Tweed Sand Bypassing Project

Reef Biota Monitoring 2020

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Executive Summary

The Tweed Sand Bypassing (TSB) project is a joint initiative of the New South Wales and Queensland State Governments, with the objectives to establish and maintain the entrance to the Tweed River, and to restore and maintain the coastal sand drift to the Southern Gold Coast. This report has been prepared by Ecological Service Professionals (ESP) to both meet the environmental obligations of the TSB project to assess ecological changes at Kirra Reef, and to establish an ecological baseline for reefs around Cook Island prior to commencement of proposed sand placement activity at Dreamtime.

Changes in the reef extent were assessed using bathymetric survey data as well as aerial and satellite imagery, including a comparison of the historical changes in the areal extent of Kirra Reef. Field surveys were completed to assess differences in benthic communities (algae, sessile and mobile invertebrates) and fish assemblages among reefs. Six reef locations were surveyed in July 2020: Kirra Reef (previously impacted reef); Cook Island West and South Reefs (potentially impacted reef); and Cook Island North Reef, Palm Beach Bait Reef, and Palm Beach Reef (comparative reefs). Differences in the composition of benthic communities among reefs were assessed over time using available historical data for the past five years.

Kirra Reef

Previous estimates of the areal extent of Kirra Reef indicate there has been substantial changes through time, with the maximum extent measured in 1995, declining to its lowest extent in 2008, then increasing again from 2010. During 1995 when Kirra Reef reached a maximum extent, there were three distinct reef areas, a shallow southern reef, a shallow eastern reef near the current groyne, and a northern section of reef section in deeper water. In 1995, the areal extent of the northern section of reef was approximately 5900 m^2. In recent years, only the northern section located in deeper waters has been uncovered, and estimates of the areal extent of the reef have not changed substantially since 2012 (<3700m^2).

Differences in the composition of benthic communities occurred at a range of spatial scales on each reef in 2020. On Kirra Reef, the differences between horizontal and vertical surfaces were primarily driven by increased coverage of macroalgae on horizontal surfaces, and conversely increased coverage of sessile invertebrates (primarily ascidians) on vertical surfaces. A reduction in the coverage of sessile invertebrates on horizontal surfaces compared with vertical surfaces may be indicative of smothering from sand. However, difference between surface orientation appeared to be more likely influenced by other factors such as disturbance ecology and natural variation, timing of when reef habitat became available, differences in the settlement and recruitment of benthic species and / or the survival due to differences in the assemblage of predators present at Kirra Reef relative to other reefs.

In 2020, the algal assemblages on reefs were dominated by turf algae, with other groups, such as foliose macroalgae (e.g. *Sargassum* spp. *Dictyota* sp. and *Padina* sp.), crustose coralline algae and articulate coralline algae (e.g. *Jania* sp.) also present. The coverage of turf forming algae on Kirra Reef was lower than at the other reefs. However, the coverage of macroalgae (dominated by *Sargassum* spp.), was higher at Kirra Reef. Sargassum was only

recorded at Kirra Reef, which is likely a result of establishment following exhumation once sand delivery had normalised. Differences in the composition of algal assemblages is likely the result of the timing and magnitude of physical disturbance, availability of spores at the time of disturbance or exhumation, and other more complex ecological interactions with herbivorous species, which are likely to differ among the reefs.

In 2020, the diversity of sessile invertebrate assemblages also differed at a range of spatial scales and was typically greater on vertical than horizontal surfaces. A total of 92 taxa were recorded across all vertical surfaces and 78 taxa recorded across all horizontal surfaces. There were differences in the total number of taxa recorded between vertical and horizontal surfaces, which was most pronounced at Kirra Reef, with a total of 62 taxa recorded on vertical surfaces and only 27 taxa on horizontal surfaces of the reef. The sessile assemblages on vertical surfaces at Kirra Reef were the most diverse. The composition of sessile invertebrate assemblages generally differed between Kirra Reef and each of the other reefs on both surface orientations (with the exception of horizontal surfaces at Palm Beach Bait Reef). The sessile invertebrate assemblage on Kirra Reef became more similar in composition and in 2020, more diverse than those recorded on other reefs not exposed to TSB associated impacts. Furthermore, the 2020 survey was the first time an assessment of the sessile assemblages was completed on Palm Beach Bait Reef. Both Palm Beach Bait Reef and Kirra Reef have a similar areal extent and degree of sand burial and are in a similar position relative to the dynamic sandy shoreline. The sessile invertebrate assemblages did not differ in composition between Kirra and Palm Beach Bait reefs.

In the July 2020, a variety of echinoderms dominated the mobile invertebrates observed on the reefs, with feather stars (particularly *Cenolia* spp.) being the most abundant on Kirra Reef and the comparative reefs. Several other urchin and sea star species were also present, with their abundance differing among the reefs.

In the July 2020, a total of 116 bony and cartilaginous fishes, representing species from 34 families were recorded across all reefs. Most fish species recorded during 2020 surveys were common to the region; however, 28 species occurred among the reefs that had not previously been recorded, which may be related to the timing of surveys. Reef-associated fish species dominated at all reefs, and in general the composition of fish assemblages did not differ among reefs, with the exception of Cook Island South and Palm Beach Bait reefs, which both had much lower species richness than at the other reefs. There was a moderate species richness at Kirra Reef relative to the other comparative reefs, with 46 species recorded. However, the total abundance of fish was highest at Kirra Reef and Cook Island North due to the presence of dense schooling fish, particularly yellowtail scad and Eastern pomfred.

Over time, the composition of benthic and fish assemblages has differed consistently between Kirra and Palm Beach reefs, and between the various other comparative reefs assessed in the region as part of this monitoring program. On Kirra Reef, the differences between successive surveys were due to changes in the average coverage of macroalgae, turf algae, and ascidians. Given the differences in disturbance history and current disturbance regime among the reefs assessed, the benthic assemblages at Kirra Reef may never represent those found on the other reefs in the area within the short to medium term. Despite being dissimilar, the benthic communities at Kirra Reef are now considered to be representative of a mature assemblage of both algae and sessile invertebrates, reflecting the ecology of the reef and comparable to that found on other reefs with similar exposure and depth characteristics (i.e. Palm Beach Bait Reef). The benthic community occurring on Kirra Reef should be considered unique to the region, with the differences among reefs, including between other comparative reef locations providing an understanding of the natural variability over a range of spatial scales within the region. This information is essential when assessing changes in these communities due to sand burial and other factors of disturbance. Differences in the composition of reef communities reflect the subtle differences in ecological and abiotic conditions (particularly nutrient availability, wave climate and local sand dispersal), as well as potential differences in anthropogenic pressures (e.g. recreational fishing) among reefs.

Recommendations

The TSB monitoring program has provided evidence of the recovery in reef communities through time in response to almost complete burial of the reef in 2010. Since being uncovered, there has been an increase in the coverage and diversity of algal and sessile invertebrate assemblages growing on the reef and a change to a more diverse fish assemblage indicative of the variety of 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, continual ecological monitoring of Kirra Reef is likely to only provide an understanding of the processes contributing to community succession over the coming years. It is therefore recommended that monitoring of the response in benthic communities is completed before and after any planned changes to the program and that the environmental monitoring components be reviewed to better reflect a leading indicator of change in operations, such as the development of thresholds for changes in the monthly or annual volume of sand delivered; and / or completion of hydrographic surveys and a comparison of the change in bottom depth year to year allowing for a degree of natural variability due to normal wave action and long-shore sand transport. An event or trigger-based monitoring program with the proposed triggers including operational changes in TSB (relative to those undertaking between 2010 and 2020), and/or indicators directly related to sand deposition such as sedimentation above a threshold (as measured using hydrographic survey) or a substantial change in the accretion / erosion of sand around the reef measured through changes in reef area from aerial photos or direct hydrographic survey would be suitable triggers to warrant further assessments.

Cook Island Baseline Assessment

The benthic communities on Cook Island reefs, typically had a high average coverage of macroalgae (particularly turf forming species) and coralline algae, which was relatively consistent among different reef locations and surface orientations. There were differences in the composition of assemblages among reefs in close proximity (i.e. within hundreds of meters), which highlights the role that abiotic conditions such as wave exposure and reef aspect can play in reef ecology.

The sessile assemblages on Cook Island South were typical of reef communities throughout the South East Queensland region, being dominated by an increased coverage of longer-lived hard corals, large ascidian and sponge colonies. The reefs around Cook Island also had a moderate abundance of urchins and herbivorous fish species, which may reduce competition between algae and sessile invertebrates allowing those species to become more abundant. These mobile species (urchins and fish) are less likely to be impacted by sand disposal unless there is a substantial change in the coverage of particular sessile species on the reefs, indirectly impacting on food resources available on the reefs. A moderate to dense patch of seagrass was also recorded at the Cook Island West Reef adjacent to Cook Island. The seagrass community occurred between macroalgae, rock and rubble on sand and was dominated by *Halophila ovalis*, covering approximately 32% to 52% of the space where it was recorded.

The sessile invertebrate, algal and seagrass species recorded on the reefs are susceptible to the impacts of smothering and scouring from sand (as evidenced by the historical changes at Kirra Reef), and therefore, impacts of sand disposal on these assemblages should be monitored before, during and following any sand disposal activity.

The benthic communities around Cook Island are considered in good condition with a diverse assemblage of sessile invertebrates, including abundant hard and soft corals, and a diverse fish assemblage representative of reef communities in the region. Differences in the composition of fish assemblages between Cook Island and other reefs assessed may be due to the establishment of Cook Island Aquatic Reserve which has limited any effect of recreational fishing, particularly on herbivorous fish species.

Recommendations

Across all reefs surveyed, benthic communities have been relatively stable in recent years (i.e. since 2015) and sand delivery has been relatively consistent despite small scale differences among reefs. The potential ecological effect size or magnitude of any impact due to sand disposal can be determined based on the response of reef communities at Kirra Reef over several years. This past response provides suitable indicator species and likely trajectories of succession for targeted monitoring to occur at Cook Island. In particular, based on the lessons learnt at Kirra Reef, monitoring of the impacts of sand disposal can be measured directly (sediment accumulation, coverage of reef vs sand area and sand dispersal) and through the response of biotic indicator species also assessed such as the change in coverage of hard and soft coral, algae and seagrass.

Due to the high spatial and temporal variability, multiple surveys are recommended to account for natural variability within and between reefs when establishing a suitable ecological baseline. In this case it is recommended that at least one additional baseline monitoring event should be completed at Cook Island prior to planned sand disposal activities, and ongoing monitoring at both Cook Island and nearby reference sites completed during and after the disposal required to determine any potential impacts of future TSB operations adjacent to the reserve where possible to do so.

It is recommended that the monitoring program focus on key indicator species that are known to be impacted by sedimentation changes in the coverage of hard and soft corals, ascidians and seagrass. Note that seagrass has only been recorded at one area around Cook Island, therefore a measure of direct impact would be necessary as suitable comparative areas may be difficult to identify.

Monitoring the impacts of sand deposition could include direct measures of sedimentation at areas adjacent to sensitive ecological receptor communities (i.e. coral reefs and seagrass areas that could be smothered) would provide a leading indicator as to the potential for any impact and may also be used to trigger any additional assessment of the reef communities, where background sedimentation is exceeded.

1 Introduction

1.1 Background

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

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. Following a period of sand oversupply (a corrective measure between 2001 and 2008 to replenish lost sand), the system has been transporting approximately 500,000 m^3/year, which is aligned with normal quantities of sand transported northwards along the coast due to longshore drift.

Figure 1.1 Fixed sand bypassing system (TSB, 2020)

Kirra Reef is a rocky reef outcrop, located approximately 500 m offshore of Kirra Beach on the Southern Gold Coast. The reef is naturally subject to shifting sand movements that cover and uncover parts of the reef. The extent of exposure of Kirra Reef has varied due to anthropogenic changes to the coastal environment, including exposure following extension of the Tweed River training walls (in 1965) and being almost completely buried by sand following the period of sand oversupply by TSB (in 2008). The nearshore location may also make the reef susceptible to physical disturbance from storms and wave action. Since 2012, Kirra Reef has been partly uncovered and the extent of reef exposed has been relatively stable (Ecosure 2016; FRC Environmental 2019). The TSB operates under several environmental and planning approvals covering different project elements. As part of the requirements of various approvals, ongoing monitoring of the marine biota at Kirra Reef is required, and has been completed for over 20 years. Most recently the monitoring has been completed as part of the Environmental Management System (EMS) Sub-Plan B14 Kirra Reef Management Plan.

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. The dredge deposits sand in approved placement areas spread along the Tweed Coast and Southern Gold Coast. To allow for flexibility, a sand placement area at Letitia is in use and one at Dreamtime has been proposed. 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 risk of cumulative impacts due to sand disposal is considered low considering the relatively low volume of sand proposed for disposal at Dreamtime.

The Review of Environmental Factors (REF) for the Dreamtime and Letitia areas was approved in 2019 and specified a monitoring program that should include monitoring of 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 data-set to account for temporal variability (APP 2019).

1.2 Scope of Works

The overall objective of the biota monitoring in 2020 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. Comparative reefs were used across the two separate monitoring programs to increase the power to detect changes in benthic communities; however, each program had specific aims.

The specific aims of monitoring at Kirra Reef in 2020 were to:

- Determine any ongoing potential impacts of the sand bypassing system since reef emergence and succession (particularly over the past five years).
- Assess the need for ongoing annual monitoring at Kirra Reef and to develop (and / or outline further information required to develop) triggers for event-based monitoring, where required for future monitoring.

The specific aim of monitoring at Cook Island in 2020 was to:

- Collect baseline data at Cook Island Aquatic Reserve to support future assessments of potential impacts to reef habitats.

2 Methods

2.1 Reef Extent

2.1.1 Bathymetric Surveys

Annual bathymetric survey data for Kirra Reef was obtained by TSB for 2018, 2019 and 2020. The depth and coordinate data were converted to the same datum (GDA2020) prior to converting to a digital elevation model in ESRI ArcGIS using interpolation among the point cloud. The Kriging method was used by averaging among the nearest 12 points. Differences in the depth of subsequent digital elevation models for each year were then subtracted to assess the increase or decrease in depth around Kirra Reef. The digital elevation models and change in depth were then mapped relative to the 2020 reef extent.

2.1.2 Aerial Imagery

Image analysis of the current areal extent (m^2) of exposed reef at Kirra Reef was completed using aerial and satellite imagery obtained from Google Earth and QLD Globe (QLD Government 2020) for May 2020 in ESRI ArcGIS, and compared with previous assessments of reef area obtained from past reports. The total areal area exposed was calculated in square metres.

2.2 Field Survey

2.2.1 Reef Locations

Based on a desktop review of existing reports from the region (Appendix A), six reef locations were surveyed in 2020 (Figure 2.1), including:

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

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

2.2.2 Timing

Annual monitoring at Kirra Reef has historically occurred between April and July (refer to Appendix A). The results reported here were collected over three days between the 6–10 July 2020 (for consistency with the previous monitoring). Sea conditions were favourable with low to moderate swell (1–2 m) and southwest to south-easterly winds (5–10 knots). Water clarity was good (approximately 10–15 m).

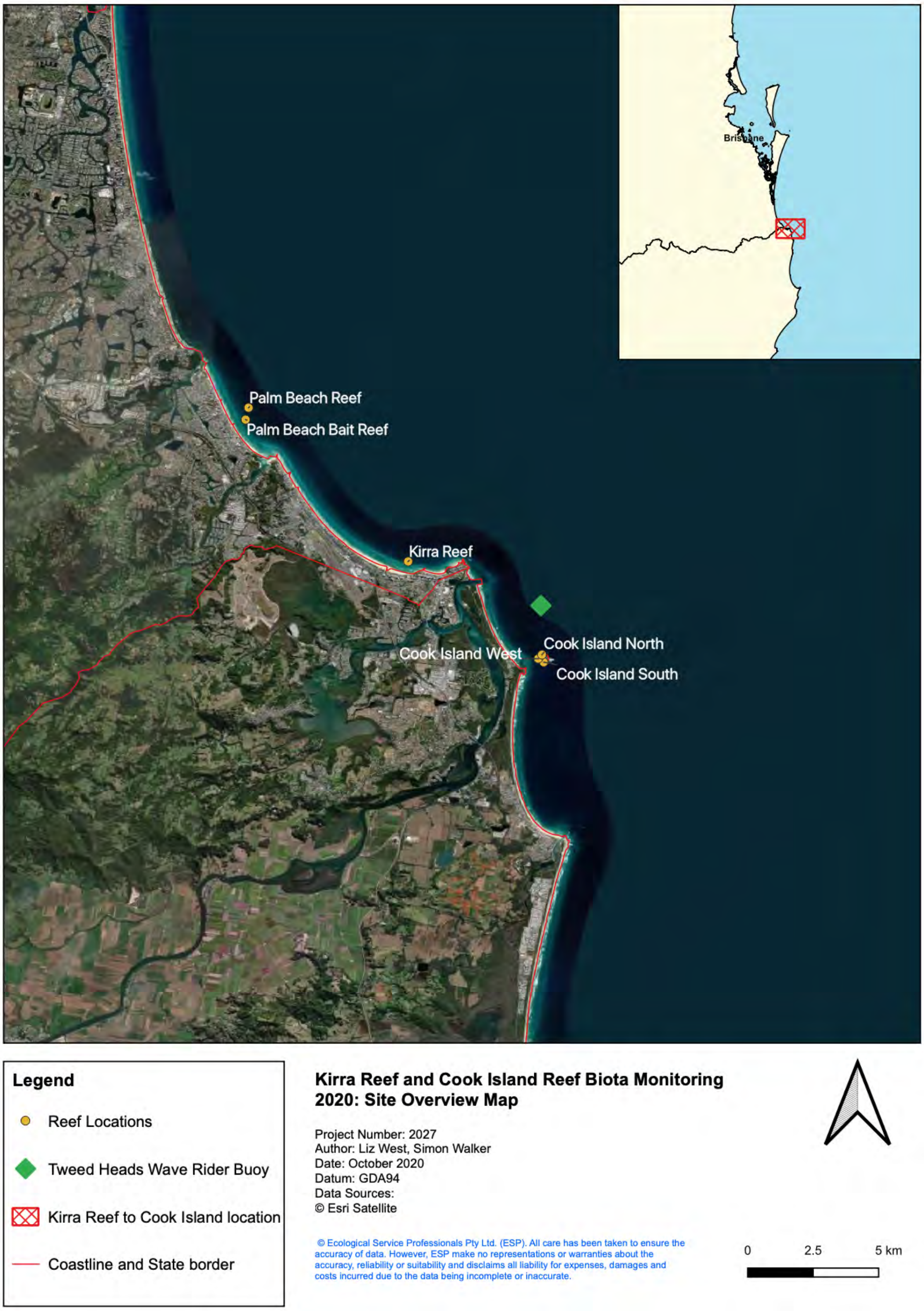


Figure 2.1 Reef locations for Biota Monitoring in 2020

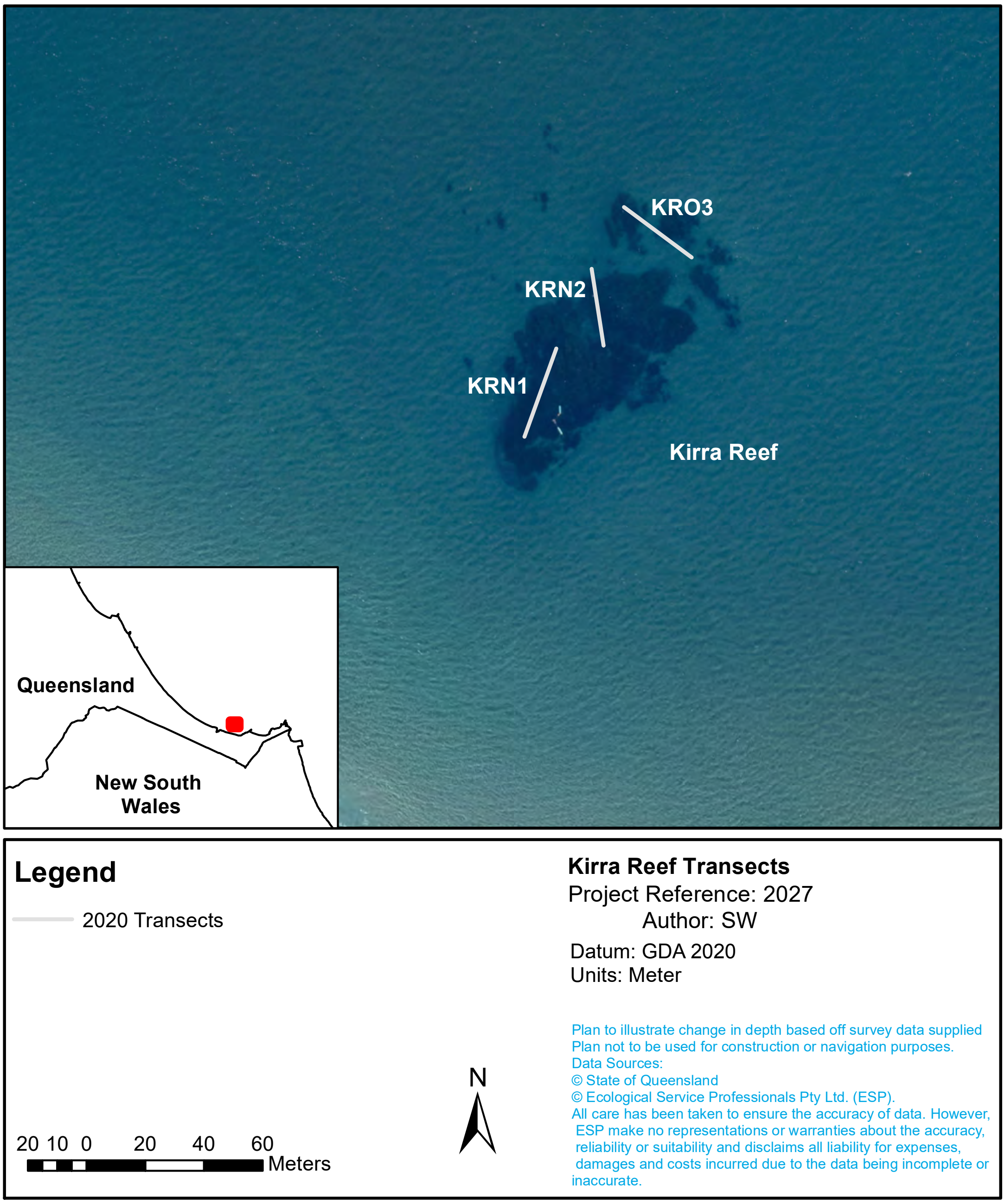


Figure 2.2 Location of transects surveyed in 2020 at Kirra Reef

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

Reef Location	Transect (Sites)	Transect Start *		Transect End *	
		Easting	Northing	Easting	Northing
Kirra Reef (KR)	KRN1	552092.6	6884633.4	552103.6	6884663.3
	KRN2	552119.6	6884664.4	552115.6	6884690.4
	KRO3	552149.5	6884694.4	552126.5	6884711.4
Palm Beach Reef (PB)	PB1	546714.6	6890406.1	546698.9	6890390.5
	PB2	546691.4	6890379.5	546703.1	6890367.0
	PB3	546722.2	6890368.6	546742.6	6890359.5
Palm Beach Bait Reef (PBBR)	PBB1	546676.4	6890149.4	546663.8	6890129.5
	PBB2	546668.5	6890103.1	546671.7	6890080.6
	PBB3	546679.3	6890113.2	546683.0	6890087.8
Cook Island North Reef (CIN)	CIN1	556661.9	6881208.9	556695.4	6881238.6
	CIN2	556597.8	6881156.0	556628.2	6881185.1
	CIN3	556561.3	6881116.3	556581.5	6881140.3
Cook Island South Reef (CIS)	CIS1	556616.3	6880882.4	556635.5	6880864.6
	CIS2	556655.1	6880856.6	556689.6	6880836.5
	CIS3	556675.0	6880848.1	556705.4	6880858.6
Cook Island West Reef (CIW)	CIW1	556382.3	6881028.6	556406.9	6881037.1
	CIW2	556424.4	6881040.1	556446.1	6881029.0
	CIW3	556460.8	6881033.7	556478.7	6881048.3

