	2021	2022	Average dissimilarity = 35.8		
Turf Algae	63.9	56.5	10.7	1.3	29.9
Coralline algae	2.2	9.2	5.0	0.8	14.0
Hard coral	1.5	8.5	4.9	0.6	13.6
Macroalgae	8.7	0.6	4.7	1.2	13.0
Ascidians	5.9	4.8	3.1	1.1	8.6
Sponges	1.6	5.0	2.8	0.9	7.8
Soft coral	1.7	2.0	1.6	0.7	4.6
	2022	2023	Average dissimilarity = 57.7		
Macroalgae	0.6	36.0	19.3	1.2	33.5
Turf Algae	56.5	34.3	15.9	1.5	27.5
Coralline Algae	9.2	6.5	5.6	0.9	9.7
Hard coral	8.5	4.4	5.4	0.7	9.4
Ascidian	4.8	8.5	4.2	0.8	7.2
Sponge	5.0	3.1	3.0	1.0	5.1
	2023	2024	Average dissimilarity = 55.9		
Macroalgae	36.0	4.7	19.5	1.2	34.8
Turf Algae	34.3	64.1	18.7	1.6	33.4
Ascidian	8.5	1.8	4.6	0.8	8.3
Coralline Algae	6.5	0.1	3.7	0.8	6.7
Hard coral	4.4	3.4	3.6	0.6	6.4
Sponge	3.1	1.2	2.0	0.7	3.6

Table B.5.17 SIMPER differences in sessile assemblages at Palm Beach Reef among survey periods (2016 to 2024)

Taxonomic Group	Average Abundance		Average Dissimilarity	Dissimilarity/SD	Contribution%
	2016	2018	Average dissimilarity = 77.4		
Ascidian	5.7	65.1	30.7	1.9	39.7
Turf Algae	62.0	17.5	25.8	1.9	33.3
Sponge	11.4	0.1	5.9	1.2	7.6
Hard coral	5.5	4.3	4.3	0.6	5.5
Coralline Algae	8.3	0.9	4.1	1.2	5.3
	2018	2019	Average dissimilarity = 69.4		
Ascidian	65.1	19.7	26.8	1.8	38.7
Turf Algae	17.5	28.5	15.5	1.9	22.3
Macroalgae	3.8	22.2	10.8	1.3	15.5
Soft Coral	1.5	10.2	5.4	0.8	7.9
Anemone	2.2	6.9	4.1	0.8	5.8
	2019	2020	Average dissimilarity = 64.4		
Turf Algae	28.5	80.2	27.0	3.4	42.0
Macroalgae	22.2	0.3	11.5	1.4	17.9
Ascidian	19.7	2.9	9.1	1.1	14.1
Soft Coral	10.2	1.6	5.4	0.8	8.4
Sponge	2.0	7.8	3.8	1.2	5.9
Anemone	6.9	1.1	3.6	0.8	5.5
	2020	2021	Average dissimilarity = 36.4		
Turf Algae	80.2	56.7	12.6	1.6	34.7
Ascidian	2.9	15.6	7.0	1.2	19.2
Bivalves	0.0	12.4	6.4	0.9	17.6
Sponge	7.8	3.3	3.5	1.2	9.6
Hard coral	0.8	3.3	1.9	0.6	5.3
Coralline Algae	0.8	3.0	1.7	0.6	4.6
	2021	2022	Average dissimilarity = 35.4		
Turf Algae	56.7	68.3	9.0	1.4	25.4
Ascidian	15.6	3.8	6.7	1.2	18.9
Bivalves	12.4	2.6	6.0	0.9	16.9
Hard coral	3.3	7.4	4.0	0.9	11.3
Sponge	3.3	5.2	2.7	1.1	7.5
Coralline Algae	3.0	2.4	2.1	0.7	6.0
Soft Coral	1.4	4.1	2.1	0.8	5.9
	2022	2023	Average dissimilarity = 42.1		
Turf Algae	68.3	43.9	14.0	1.5	33.2
Bivalves	2.6	12.4	5.8	1.1	13.8
Soft Coral	4.1	9.9	4.8	0.8	11.3
Ascidian	3.8	10.7	4.7	1.0	11.1
Hard coral	7.4	6.7	4.4	1.0	10.5
Sponge	5.2	5.6	3.3	0.9	7.7
Anemone	2.1	2.4	1.7	0.9	4.0
	2023	2024	Average dissimilarity = 41.6		
Turf Algae	43.9	66.4	13.5	1.5	32.4
Bivalves	12.4	9.8	6.0	1.1	14.4
Soft Coral	9.9	0.4	5.0	0.8	12.0
Ascidian	10.7	8.4	4.8	1.1	11.5
Hard coral	6.7	2.1	3.4	1.0	8.1
Sponge	5.6	3.6	2.9	0.8	7.1
Macroalgae	1.8	2.9	2.0	0.6	4.8

Table B.5.18 PERMANOVA of the difference in the fish assemblages among reefs in 2024

PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Reef	5	3097	2.90	**0.001**
Error	11	1068		

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.5.19 SIMPER of the differences in the fish assemblages

Species	Average MaxN (4th Root Transformed)		Average Dissimilarity	Dissimilarity/ SD	Contribution %
	Cook Island South	Kirra Reef	Average dissimilarity = 58.3		
Trachurus novaezelandiae	0.00	4.70	5.3	5.6	9.1
Lutjanus fulviflamma	0.00	1.52	1.7	7.4	2.9
Pseudocaranx georgianus	0.00	1.39	1.6	1.3	2.8
Abudefduf whitleyi	1.21	0.00	1.3	1.3	2.3
Abudefduf vaigiensis	1.32	0.40	1.3	1.4	2.3
Schuettea scalaripinnis	1.25	0.00	1.3	0.7	2.2
Scorpis lineolata	1.57	1.29	1.3	3.3	2.2
Pomacentrus coelestis	1.25	0.40	1.3	1.2	2.2
Abudefduf sexfasciatus	1.15	0.00	1.3	1.3	2.2
Plectroglyphidodon apicalis	1.11	0.00	1.3	5.6	2.2
Prionurus microlepidotus	0.00	1.06	1.2	7.4	2.1
Sphyraena obtusata	0.00	1.06	1.2	7.4	2.1
Stethojulis interrupta	0.33	1.39	1.2	2.0	2.0
Orectolobus ornatus	0.00	1.00	1.1	13.6	1.9
Dascyllus trimaculatus	1.06	1.07	1.1	1.3	1.9
Parupeneus spilurus	0.40	1.38	1.1	1.6	1.9
*Acanthopagrus australis**	0.79	1.15	1.0	1.4	1.7
Alectis ciliaris	0.00	0.84	1.0	1.3	1.7
Plectorhinchus flavomaculatus	0.33	1.13	0.9	1.5	1.6
Plectroglyphidodon gascoynei	1.11	0.40	0.9	1.7	1.6
Gerres subfasciatus	0.75	0.00	0.9	0.7	1.5
Stethojulis bandanensis	1.13	0.40	0.9	1.4	1.5
Plagiotremus tapeinosoma	1.06	0.33	0.9	1.4	1.5
Cheilio inermis	0.67	0.00	0.8	1.3	1.4
Thalassoma amblycephalum	1.11	1.71	0.8	0.9	1.3
Cheilinus chlorourus	0.00	0.67	0.8	1.3	1.3
Neotrygon australiae	0.00	0.67	0.8	1.3	1.3
Chromis margaritifer	0.77	0.40	0.8	1.2	1.3
Chaetodon citrinellus	0.00	0.67	0.7	1.3	1.3
Parma unifasciata	0.00	0.67	0.7	1.3	1.3
Cirripectes alboapicalis	0.67	0.00	0.7	1.3	1.3
Hemigymnus fasciatus	0.67	0.00	0.7	1.3	1.3
Sufflamen chrysopterum	0.33	1.00	0.7	1.3	1.3
Plectroglyphidodon fasciolatus	1.00	0.96	0.7	2.0	1.2
Labroides dimidiatus	0.73	0.77	0.7	1.0	1.1
Orectolobus maculatus	0.33	0.67	0.7	1.1	1.1
Siganus fuscescens	0.67	0.77	0.6	1.0	1.1
Goniistius vestitus	0.67	1.19	0.6	1.0	1.0
Parupeneus multifasciatus	0.40	0.40	0.6	0.8	1.0
Pomacentrus bankanensis	0.40	0.33	0.6	0.9	1.0
Lutjanus russellii	0.00	0.44	0.5	0.7	0.9
Plectroglyphidodon leucozonus	0.00	0.47	0.5	0.7	0.9
Parma polylepis	0.67	0.67	0.5	0.8	0.9
Monodactylus argenteus	0.47	0.00	0.5	0.7	0.8
Pomacentrus chrysurus	0.33	0.33	0.5	0.8	0.8
Anampses caeruleopunctatus	0.73	1.06	0.5	0.8	0.8
Siganus spinus	0.00	0.40	0.5	0.7	0.8
Halichoeres nebulosus	0.73	1.13	0.5	0.9	0.8
Chaetodon auriga	0.00	0.40	0.5	0.7	0.8
Coris dorsomacula	0.00	0.40	0.5	0.7	0.8
Mulloidichthys vanicolensis	0.00	0.40	0.5	0.7	0.8
Caranx melampygus	0.33	0.00	0.4	0.7	0.7
Centropyge tibicen	0.33	0.00	0.4	0.7	0.7