*Datum: GDA2020 UTM Zone 56J

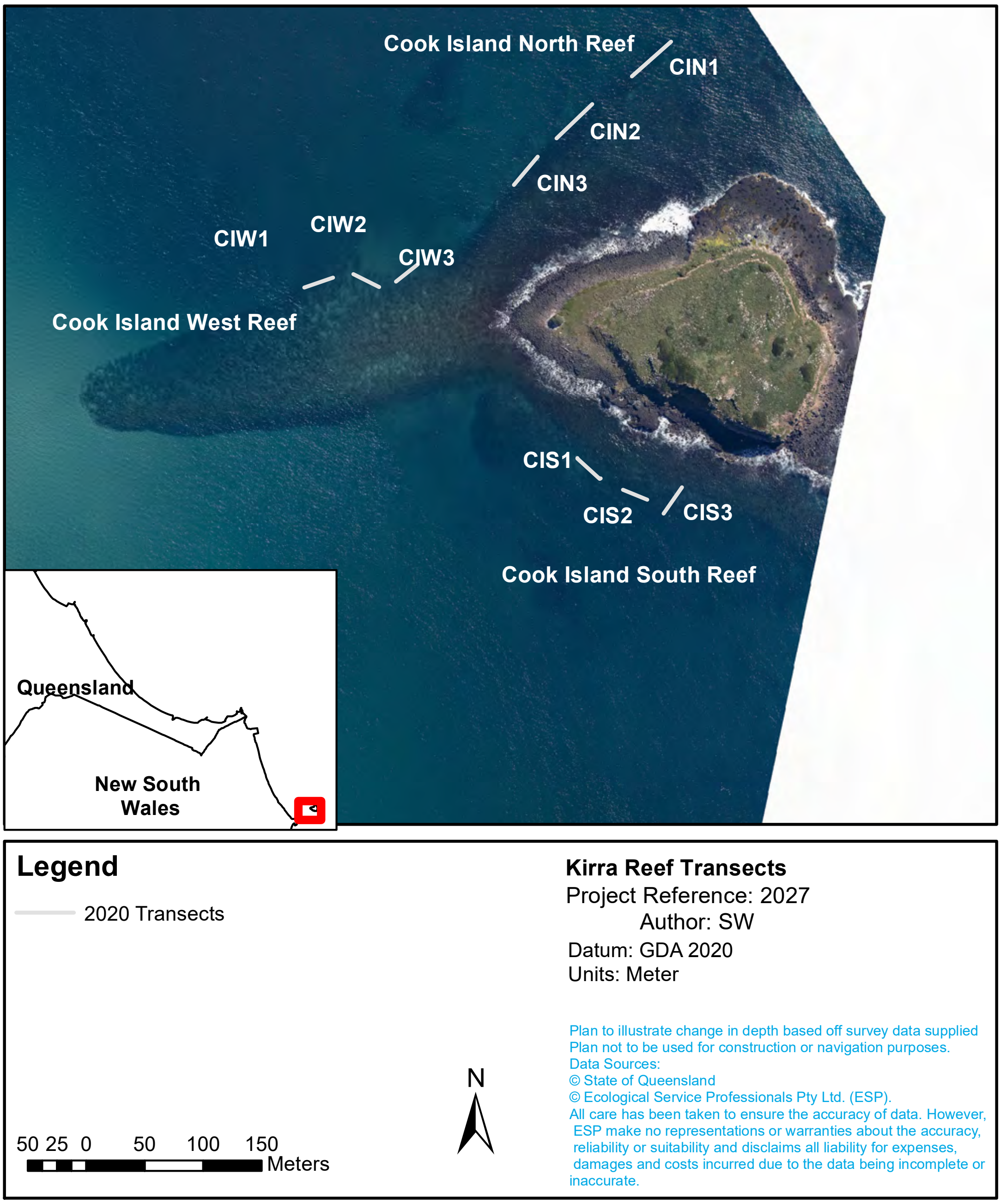


Figure 2.3 Location of transects surveyed in 2020 at the three reef locations around Cook Island

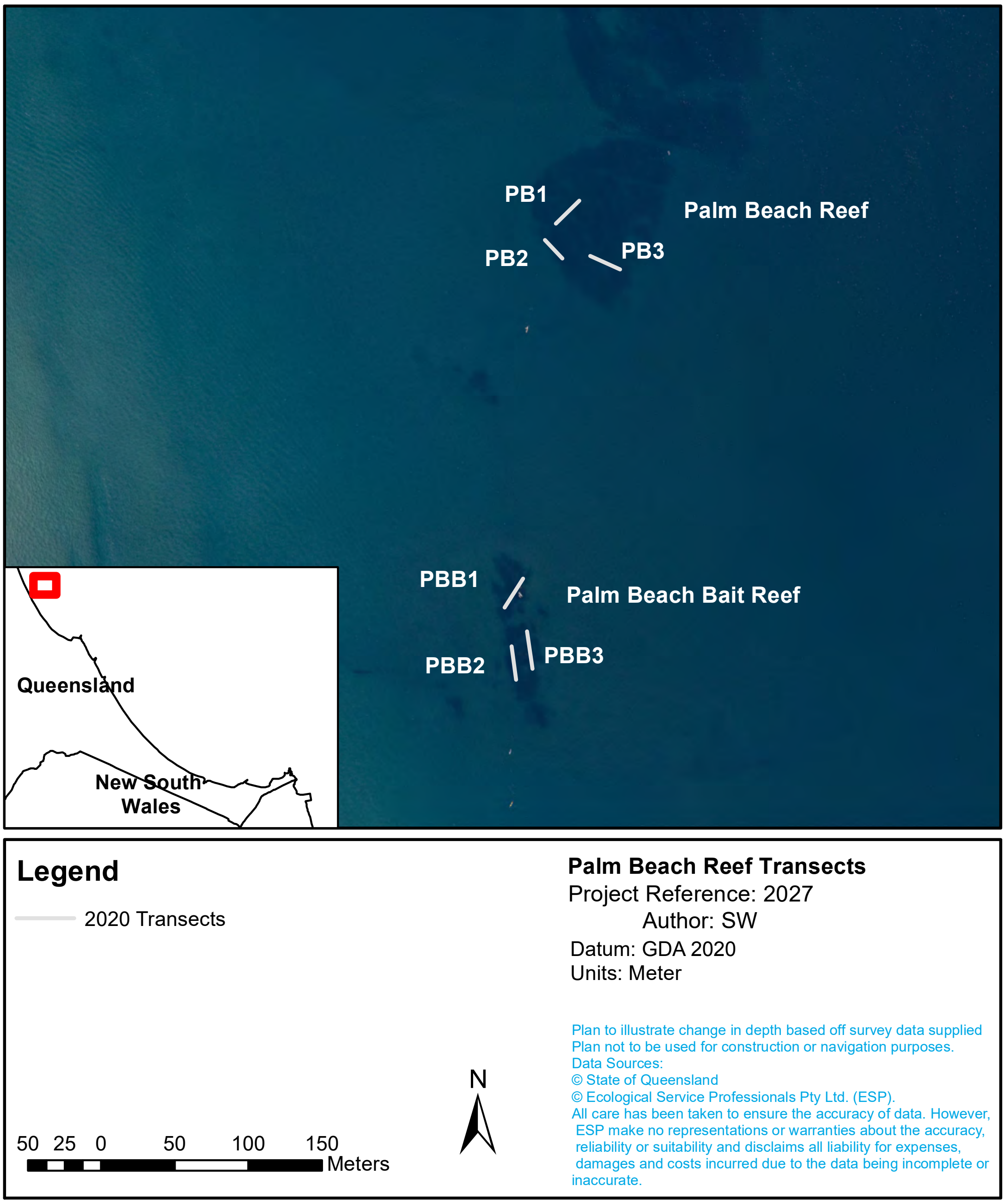


Figure 2.4 Location of transects surveyed in 2020 at Palm Beach Reef and Palm Beach Bait Reef

2.2.3 Benthic Communities

Benthic communities (including algal, sessile invertebrate and mobile invertebrate assemblages) were quantified at each reef location using 15 photo quadrats each separated by at least 1 metre and taken from both horizontal and vertical surfaces along three 25 m georeferenced transects (i.e. a total of 45 horizontal quadrats and 45 vertical quadrats were collected at each reef location). Transects within each reef location were approximately 20 to 25 metres long and based on those used in previous surveys, where appropriate (refer to Appendix A). The position of the start and end points of each transect were recorded using a handheld GPS (Accuracy ± 4 m) (

Table 2.1; Figure 2.2 to Figure 2.4). Photo quadrats were collected using a remotely operated underwater vehicle (ROV; Figure 2.5) and were supplemented by in-situ ROV searches targeting taxonomic identification, as well as cryptic, invasive and threatened species.

A fully qualified and equipped SCUBA dive team completed additional searches to create a voucher collection of preserved specimens used to verify identification of taxa from the imagery. Voucher specimens were collected where necessary to confirm identifications where this could not be done from images or by divers in the field. Divers found limited exhumed rock at Kirra Reef and as such photo-quadrats in these areas were not taken.

Palm Beach Bait Reef had a low vertical relief without many vertical surfaces and patches of reef were distributed among sand (coverage of sand averaged 23% of the surface area of the reef) relative to other reefs. An assessment of vertical surfaces was therefore not completed at Palm Beach Bait Reef and only assemblages on horizontal surfaces were assessed relative to those on other reefs.

a)

b)

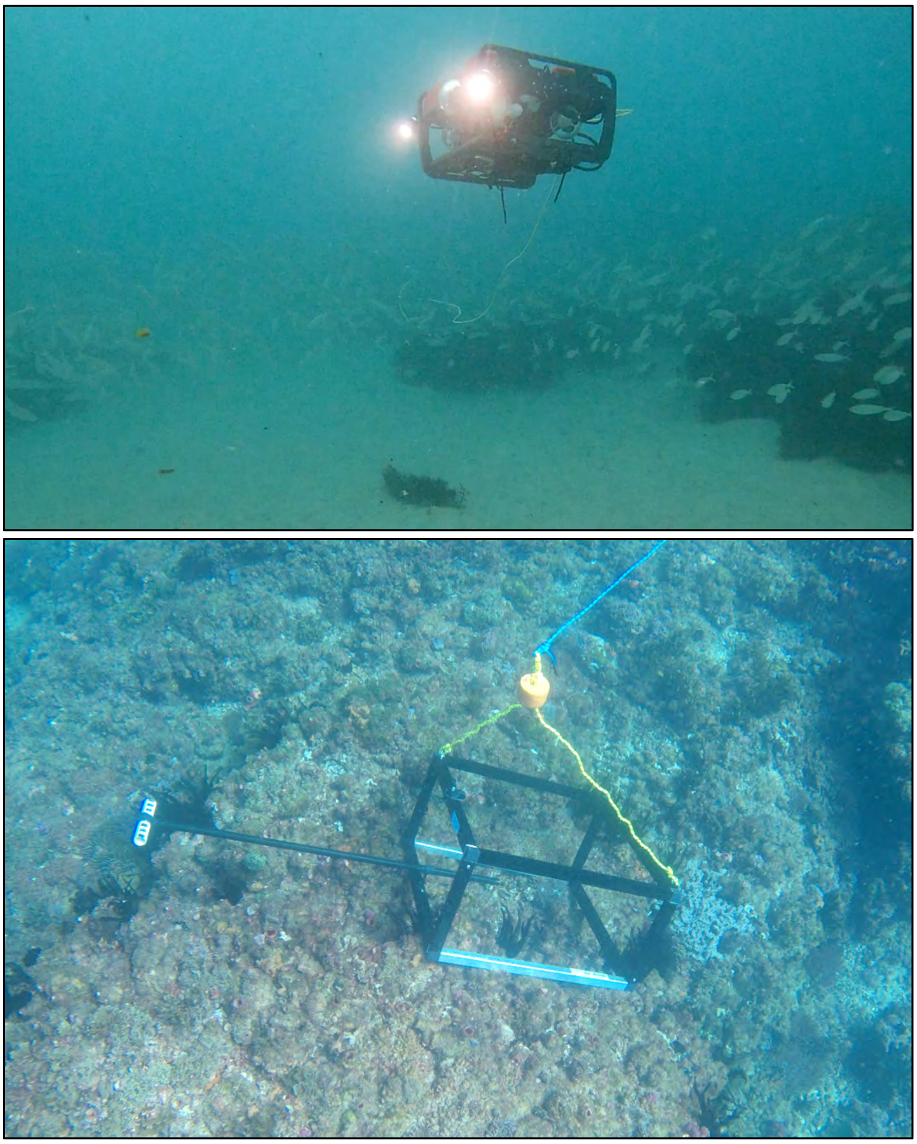


Figure 2.5 Survey methods used included a) ROV; and b) RUV deployed at each reef location

2.2.3.1 Data Management and Analysis

The abundance and type of large benthic invertebrates including echinoderms (e.g. urchins, sea stars, holothurians), crustaceans (crabs, stomatopods and lobsters), and molluscs (e.g. octopus, clams, oysters and nudibranchs) were recorded from each photo collected along georeferenced transects and compared among reefs. Data were pooled among each of the photos for different surface orientations.

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 reef assemblages. Up to 50 stratified random points were overlayed on each of the photo-quadrats based on standard approaches modified where appropriate and using Coral Point Count (CPCe) software (Kohler & Gill 2006), adapted where required to characterise the composition of benthic temperate rocky and artificial reefs in region (Schlacher-Hoenlinger et al. 2009; Walker et al. 2007; Walker and Schlacher 2014). The benthic communities (including hard and soft corals, hydrozoans, zoanthids, sponges, ascidians, bryozoans, bivalves, barnacles, macroalgae, turfing 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 years). Voucher specimens were collected 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 2020, 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 location (Cook Island South, Cook Island North, Cook Island West, Kirra Reef, Palm Beach Reef) as fixed factors, and site (transects nested in location) 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

[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.

PERcentages (SIMPER) routine[3] (Clarke & Warwick 1994). Spatial differences in the composition of the 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. Differences were visualised using graphs of the mean coverage (± standard error (SE)) for each variable.

To compare differences among reef locations (location) over the previous five years (between 2012 and 2020), the data for benthic assemblages on horizontal surfaces only were aggregated to an appropriate taxonomic level to match previous assessments (usually basic benthic cover categories such as hard corals, ascidians, sponges, coralline algae and macroalgae). Spatial and temporal differences were then assessed with a 2-factor PERMANOVA based on untransformed data, with survey year and location as the fixed factors. Differences in the composition of the benthic assemblages among locations through time were visualised using non-metric multidimensional scaling ordinations. Note that sites were aggregated within each reef locations as there was no differentiation in provided for sites within reefs in 2018 and 2019.

2.2.4 Fish Communities

The established method of analysis of video from multiple remote underwater video stations (RUVS; Figure 2.5b) was used to assess the abundance and diversity of fish assemblages among reefs (Cappo et al. 2003). Three RUVS, separated by more than 25 m, were deployed at each reef location for a minimum of one hour (only 60 minutes of footage was viewed). In addition, active standardised searches (30 minutes search time) for fish was completed using an ROV. In our experience, using an ROV reduces behavioural bias caused by SCUBA diver-fish interactions. Targeted searches in both open water and specific habitat types (overhangs, caves and in structurally complex habitat like macroalgae) was completed for species of conservation significance, cryptic and invasive species using both the ROV and SCUBA diver searches.

2.2.4.1 Data Management and Analysis

Fish assemblages and other mobile invertebrates were determined for each monitoring station from both RUVS and ROV video imagery. Fish were identified to species where possible, if this was not possible (due to poor imagery or defining features), fish were identified to a higher taxonomic level, usually Family. The species recorded at each reef and

[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.
[4] Non-metric multi-dimensional scaling (nMDS) ordinations attempt to 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.

the relative abundance (based on a measure of MaxN) of each species was determined from the video footage and pooled for the three stations. Fish assemblages were aggregated based on trophic level and graphed to show the percentage of species recorded and fish abundance using MaxN abundance for each reef.

The RUVS deployed at Palm Beach Bait Reef was pushed against a rock wall by wave surge after 15 minutes of deployment, therefore, only 6 fish species were recorded, and the data were excluded from any direct comparisons with the other reefs. Only 11 records of fish across all reefs were excluded from the data as the individuals could not be identified from the footage, mainly due to the distance from the camera.

Differences in the composition of assemblages (species and relative abundance as measured by MaxN) was transformed to presence / absence (due to the overabundance of some schooling species) and transformed to a Bray Curtis Similarity matrix. Differences were then compared among reefs using a one-factor Analysis of Similarity (ANOSIM) and the summed assemblages for each reef were visualised using non-metric Multidimensional Scaling (Clarke & Warwick 1994).

2.2.5 Quality Assurance and Control

Suitable Quality Control & Assurance (QAQC) measures, including use of suitably qualified people, 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 methods such as RUVS and photo-quadrats. A total of 10% of images were reanalysed by another suitably qualified person and the differences among images were compared 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 based on database searches and available literature and data, including the Commonwealth Department of Agriculture, Water and Environment (DAWE) Protected Matters Search Tool (PMST) for a 2 km buffer of the coastline between Cook Island and Palm Beach (DAWE 2020; Appendix B) and National Introduced Marine Pest Information System (NIMPIS 2020). Additional timed searches for species of significance for conservation and invasive species were completed using ROV and divers as outlined in Sections 2.2.3 and 2.2.4.

2.4 Abiotic Conditions

2.4.1 Water Quality

Duplicate water quality profiles were taken at each site using a calibrated YSI ProDSS hand-held water quality meter from the surface to the bottom to measure salinity, conductivity, temperature, dissolved oxygen, pH and turbidity. Each parameter was logged continuously at 5 second intervals to collect at least three sample points per metre, vertically through the water column. Photosynthetic Active Radiation (PAR: available light spectrum used by coral and algae for photosynthesis) was also measured at the surface and bottom at Cook Island

South, Cook Island West and Kirra Reef using an underwater Apogee Quantum PAR meter calibrated for use in marine water.

Note that the water quality data collected during this survey 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 2020) for the Tweed Heads wave rider buoy, located approximately 1.6 km offshore in 22 m water depth (refer to Figure 2.1). Data were graphed to provide a record of physical conditions preceding monitoring and compared to previous assessments of abiotic conditions of the region.

3 Results

3.1 Kirra Reef Extent

3.1.1 Bathymetric Surveys

There was no substantial change in the depth around Kirra Reef between July 2019 and May 2020 from bathymetric survey results, with on average less than 20 cm difference in sand height (as shown as white areas on Figure 3.1). In comparison the offshore bar running along Kirra Beach has built up by approximately 0.8 to 1.4 m in height during that time (Figure 3.2). It is common for an offshore bar to form on dynamic sandy beaches during winter months to dissipate wave energy (Short 2019). Change in depth around Kirra Reef was less substantial between July 2019 and May 2020 than between June 2018 and July 2019, when some areas became shallower around the southern side of Kirra Reef. The estimated reef extent from aerial imagery remained relatively stable during this time (Section 3.1.2). There was a change in the surveyed depth above Kirra Reef between years (of -1.4 m to 1.6 m in sections), which may correspond to a reduction in the coverage of macroalgae (such as the dense fronds of *Sargassum* spp. macroalgae observed on the horizontal surfaces in the middle of the reef; refer to Section 3.2.2) and a small change in the distribution of sand in other places around the reef. An annual comparison of survey data to determine the change in depth around the reef may be a suitable indicator to trigger a survey of changes in benthic fauna and flora relative to comparative reefs nearby.

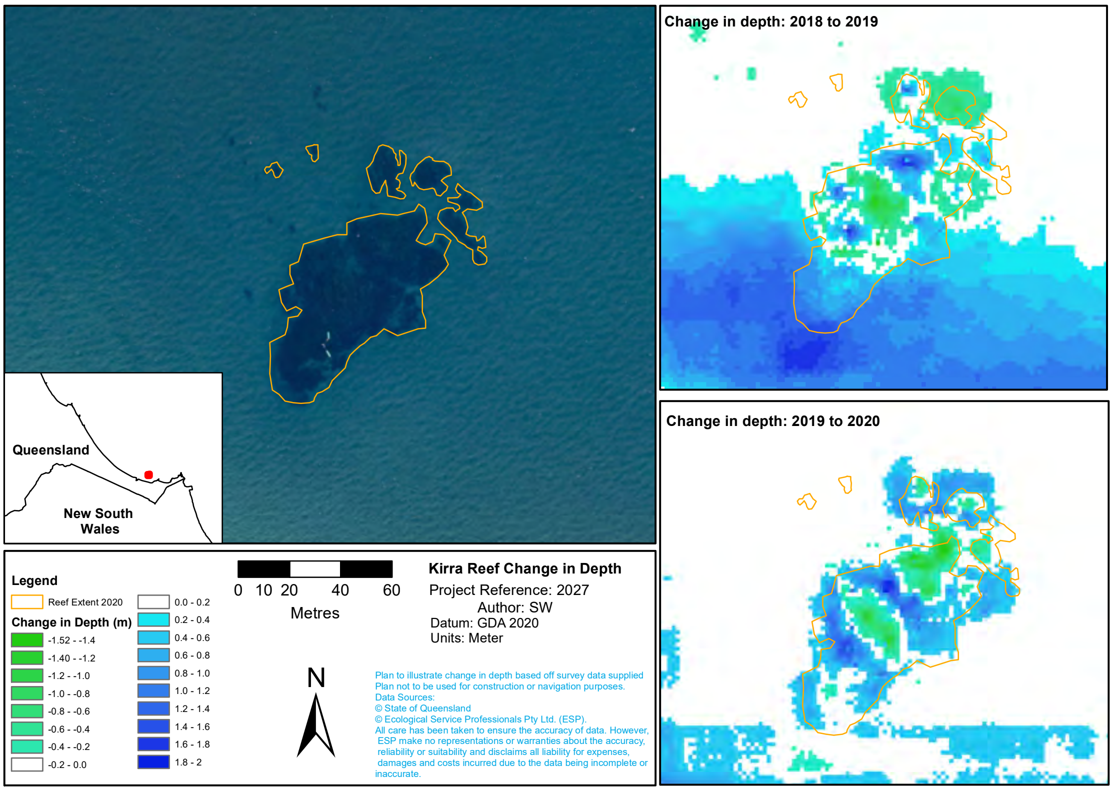


Figure 3.1 Areal extent from visual interpretation of aerial and satellite imagery (left) and changes in depth from June 2018 to July 2019 (top right); and July 2019 to May 2020 (bottom right) from bathymetric survey data

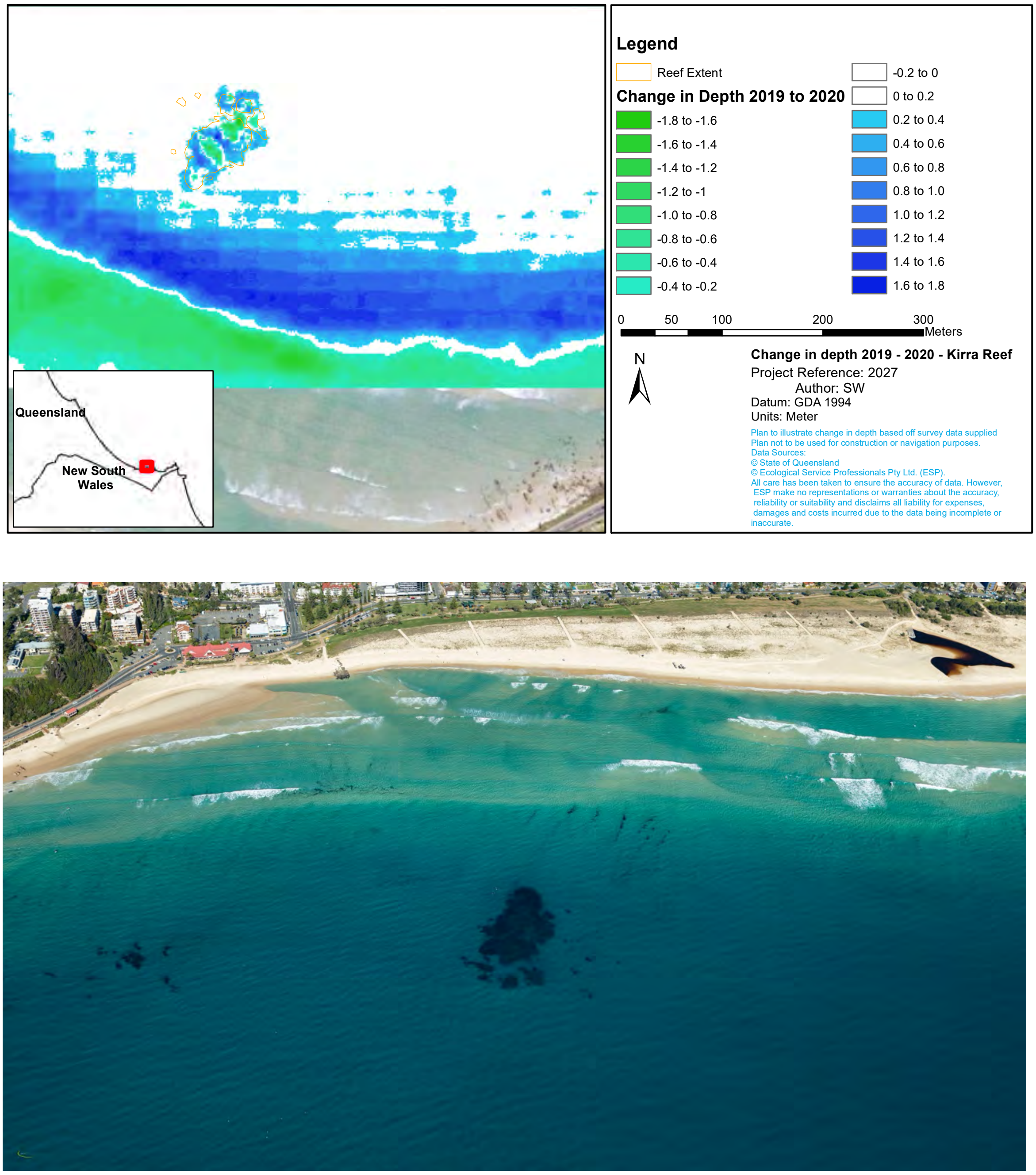


Figure 3.2 Broad scale changes around Kirra Reef between 2019 and 2020 and a recent aerial image of Kirra Reef and adjacent beach