Species	Average MaxN (4th Root Transformed)		Average Dissimilarity	Dissimilarity/ SD	Contribution %
Chiloscyllium punctatum	0.33	0.00	0.4	0.7	0.7
Cirrhitichthys falco	0.33	0.00	0.4	0.7	0.7
Parma oligolepis	1.48	1.13	0.4	2.2	0.7
Acanthurus grammoptilus	0.00	0.33	0.4	0.7	0.7
Diagramma pictum labiosum	0.00	0.33	0.4	0.7	0.7
Choerodon graphicus	0.33	0.00	0.4	0.7	0.7
Euthynnus affinis	0.33	0.00	0.4	0.7	0.7
Gymnothorax monochrous	0.33	0.00	0.4	0.7	0.7
Halichoeres marginatus	0.33	0.00	0.4	0.7	0.7
	Cook Island West	Kirra Reef	Average dissimilarity = 62.8		
Trachurus novaezelandiae	0.00	4.70	4.7	5.6	7.4
Abudefduf whitleyi	2.06	0.00	2.1	1.7	3.3
Kyphosus bigibbus	1.72	0.00	1.7	3.4	2.7
Monodactylus argenteus	1.53	0.00	1.6	1.2	2.5
Acanthurus dussumieri	1.45	0.00	1.4	4.7	2.3
Pseudocaranx georgianus	1.83	1.39	1.3	1.3	2.1
Schuettea scalaripinnis	1.39	0.00	1.3	0.7	2.1
Thalassoma amblycephalum	0.44	1.71	1.3	1.8	2.0
Abudefduf vaigiensis	1.39	0.40	1.3	1.4	2.0
Thalassoma nigrofasciatum	0.00	1.28	1.3	6.3	2.0
Scomberomorus commerson	1.26	0.00	1.3	6.3	2.0
Acanthurus grammoptilus	1.58	0.33	1.2	2.5	1.9
Dascyllus trimaculatus	1.33	1.07	1.1	1.3	1.7
Stethojulis interrupta	0.33	1.39	1.1	1.9	1.7
Sphyraena obtusata	0.00	1.06	1.1	7.7	1.7
Achoerodus viridis	1.06	0.00	1.1	12.9	1.7
Centropyge tibicen	1.06	0.00	1.1	12.9	1.7
Abudefduf bengalensis	1.02	0.00	1.0	1.3	1.6
Orectolobus ornatus	0.00	1.00	1.0	14.3	1.6
Thalassoma lunare	0.44	1.33	0.9	1.5	1.5
Parupeneus spilurus	1.16	1.38	0.9	2.1	1.5
Microcanthus strigatus	0.85	0.00	0.9	0.7	1.5
Thalassoma lutescens	0.47	1.17	0.9	1.7	1.4
Notolabrus gymnogenis	0.40	1.21	0.9	1.6	1.4
Alectis ciliaris	0.00	0.84	0.8	1.3	1.3
Plectroglyphidodon fasciolatus	0.40	0.96	0.8	1.2	1.3
Halichoeres nebulosus	0.44	1.13	0.8	1.7	1.3
Carangoides orthogrammus	0.79	0.00	0.8	1.3	1.3
Pomacentrus coelestis	0.92	0.40	0.8	1.2	1.3
Anampses caeruleopunctatus	0.40	1.06	0.8	1.5	1.2
Lutjanus fulviflamma	1.22	1.52	0.8	1.3	1.2
*Acanthopagrus australis**	1.17	1.15	0.8	2.0	1.2
Chaetodon auriga	1.06	0.40	0.7	1.6	1.2
Siganus fuscescens	1.51	0.77	0.7	1.2	1.1
Scarus ghobban	0.73	0.00	0.7	1.3	1.1
Naso brevirostris	0.71	0.00	0.7	0.7	1.1
Chaetodon flavirostris	1.00	0.33	0.7	1.3	1.1
Cheilinus chlorourus	0.00	0.67	0.7	1.3	1.1
Neotrygon australiae	0.00	0.67	0.7	1.3	1.1
Morwong fuscus	0.67	0.00	0.7	1.3	1.1
Parma polylepis	0.00	0.67	0.7	1.3	1.0
Naso unicornis	0.67	0.00	0.6	0.7	1.0
Plectroglyphidodon gascoynei	0.52	0.40	0.6	0.9	1.0
Parupeneus multifasciatus	0.67	0.40	0.6	1.2	1.0