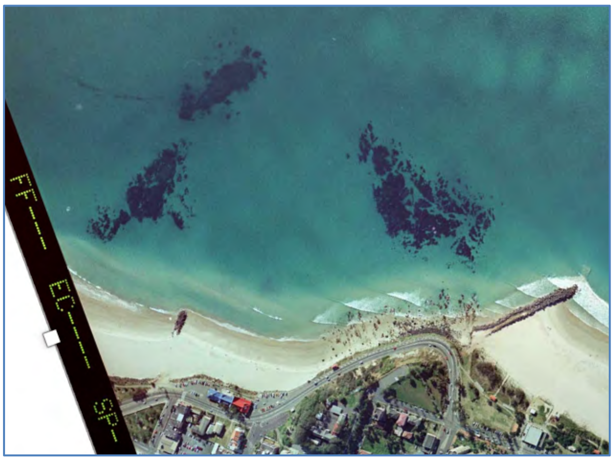
3.1.2 Aerial Imagery

In June 2020, Kirra Reef had an estimated aerial extent of 3,678 m^2 of reef recorded from visual interpretation of aerial and satellite imagery. Previous estimates of the extent of Kirra Reef from aerial photographs and satellite imagery indicate vast changes in the aerial extent through time (Figure 3.3; Appendix B, Table B.1). The areal extent of Kirra Reef in 1962 to 1965 was estimated to range between 7,000 and 13,300 m^2, which was during a time of no major artificial changes to sand movements (Boswood & Murray 1997). The maximum area of reef exposed from aerial photograph estimates was 40,813 m^2 in 1995 following a period of sand depletion in the area. Kirra Reef at this time consisted of three distinct areas, a shallow southern reef, a shallow eastern reef near the current groyne, and a northern section of reef section in deeper water (Figure 3.3c). At this time the areal extent of the northern section of reef was approximately 5900 m^2. The area of reef exposed decreased following the commencement of TSB project, with the reef almost completely covered in 2007 and 2008 and an estimated area of reef <1000 m^2 in 2010. The extent of Kirra Reef as assessed visually from aerial imagery has not changed substantially since 2012 (particularly considering the potential margin of error associated with calculating the area from aerial images). Likewise, the areal extent of Cook Island and Palm Beach Reef have not changed substantially during this time (Appendix B, Table B.1). Only the norther section of Kirra Reef is currently exposed, with the shallower southern and eastern sections remaining covered in sand.

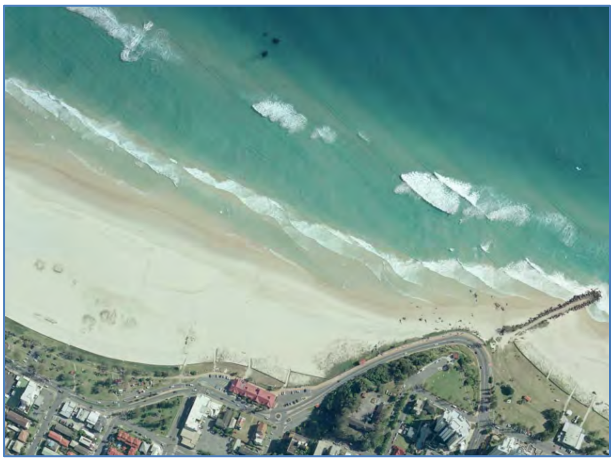
a)

b)

c)



d)



e)

f)

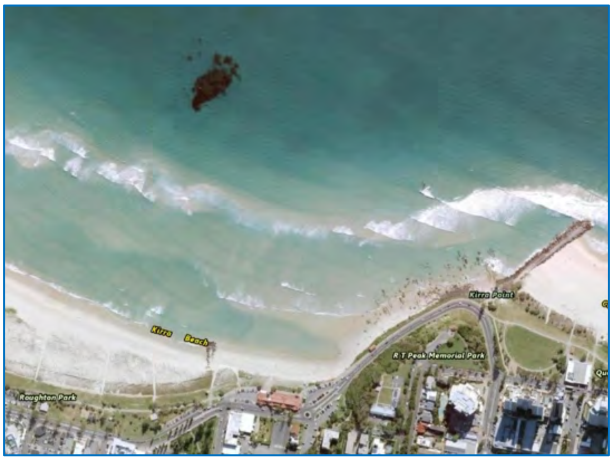


Figure 3.3 Photographs indicating major changes at Kirra Reef in (a) 1965 during a time with no major artificial changes to sand movements (TRESBP 2017); (b) 1982 following sand depletion between the 1960s and 1980s (WorleyParsons 2009); (c) 1995 at the measured maximum extent (State of Queensland 1995); (d) 2007 following an oversupply of sand during the early years of the TSB sand bypassing system (State of Queensland 2007); (e) 2018; and, (f) June 2020 with sand delivery of the TSB now matching natural longshore drift of sand (State of Queensland 2020).

3.2 Benthic Communities

3.2.1 Composition of Benthic Communities

The composition of benthic communities (including both algal and sessile invertebrate assemblages) differed at a range of spatial scales, with significant differences in composition of communities evident between Kirra and the other reefs on both horizontal and vertical surfaces[5] (Figure 3.4a; PERMANOVA, Appendix D, Table D.1). There were also differences in the composition of benthic communities among reef locations including those separated by only a few hundred metres at Cook Island[1]. Differences between vertical and horizontal surfaces were most pronounced at Kirra Reef relative to other reefs (Figure 3.4a). On Kirra Reef, the higher coverage of turf algae and *Sargassum* spp. on horizontal compared with vertical surfaces contributed most to the difference in the average coverage of sessile assemblages among surface orientations, accounting for 38% of the dissimilarity between the two groups (SIMPER Appendix D, Table D.2). In contrast, the two ascidians *Polycarpa procera* and *Herdmania momus* covered up to 23% of the area on vertical surfaces and 7% on horizontal surfaces, contributing a further 18% to the dissimilarity between assemblages on difference surface orientations on Kirra Reef (SIMPER Appendix D, Table D.2).

The differences in the composition of benthic communities were likely due to a range of site-specific factors including differences in the disturbance regime and the length of time since sand burial (as Kirra Reef was almost completely buried in 2007 and 2008), abiotic factors (such as wave action), settlement and recruitment of sessile species, water quality (including nutrient availability), and / or variation in the abundance of herbivorous fauna between reefs. Of note, there was a moderate to dense patch of seagrass recorded at Cook Island West adjacent to Cook Island. The seagrass community occurred between macroalgae, rock and rubble on sand and was dominated by *Halophila ovalis*, covering approximately 32% to 52% of the space where it was recorded (Figure 3.5). While there are anecdotal records of the seagrass occurring in this location, this is the first time it has been recorded as part of the TSB assessment. Marine vegetation, including seagrass, are protected under the NSW Fisheries Management Act 1995.

Bare sand and rubble habitat covered the most area on horizontal surfaces at Palm Beach Bait Reef (23%) and horizontal surfaces at Cook Island West (20%) (Figure 3.6a; Figure 3.7; Figure 3.8). Elsewhere the coverage of sand and rubble was more similar among surface orientations and reef locations covering less than 8% of the surface area (Figure 3.8).

[5] Benthic communities PERMANOVA Orientation vs Reef interaction MS = 8186 pseudo-$F_{4,10}$ = 4.48, $p = 0.002$; Pairwise tests for differences among reefs for horizontal and vertical surfaces: CIW≠CIS≠CIN≠KR≠PB *p(MC)* < 0.05;

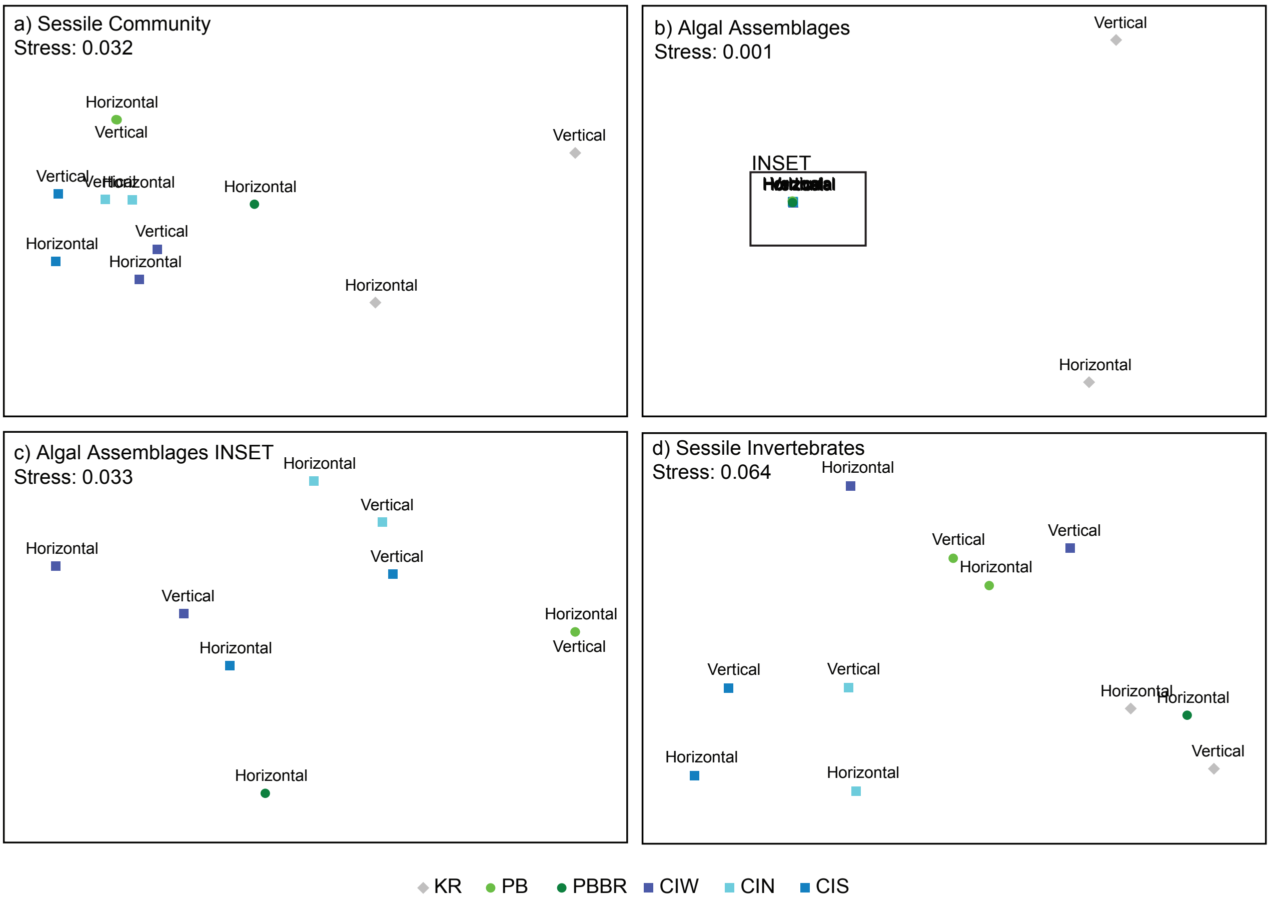


Figure 3.4 nMDS ordination showing difference in the composition of benthic assemblages between surface orientations and reefs for (a) the sessile community, (b-c) algal assemblages, and (d) sessile invertebrate assemblages

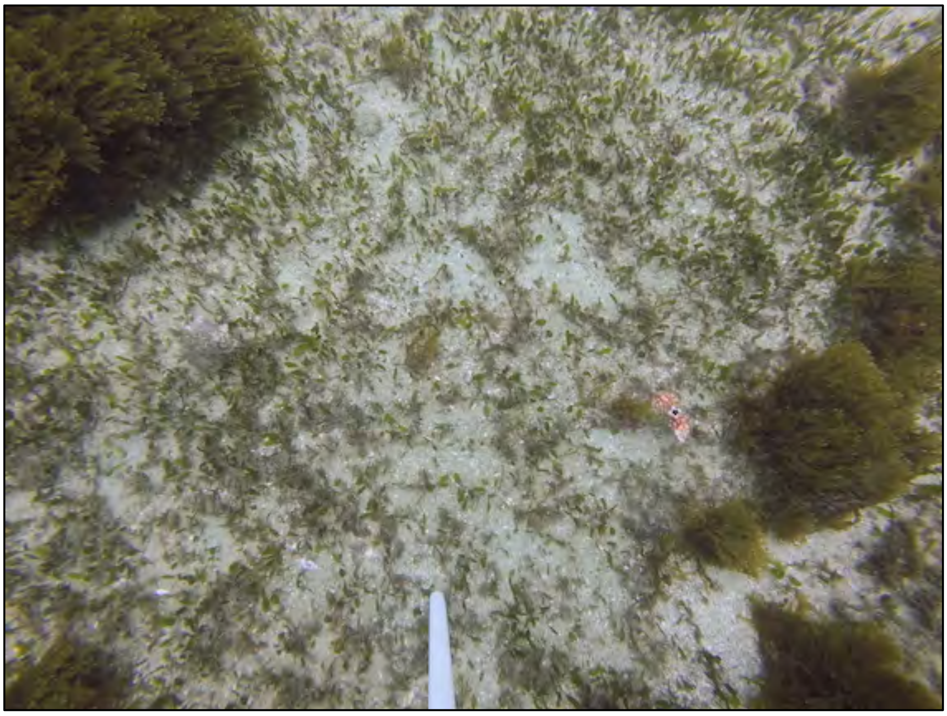


Figure 3.5 Seagrass *Halophila ovalis* at Cook Island West

a)

b)

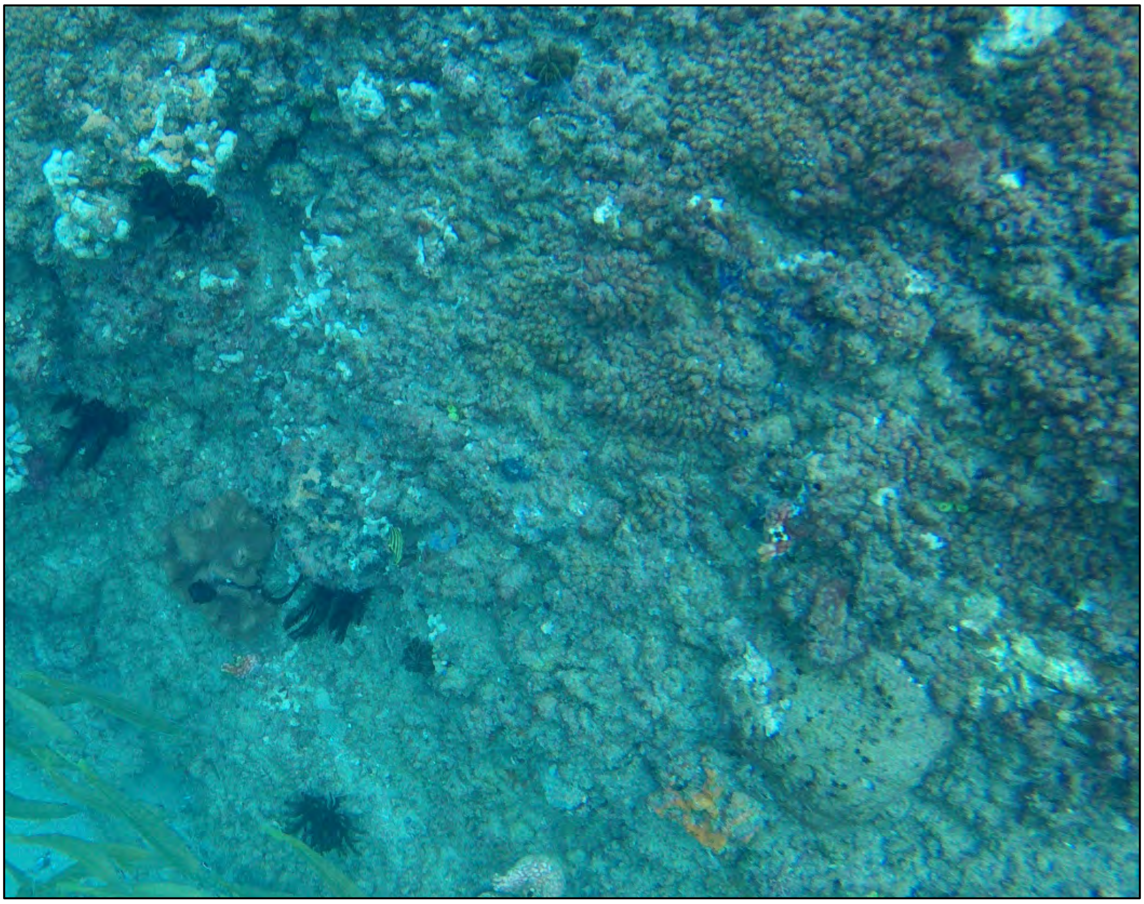


Figure 3.6 Benthic assemblages on a) horizontal and (b) vertical surfaces at Palm Beach

Figure 3.7 Benthic habitat on horizontal surface at Palm Beach Bait Reef

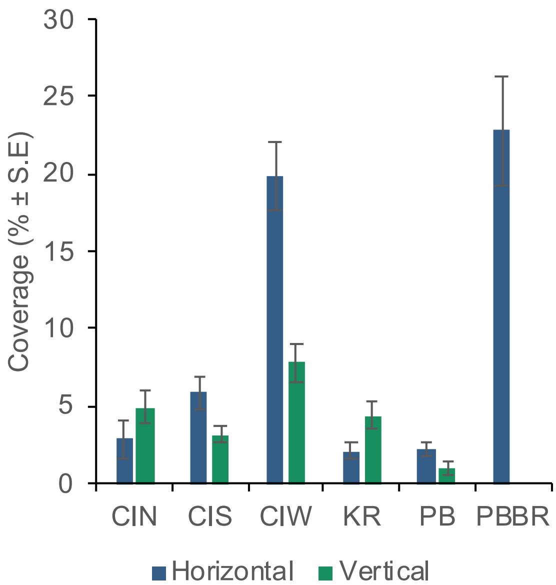


Figure 3.8 Coverage of bare (sand & rubble) habitat between surface orientations, among reefs

3.2.2 Algal Assemblages

The algal assemblages on all reefs were dominated by turf algae, with other groups such as foliose macroalgae (including *Sargassum* sp., *Dictyota* sp. and *Padina* sp.), crustose coralline algae and articulate coralline algae (e.g. *Jania* sp.) also present. The composition of algal assemblages differed at a range of spatial scales, with differences in the coverage of algae occurring among reefs on both horizontal and vertical surfaces[6] (Figure 3.4b & c; Figure 3.10; PERMANOVA, Appendix D, Table D.3). On horizontal and vertical surfaces, there were often differences in the composition of algal assemblages among the reefs, particularly between Kirra and other reefs, with the exception of Cook Island West which did not differ significantly in composition from Kirra Reef, despite having almost double the coverage of turfing algae (Figure 3.4b & c; PERMANOVA pairwise comparisons, Appendix D, Table D.3; Table D.4; SIMPER Table D.5).

The average coverage of macroalgae was similar between the surface orientations on each reef, except at Kirra Reef, which had a higher coverage on horizontal surfaces (Figure 3.9a; Table D.4). Coverage of turf algae was highest on both vertical and horizontal surfaces on Palm Beach Reef (80%) on both horizontal and vertical surfaces and was lowest on Kirra Reef on vertical surfaces (15%) (Figure 3.9a; Figure 3.10). In contrast, the coverage of macroalgae on Kirra Reef was much higher, particularly on horizontal surfaces (25%; Figure 3.9b). Differences in the coverage of turfing algae between Kirra and the other reefs contributed 50 to 60% of the difference in algal assemblages among those reefs (Figure 3.9b; SIMPER Appendix D, Table D.5). *Sargassum* spp. covered on average 22% of horizontal surfaces and 10% on vertical surfaces on Kirra Reef (Figure 3.10). *Sargassum* spp. was largely absent at all other reef locations, with the difference accounting for up to 26% of the difference in algal assemblages between Kirra Reef and the other reefs (SIMPER; Appendix D, Table D.5). On Cook Island reefs, there was typically a high average coverage of macroalgae (particularly turf forming species) and articulate coralline algae, which was relatively consistent among different reef sites and surface orientations (Figure 3.9a,b; Figure 3.11 & Figure 3.12; PERMANOVA Appendix D, Table D.4). Seagrass was also present at Cook Island West (Figure 3.5).

[6] Algal assemblages PERMANOVA Orientation vs Reef interaction MS = 6741, pseudo-$F_{4,10}$ = 4.29, p = 0.001; Pairwise tests for differences among reefs for vertical surfaces: CIW≠CIS≠CIN≠KR≠PB *p(MC)* < 0.05; Pairwise tests for differences among reefs for horizontal surfaces: KR = CIW, KR = PBBR, CIW = CIN all other pairwise comparisons not equal *p(MC)* < 0.05

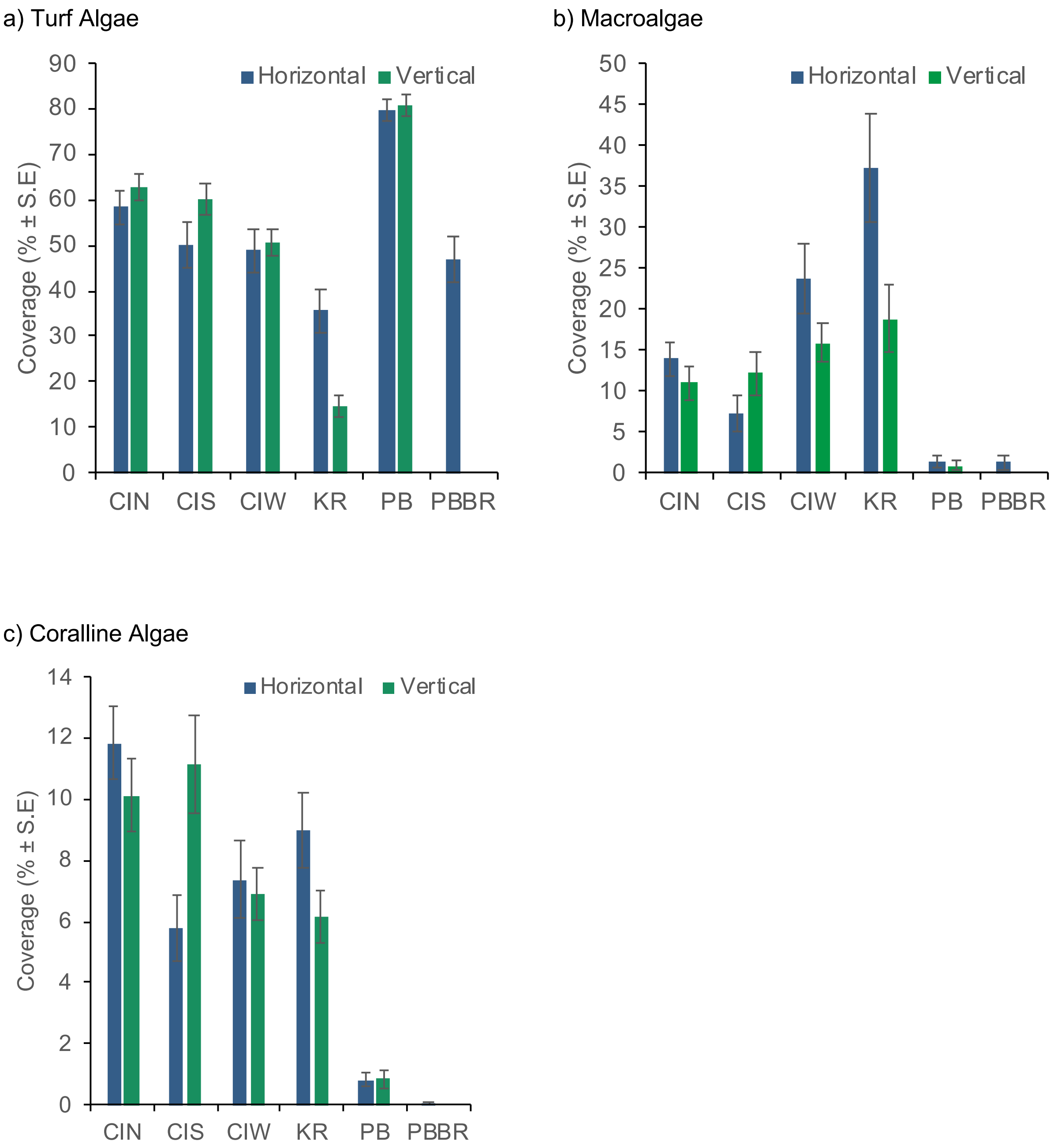
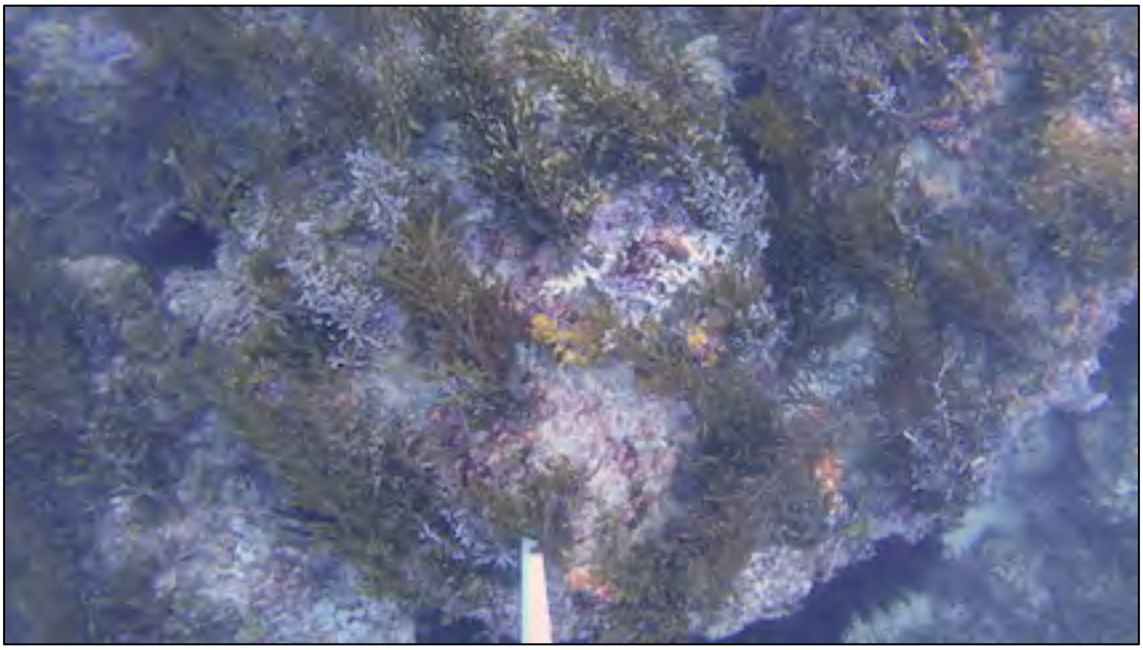


Figure 3.9 Average coverage (% ± SE) of turf algae, macroalgae and coralline algae, among reefs on vertical and horizontal surfaces in 2020

a)



b)

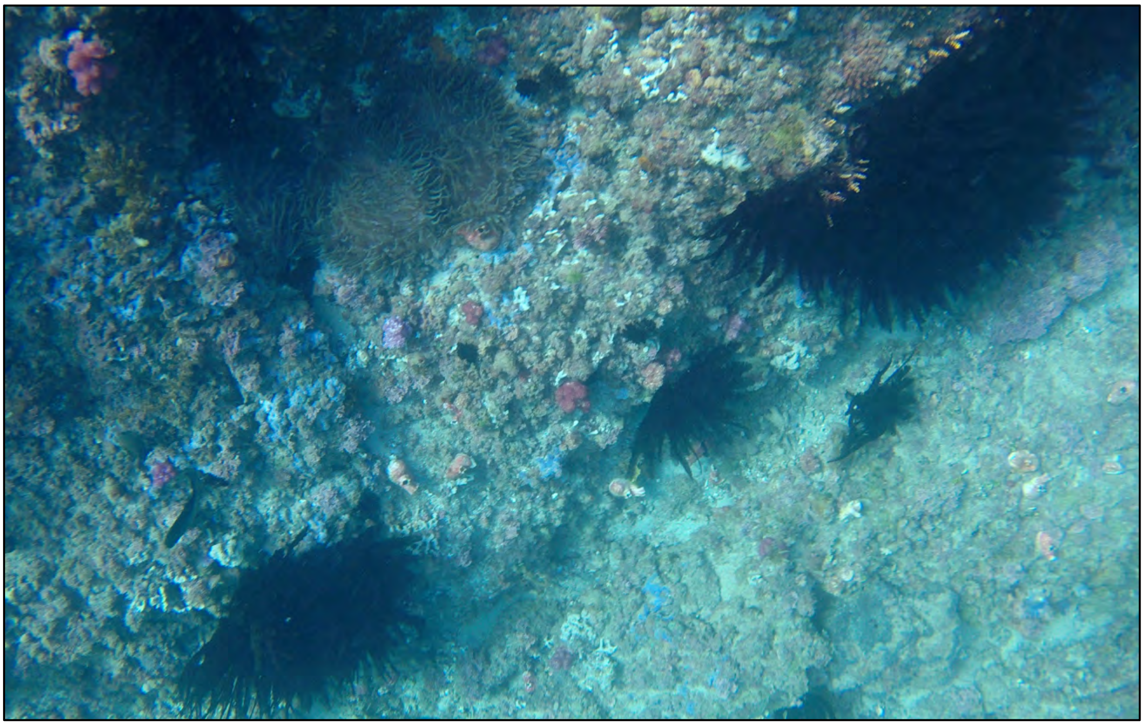
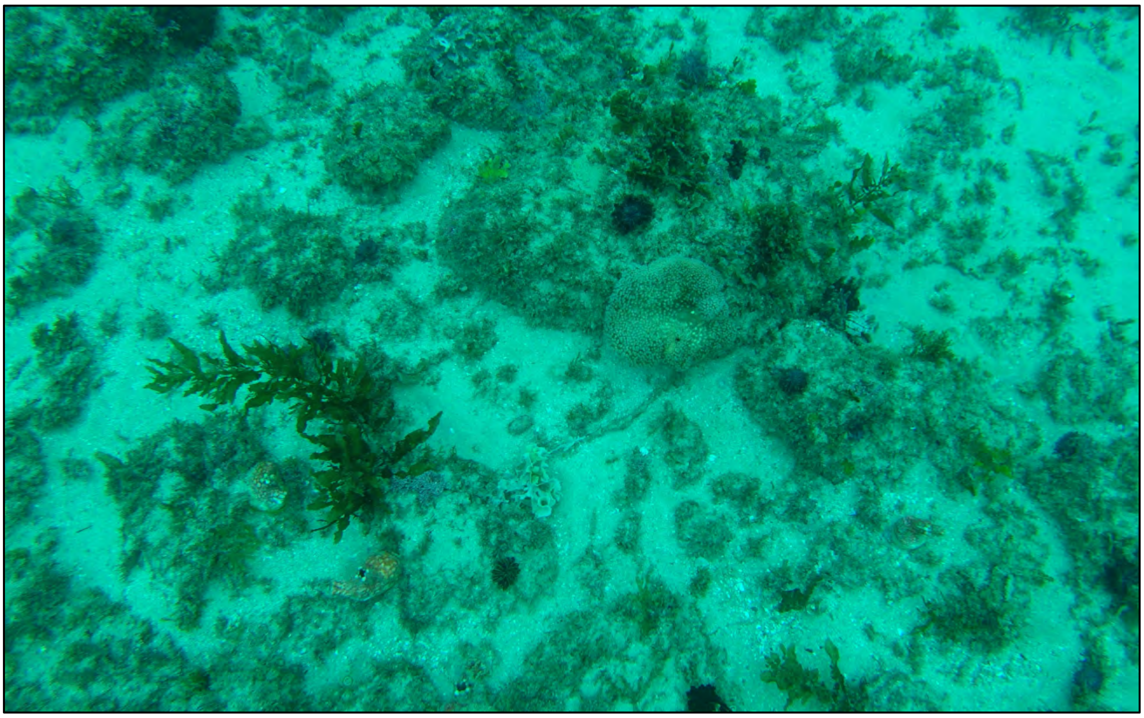


Figure 3.10 Example benthic assemblages on a) horizontal and (b) vertical surfaces at Kirra Reef

a)



b)

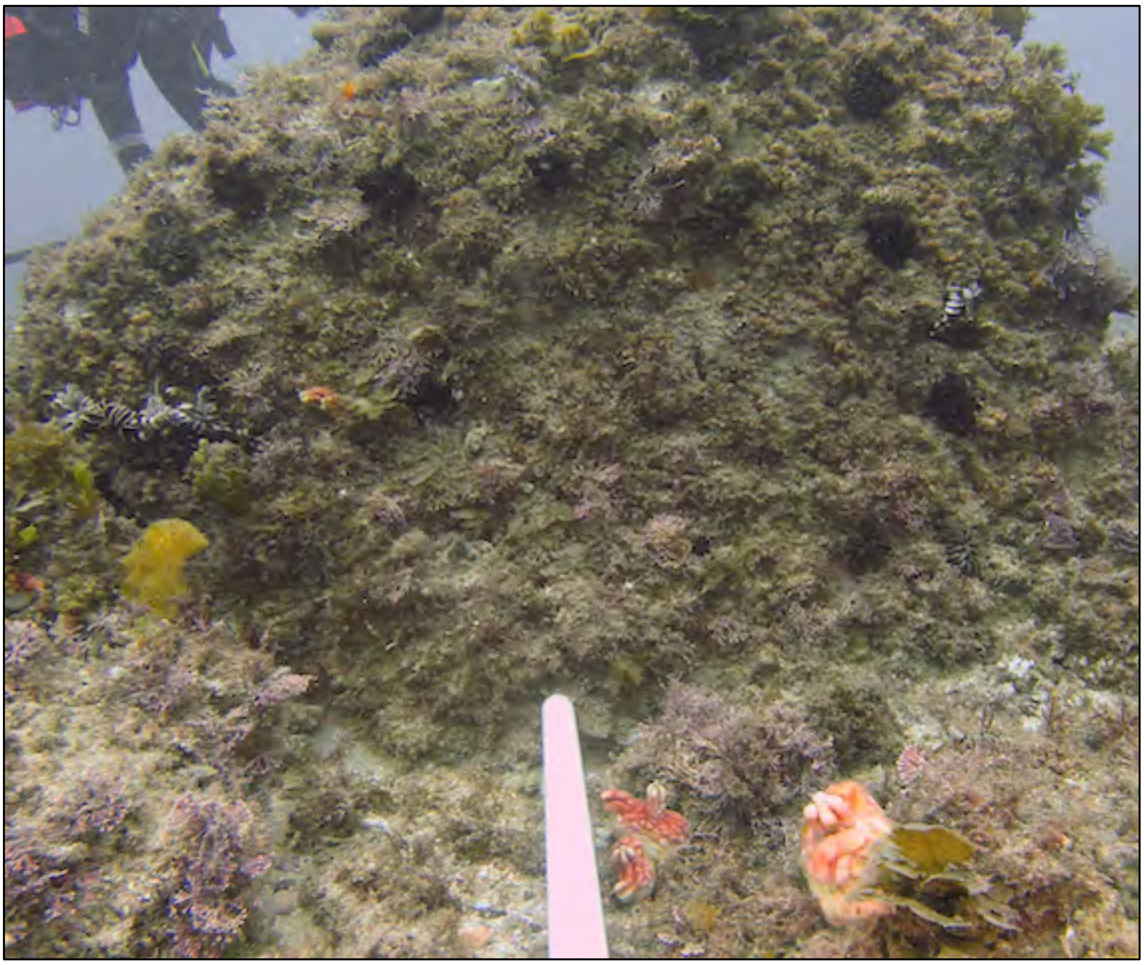
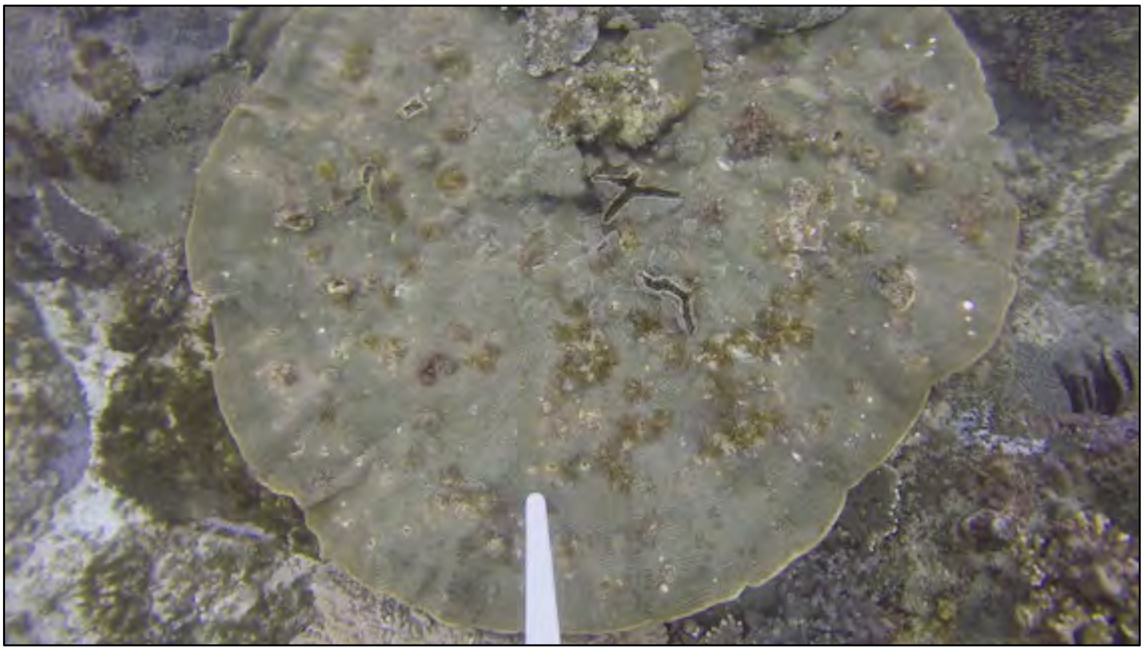


Figure 3.11 Reef habitat on (a) horizontal and (b) vertical surfaces at Cook Island West

a)



b)

Figure 3.12 Reef habitat on (a) horizontal and (b) vertical surfaces at Cook island South

3.2.3 Sessile Invertebrate Assemblages

In 2020, a total of 92 taxa were recorded across all vertical surfaces and 78 taxa recorded across all horizontal surfaces. There were differences in the total number of taxa recorded between vertical and horizontal surfaces, which was most pronounced at Kirra Reef, with a total of 62 taxa recorded on vertical surfaces and only 27 taxa on horizontal surfaces of the reef (Figure 3.13).

The composition of sessile invertebrate assemblages (presence and % coverage of each taxonomic group) generally differed between Kirra Reef and each of the other reefs regardless of surface orientation, except for the composition on horizontal surfaces, which did not differ between Kirra and Palm Beach Bait reefs[7] (Figure 3.10; PERMANOVA Orientation x Reef pairwise comparisons Table D.6). Both of these reefs have a similar extent and degree of sand burial and are closer to the dynamic sandy shoreline than the other reefs (Figure 3.8). There were consistent differences in the composition of assemblages growing on vertical surfaces among the reefs, except between Cook Island North and Cook Island South reefs, which did not differ[8] (Appendix D, Table D.6).

On Kirra Reef, the average coverage of the dominant ascidians *Polycarpa procera*, *Herdmania momus*, and *Pyura stolonifera*, and several encrusting sponges, was much higher than on other reefs (Figure 3.14a,e,f; PERMANOVA, Table D.8b,c). This difference contributed approximately 50 to 60% of the dissimilarity in the composition of sessile invertebrate assemblages among reefs. In comparison, the coverage of hard corals (such as those from the genus *Paragoniastrea, Turbinaria* and encrusting *Porites*) often covered more area on reefs at Cook Island than on Kirra or Palm Beach reefs; however, the difference in coverage contributed less than 10% of the dissimilarity in assemblage composition among reefs (SIMPER Appendix D,

[7] Sessile Invertebrates - PERMANOVA Orientation vs Reef interaction MS =17562 pseudo-$F_{4,10}$ = 2.78, p = 0.001; Pairwise tests for differences among reefs for horizontal and vertical surfaces: CIW≠CIS≠CIN≠KR≠PB *p(MC)* < 0.05; vertical surfaces: CIN = CIS *p(MC)* = 0.245; horizontal surfaces KR = PBBR *p(MC)* = 0.142
[8] PERMANOVA Pairwise comparisons CIN vs CIS t = 1.18, p = 0.245

Table D.9 & Table D.10).

On Kirra Reef, the average coverage of sessile fauna was much higher on vertical than horizontal surfaces[9] (Figure 3.14). This was to be expected as horizontal surfaces tended to have a greater coverage of algae, which can out compete sessile invertebrates, and in the past Kirra Reef has had more prevalent smothering from sand, which typically covers more area on horizontal than vertical surfaces (Figure 3.9). The average coverage of sessile assemblages was similar between vertical and horizontal surfaces at Cook Island West and Palm Beach Reef (Figure 3.14a; PERMANOVA Appendix D, Table D.8). In contrast, the coverage of sessile assemblages recorded on Cook Island North and Cook Island South reefs was typically higher on horizontal than vertical surfaces (Figure 3.14b), due to the dominance of longer lived hard corals covering a large proportion of the surface area on horizontal surfaces (Figure 3.14c).

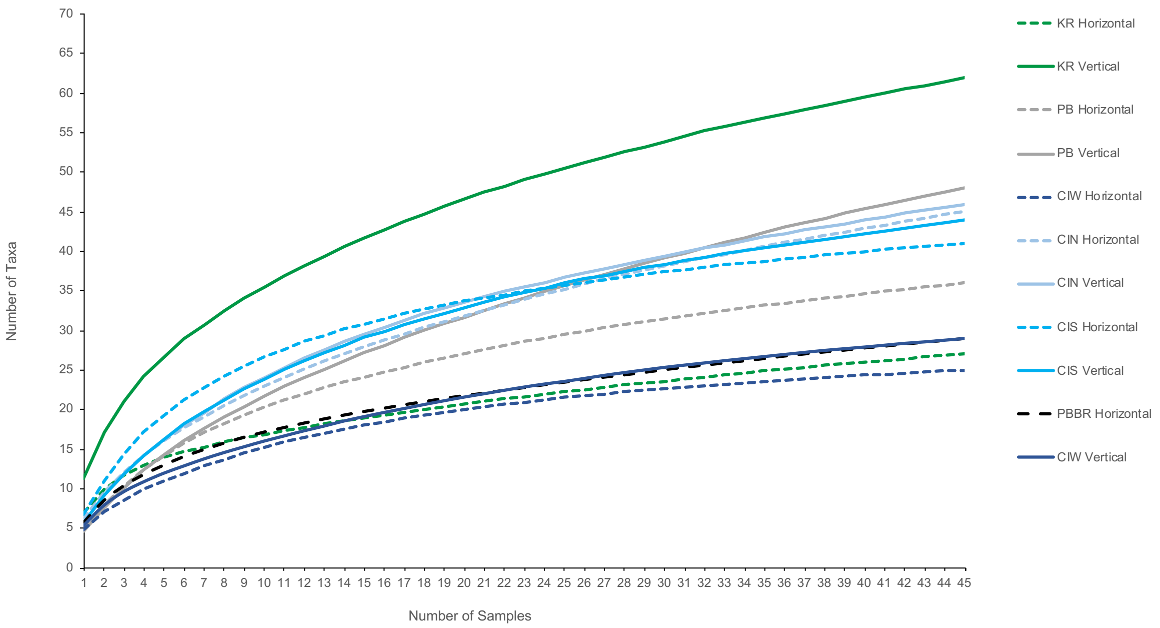


Figure 3.13 Taxonomic accumulation curves for sessile invertebrate assemblages for each reef x surface orientation combination

[9] Coverage of Sessile Invertebrates PERMANOVA Orientation vs Reef interaction $MS_{4,10}$ = 8078, pseudo-$F_{4,10}$ = 98.79, p = 0.001; Pairwise tests horizontal ≠ vertical at KR, CIN & CIS, *p(MC)* < 0.05 horizontal = vertical at CIW & PB

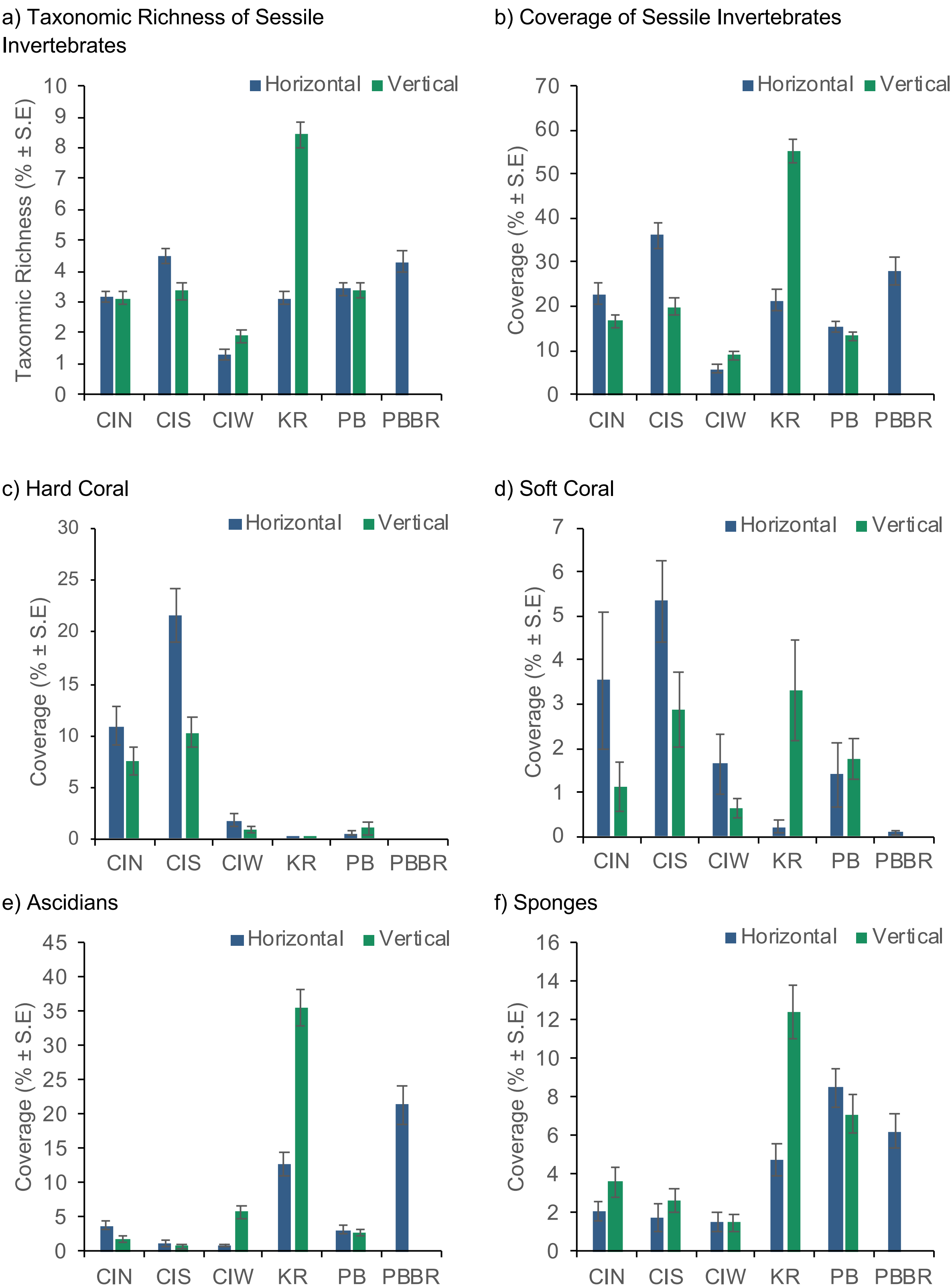
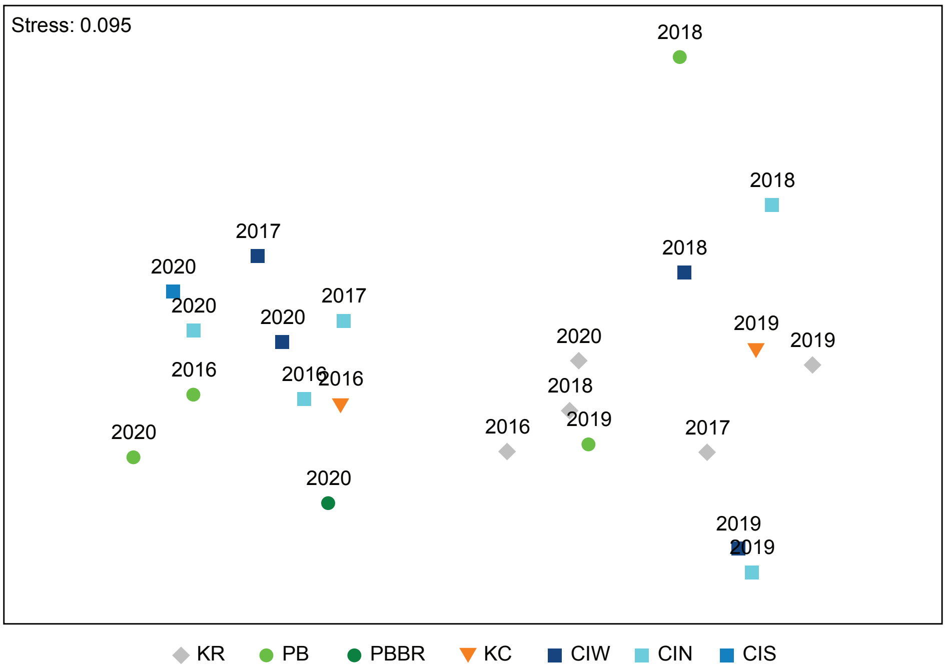


Figure 3.14 Average taxonomic richness and coverage (% ± SE) of all sessile invertebrates and average coverage of dominant sessile invertebrates categories, among reefs on vertical and horizontal surfaces in 2020 (Blue – Horizontal; Green – Vertical)

3.2.4 Historic Comparison of Benthic Communities

The composition of benthic communities (algae and sessile invertebrates identified to a broad taxonomic level) differed consistently between Kirra and Palm Beach Reefs (most commonly surveyed) and the various other reefs assessed over time[10] (Figure 3.15; PERMANOVA Survey x Reef Interaction; pairwise comparisons Appendix D, Table D.11). In the past 5 years (since 2016), the composition of benthic communities on all reefs assessed have differed between successive years where surveys have been completed (Figure 32; PERMANOVA pairwise comparisons, Table D.11, Table 5.11g).