Species	Average MaxN (4^{th} Root Transformed)		Average Dissimilarity	Dissimilarity/ SD	Contribution %
Scorpis lineolata	0.67	1.29	0.6	1.1	1.0
Labroides dimidiatus	0.73	0.77	0.6	1.0	0.9
Chromis margaritifer	0.44	0.40	0.6	0.9	0.9
Parma unifasciata	0.33	0.67	0.6	1.1	0.9
Goniistius vestitus	0.67	1.19	0.5	1.1	0.8
Stethojulis bandanensis	0.33	0.40	0.5	0.9	0.8
Amphiprion akindynos	0.47	0.00	0.5	0.7	0.7
Plectroglyphidodon leucozonus	0.00	0.47	0.5	0.7	0.7
Lutjanus russellii	0.00	0.44	0.5	0.7	0.7
Orectolobus maculatus	0.67	0.67	0.5	0.8	0.7
Naso tonganus	0.47	0.00	0.4	0.7	0.7
Pomacentrus chrysurus	0.33	0.33	0.4	0.8	0.7
Acanthurus sp. 1	0.79	1.06	0.4	1.0	0.7
Chaetodon citrinellus	1.06	0.67	0.4	0.8	0.7
Siganus spinus	0.00	0.40	0.4	0.7	0.6
Coris dorsomacula	0.00	0.40	0.4	0.7	0.6
Mulloidichthys vanicolensis	0.00	0.40	0.4	0.7	0.6
Dascyllus reticulatus	0.40	0.00	0.4	0.7	0.6
Gomphosus varius	0.40	0.00	0.4	0.7	0.6
Plectroglyphidodon apicalis	0.40	0.00	0.4	0.7	0.6
Canthigaster bennetti	0.40	0.00	0.4	0.7	0.6
Prionurus microlepidotus	1.43	1.06	0.4	2.3	0.6
Diagramma pictum labiosum	0.00	0.33	0.3	0.7	0.5

Table B.5.20 PERMANOVA of the difference in the fish species richness among reefs in 2023

a) PERMANOVA Source	(a) Max N			
	df	MS	Pseudo-F	P(perm)
Reef	5	101.55	3.6133	0.053
Error	11	28.106		
Pairwise Tests	t Value	P (MC)		
CIN, CIS	1.25	0.279		
CIN, CIW	2.34	0.093		
CIN, KR	3.92	**0.013**		
CIN, PBBR	2.24	0.122		
CIN, PBR	2.02	0.119		
CIS, CIW	1.43	0.223		
CIS, KR	1.86	0.142		
CIS, PBBR	2.91	0.053		
CIS, PBR	1.27	0.249		
CIW, KR	0.39	0.732		
CIW, PBBR	2.96	0.065		
CIW, PBR	0.05	0.965		
KR, PBBR	7.85	**0.005**		
KR, PBR	0.39	0.713		
PBBR, PBR	2.46	0.094		

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).