On Kirra Reef, the differences in composition between successive surveys were due changes in the average coverage of macroalgae, turf algae and ascidians, which combined accounted for up to 82% of the difference between the surveys on that reef (SIMPER Table D.12). In particular, the coverage of ascidians on horizontal surfaces has increased to a high of 42% in 2019 and has since declined to 13% in 2020 (Table D.12). Sponges have typically covered less area and covered approximately 5% of the area of Kirra Reef in 2020. The coverage of soft and hard corals on horizontal surfaces has increased to 2% on Kirra Reef in 2020, which is indicative of the sessile invertebrates becoming more similar in composition to those recorded on several of the other reefs (Table D.12). An increase in the coverage of hard and soft corals would likely result in more similar composition of benthic communities with those found on surrounding reefs, but many of these species are slow growing so may take considerable time to become established and cover more than 5% on Kirra Reef (Walker & Schlacher 2014).



[10] Benthic Communities over time - PERMANOVA Period x Reef interaction MS =17816 pseudo-$F_{11,995}$ = 16.53, p = 0.001; Pairwise tests for differences among reefs over time are provided in Appendix D; Table D.11b-g.

Figure 3.15 nMDS ordination of the difference in the composition of benthic assemblages on horizontal surfaces between Kirra and Palm Beach Reefs between 2010 and 2020 (KC = Kingscliff Reef – not surveyed in 2020)

3.3 Mobile Invertebrate Assemblages

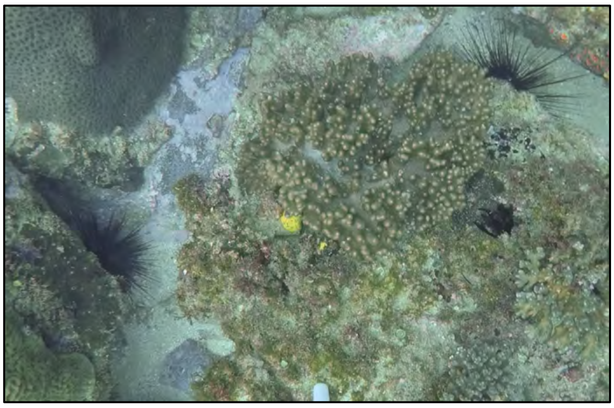
A variety of echinoderms dominated the mobile invertebrates observed on the reefs, with feather stars (particularly *Cenolia* spp.) being the most abundant at all reef (except Cook Island South) (Table 3.1). Kirra Reef had the highest abundance of mobile invertebrates and the Cook Island reefs had the highest diversity compared with other reef locations (Table 3.1). On the reefs around Cook Island there was also a moderate abundance of urchins dominated by needle spined (*Diadema savignyi*) and also including pencil (*Phyllacanthus parvispinus*) and cake (*Tripneustes gratilla*) urchins (Figure 3.16). In addition to the mobile sessile invertebrate species recorded in quadrats, an octopus, squid and cuttlefish were observed on the ROV and RUV footage (Figure 3.16d; also refer to 3.4.1).

Table 3.1 Differences in the average abundance (±SE) of mobile invertebrates among reefs on (a) horizontal and (b) vertical surfaces

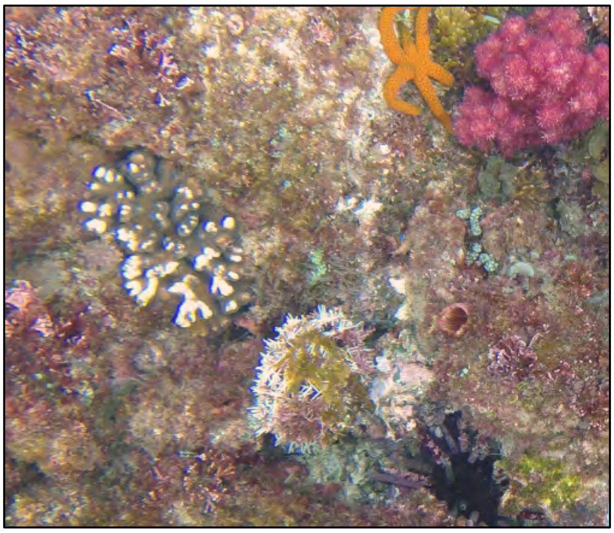
Orientation		a) Horizontal						b) Vertical				
Reef		**CIN**	**CIS**	**CIW**	**KR**	**PB**	**PBBR**	**CIN**	**CIS**	**CIW**	**KR**	**PB**
Class Crinoidea (Feather stars)												
Cenolia glebosis	Mean	15.3	4.3	39.0	54.7	1.3	30.7	28.0	2.3	34.0	58.7	5.0
	S.E.	0.1	0.5	1.8	5.3	0.3	3.5	0.7	0.4	8.2	3.8	1.6
Cenolia sp.1	Mean	1.0	0.0	20.7	4.3	0.0	2.0	0.0	0.0	13.0	4.7	0.0
	S.E.	0.3	0.0	4.7	0.3	0.0	0.5	0.0	0.0	3.0	1.1	0.0
Cenolia sp.2	Mean	0.7	0.0	3.0	4.0	0.0	0.0	1.0	0.0	23.3	5.7	0.0
	S.E.	0.1	0.0	0.8	0.7	0.0	0.0	0.4	0.0	4.0	1.3	0.0
Oxycomanthus bennetti	Mean	0.0	0.0	0.7	0.7	0.0	0.0	0.3	0.0	2.7	2.0	0.0
	S.E.	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0	1.0	0.3	0.0
Class Echinoidea (Sea Urchins)												
Diadema savignyi	Mean	4.0	4.7	4.0	1.0	0.3	0.0	5.3	3.3	3.5	0.0	0.3
	S.E.	0.7	1.2	1.2	0.3	0.1	0.0	0.8	0.8	1.3	0.0	0.1
Phyllacanthus parvispinus	Mean	0.3	1.7	2.3	0.7	2.7	0.0	1.3	1.7	2.0	0.7	3.0
	S.E.	0.1	0.1	0.5	0.1	0.6	0.0	0.1	0.1	0.4	0.3	0.7
Tripneustes gratilla	Mean	1.0	0.3	0.0	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.0
	S.E.	0.4	0.1	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0
Class Asteroidea (Sea stars)												
Echinaster luzonicus	Mean	0.7	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.7
	S.E.	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3
Echinometra mathaei	Mean	0.7	0.0	0.7	1.3	0.7	0.0	0.0	0.0	0.0	0.7	0.0
	S.E	0.3	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0
Pentagonaster dubeni	Mean	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	S.E	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a) Dense feather stars (*Cenolia glebosis)* clustered on Kirra Reef

b) *Diadema* urchins on Cook Island South.



c) Urchins (*Tripneustes gratilla* & *Phyllacanthus parvispinus*) and seastar (*Echinometra mathaei*) at Cook Island North



d) Octopus at Kirra Reef

e) Pencil urchin (*Phyllacanthus parvispinus)* at Palm Beach Reef

f) Seastar (*Echinometra mathaei*) at Palm Beach Reef

Figure 3.16 Mobile invertebrates recorded on reefs in 2020

3.4 Fish Assemblages

A total of 116 bony and cartilaginous fish species, from 34 families were recorded across all reefs in the July 2020 survey (Appendix E). Labridae (wrasses) and Pomacentridae (damselfishes) were the most diverse families, with 23 and 15 species, respectively. Most species recorded in July 2020 had previously been recorded; however, 28 species of fish had not previously been recorded (Appendix E). Cartilaginous fish recorded included:

- spotted wobbegong (*Orectolobus maculatus*) at Cook Island North, Cook Island West and Kirra Reef;
- white-spotted eagle ray (*Aetobatus ocellatus*) at Palm Beach Bait Reef, Kirra Reef and Palm Beach Reef (Figure 3.17a); and,
- blotched fantail ray (*Taeniura meyeni*) at Kirra Reef.

Other species observed included a squid (*Uroteuthis* sp.) at Palm Beach Bait Reef and Cook Island West, cuttlefish (*Sepia* sp.) at Cook Island West, octopus (*Octopus* sp.) at Kirra and several green turtles (*Chelonia mydas*) at Cook Island West and Cook Island North.

There was no significant difference in the composition of fish assemblages among reefs (ANOSIM Global R = 0.06, $p > 0.05$) due to a high degree of variation between each of the replicate RUVS; however, based on a visual assessment of the nMDS ordination of the summed MaxN within a reef location there were only subtle differences in assemblages among reefs. The assemblages were more similar at Kirra, Cook Island North, Cook Island West and Palm Beach reefs (Figure 3.18). Cook Island South and Palm Beach Bait reefs were more dissimilar due to a lower number of total species present. Increasing the number of replicate RUVs from three to five would likely improve the statistical result in this case.

Most fish species recorded were common to the region. No threatened or protected fish species listed under the Queensland's *Nature Conservation Act 1992* or nationally under the Commonwealth's *Environmental Protection and Biodiversity Conservation Act 1999* were recorded in the 2020 survey. The eastern blue groper (*Achoerodus viridis*) is partly protected under the 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 Cook Island West (MaxN = 2), Cook Island North (MaxN = 3), and Palm Beach Reef (MaxN = 1) (Figure 3.17b). No invasive fish species were recorded.

a) White-spotted eagle ray (*Aetobatus ocellatus*) b) Eastern blue groper (*Achoerodus viridis*)

Figure 3.17 White-spotted eagle ray and Eastern blue grouper recorded in 2020

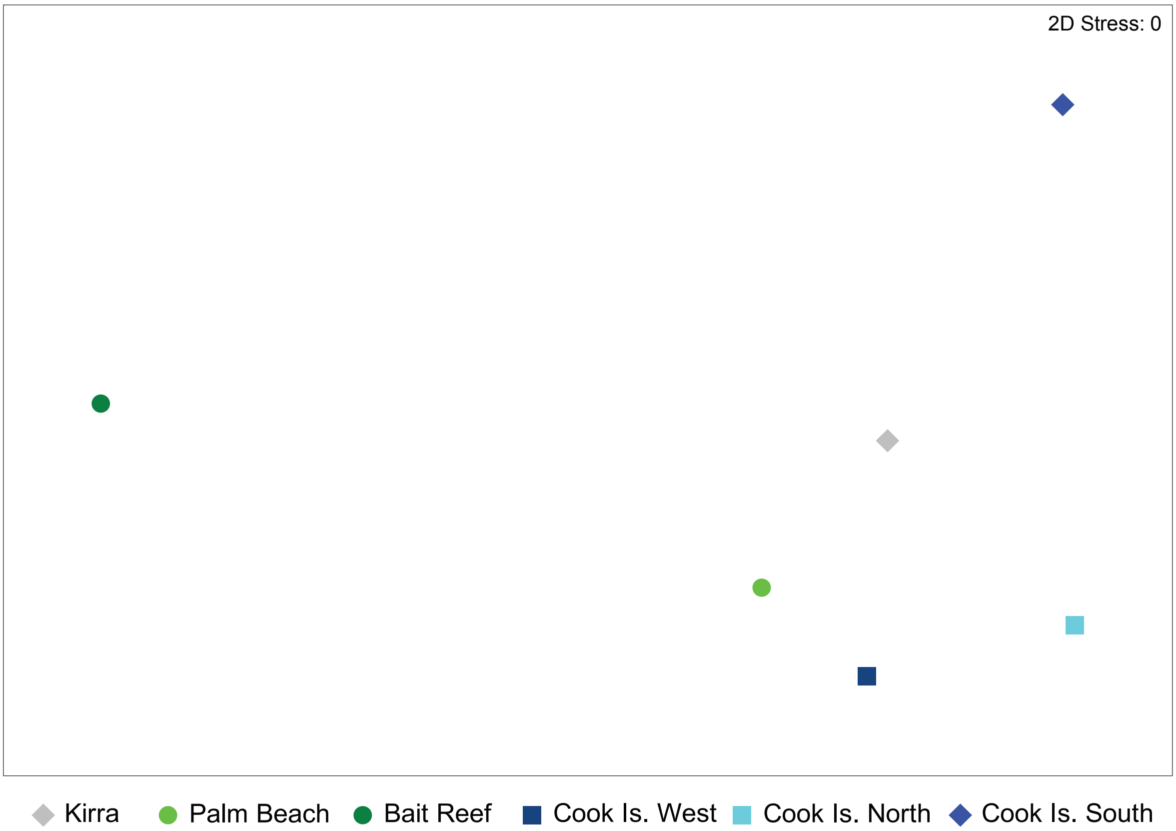


Figure 3.18 nMDS ordination of the differences in the composition of fish assemblage among reefs in 2020

3.4.1 Species Richness of Fish Assemblages

In 2020, species richness varied among reefs, with the highest number of species recorded at Cook Island North (65 species) and Cook Island West (61 species), followed by Kirra Reef (46 species) and Palm Beach Reef (42 species), and fewest species recorded at Cook Island South (21 species) (Figure 3.19; Table 3.2; Appendix E). In the past few years, there has been little difference in the species richness between Kirra and Palm Beach reefs during any one survey, despite differences in the total number of species between survey periods (Figure 3.19). A variety of fish species have been recorded on the reefs during the various surveys between 1995 and 2020 (Figure 3.19). Differences in the numbers of species identified may be related to changes in sampling techniques, personnel completing the surveys and monitoring events occurring during different times of the year.

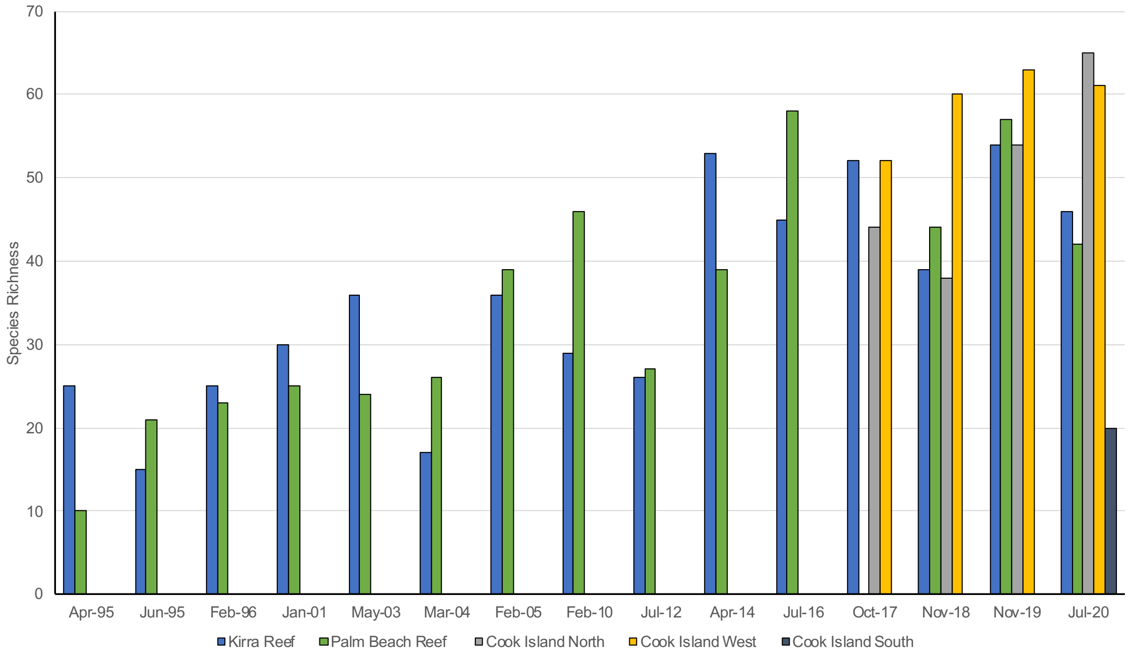


Figure 3.19 The total abundance of species at each site sampled during field surveys between 1995 and 2020. Where no fish were recorded at a site, the site was not sampled that year.

Table 3.2 Total species richness and abundance among the reefs in 2020

	Kirra Reef	Palm Beach Reef	Palm Beach Bait Reef	Cook Island North Reef	Cook Island West Reef	Cook Island South Reef
Total Species Richness	46	42	6	65	61	20
Total Abundance (Summed MaxN)	496	170	314	471	211	27

3.4.2 Relative Abundance of Fish Assemblages

The total abundance of fish (summed MaxN from RUV footage) was highest at Kirra Reef and Cook Island North, with a total of 496 and 471 individuals recorded, respectively (Table 3.2). While not directly comparable due failures in data collection limiting the extent of video assessed, fish were also abundant at Palm Beach Bait Reef with a total of 314 individuals recorded. The lowest abundance was recorded at Cook Island South with only 27 individuals (Table 3.2). Abundant schools (approximately 100 to 400 individuals) of yellowtail scad (*Trachurus novaezelandiae*) dominated the assemblages at Palm Beach Bait, Kirra and Palm Beach reefs (Figure 3.20). Large schools of Eastern pomfred (*Schuettea scalaripinnis*) made up the majority of the total abundance at Cook Island North Reef. Large schools of fish (i.e. yellowtail scad) were not present at Cook Island South during this survey.

Excluding the schooling fish, several species of herbivorous surgeonfish were frequently recorded and abundant at all reefs. Gunther's wrasse (*Psuedolabrus guentheri*) was the only fish recorded at all reefs, and had a similar abundance at each reef. Stripey (*Microcanthus strigatus*), green moon wrasse (*Thalassoma lutescens*), backsaddle goatfish (*Parupeneus spilurus*), and banded goatfish (*Parupeneus multifasciatus*) occurred at all reefs excluding Palm Beach Bait Reef. Yellowfin Bream (*Acanthopagrus australis*) was also frequently at all reefs, excluding Kirra and Cook Island South reefs, with up to 35 individuals recorded at Cook Island West Reef (Appendix E, Table E.2).

a)

b)

Figure 3.20 Dense school of yellowtail scad at a) Kirra Reef and (b) Palm Beach reefs

a) Goldspotted Sweetlip (*Plectorhinchus flavomaculatus*) at Cook Island West Reef

b) Starry puffer (*Arothron stellatus*) at Palm Beach Reef

c) Eastern pomfret (*Schuettea scalaripinnis*) at Kirra Reef

d) Blue angelfish (*Pomacanthus semicirculatus*) at Cook Island North Reef

e) Barred soapfish (*Diploprion bifasciatum*) at Cook Island South Reef

f) Clown Triggerfish (*Balistoides conspicillum*) at Cook Island North Reef

Figure 3.21 Examples of fish species observed on RUVS among the reefs in July 2020

3.4.3 Trophic Level and Habitat Preferences of Fish

The trophic level composition of fish assemblages varied among reefs (Figure 3.22 and Table E.2). The trophic composition at Kirra Reef and Palm Beach Reef was dominated by carnivorous species (41 and 45% of species respectively), with omnivores the next most diverse group accounting for 25 and 34% of species, respectively. Other trophic groups such as omnivorous species with herbivorous tendencies, corallivorous, planktivorous, and herbivorous species each contributed less than 10% of the composition (Figure 3.22). The only detritivore species (mimic surgeonfish *Acanthurus pyroferus*) was recorded at Kirra Reef (Table E.2). The trophic composition was similar between Cook Island North and Cook Island West reefs, which was expected given their close proximity, with assemblages dominated by omnivorous species and omnivorous species with herbivorous tendencies, and carnivorous species, with fewer herbivorous, corallivorous and planktivorous species. Cook Island South and Palm Beach Bait reefs had a lower diversity in trophic composition with assemblages dominated by carnivores and omnivores (Figure 3.22).

Between 84 and 91% of species recorded at each reef during the 2020 survey were reef-associated species, which was expected (Table E.2). Pelagic species were more abundant at Cook Island West and Palm Beach reefs than on the other reefs, with up to six species recorded (Table E.2).

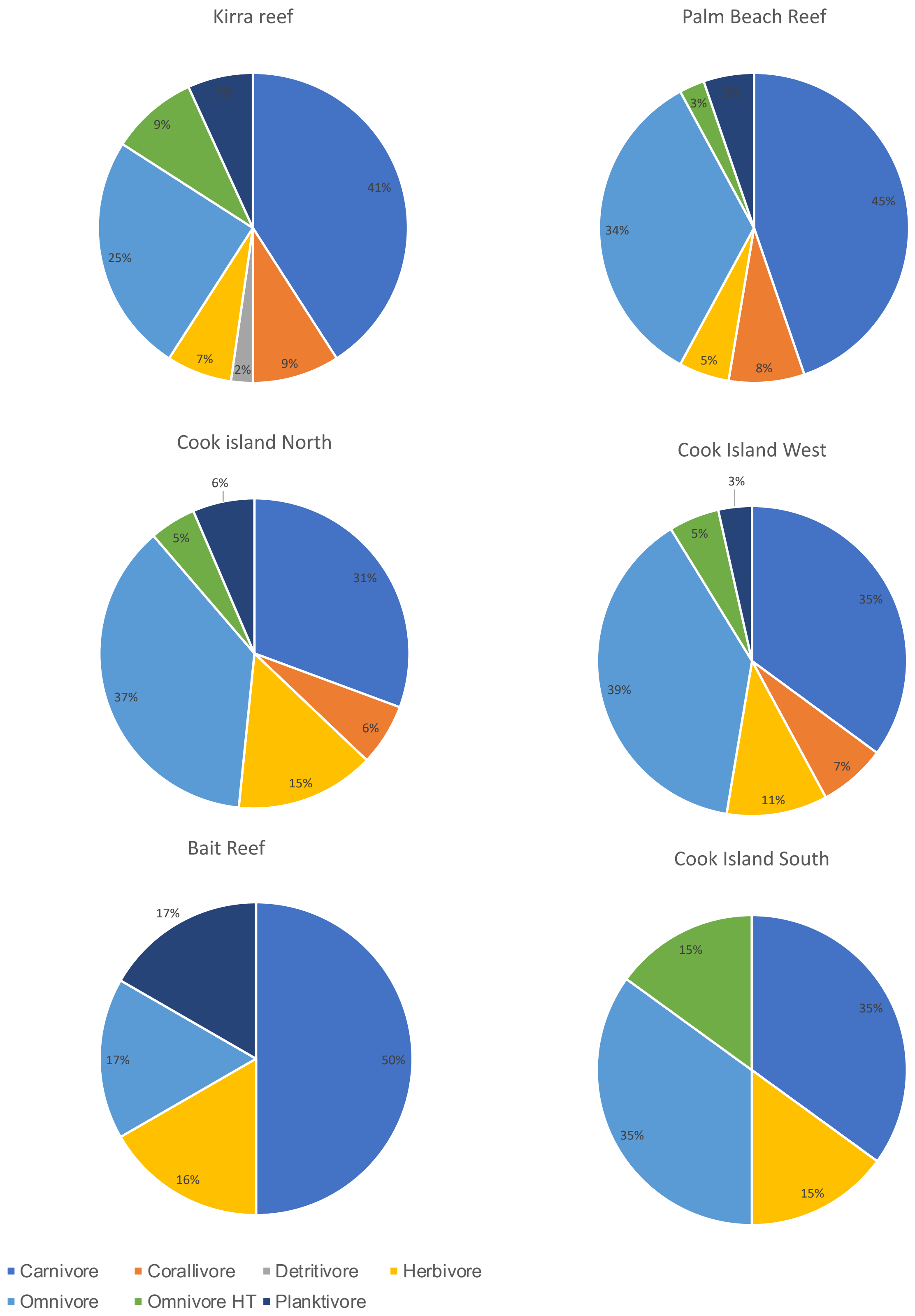


Figure 3.22 Composition of fish communities (number of species) recorded at each reef system in relation to the trophic level

3.5 Threatened and Invasive Species

3.5.1 Species of Conservation Significance

Of the species listed on the Protected Matters Search Tool as potentially occurring in the area (Appendix C; Figure 3.23), several species of conservation significance are known or likely to frequent the reefs, including:

- black rockcod (*Epinephelus daemelii*) listed as vulnerable.
- humpback whale (*Megaptera novaeangliae*) listed as vulnerable and migratory
- southern right whale (*Eubalaena australis*), listed as endangered and migratory
- loggerhead turtle (*Caretta caretta*), listed as endangered and migratory
- green turtle (*Chelonia mydas*) listed as vulnerable and migratory (Figure 3.23)
- leatherback turtle (*Dermochelys coriacea*) listed as endangered and migratory
- hawksbill turtle (*Eretmochelys imbricate*) listed as vulnerable and migratory
- grey nurse shark (*Carcharias taurus*) listed as critically endangered
- great white shark (*Carcharodon carcharias*) listed as vulnerable and migratory
- Indo-Pacific humpback dolphin (*Sousa chinensis*) listed as migratory, and
- manta ray (*Manta alfredi*) listed as migratory.

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

Figure 3.23 Green turtle (*Chelonia mydas*) at Cook Island

3.5.2 Introduced Species

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

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

3.6 Abiotic Conditions

3.6.1 Water Quality

To assess water quality conditions at each reef during the field survey, depth profiles for several physicochemical parameters were assessed. In 2020, the temperature, salinity, pH, concentration of dissolved oxygen and turbidity were relatively consistent both with depth and among the reefs (Figure 3.5). Surface and bottom PAR was also measured at Cook Island South, Cook Island West and Kirra Reef, with benthic light attention ranging from 0.5 to 0.8 µmol/s^2. It declined by between 73% and 92% with depth. PAR can be influenced by a range of factors including the time when samples were collected and weather conditions (e.g. amount of incident sunlight due to cloud cover or season), which is more likely given that the turbidity remained low (<1 NTU) among all reefs.

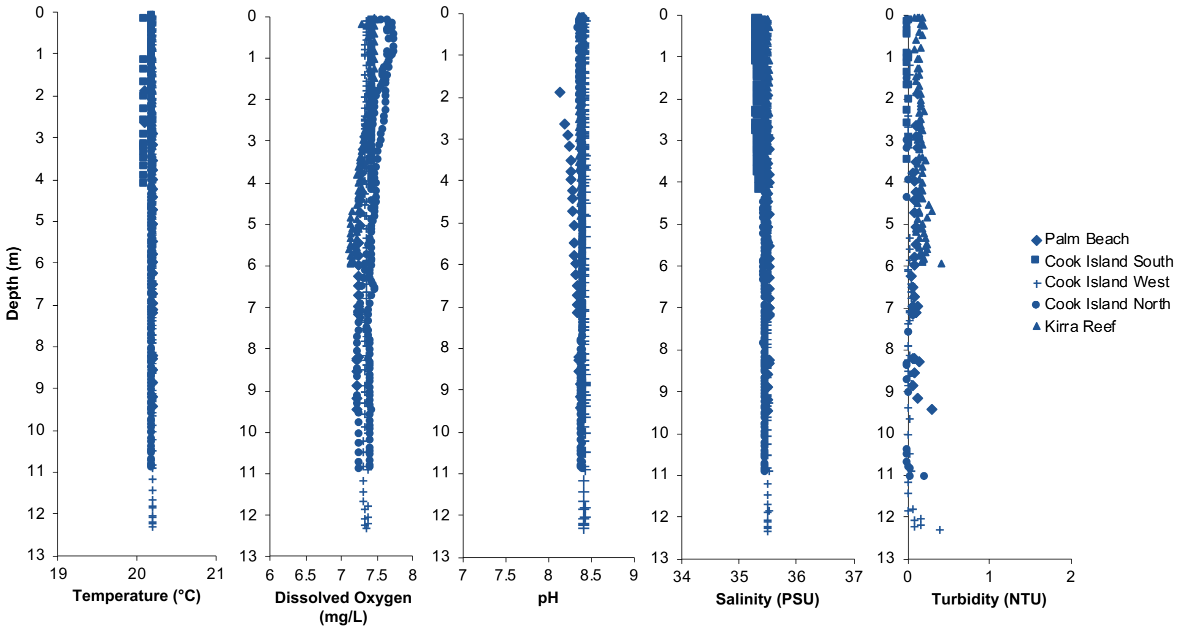


Figure 3.24 Vertical profiles of physicochemical water quality parameters among sites

3.6.2 Wave Conditions

The swell direction in the region typically ranges from a north-north-west to south-south-east direction (Figure 3.25; Ecosure 2016). Between 10 July 2019 and 10 July 2020, swell direction was predominantly from the east (57%) and northeast (35%), with most waves <1 m (39%) or 1 to 2 m (57%) (Figure 3.25). During the period assessed, significant wave heights (>3 m) were rare (<1%) and only occurred on 2 days (13 and 14 February 2020), predominantly from the east-north-east (Figure 3.25). Previous analyses of long-term (01/01/2000 to 31/05/2016) wave data for Tweed Heads by Ecosure indicates swell occurs predominately from an east (36%) or east-south-east (34%) direction and waves are generally < 1 m (26%) or 1 to 2 m (40%), with significant wave heights (>3 m) also rare (<1%) (Ecosure 2016). Overall, swell in the year prior to the survey (10 July 2019 to 10 July 2020) was typical of the region, with significant wave events unlikely to cause major changes to sand movements in the region.

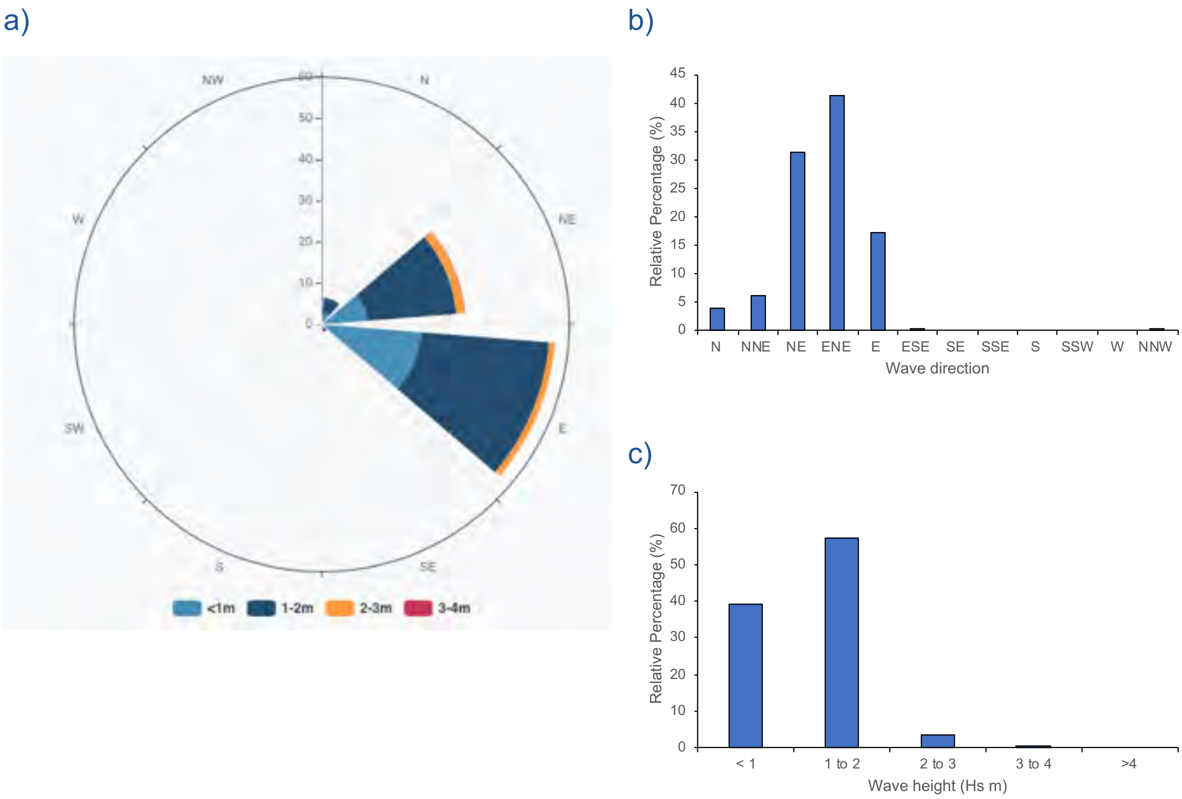


Figure 3.25 Wave data collected at Tweed Heads wave rider buoy between 10 July 2019 and 10 July 2020, showing a) wave heights and direction; b) percent relative frequency of wave directions and precent relative frequency of wave heights.

4 Discussion and Conclusions

4.1 Kirra Reef

4.1.1 Changes in Reef Area

On Kirra Reef, there has been large changes in the area of exposed rock through time, either through sand burial or exhumation, resulting in changes to the benthic communities capable of growing on the reef. Prior to major artificial changes in sand movements (other than minor influences of the original Tweed River training walls built in 1891), Kirra Reef was partially covered by sand, which naturally varied as a result of longshore drift of sand. 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 and the commencement of the TSB project between the mid-1980s to 2001, resulted in sand accretion, with the extent of Kirra Reef decreasing, but a relatively large area still remained uncovered. During the initial years of operating the sand bypassing system between 2001 to 2008, large quantities of sand were delivered to Southern Gold Coast beaches, and as predicted in the Environmental Impact Statement (EIS), 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 drift of sand since 2008. In 2009, parts of Kirra Reef were uncovered, likely due to a series of storm events and the removal of sand from the intertidal zone. The area of uncovered reef increased between 2009 and 2012 and has been relatively stable since 2012. The extent of Kirra Reef is unlikely to substantially change unless there are successive major storms in the region (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.

In 2020, the areal extent was assessed using satellite imagery and change in depth based on 2018, 2019 and 2020 hydrographic surveys. There has been little change in the areal extent and depth of sand around Kirra Reef over the past 12 months. Indeed, there has been little change in the areal extent since 2012, which is indicative of greater balance in the sand transport budget as a result of past changes to the TSB operation. The stability in the availability and extent of rock habitat has enabled the benthic community to increase in biodiversity, with an increase in the coverage of sessile invertebrates displacing foliose macroalgae and other early colonising species in some sections of the reef, particularly on vertical surfaces.

4.1.2 Benthic Communities

Following exhumation in 2009, the benthic faunal and floral communities on Kirra Reef have shown signs of succession, becoming more similar to reefs in the Gold Coast and Tweed Coast Region. However, in recent years the monitoring program has shown succession slowing with consistent differences, in that benthic communities at Kirra Reef that were dominated by differences in the coverage of foliose and turfing macroalgae and ascidians, with low cover of soft and hard corals. Mobile benthic invertebrates, dominated by feather stars, were also abundant at Kirra Reef compared with other reefs. Temporal variability among reefs has been attributed to natural variation (including storms and ongoing disturbance from shifting sands and wave action) but may also be due to differences in the timing of when reef habitat became available, differences in the settlement and recruitment of benthic species and / or the survival due to differences in the assemblage of predators present at Kirra Reef relative to other reefs.

Despite changes in the composition of benthic communities through time, it appears that Kirra Reef has not changed substantially in the coverage of sessile fauna on horizontal surfaces relative to other reefs, and indeed in the 2020 survey, there is a more diverse sessile invertebrate assemblage occurring on vertical surfaces, with a higher total and average species richness than recorded at the other reefs around Cook Island that are dominated by longer-lived hard coral species and macroalgae.

4.1.3 Algal Assemblages

Fleshy macroalgae such as Sargassum can colonise bare substrata before other taxa such as sessile invertebrates, causing physical damage to sessile invertebrates that have recently settled, preventing them from establishing on tropical coral reefs (Diaz-Pulido & McCook 2002). Macroalgae and turf algae dominated (34–59% cover) benthic communities at Kirra Reef prior to the commencement of TSB and have also dominated in recent years on horizontal surfaces. The high coverage of Sargassum in recent years may be indicative of the more recent disturbance history at Kirra Reef, which may have been timed with a recruitment pulse enabling a high proportion of the area to be colonised by macroalgae (McCook et al. 2001) or could reflect a reduced abundance of herbivorous fish and invertebrates, which can be important in controlling fleshy macroalgae on reefs (McCook 1997; McCook et al. 2001). The exact mechanism for why the algal assemblages differ among the reefs has not been specifically tested; however, a greater proportion of herbivorous fish was recorded at Cook Island reefs than at Kirra or Palm Beach reef (Figure 3.22), which may have contributed to reduced coverage of some algal species on those reefs. Cook Island reefs and Palm Beach Reef are also likely to be more sheltered from wave action than Kirra Reef. While horizontal and vertical surfaces differed at Kirra reef (indicative of potential impacts from smothering), sedimentation impacts to algal communities such as reduced crustose coralline algae (Fabricius and De'ath 2001) or reduced density and growth of young Sargassum (Umar et al. 1998) do not appear to be evident given the relatively similar or higher abundance of these species at Kirra Reef compared to other reefs.

4.1.4 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. Generally, in 2020, the sessile invertebrate assemblages on Kirra Reef were more diverse than in previous surveys, and similar in composition or more diverse than that recorded on other nearshore reefs such as

Palm Beach Bait Reef, which are not exposed to impacts associated with the TSB. While there was a lack of abundant hard coral species (covering on average less than 0.5% of the area) on Kirra Reef, the coverage of soft corals was the highest recorded among the reefs and there was also high coverage of sessile ascidians and sponges (Figure 3.14). Both hard and soft corals have typically been low in previous survey. Hard corals averaged 0–2% in 1995 and 1996 prior to TSB and between 2003 and 2005 following the commencement of TSB and was <0.2% between 2010 and 2019 following emergence from burial. Soft corals averaged 2–10% in 1995 and 1996 prior to TSB, 1–6% between 2003 and 2005 following the commencement of TSB and <1% between 2010 and 2019 following emergence from burial. Overall, many of sessile invertebrates are susceptible to impacts from smothering and sand scouring, and the high abundance on Kirra Reef, including hard and soft coral, in 2020 is indicative of assemblages that are recovering from past impacts.

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 may always differ from surrounding reefs. This may be due to natural spatial variation in a range of factors, including larval supply and survival, density of predators and disturbance regime. For example, Palm Beach is generally deeper and less prone to wave action and Cook Island is likely to have greater nutrient availability due to the large bird colonies in the area fertilising the water from faeces. Ideally the comparative reefs would be standardised for reef depth and also distance from the shore so that they are exposed to relatively similar physical disturbance vectors; however, there are limited reefs along the coast that are representative of the range of conditions experienced at Kirra Reef. Maximising the number of reef locations will provide greatest opportunity to assess the relative change over time given the degree of natural variability likely to occur. Assessing the relative difference in assemblages among these comparative reefs provides the degree of natural variation likely to occur due to other coastal processes operating in the local area. In 2020, Palm Beach Bait Reef (an inshore low vertical relief reef) was assessed for the first time, and the sessile invertebrate assemblages did not differ from those recorded at Kirra Reef on horizontal surfaces (although algal assemblage differed). While the lower profile of Palm Beach Bait Reef limited the availability of vertical surfaces, Palm Beach Bait Reef had a similar sessile invertebrate assemblage to Kirra Reef on horizontal surfaces. Palm Beach Bait Reef is at a similar depth to Kirra, close to a dynamic sandy shore, and appears to provide a good comparative reef for ongoing monitoring of changes in benthic communities at Kirra Reef where this is required.

4.1.5 Fish Assemblages

There was generally no difference in the overall composition of fish assemblages among reefs. A total of 116 bony and cartilaginous fishes, representative of 34 families were recorded across all reefs in 2020 with species from the families Labridae (wrasses) and Pomacentridae (damselfishes) being the most diverse. Most fish species recorded were common to the region and have previously been recorded; however, in the July 2020 survey, an additional 28 species not previously recorded were observed across all 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 2020 survey. The eastern blue groper (*Achoerodus viridis*) is partly protected under the 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 Cook Island West, Cook Island North and Palm Beach reefs. No invasive fish species were recorded in 2020.

At Kirra Reef there was moderate species richness relative to the other reefs, but the highest abundance due to the presence of numerous schools of yellowtail scad (*Trachurus novaezelandiae*). Carnivorous species dominated the assemblage on Kirra Reef accounting for 41% of the species occurring on the reef. Omnivorous fish were also common. In contrast, fish assemblages at Cook Island reefs were dominated by a more even spread of carnivorous and omnivorous species and had a greater proportion of herbivores present. Differences in the composition of fish among the reefs could alter the composition of benthic communities, for example, it is known that having a suitable number and diversity of grazing herbivores can control algal populations on tropical reefs (Hughes et al. 2007; Burkepike & Hay 2008) creating space for other species such as hard corals and other sessile invertebrates to settle and grow. Differences in the composition of fish assemblages can be related to a variety of factors, including differences in recreational fishing pressure (Edwards et al. 2014; Pinheiro & Joyeux 2015).

4.1.6 Recommendations for Ongoing Monitoring

Sand delivery through the sand bypassing system has been relatively consistent (mimicking natural longshore movements) since 2008, and in recent years since 2016, the benthic communities have been relatively stable (but subject to natural variation and ongoing disturbance from shifting sands, wave action and consumers). Results in 2020 were similar to recent reef monitoring program reports which have shown relatively consistent results, in that:

- the greatest temporal change at Kirra Reef has been in the area of exposed reef, which has remained relatively stable since 2012;
- benthic communities at Kirra Reef have been dominated by macroalgae and ascidians, with low cover of soft and hard corals since 2014; and,
- benthic communities at Kirra Reef differ significantly from communities at most of the comparative reefs in the region that do not share the same disturbance history (except for sessile invertebrates on horizontal surfaces at Palm Beach Bait Reef in 2020); Despite the apparent differences, the community on Kirra Reef has a diverse group of sessile invertebrates, macroalgae and fish occurring there, which is representative of the diversity of communities found elsewhere.

Given the consistent results over the past few years of monitoring, it is recommended that the program moves to a trigger-based event monitoring program. The proposed triggers could include abiotic changes such as operational changes in TSB and/or indicators directly related to sand deposition e.g. sedimentation above a threshold (as measured using hydrographic survey) or a substantial change in the accretion / erosion of sand around the reef as measured through changes in reef area from aerial photos or direct hydrographic survey.

4.2 Cook Island Aquatic Reserve Baseline

The current survey assessed communities at three separate reef locations at Cook Island, as well as several other reefs in the region. Cook Island reefs were generally dominated by a high abundance of macroalgae (particularly turf forming species) and articulate coralline algae, which was relatively consistent among different reef locations around the island and surface orientations. These reefs generally had a high cover of long-lived hard corals (such as those from the genus *Paragoniastrea, Turbinaria* and encrusting *Porites*) compared to other reefs in the region. Particularly, Cook Island North and Cook Island South reef locations, which had a higher proportion of hard coral typically growing on horizontal surfaces. There were differences in benthic communities among reef locations separated by only a few hundred metres, indicating a diverse array of communities around the island. Of note, there was a moderate to dense patch of seagrass (dominated by *Halophila ovalis*), which are protected under the NSW *Fisheries Management Act 1995*, recorded at Cook Island West adjacent to Cook Island. Cook Island reefs had the highest diversity of mobile invertebrate assemblages compared to other reefs, including a variety of feather stars, sea urchins and sea stars. A diverse and abundant fish community inhabited the Cook Island reefs, including large schools of Eastern pomfred (*Schuettea scalaripinnis*) and yellowtail scad at some locations. A greater proportion of herbivorous fish was recorded at Cook Island reefs. Green turtles (listed as threatened and migratory under the EPBC Act) and the eastern blue groper (*Achoerodus viridis*) partly protected under the Fisheries Management (General) Regulation 2019 were also recorded at Cook Island reefs.

The Cook Island Aquatic Reserve forms an important part of the NSW Marine Protected Areas, which are managed under legislation to protect marine biodiversity and to support marine science, recreation and education. Several protected and threatened species (e.g. giant Queensland groper) are known to occur within the Aquatic Reserve. Given the high ecological value of Cook Island and spatial and temporal differences in the composition of benthic communities and fish assemblages among the reef locations around Cook Island, we would recommend completing multiple surveys prior to any sand disposal to provide a suitable baseline for benthic and fish communities against which changes can be assessed. At least one additional baseline monitoring event should be completed within 6 months prior to any disposal activities to account for high natural variability in the region. Ongoing monitoring at Cook Island Aquatic Reserve following any sand disposal activities should be completed at adequate spatial and temporal scales to determine any potential impacts of future TSB operations adjacent to benthic communities in the Reserve.

It is recommended that the monitoring program focus on key indicator species that are known to be impacted by changes in sedimentation such as the coverage of hard and soft corals, ascidians and seagrass. Note that seagrass has only been recorded at one area around Cook Island, therefore a measure of direct impact before, during and after sand disposal would be necessary as suitable comparative areas may be difficult to identify.

The monitoring program should also include direct measures of sedimentation into the monitoring program, as this would provide a leading indicator as to the potential for any impact and may also be used to trigger any additional assessment of the reef communities, where background sedimentation is exceeded.

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Appendix A Desktop Review for Site Selection

There are differences in the location of comparative reef among years in the Kirra Reef Biota Monitoring Program (ESP 2019; Table A.1). Ideally the comparative reefs would be standardised for reef depth and also distance from the shore so that they are exposed to relatively similar physical disturbance vectors; however, there are limited reefs along the coast that are representative of the range of conditions experienced at Kirra Reef. Given the disturbance history of natural and artificial sand movement (e.g. almost complete burial between 2006 and 2008) and unique position (e.g. shallow, close to shore and subject to shifting sands and wave action), benthic communities at Kirra Reef may always differ from surrounding reefs (ESP 2019). This may be due to natural spatial variation in a range of factors, including larval supply and survival, density of predators and disturbance regime. For example, Palm Beach is generally deeper and less prone to wave action and Cook Island is likely to have greater nutrient availability due to the large bird colonies in the area fertilising the water from faeces. Maximising the number of reef locations will provide greatest opportunity to assess the relative change over time given the degree of natural variability likely to occur. A review of potential reef locations (Figure A3.1) is provided in Table A3.2 and was based upon an assessment of aerial imagery and nearshore bathymetry (Google Earth 2020; Queensland Government 2020a); existing information presented in TSB reports (Ecosure 2016; frc environmental 2017; 2018; 2019) and local knowledge (from ecologist previously involved in the monitoring and local divers). Overall, proposed sites for the 2020 Kirra Reef Biota Monitoring Program were selected based on:

- Physical attributes (e.g. depth, swell exposure, natural disturbances etc), with similarities to previously impacted (Kirra Reef) and potentially impacted (between Cook Island and Fingal Head) sites desirable for comparative sites
- Benthic assemblages present, with similarities to previously impacted (Kirra Reef) and potentially impacted (between Cook Island and Fingal Head) sites desirable for comparative sites
- Consistency with the historic reef monitoring program in order to assess temporal variation (Table A3.1) and alignment with TSB environmental monitoring obligations, and
- Logistics and safety, which can also influence the suitability of repeatedly accessing reefs each year.