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)

Scientific Name		KR	PBR	PBBR	CIW	CIN	CIS
Class Asteroidea (sea stars)							
Echinaster luzonicus	Mean	0.00	0.20	0.00	0.03	0.00	0.01
	S.E.	0.00	0.04	0.00	0.02	0.00	0.01
Linckia laevigata	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
Pseudonepanthia nigrobrunnea	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
Tamaria sp.	Mean	0.00	0.00	0.00	0.01	0.00	0.00
	S.E.	0.00	0.00	0.00	0.01	0.00	0.00
Class Crinoidea (feather stars)							
Anneissia bennetti	Mean	0.03	0.00	0.01	0.07	0.01	0.00
	S.E.	0.02	0.00	0.01	0.04	0.01	0.00
Cenolia glebosus	Mean	1.57	0.04	1.01	0.51	1.51	0.31
	S.E.	0.22	0.02	0.14	0.12	0.18	0.08
Cenolia sp.	Mean	0.39	0.00	0.18	0.01	0.00	0.00
	S.E.	0.09	0.00	0.06	0.01	0.00	0.00
Comaster nobilis	Mean	0.00	0.00	0.02	0.09	0.01	0.01
	S.E.	0.00	0.00	0.02	0.04	0.01	0.01
Class Echinoidea (sea urchins)							
Centrostephanus rodgersii	Mean	0.00	0.14	0.00	0.01	0.11	0.03
	S.E.	0.00	0.04	0.00	0.01	0.04	0.02
Diadema savignyi	Mean	0.04	0.30	0.00	0.49	0.26	0.27
	S.E.	0.02	0.08	0.00	0.12	0.06	0.06
Echinometra mathaei	Mean	0.03	0.00	0.00	0.00	0.00	0.00
	S.E.	0.02	0.00	0.00	0.00	0.00	0.00
Echinothrix calamaris	Mean	0.00	0.00	0.00	0.01	0.03	0.00
	S.E.	0.00	0.00	0.00	0.01	0.02	0.00
Phyllacanthus parvispinus	Mean	0.06	0.15	0.00	0.05	0.11	0.10
	S.E.	0.03	0.04	0.00	0.02	0.05	0.04
Tripneustes sp.	Mean	0.02	0.28	0.00	3.43	0.17	0.03
	S.E.	0.02	0.10	0.00	0.44	0.07	0.02
Class Holothuroidea (sea cucumbers)							
Actinopyga miliaris	Mean	0.00	0.00	0.00	0.01	0.00	0.00
	S.E.	0.00	0.00	0.00	0.01	0.00	0.00
Holothuria atra	Mean	0.00	0.00	0.00	0.01	0.00	0.03
	S.E.	0.00	0.00	0.00	0.01	0.00	0.02
Class Decapoda							
Panulirus versicolor	Mean	0.01	0.00	0.00	0.00	0.01	0.03
	S.E.	0.01	0.00	0.00	0.00	0.01	0.02
Percnon planissimum	Mean	0.00	0.00	0.00	0.01	0.00	0.00
	S.E.	0.00	0.00	0.00	0.01	0.00	0.00
Class Cephalopoda							
Octopus tetricus	Mean	0.01	0.01	0.00	0.00	0.00	0.00
	S.E.	0.01	0.01	0.00	0.00	0.00	0.00
Class Gastropoda							
Drupella 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
Hypselodoris obscura	Mean	0.00	0.00	0.00	0.00	0.01	0.00
	S.E.	0.00	0.00	0.00	0.00	0.01	0.00
Hypselodoris whitei	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

Appendix D July 2024 Fish Species List

Table D.5.21 Fish species recorded in July 2024 survey, not recorded in previous surveys

Scientific Name	Common Name	Reef Recorded at
Acanthuridae		
Acanthurus triostegus	convict surgeonfish	Palm Beach Reef
Naso brevirostris	spotted unicornfish	Cook Island West
Carangidae		
Alectis ciliaris	pennantfish	Kirra Reef, Palm Beach Reef
Trachurus declivis	common jack mackerel	Palm Beach Reef
Cirrhitidae		
Cyprinocirrhites polyactis	lyretail hawkfish	Palm Beach Bait Reef
Holocentridae		
Sargocentron diadema	crown squirrelfish	Cook Island North
Kyphosidae		
Kyphosus cinerascens	snubnose drummer	Palm Beach Bait Reef
Microdesmidae		
Ptereleotris evides	arrow dartgoby	Cook Island South
Monacanthidae		
Cantherhines pardalis	honeycomb leatherjacket	Palm Beach Reef
Cantheschenia grandisquamis	largescale leatherjacket	Cook Island West
Ophichthidae		
Myrichthys maculosus	ocellate snake eel	Palm Beach Reef
Scombridae		
Euthynnus affinis	mackerel tuna	Palm Beach Reef, Cook Island South
Tetraodontidae		
Canthigaster amboinensis	ambon toby	Cook Island North

Table D.5.22 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 2024 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		3		12	1	1
Acanthurus grammoptilus	inshore surgeonfish	H	R	1	2		9		*
Acanthurus triostegus	convict surgeonfish	H	R		*				
Acanthurus sp. 1[16]	dusky or greyhead surgeonfish	H	R	2	5		2	3	4
Naso brevirostris	spotted unicornfish	O - HT	R				21		
Naso tonganus	humpnose unicornfish	H	R				4		
Naso unicornis	bluespine unicornfish	H	R				16	1	
Paracanthurus hepatus	blue tang	P	R				*		
Prionurus microlepidotus	Australian sawtail	H	R	2	2		6	1	
Aulostomidae									
Aulostomus chinensis	Pacific trumpetfish	CA	R		1				
Apogonidae									
Ostorhinchus cookii	Cook's cardinalfish	CA	R	*					
Ostorhinchus limenus	Sydney cardinalfish	CA	R	1					*
Balistidae									
Sufflamen bursa	pallid triggerfish	CA	R					1	
Sufflamen chrysopterum	eye-stripe triggerfish	CA	R	1	1	1	1	2	1
Sufflamen fraenatum	bridled triggerfish	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.

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
Balistidae (unidentified)	triggerfish	CA	R		1				
Blenniidae									
Cirripectes alboapicalis	whitedotted blenny	H	R					1	1
Plagiotremus tapeinosoma	piano fangblenny	CA	R	1	1	1		4	2
Caesionidae									
Pterocaesio digramma	double-lined fusilier	P	R			10			
Carangidae									
Alectis ciliaris	pennantfish	CA	P/R	3	10				
Carangoides chrysophrys	longnose trevally	CA	P		17	1			
Carangoides orthogrammus	thicklip trevally	CA	P/R				2		
Caranx melampygus	bluefin trevally	CA	P		1		1	2	1
Pseudocaranx georgianus	silver trevally	CA	P	22	1	6	60		
Trachurus declivis	common jack mackerel	P	P		40				
Trachurus novaezelandiae	yellowtail scad	P	P	1000	1500	1500			
Chaetodontidae									
Chaetodon auriga	threadfin butterflyfish	C	R	2	3		2		
Chaetodon citrinellus	citron butterflyfish	C	R	1	3		2	1	
Chaetodon flavirostris	dusky butterflyfish	C	R	1	3		1		
Chaetodon kleinii	Klein's butterflyfish	O	R	1	*			4	
Chaetodon lunula	racoon butterflyfish	O	R		1				
Chaetodon vagabundus	vagabond butterflyfish	O	R		1				
Heniochus acuminatus	longfin bannerfish	P	R					*	
Cirrhitidae									
Cirrhitichthys aprinus	blotched hawkfish	CA	R	1	*	2	*		*
Cirrhitichthys falco	dwarf hawkfish	CA	R	1	2			*	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
Cyprinocirrhites polyactis	lyretail hawkfish	P	R			1			
Paracirrhites forsteri	freckled hawkfish	CA	R		1				
Dasyatidae									
Neotrygon kuhlii	bluespotted maskray	CA	R	1					
Diodontidae									
Dicotylichthys punctulatus	threebar porcupinefish	CA	R		*	1			*
Diodon hystrix	spotted porcupinefish	CA	R					1	*
Enoplosidae									
Enoplosus armatus	old wife	CA	R						*
Fistulariidae									
Fistularia commersonii	smooth flutemouth	CA	R		1	1			
Gerreidae									
Gerres subfasciatus	common silverbiddy	CA	P						26
Gobiidae (unidentified)	goby	CA	R						1
Haemulidae									
Diagramma pictum labiosum	painted sweetlips	CA	P/R	1					
Plectorhinchus flavomaculatus	goldspotted sweetlips	CA	P/R	2	*	2	2	1	1
Hemiscylliidae									
Chiloscyllium punctatum	grey carpet shark	CA	R						1
Holocentridae									
Sargocentron diadema	crown squirrelfish	CA	R					*	
Kyphosidae									
Kyphosus bigibbus	grey drummer	H	R		1	1	34	2	1
Kyphosus cinerascens	snubnose drummer	O - HT	R			1			
Labridae									