Site selection and rational for the ongoing monitoring program, includes:

- Kirra Reef – as required under as required under EMS Subplan B14 to assess potential impacts of the sand bypassing system activities
- Cook Island Reef South – potentially impacted site, baseline data required for proposed sand placement activities in adjacent areas
- Cook Island Reef West – potentially impacted site, baseline data required for proposed sand placement activities in adjacent areas
- Cook Island North – unimpacted comparative site, monitored previously between 2016 and 2019 so provides a good indication of temporal variation in the region;

sampling multiple and comparative site near Cook Island will reduce spatial variability and increase the ability to detect potential impacts from the sand placement activities

- Palm Beach Reef –comparative site, monitored previously in all years (except 2017) so provides an important indication of temporal variation in the region
- Palm Beach Bait Reef– comparative site, not monitored previously, local diver suggests physical attributes (relatively shallow and close to the shore) and benthic assemblages are similar to Kirra Reef.

Kingscliff reef was not included in the 2020 monitoring program as access is limited by conditions (particularly swell) so it cannot be reliability sampled in successive years (and was not sampled in 2017 and 2018 due to access constraints). The new artificial reef at Palm Beach may provide a useful indication of early recruitment and succession in the region, but is unlikely to be a good comparative site as it is much shallower than other sites (although where data is available from other monitoring programs this is likely to provide useful information of the ecology of reefs in the region). Snapper Rocks and Fingal Headland are unlikely to be useful sites as they are dynamic intertidal headlands, which will likely influence the ability reliability sampled in successive years and to detect potential impacts due to the large natural variability in exposure (from tidal and sand movements).

There may always remain spatial differences in the composition of benthic assemblages among comparative reefs, with the assemblages generally more similar to each other on comparative reefs than to Kirra Reef. This is likely due to differences in the burial characteristics of Kirra reef (among other potential influences described above). Therefore, rather than focussing on the distinct difference in assemblage composition, the comparative reefs provide an indication as to what the reef assemblages might look like following successional processes from bare habitat. The relative difference in assemblages among these comparative reefs provides the degree of natural variation likely to occur due to other coastal processes operating in the local area. Thus, it would be logical to expect that over time as the trajectory of succession continues on Kirra Reef, that the assemblages would become more similar in composition to those on comparative (undisturbed) reefs and eventually the difference between Kirra reef and the comparative reefs would be at or lower than the difference among comparative reefs. This requires an assessment of the magnitude of difference among the comparative reefs (natural spatial variability) versus the magnitude of difference between Kirra and the comparative reefs. The magnitude of difference should decline over time and be within the degree of natural spatial variability.

Table A.1 Previous sampling effort undertaken as part of the Kirra Reef Biota Monitoring Program.

Reef	Site or transect	Code	Apr 1995	Jun 1995	Feb 1996	Jan 2001	May 2003	Feb 2005	Feb 2010	Jul 2012	Apr 2014	Mar 2015	Jul 2016	May 2017	May 2018	May 2019
Kirra Reef	Kirra Reef outer 1	KRO1	✓	✓	✓	✓	-	-	-	✓	-	-	-	-	-	-
	Kirra Reef outer 2	KRO2	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-
	Kirra Reef outer 3	KRO3	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	-	-	-
	Kirra Reef inner 1	KRI1	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-	-
	Kirra Reef inner 2	KRI2	✓	✓	✓	✓	✓	-	-	✓	-	-	-	-	-	-
	Kirra Reef inner 3	KRI3	✓	✓	✓	✓	✓	-	-	-	-	-	-	-	-	-
	Kirra Reef new 1	KRN1	-	-	-	-	-	✓	✓	✓	✓	✓	✓	-	-	-
	Kirra Reef new 2	KRN2	-	-	-	-	-	✓	✓	✓	✓	✓	✓	-	-	-
	Kirra Reef new 3	KRN3	-	-	-	-	-		✓	-	-	-	-	-	-	-
	Kirra Reef (no site)	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	✓
Palm Beach	Palm Beach 1^	PB1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-
	Palm Beach 2^	PB2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-
	Palm Beach 3^	PB3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-
	Palm Beach (no sites)	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓
Cook Island	Cook Island North 1	CIN1	-	-	-	-	-	-	-	-	-	-	✓	-	-	-
	Cook Island North 2	CIN2	-	-	-	-	-	-	-	-	-	-	✓	-	-	-
	Cook Island North 3	CIN3	-	-	-	-	-	-	-	-	-	-	✓	-	-	-
	Cook Island North (no sites)*	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	✓
	Cook Island West (no sites)	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓	✓
Kingscliff	Kingscliff North 1	KCN1	-	-	-	-	-	-	-	-	-	-	✓	-	-	-
	Kingscliff North 2	KCN2	-	-	-	-	-	-	-	-	-	-	✓	-	-	-
	Kingscliff North 3	KCN3	-	-	-	-	-	-	-	-	-	-	✓	-	-	-
	Kingscliff (no sites)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓

^ Location of PB1, PB2 and PB3 has been inconsistent between surveys (e.g. between 2014 and 2015; frc environmental 2014; frc environmental 2015).

* Location of Cook Island North moved approximately 250 m north east between the 2016 and 2017 monitoring programs.

Appendix B Areal Extent

Table B.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
May 2020*	3,678	-	-
May-19	3,161	-	-
May-18	2,659	-	-
Feb-17	3,263	-	-
May-16	3,326	118,146	388,072
Mar-15	2,788	-	-
Jun-14	-	-	383,495
Apr-14	2,920	117,960	-
Jun-13	2,801	-	385,849
May-13	3,539	-	-
Aug-12	3,700	-	-
Nov-11	1,044	-	-
Jul-10		115,397	-
May-10	965	-	-
Nov-09	1,009	-	-
Apr-04	1,851	-	-
Nov-03	3,369	-	-
Aug-02	8,515	-	-
Feb-01	20,398	-	-
Oct-96	15,885	-	-
Jan-95	40,813^	-	-
Nov-89	36,265	-	-
Nov-74	>6078	-	-
Feb-72	22,111	-	-
Oct-62	>4583	-	-
Nov-35	>3350	-	-
Sep-30	>6063	-	-

1 Data prior to 2020 sourced from Ecosure 2016 and frc environmental 2019, and references herein.

* Imagery based on 10cm resolution imagery collected in May 2020 Datum: GDA2020

^note that at this time there were three sections to the reef, an inner southern section, eastern section and the northern section of the reef, of which the present day reef was part of, in deeper water. At this time the northern section of the reef was approximately 5900m^2.

Appendix C Protected Matters Search Tool Results

Australian Government
Department of the Environment and Energy

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

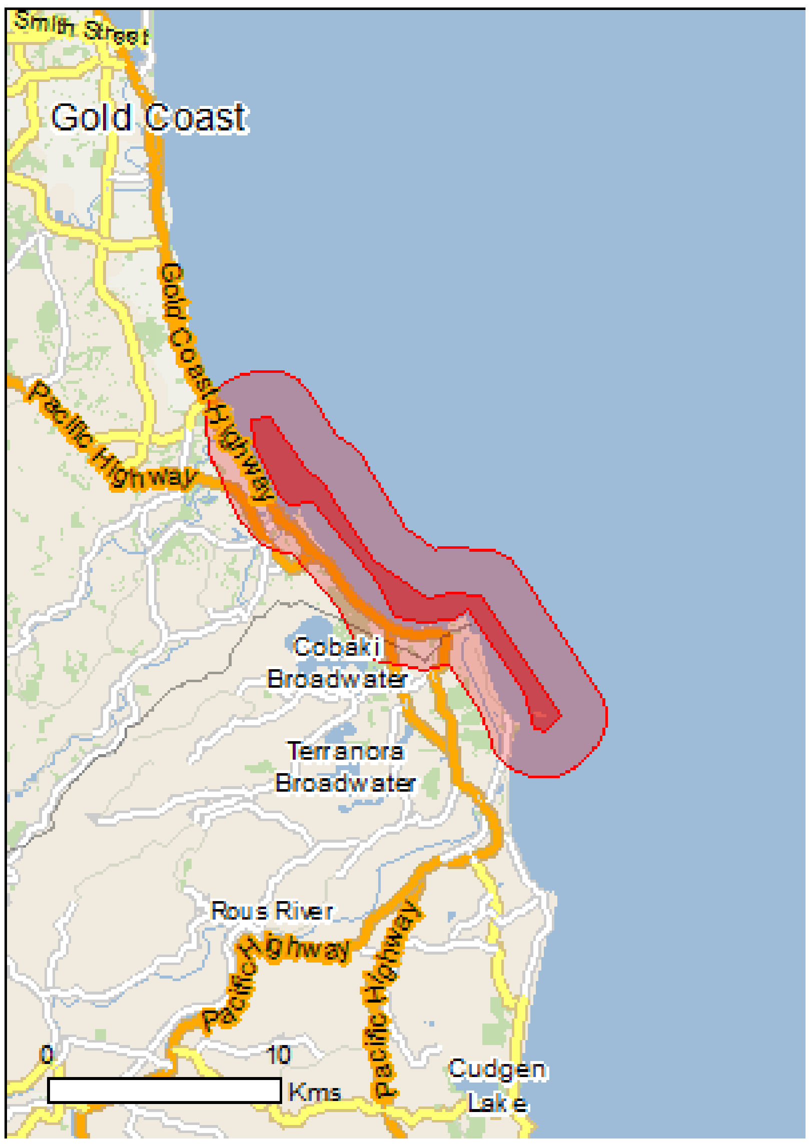
Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

Report created: 21/08/20 10:49:00

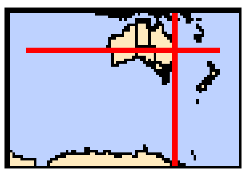
Summary
Details
- Matters of NES
- Other Matters Protected by the EPBC Act
- Extra Information

Caveat
Acknowledgements



This map may contain data which are ©Commonwealth of Australia (Geoscience Australia), ©PSMA 2010

Coordinates
Buffer: 2.0Km



Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	3
Listed Threatened Species:	88
Listed Migratory Species:	77

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	2
Commonwealth Heritage Places:	None
Listed Marine Species:	111
Whales and Other Cetaceans:	13
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	5
Regional Forest Agreements:	1
Invasive Species:	39
Nationally Important Wetlands:	2
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Ecological Communities [Resource Information]

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Name	Status	Type of Presence
Coastal Swamp Oak (Casuarina glauca) Forest of New South Wales and South East Queensland ecological community	Endangered	Community likely to occur within area
Littoral Rainforest and Coastal Vine Thickets of Eastern Australia	Critically Endangered	Community likely to occur within area
Subtropical and Temperate Coastal Saltmarsh	Vulnerable	Community likely to occur within area

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Anthochaera phrygia		
Regent Honeyeater [82338]	Critically Endangered	Foraging, feeding or related behaviour likely to occur within area
Botaurus poiciloptilus		
Australasian Bittern [1001]	Endangered	Species or species habitat likely to occur within area
Calidris canutus		
Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea		
Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
Calidris tenuirostris		
Great Knot [862]	Critically Endangered	Roosting known to occur within area
Charadrius leschenaultii		
Greater Sand Plover, Large Sand Plover [877]	Vulnerable	Roosting known to occur within area
Charadrius mongolus		
Lesser Sand Plover, Mongolian Plover [879]	Endangered	Roosting known to occur within area
Cyclopsitta diophthalma coxeni		
Coxen's Fig-Parrot [59714]	Endangered	Species or species habitat may occur within area
Diomedea antipodensis		
Antipodean Albatross [64458]	Vulnerable	Species or species habitat may occur within area
Diomedea antipodensis gibsoni		
Gibson's Albatross [82270]	Vulnerable	Species or species habitat may occur within area

Name	Status	Type of Presence
Diomedea epomophora Southern Royal Albatross [89221]	Vulnerable	Species or species habitat may occur within area
Diomedea exulans Wandering Albatross [89223]	Vulnerable	Species or species habitat may occur within area
Erythrotriorchis radiatus Red Goshawk [942]	Vulnerable	Species or species habitat likely to occur within area
Falco hypoleucos Grey Falcon [929]	Vulnerable	Species or species habitat may occur within area
Fregetta grallaria grallaria White-bellied Storm-Petrel (Tasman Sea), White-bellied Storm-Petrel (Australasian) [64438]	Vulnerable	Species or species habitat likely to occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat known to occur within area
Lathamus discolor Swift Parrot [744]	Critically Endangered	Species or species habitat known to occur within area
Limosa lapponica baueri Bar-tailed Godwit (baueri), Western Alaskan Bar-tailed Godwit [86380]	Vulnerable	Species or species habitat known to occur within area
Limosa lapponica menzbieri Northern Siberian Bar-tailed Godwit, Bar-tailed Godwit (menzbieri) [86432]	Critically Endangered	Species or species habitat may occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Pachyptila turtur subantarctica Fairy Prion (southern) [64445]	Vulnerable	Species or species habitat known to occur within area
Phoebetria fusca Sooty Albatross [1075]	Vulnerable	Species or species habitat may occur within area
Pterodroma leucoptera leucoptera Gould's Petrel, Australian Gould's Petrel [26033]	Endangered	Species or species habitat may occur within area
Pterodroma neglecta neglecta Kermadec Petrel (western) [64450]	Vulnerable	Foraging, feeding or related behaviour may occur within area
Rostratula australis Australian Painted Snipe [77037]	Endangered	Species or species habitat known to occur within area
Sternula nereis nereis Australian Fairy Tern [82950]	Vulnerable	Species or species habitat may occur within area

Name	Status	Type of Presence
Thalassarche cauta Shy Albatross [89224]	Endangered	Species or species habitat may occur within area
Thalassarche eremita Chatham Albatross [64457]	Endangered	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche salvini Salvin's Albatross [64463]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Thinornis cucullatus cucullatus Hooded Plover (eastern), Eastern Hooded Plover [90381]	Vulnerable	Species or species habitat may occur within area
Turnix melanogaster Black-breasted Button-quail [923]	Vulnerable	Species or species habitat likely to occur within area
Fish		
Epinephelus daemelii Black Rockcod, Black Cod, Saddled Rockcod [68449]	Vulnerable	Species or species habitat may occur within area
Frogs		
Litoria olongburensis Wallum Sedge Frog [1821]	Vulnerable	Species or species habitat known to occur within area
Mixophyes fleayi Fleay's Frog [25960]	Endangered	Species or species habitat likely to occur within area
Insects		
Argynnis hyperbius inconstans Australian Fritillary [88056]	Critically Endangered	Species or species habitat may occur within area
Phyllodes imperialis smithersi Pink Underwing Moth [86084]	Endangered	Species or species habitat may occur within area
Mammals		
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat may occur within area
Chalinolobus dwyeri Large-eared Pied Bat, Large Pied Bat [183]	Vulnerable	Species or species habitat likely to occur within area
Dasyurus maculatus maculatus (SE mainland population) Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quoll (southeastern mainland population) [75184]	Endangered	Species or species habitat likely to occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area

Name	Status	Type of Presence
Megaptera novaeangliae		
Humpback Whale [38]	Vulnerable	Congregation or aggregation known to occur within area
Petauroides volans		
Greater Glider [254]	Vulnerable	Species or species habitat may occur within area
Phascolarctos cinereus (combined populations of Qld, NSW and the ACT)		
Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) [85104]	Vulnerable	Species or species habitat known to occur within area
Potorous tridactylus tridactylus		
Long-nosed Potoroo (SE Mainland) [66645]	Vulnerable	Species or species habitat likely to occur within area
Pseudomys novaehollandiae		
New Holland Mouse, Pookila [96]	Vulnerable	Species or species habitat likely to occur within area
Pteropus poliocephalus		
Grey-headed Flying-fox [186]	Vulnerable	Roosting known to occur within area
Xeromys myoides		
Water Mouse, False Water Rat, Yirrkoo [66]	Vulnerable	Species or species habitat likely to occur within area
Other		
Thersites mitchellae		
Mitchell's Rainforest Snail [66774]	Critically Endangered	Species or species habitat likely to occur within area
Plants		
Acacia attenuata		
[10690]	Vulnerable	Species or species habitat likely to occur within area
Acronychia littoralis		
Scented Acronychia [8582]	Endangered	Species or species habitat known to occur within area
Arthraxon hispidus		
Hairy-joint Grass [9338]	Vulnerable	Species or species habitat likely to occur within area
Baloghia marmorata		
Marbled Balogia, Jointed Baloghia [8463]	Vulnerable	Species or species habitat may occur within area
Bosistoa transversa		
Three-leaved Bosistoa, Yellow Satinheart [16091]	Vulnerable	Species or species habitat likely to occur within area
Cryptocarya foetida		
Stinking Cryptocarya, Stinking Laurel [11976]	Vulnerable	Species or species habitat known to occur within area
Cryptostylis hunteriana		
Leafless Tongue-orchid [19533]	Vulnerable	Species or species habitat may occur within area
Cynanchum elegans		
White-flowered Wax Plant [12533]	Endangered	Species or species habitat may occur within area
Diploglottis campbellii		
Small-leaved Tamarind [21484]	Endangered	Species or species habitat may occur within area
Endiandra floydii		
Floyd's Walnut [52955]	Endangered	Species or species habitat likely to occur within area

Name	Status	Type of Presence
Endiandra hayesii Rusty Rose Walnut, Velvet Laurel [13866]	Vulnerable	Species or species habitat likely to occur within area
Fontainea australis Southern Fontainea [24037]	Vulnerable	Species or species habitat may occur within area
Gossia fragrantissima Sweet Myrtle, Small-leaved Myrtle [78867]	Endangered	Species or species habitat may occur within area
Macadamia integrifolia Macadamia Nut, Queensland Nut Tree, Smooth-shelled Macadamia, Bush Nut, Nut Oak [7326]	Vulnerable	Species or species habitat known to occur within area
Macadamia tetraphylla Rough-shelled Bush Nut, Macadamia Nut, Rough-shelled Macadamia, Rough-leaved Queensland Nut [6581]	Vulnerable	Species or species habitat known to occur within area
Phaius australis Lesser Swamp-orchid [5872]	Endangered	Species or species habitat known to occur within area
Randia moorei Spiny Gardenia [10577]	Endangered	Species or species habitat known to occur within area
Samadera bidwillii Quassia [29708]	Vulnerable	Species or species habitat may occur within area
Sophora fraseri [8836]	Vulnerable	Species or species habitat likely to occur within area
Syzygium hodgkinsoniae Smooth-bark Rose Apple, Red Lilly Pilly [3539]	Vulnerable	Species or species habitat likely to occur within area
Syzygium moorei Rose Apple, Coolamon, Robby, Durobby, Watermelon Tree, Coolamon Rose Apple [12284]	Vulnerable	Species or species habitat known to occur within area
Thesium australe Austral Toadflax, Toadflax [15202]	Vulnerable	Species or species habitat may occur within area
Reptiles		
Caretta caretta Loggerhead Turtle [1763]	Endangered	Breeding known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Coeranoscincus reticulatus Three-toed Snake-tooth Skink [59628]	Vulnerable	Species or species habitat may occur within area
Delma torquata Adorned Delma, Collared Delma [1656]	Vulnerable	Species or species habitat may occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat known to occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat known to occur within area

Name	Status	Type of Presence
Furina dunmalli Dunmall's Snake [59254]	Vulnerable	Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding likely to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Sharks		
Carcharias taurus (east coast population) Grey Nurse Shark (east coast population) [68751]	Critically Endangered	Species or species habitat likely to occur within area
Carcharodon carcharias White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat known to occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Breeding may occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Species or species habitat may occur within area

Listed Migratory Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Migratory Marine Birds		
Anous stolidus Common Noddy [825]		Species or species habitat likely to occur within area
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardenna carneipes Flesh-footed Shearwater, Fleshy-footed Shearwater [82404]		Species or species habitat known to occur within area
Ardenna grisea Sooty Shearwater [82651]		Species or species habitat may occur within area
Ardenna pacifica Wedge-tailed Shearwater [84292]		Breeding known to occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat known to occur within area
Diomedea antipodensis Antipodean Albatross [64458]	Vulnerable	Species or species habitat may occur within area
Diomedea epomophora Southern Royal Albatross [89221]	Vulnerable	Species or species habitat may occur within area
Diomedea exulans Wandering Albatross [89223]	Vulnerable	Species or species habitat may occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat known to occur within area

Name	Threatened	Type of Presence
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Species or species habitat known to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Phoebetria fusca Sooty Albatross [1075]	Vulnerable	Species or species habitat may occur within area
Sternula albifrons Little Tern [82849]		Breeding may occur within area
Thalassarche cauta Shy Albatross [89224]	Endangered	Species or species habitat may occur within area
Thalassarche eremita Chatham Albatross [64457]	Endangered	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche salvini Salvin's Albatross [64463]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Migratory Marine Species		
Balaena glacialis australis Southern Right Whale [75529]	Endangered*	Species or species habitat likely to occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat may occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat may occur within area
Carcharodon carcharias White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat known to occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Breeding known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat known to occur within area
Dugong dugon Dugong [28]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat known to occur within area
Lamna nasus Porbeagle, Mackerel Shark [83288]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding likely to occur within area
Manta alfredi Reef Manta Ray, Coastal Manta Ray, Inshore Manta Ray, Prince Alfred's Ray, Resident Manta Ray [84994]		Species or species habitat may occur within area
Manta birostris Giant Manta Ray, Chevron Manta Ray, Pacific Manta Ray, Pelagic Manta Ray, Oceanic Manta Ray [84995]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Congregation or aggregation known to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Orcaella heinsohni Australian Snubfin Dolphin [81322]		Species or species habitat likely to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish [68442]	Vulnerable	Breeding may occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Species or species habitat may occur within area
Sousa chinensis Indo-Pacific Humpback Dolphin [50]		Breeding known to occur within area
Migratory Terrestrial Species		
Cuculus optatus Oriental Cuckoo, Horsfield's Cuckoo [86651]		Species or species habitat may occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat known to occur within area
Monarcha melanopsis Black-faced Monarch [609]		Species or species habitat known to occur within area
Monarcha trivirgatus Spectacled Monarch [610]		Species or species habitat known to occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Species or species habitat known to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat known to occur within area
Migratory Wetlands Species		

Name	Threatened	Type of Presence
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat known to occur within area
Arenaria interpres Ruddy Turnstone [872]		Roosting known to occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Roosting known to occur within area
Calidris alba Sanderling [875]		Roosting known to occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Calidris ruficollis Red-necked Stint [860]		Roosting known to occur within area
Calidris subminuta Long-toed Stint [861]		Roosting known to occur within area
Calidris tenuirostris Great Knot [862]	Critically Endangered	Roosting known to occur within area
Charadrius bicinctus Double-banded Plover [895]		Roosting known to occur within area
Charadrius leschenaultii Greater Sand Plover, Large Sand Plover [877]	Vulnerable	Roosting known to occur within area
Charadrius mongolus Lesser Sand Plover, Mongolian Plover [879]	Endangered	Roosting known to occur within area
Gallinago hardwickii Latham's Snipe, Japanese Snipe [863]		Roosting known to occur within area
Gallinago megala Swinhoe's Snipe [864]		Roosting likely to occur within area
Gallinago stenura Pin-tailed Snipe [841]		Roosting likely to occur within area
Limosa lapponica Bar-tailed Godwit [844]		Species or species habitat known to occur within area
Limosa limosa Black-tailed Godwit [845]		Roosting known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Numenius minutus Little Curlew, Little Whimbrel [848]		Roosting known to occur within area
Numenius phaeopus Whimbrel [849]		Roosting known to occur within area
Pandion haliaetus Osprey [952]		Breeding known to occur within area

Name	Threatened	Type of Presence
Pluvialis fulva Pacific Golden Plover [25545]		Roosting known to occur within area
Pluvialis squatarola Grey Plover [865]		Roosting known to occur within area
Thalasseus bergii Crested Tern [83000]		Breeding known to occur within area
Tringa brevipes Grey-tailed Tattler [851]		Roosting known to occur within area
Tringa incana Wandering Tattler [831]		Roosting known to occur within area
Tringa nebularia Common Greenshank, Greenshank [832]		Species or species habitat known to occur within area
Tringa stagnatilis Marsh Sandpiper, Little Greenshank [833]		Roosting known to occur within area
Xenus cinereus Terek Sandpiper [59300]		Roosting known to occur within area

Other Matters Protected by the EPBC Act

Commonwealth Land [Resource Information]

The Commonwealth area listed below may indicate the presence of Commonwealth land in this vicinity. Due to the unreliability of the data source, all proposals should be checked as to whether it impacts on a Commonwealth area, before making a definitive decision. Contact the State or Territory government land department for further information.