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
Achoerodus viridis	eastern blue groper	CA	R		1		2	3	1
Anampses caeruleopunctatus	diamond wrasse	CA	R	2	1	1	2	2	2
Anampses neoguinaicus	blackback wrasse	CA	R						1
Cheilinus chlorourus	floral Maori wrasse	CA	R	1	1				
Cheilio inermis	sharpnose wrasse	CA	R					1	1
Choerodon graphicus	graphic tuskfish	CA	R		1				1
Coris dorsomacula	pinklined wrasse	O	R	2			*	1	
Gomphosus varius	birdnose wrasse	CA	R				2	1	
Halichoeres hortulanus	checkerboard wrasse	O	R				1		
Halichoeres marginatus	dusky wrasse	CA	R			2	1	1	1
Halichoeres nebulosus	cloud wrasse	CA	R	2	2		3	4	2
Hemigymnus fasciatus	fiveband wrasse	O	R						1
Labroides dimidiatus	common cleaner fish	CA	R	3	1	1	2	1	2
Notolabrus gymnogenis	crimsonband wrasse	CA	R	3	1	1	2	2	2
Pseudolabrus guentheri	Günther's wrasse	CA	R	5	3	2	2	3	2
Scarus ghobban	bluebarred parrotfish	H	R				2		
Stethojulis bandanensis	redspot wrasse	CA	R	2	2		1	2	2
Stethojulis interrupta	brokenline wrasse	O	R	6	1	1	1	2	1
Thalassoma amblycephalum	bluntheaded wrasse	P	R	11	1	17	3		10
Thalassoma lunare	moon wrasse	CA	R	5	5	7	3	1	5
Thalassoma lutescens	green moon wrasse	CA	R	5	4	2	4	4	1
Thalassoma nigrofasciatum[17]	blackbarred wrasse	O	R	4	1	1		2	1

[17] There are few disguising features between *Thalassoma nigrofasciatum* and the closely related *Thalassoma jansenii*, however, based on species distributions, 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)[18]	wrasse		R	3	1	1			2
Latridae									
Goniistius vestitus	crested morwong	O	R	2	1	1	1	2	1
Morwong fuscus	red morwong	O	R		1		1	1	*
Lutjanidae									
Lutjanus argentimaculatus	mangrove jack	CA	R			1			
Lutjanus fulviflamma	blackspot snapper	CA	R	11	1		19	1	
Lutjanus gibbus	paddletail	CA	R	1					
Lutjanus russellii	Moses' snapper	CA	R	3					*
Microcanthidae									
Atypichthys strigatus	mado	O	R	1		7			
Microcanthus strigatus	stripey	O	R	14	*		42		*
Microdesmidae									
Ptereleotris evides	arrow dartgoby	P	R						1
Monacanthidae									
Cantherhines pardalis	honeycomb leatherjacket	CA	R		1				
Cantheschenia grandisquamis	largescale leatherjacket	O	R				1		
Meuschenia trachylepis	yellowfin leatherjacket	O	R				1		
Paraluteres prionurus	blacksaddle filefish	O	R				1		
Monodactylidae									
Monodactylus argenteus	silver moony	P	P		250		60		4
Schuettea scalaripinnis	eastern pomfred	P	P	2			300	*	200
Mullidae									

[18] 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	2					
Parupeneus cyclostomus	goldsaddle goatfish	CA	R		1				
Parupeneus multifasciatus	banded goatfish	CA	R	2	2		1		2
Parupeneus spilurus	blacksaddle goatfish	CA	R	7	1	2	38	2	2
Muraenidae									
Gymnothorax monochrous	monotone moray	CA	R						1
Gymnothorax thyrsoideus	greyface moray	CA	R	1		*			
Gymnothorax sp.	unknown eel	CA	R					1	
Myliobatidae									
Aetobatus ocellatus	whitespotted eagle ray	CA	P/R	1					
Ophichthidae									
Myrichthys maculosus	ocellate snake eel	CA	R		1				
Orectolobidae									
Orectolobus maculatus	spotted wobbegong	CA	R	1	1		1	2	1
Orectolobus ornatus	banded wobbegong	CA	R	1		1	*	1	
Ostraciidae									
Ostracion cubicum	yellow boxfish	O - HT	R		1			1	
Pempheridae									
Pempheris affinis	blacktip bullseye	P	R				*	*	
Pinguipedidae									
Parapercis stricticeps	whitestreak grubfish	O	R				*		
Pomacanthidae									
Centropyge bicolor	bicolour angelfish	O	R				1		
Centropyge tibicen	keyhole angelfish	O - HT	R		3		2		1
Pomacentridae									

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 bengalensis	Bengal sergeant	O	R		2		12		1
Abudefduf sexfasciatus	scissortail sergeant	P	R		10				15
Abudefduf vaigiensis	Indo-Pacific sergeant	O	R	2	100		19	*	25
Abudefduf whitleyi	Whitley's sergeant	O	R	1			140	9	13
Amphiprion akindynos	Barrier Reef anemonefish	O	R				4	*	*
Chromis margaritifer	whitetail puller	O	R	2		1	3	1	3
Chromis nitida	yellowback puller	O - HT	R					*	
Dascyllus reticulatus	headband humbug	O	R				2	*	
Dascyllus trimaculatus	threespot humbug	O	R	24	2		22	*	12
Parma oligolepis	bigscale scalyfin	O - HT	R	2	5	4	2	2	7
Parma polylepis	banded scalyfin	O - HT	R	1		1		1	1
Parma unifasciata	girdled scalyfin	O - HT	R	1	1	3	1	7	
Plectroglyphidodon apicalis	yellowtip gregory	O - HT	R	1			2	2	3
Plectroglyphidodon fasciolatus	Pacific gregory	O - HT	R	6	3	3	2	2	1
Plectroglyphidodon gascoynei	Coral Sea gregory	O - HT	R	2	1		6	2	3
Plectroglyphidodon leucozonus	whiteband damsel	H	R	4	*	2		2	
Pomacentrus bankanensis	speckled damsel	O - HT	R	1	1				2
Pomacentrus chrysurus	whitetail damsel	O - HT	R	1	*		1		1
Pomacentrus coelestis	neon damsel	O - HT	R	2	5	1	6	*	30
Pomacentrus wardi	Ward's damsel	H	R		2		1		
Scombridae									
Euthynnus affinis	mackerel tuna	CA	P		9				1
Scomberomorus commerson	Spanish mackerel	CA	P				4	2	
Scorpaenidae									
Dendrochirus zebra	zebra lionfish	CA	R					*	

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
Pterois antennata	spotfin lionfish	CA	R				*		
Scorpaena jacksoniensis	eastern red scorpionfish	CA	R	*					*
Scorpididae									
Scorpis lineolata	silver sweep	P	R	8	3	1	1	*	33
Serranidae									
Diploprion bifasciatum	barred soapfish	CA	R		1		1		
Epinephelus fasciatus	blacktip grouper	CA	R		1				*
Serranidae (unidentified)	grouper / cod	CA	R			1		1	
Siganidae									
Siganus fuscescens	black rabbitfish	H	R	3	4	1	9	2	1
Siganus spinus	scribbled rabbitfish	H	R	2	1				
Sparidae									
*Acanthopagrus australis**[19]	yellowfin bream*	CA	P/R	11	6	9	5	4	2
Sphyraenidae									
Sphyraena obtusata	striped barracuda	CA	P/R	2	2				
Tetraodontidae									
Arothron hispidus	stars-and-stripes puffer	O	R	1	*				
Arothron stellatus	starry puffer	O	R	*	*		*		
Arothron sp.	unknown puffer	O	R	2		1		1	
Canthigaster bennetti	blackspot toby	O - HT	R		1		2		
Canthigaster valentini	blacksaddle toby	O - HT	R		1				*
Canthigaster amboinensis	ambon toby	O - HT	R					1	
Zanclidae									

[19] 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
Zanclus cornutus	moorish idol	CA	R		21		1		
Unidentified species[20]				1	60				1

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 diver footage, not recorded on UBRUVS footage and, therefore, no comparable Max N value derived

[20] 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.