Name
Commonwealth Land -
Commonwealth Land - Australian Telecommunications Commission

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
Actitis hypoleucos Common Sandpiper [59309]		Species or species habitat known to occur within area
Anous stolidus Common Noddy [825]		Species or species habitat likely to occur within area
Anseranas semipalmata Magpie Goose [978]		Species or species habitat may occur within area
Apus pacificus Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardea alba Great Egret, White Egret [59541]		Breeding known to occur within area
Ardea ibis Cattle Egret [59542]		Species or species habitat may occur within area
Arenaria interpres Ruddy Turnstone [872]		Roosting known to occur within area
Calidris acuminata Sharp-tailed Sandpiper [874]		Roosting known to occur

Name	Threatened	Type of Presence
		within area
Calidris alba Sanderling [875]		Roosting known to occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
Calidris melanotos Pectoral Sandpiper [858]		Species or species habitat may occur within area
Calidris ruficollis Red-necked Stint [860]		Roosting known to occur within area
Calidris subminuta Long-toed Stint [861]		Roosting known to occur within area
Calidris tenuirostris Great Knot [862]	Critically Endangered	Roosting known to occur within area
Calonectris leucomelas Streaked Shearwater [1077]		Species or species habitat known to occur within area
Catharacta skua Great Skua [59472]		Species or species habitat may occur within area
Charadrius bicinctus Double-banded Plover [895]		Roosting known to occur within area
Charadrius leschenaultii Greater Sand Plover, Large Sand Plover [877]	Vulnerable	Roosting known to occur within area
Charadrius mongolus Lesser Sand Plover, Mongolian Plover [879]	Endangered	Roosting known to occur within area
Charadrius ruficapillus Red-capped Plover [881]		Roosting known to occur within area
Diomedea antipodensis Antipodean Albatross [64458]	Vulnerable	Species or species habitat may occur within area
Diomedea epomophora Southern Royal Albatross [89221]	Vulnerable	Species or species habitat may occur within area
Diomedea exulans Wandering Albatross [89223]	Vulnerable	Species or species habitat may occur within area
Diomedea gibsoni Gibson's Albatross [64466]	Vulnerable*	Species or species habitat may occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat known to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Species or species habitat known to occur within area
Gallinago hardwickii Latham's Snipe, Japanese Snipe [863]		Roosting known to occur within area

Name	Threatened	Type of Presence
Gallinago megala Swinhoe's Snipe [864]		Roosting likely to occur within area
Gallinago stenura Pin-tailed Snipe [841]		Roosting likely to occur within area
Haliaeetus leucogaster White-bellied Sea-Eagle [943]		Species or species habitat known to occur within area
Heteroscelus brevipes Grey-tailed Tattler [59311]		Roosting known to occur within area
Heteroscelus incanus Wandering Tattler [59547]		Roosting known to occur within area
Himantopus himantopus Pied Stilt, Black-winged Stilt [870]		Roosting known to occur within area
Hirundapus caudacutus White-throated Needletail [682]	Vulnerable	Species or species habitat known to occur within area
Larus novaehollandiae Silver Gull [810]		Breeding known to occur within area
Lathamus discolor Swift Parrot [744]	Critically Endangered	Species or species habitat known to occur within area
Limosa lapponica Bar-tailed Godwit [844]		Species or species habitat known to occur within area
Limosa limosa Black-tailed Godwit [845]		Roosting known to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Monarcha melanopsis Black-faced Monarch [609]		Species or species habitat known to occur within area
Monarcha trivirgatus Spectacled Monarch [610]		Species or species habitat known to occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Species or species habitat known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Numenius minutus Little Curlew, Little Whimbrel [848]		Roosting known to occur within area
Numenius phaeopus Whimbrel [849]		Roosting known to occur within area

Name	Threatened	Type of Presence
Pachyptila turtur Fairy Prion [1066]		Species or species habitat known to occur within area
Pandion haliaetus Osprey [952]		Breeding known to occur within area
Phoebetria fusca Sooty Albatross [1075]	Vulnerable	Species or species habitat may occur within area
Pluvialis fulva Pacific Golden Plover [25545]		Roosting known to occur within area
Pluvialis squatarola Grey Plover [865]		Roosting known to occur within area
Puffinus carneipes Flesh-footed Shearwater, Fleshy-footed Shearwater [1043]		Species or species habitat known to occur within area
Puffinus griseus Sooty Shearwater [1024]		Species or species habitat may occur within area
Puffinus pacificus Wedge-tailed Shearwater [1027]		Breeding known to occur within area
Recurvirostra novaehollandiae Red-necked Avocet [871]		Roosting known to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat known to occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat known to occur within area
Sterna albifrons Little Tern [813]		Breeding may occur within area
Sterna bergii Crested Tern [816]		Breeding known to occur within area
Thalassarche cauta Shy Albatross [89224]	Endangered	Species or species habitat may occur within area
Thalassarche eremita Chatham Albatross [64457]	Endangered	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche salvini Salvin's Albatross [64463]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Thinornis rubricollis rubricollis Hooded Plover (eastern) [66726]	Vulnerable*	Species or species habitat may occur within area

Name	Threatened	Type of Presence
Tringa nebularia Common Greenshank, Greenshank [832]		Species or species habitat known to occur within area
Tringa stagnatilis Marsh Sandpiper, Little Greenshank [833]		Roosting known to occur within area
Xenus cinereus Terek Sandpiper [59300]		Roosting known to occur within area
Fish		
Acentronura tentaculata Shortpouch Pygmy Pipehorse [66187]		Species or species habitat may occur within area
Campichthys tryoni Tryon's Pipefish [66193]		Species or species habitat may occur within area
Corythoichthys amplexus Fijian Banded Pipefish, Brown-banded Pipefish [66199]		Species or species habitat may occur within area
Corythoichthys ocellatus Orange-spotted Pipefish, Ocellated Pipefish [66203]		Species or species habitat may occur within area
Festucalex cinctus Girdled Pipefish [66214]		Species or species habitat may occur within area
Filicampus tigris Tiger Pipefish [66217]		Species or species habitat may occur within area
Halicampus grayi Mud Pipefish, Gray's Pipefish [66221]		Species or species habitat may occur within area
Hippichthys cyanospilos Blue-speckled Pipefish, Blue-spotted Pipefish [66228]		Species or species habitat may occur within area
Hippichthys heptagonus Madura Pipefish, Reticulated Freshwater Pipefish [66229]		Species or species habitat may occur within area
Hippichthys penicillus Beady Pipefish, Steep-nosed Pipefish [66231]		Species or species habitat may occur within area
Hippocampus kelloggi Kellogg's Seahorse, Great Seahorse [66723]		Species or species habitat may occur within area
Hippocampus kuda Spotted Seahorse, Yellow Seahorse [66237]		Species or species habitat may occur within area
Hippocampus planifrons Flat-face Seahorse [66238]		Species or species habitat may occur within area
Hippocampus trimaculatus Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720]		Species or species habitat may occur within area
Hippocampus whitei White's Seahorse, Crowned Seahorse, Sydney Seahorse [66240]		Species or species habitat likely to occur within area
Lissocampus runa Javelin Pipefish [66251]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Maroubra perserrata Sawtooth Pipefish [66252]		Species or species habitat may occur within area
Micrognathus andersonii Anderson's Pipefish, Shortnose Pipefish [66253]		Species or species habitat may occur within area
Micrognathus brevirostris thorntail Pipefish, Thorn-tailed Pipefish [66254]		Species or species habitat may occur within area
Microphis manadensis Manado Pipefish, Manado River Pipefish [66258]		Species or species habitat may occur within area
Solegnathus dunckeri Duncker's Pipehorse [66271]		Species or species habitat may occur within area
Solegnathus hardwickii Pallid Pipehorse, Hardwick's Pipehorse [66272]		Species or species habitat may occur within area
Solegnathus spinosissimus Spiny Pipehorse, Australian Spiny Pipehorse [66275]		Species or species habitat may occur within area
Solenostomus cyanopterus Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183]		Species or species habitat may occur within area
Solenostomus paradoxus Ornate Ghostpipefish, Harlequin Ghost Pipefish, Ornate Ghost Pipefish [66184]		Species or species habitat may occur within area
Stigmatopora nigra Widebody Pipefish, Wide-bodied Pipefish, Black Pipefish [66277]		Species or species habitat may occur within area
Syngnathoides biaculeatus Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279]		Species or species habitat may occur within area
Trachyrhamphus bicoarctatus Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280]		Species or species habitat may occur within area
Urocampus carinirostris Hairy Pipefish [66282]		Species or species habitat may occur within area
Vanacampus margaritifer Mother-of-pearl Pipefish [66283]		Species or species habitat may occur within area
Mammals		
Dugong dugon Dugong [28]		Species or species habitat may occur within area
Reptiles		
Astrotia stokesii Stokes' Seasnake [1122]		Species or species habitat may occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Breeding known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Foraging, feeding or

Name	Threatened	Type of Presence
		related behaviour known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Species or species habitat known to occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat known to occur within area
Hydrophis elegans Elegant Seasnake [1104]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding likely to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Foraging, feeding or related behaviour known to occur within area
Pelamis platurus Yellow-bellied Seasnake [1091]		Species or species habitat may occur within area

Whales and other Cetaceans [Resource Information]

Name	Status	Type of Presence
Mammals		
Balaenoptera acutorostrata Minke Whale [33]		Species or species habitat may occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat may occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat may occur within area
Delphinus delphis Common Dophin, Short-beaked Common Dolphin [60]		Species or species habitat may occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area
Grampus griseus Risso's Dolphin, Grampus [64]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Congregation or aggregation known to occur within area
Orcaella brevirostris Irrawaddy Dolphin [45]		Species or species habitat likely to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Sousa chinensis Indo-Pacific Humpback Dolphin [50]		Breeding known to occur within area
Stenella attenuata Spotted Dolphin, Pantropical Spotted Dolphin [51]		Species or species habitat may occur within area

Name	Status	Type of Presence
Tursiops aduncus Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418]		Species or species habitat likely to occur within area
Tursiops truncatus s. str. Bottlenose Dolphin [68417]		Species or species habitat may occur within area

Extra Information

State and Territory Reserves [Resource Information]

Name	State
Burleigh Head	QLD
Cook Island	NSW
Currumbin Hill	QLD
Tallebudgera Creek	QLD
Ukerebagh	NSW

Regional Forest Agreements [Resource Information]

Note that all areas with completed RFAs have been included.

Name	State
North East NSW RFA	New South Wales

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Acridotheres tristis Common Myna, Indian Myna [387]		Species or species habitat likely to occur within area
Anas platyrhynchos Mallard [974]		Species or species habitat likely to occur within area
Carduelis carduelis European Goldfinch [403]		Species or species habitat likely to occur within area
Columba livia Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Lonchura punctulata Nutmeg Mannikin [399]		Species or species habitat likely to occur within area
Passer domesticus House Sparrow [405]		Species or species habitat likely to occur within area
Pycnonotus jocosus Red-whiskered Bulbul [631]		Species or species habitat likely to occur within area
Streptopelia chinensis Spotted Turtle-Dove [780]		Species or species habitat likely to occur

Name	Status	Type of Presence
		within area
Sturnus vulgaris Common Starling [389]		Species or species habitat likely to occur within area
Frogs		
Rhinella marina Cane Toad [83218]		Species or species habitat known to occur within area
Mammals		
Bos taurus Domestic Cattle [16]		Species or species habitat likely to occur within area
Canis lupus familiaris Domestic Dog [82654]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Feral deer Feral deer species in Australia [85733]		Species or species habitat likely to occur within area
Lepus capensis Brown Hare [127]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Rattus norvegicus Brown Rat, Norway Rat [83]		Species or species habitat likely to occur within area
Rattus rattus Black Rat, Ship Rat [84]		Species or species habitat likely to occur within area
Sus scrofa Pig [6]		Species or species habitat likely to occur within area
Vulpes vulpes Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Alternanthera philoxeroides Alligator Weed [11620]		Species or species habitat likely to occur within area
Anredera cordifolia Madeira Vine, Jalap, Lamb's-tail, Mignonette Vine, Anredera, Gulf Madeiravine, Heartleaf Madeiravine, Potato Vine [2643]		Species or species habitat likely to occur within area
Asparagus aethiopicus Asparagus Fern, Ground Asparagus, Basket Fern, Sprengi's Fern, Bushy Asparagus, Emerald Asparagus [62425]		Species or species habitat likely to occur within area
Asparagus africanus Climbing Asparagus, Climbing Asparagus Fern [66907]		Species or species habitat likely to occur within area
Asparagus plumosus Climbing Asparagus-fern [48993]		Species or species habitat likely to occur within area

Name	Status	Type of Presence
Asparagus scandens		
Asparagus Fern, Climbing Asparagus Fern [23255]		Species or species habitat likely to occur within area
Cabomba caroliniana		
Cabomba, Fanwort, Carolina Watershield, Fish Grass, Washington Grass, Watershield, Carolina Fanwort, Common Cabomba [5171]		Species or species habitat likely to occur within area
Chrysanthemoides monilifera		
Bitou Bush, Boneseed [18983]		Species or species habitat likely to occur within area
Chrysanthemoides monilifera subsp. rotundata		
Bitou Bush [16332]		Species or species habitat likely to occur within area
Dolichandra unguis-cati		
Cat's Claw Vine, Yellow Trumpet Vine, Cat's Claw Creeper, Funnel Creeper [85119]		Species or species habitat likely to occur within area
Genista sp. X Genista monspessulana		
Broom [67538]		Species or species habitat may occur within area
Hymenachne amplexicaulis		
Hymenachne, Olive Hymenachne, Water Stargrass, West Indian Grass, West Indian Marsh Grass [31754]		Species or species habitat likely to occur within area
Lantana camara		
Lantana, Common Lantana, Kamara Lantana, Large-leaf Lantana, Pink Flowered Lantana, Red Flowered Lantana, Red-Flowered Sage, White Sage, Wild Sage [10892]		Species or species habitat likely to occur within area
Pinus radiata		
Radiata Pine Monterey Pine, Insignis Pine, Wilding Pine [20780]		Species or species habitat may occur within area
Rubus fruticosus aggregate		
Blackberry, European Blackberry [68406]		Species or species habitat likely to occur within area
Salvinia molesta		
Salvinia, Giant Salvinia, Aquarium Watermoss, Kariba Weed [13665]		Species or species habitat likely to occur within area
Senecio madagascariensis		
Fireweed, Madagascar Ragwort, Madagascar Groundsel [2624]		Species or species habitat likely to occur within area
Reptiles		
Hemidactylus frenatus		
Asian House Gecko [1708]		Species or species habitat likely to occur within area
Ramphotyphlops braminus		
Flowerpot Blind Snake, Brahminy Blind Snake, Cacing Besi [1258]		Species or species habitat likely to occur within area

Nationally Important Wetlands [Resource Information]

Name	State
Cook Island Nature Reserve	NSW
Ukerebagh Island Nature Reserve	NSW

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-28.200892 153.577993,-28.200892 153.579023,-28.200287 153.576963,-28.187881 153.572156,-28.159735 153.551214,-28.162762 153.545377,-28.164275 153.533361,-28.162459 153.522374,-28.15126 153.516195,-28.123407 153.490789,-28.124315 153.481519,-28.120076 153.477399,-28.102815 153.468473,-28.094941 153.467443,-28.093729 153.473966,-28.110992 153.487356,-28.116442 153.495252,-28.143086 153.514135,-28.156103 153.535077,-28.153984 153.545034,-28.154892 153.555677,-28.196354 153.586576,-28.201498 153.580396,-28.200892 153.577993

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- -Office of Environment and Heritage, New South Wales
- -Department of Environment and Primary Industries, Victoria
- -Department of Primary Industries, Parks, Water and Environment, Tasmania
- -Department of Environment, Water and Natural Resources, South Australia
- -Department of Land and Resource Management, Northern Territory
- -Department of Environmental and Heritage Protection, Queensland
- -Department of Parks and Wildlife, Western Australia
- -Environment and Planning Directorate, ACT
- -Birdlife Australia
- -Australian Bird and Bat Banding Scheme
- -Australian National Wildlife Collection
- -Natural history museums of Australia
- -Museum Victoria
- -Australian Museum
- -South Australian Museum
- -Queensland Museum
- -Online Zoological Collections of Australian Museums
- -Queensland Herbarium
- -National Herbarium of NSW
- -Royal Botanic Gardens and National Herbarium of Victoria
- -Tasmanian Herbarium
- -State Herbarium of South Australia
- -Northern Territory Herbarium
- -Western Australian Herbarium
- -Australian National Herbarium, Canberra
- -University of New England
- -Ocean Biogeographic Information System
- -Australian Government, Department of Defence
- Forestry Corporation, NSW
- -Geoscience Australia
- -CSIRO
- -Australian Tropical Herbarium, Cairns
- -eBird Australia
- -Australian Government – Australian Antarctic Data Centre
- -Museum and Art Gallery of the Northern Territory
- -Australian Government National Environmental Science Program
- -Australian Institute of Marine Science
- -Reef Life Survey Australia
- -American Museum of Natural History
- -Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
- -Tasmanian Museum and Art Gallery, Hobart, Tasmania
- -Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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Appendix D Detailed Statistical Analyses

Table D.1 PERMANOVA of the difference in the composition of benthic communities among reefs in 2020

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	7675	**4.20**	**0.003**
Reef	5	50703	**11.05**	**0.001**
Site (Reef)	12	4659	**5.76**	**0.001**
Orientation x Reef	4	8186	**4.48**	**0.002**
Orientation x Site (Reef)	10	1827	**2.26**	**0.001**
Error	462	808		
Pairwise Comparisons	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
KR vs PB	**3.10**	**0.001**	**4.32**	**0.001**
KR vs PBBR	**2.07**	**0.023**	**No test**	
KR vs CIW	**1.93**	**0.024**	**3.48**	**0.001**
KR vs CIS	**2.41**	**0.002**	**4.09**	**0.001**
KR vs CIN	**2.31**	**0.006**	**3.79**	**0.001**
CIW vs CIN	**1.93**	**0.009**	**2.47**	**0.002**
CIW vs CIS	**1.94**	**0.005**	**2.98**	**0.001**
CIW vs PB	**3.15**	**0.001**	**4.80**	**0.001**
CIN vs CIS	**2.19**	**0.002**	**2.09**	**0.002**
CIN vs PB	**4.28**	**0.001**	**3.36**	**0.001**
CIS vs PB	**3.65**	**0.001**	**5.08**	**0.001**
CIS vs PBBR	**2.49**	**0.001**		
CIW vs PBBR	**2.24**	**0.004**		
CIN vs PBBR	**2.70**	**0.001**		
PB vs PBBR	**3.44**	**0.001**		
d) Horizontal vs Vertical	t Value	P (MC)		
KR	**2.84**	**0.002**		
PB	1.00	0.475		
CIW	1.25	0.238		
CIN	1.31	0.155		
CIS	**1.80**	**0.015**		

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 D.2 SIMPER of the difference in the composition of benthic communities between horizontal and vertical surfaces on Kirra Reef

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Horizontal	Vertical	Average dissimilarity = 67.13		
Turf algae	35.6	14.7	13.12	1.41	19.54
Sargassum sp	22.2	10.4	12.58	1.03	18.73
Polycarpa procera	6.7	13.1	6.3	1.12	9.39
Herdmania momus	0.0	10.3	5.57	0.89	8.3
Articulate Coralline Algae	8.8	6.1	4.16	1.13	6.2
Pyura stolonifera	4.9	6.7	4.11	0.88	6.12
Heteractis sp.	3.3	2.5	2.63	0.61	3.92
Spheciospongia confoederata	1.0	2.6	1.77	0.57	2.64
Haliclona sp. 2	2.5	1.8	1.59	1.02	2.37
Dictyota sp. 2	2.8	0.3	1.53	0.77	2.28
Dendronephtya sp. 2	0.0	2.5	1.33	0.34	1.98
Cribrochalina sp. 2	0.0	2.4	1.3	0.47	1.94
Caulerpa peltata	2.0	0.1	1.13	0.62	1.69
Polycarpa sp. 1	0.0	2.1	1.13	0.78	1.68
Cnemidocarpa stolonifera	1.1	2.2	1.12	1.1	1.67
Cribrochalina sp. 1	0.0	1.3	0.73	0.55	1.09
Padina sp. 1	1.1	0.0	0.62	0.46	0.92

Table D.3 PERMANOVA of the difference in the composition of algal assemblages among reefs in 2020

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	3485	2.22	0.069
Reef	5	39220	**9.66**	**0.001**
Site (Reef)	12	4127	**8.90**	**0.001**
Orientation x Reef	4	6741	**4.29**	**0.001**
Orientation x Site (Reef)	10	1572	**3.39**	**0.001**
Error	462	464		
Pairwise Tests	b) Horizontal Surfaces		c) Vertical Surfaces	
	t Value	P (MC)	t Value	P (MC)
KR vs PB	**3.10**	**0.005**	**3.76**	**0.002**
KR vs PBBR	**2.20**	**0.03**	No Test	
KR vs CIW	1.73	0.064	**3.01**	**0.005**
KR vs CIS	**2.23**	**0.026**	**3.38**	**0.002**
KR vs CIN	**2.22**	**0.033**	**3.22**	**0.006**
CIW vs CIN	1.88	0.051	**2.61**	**0.005**
CIW vs CIS	**1.75**	**0.048**	**2.69**	**0.006**
CIW vs PB	**3.03**	**0.001**	**5.29**	**0.001**
CIN vs CIS	**2.54**	**0.006**	**2.28**	**0.023**
CIN vs PB	**7.24**	**0.001**	**5.25**	**0.003**
CIS vs PB	**4.50**	**0.001**	**6.18**	**0.001**
CIS vs PBBR	1.40	0.169		
CIW vs PBBR	**1.95**	**0.037**		
CIN vs PBBR	**2.81**	**0.006**		
PB vs PBBR	**3.68**	**0.004**		
d) Horizontal vs Vertical	t Value	P (MC)		
KR	**2.34**	**0.02**		
PB	1.44	0.25		
CIW	1.09	0.39		
CIN	1.49	0.21		
CIS	1.89	0.06		

Table D.4 PERMANOVA of the difference in the coverage of algae among reefs in 2020

Source	df	a) Macroalgae MS	Pseudo-F	P(perm)	(b) Turfing Algae MS	Pseudo-F	P(perm)		(c) Coralline Algae MS	Pseudo-F	P(perm)
Orientation	1	2901	7.41	**0.017**	50	0.09	0.759		1	0.01	0.941
Reef	5	6508	5.84	**0.014**	28964	27.33	**0.001**		1265	7.93	**0.005**
Site (Reef)	12	1135	13.52	**0.001**	1076	5.97	**0.001**		162	3.83	**0.001**
Orientation x Reef	4	971	2.48	0.103	3171	5.60	**0.011**		224	2.39	0.125
Orientation x Site (Reef)	10	391	4.67	**0.001**	566	3.14	**0.001**		94	2.23	**0.016**
Error	462	84			180				42		
Pairwise Tests		d) Locations			(e) Horizontal		(f) Vertical		(g) Locations		
		t	P (MC)		t	P(MC)	t	P(MC)	t	P(MC)	
KR vs PB		2.74	0.063		5.30	**0.008**	15.74	**0.001**	3.99	**0.016**	
KR vs PBBR		3.26	**0.026**		1.08	0.328			3.75	**0.013**	
KR vs CIW		0.90	0.410		1.28	0.281	8.18	**0.001**	0.15	0.907	
KR vs CIS		2.60	0.060		1.50	0.207	9.19	**0.002**	0.52	0.629	
KR vs CIN		2.57	0.061		2.74	0.050	11.41	**0.001**	1.57	0.190	
CIW vs CIN		2.44	0.073		1.54	0.208	7.29	**0.003**	1.37	0.224	
CIW vs CIS		2.48	0.069		0.15	0.900	3.11	**0.030**	0.54	0.612	
CIW vs PB		2.70	**0.046**		4.96	**0.008**	18.96	**0.001**	2.59	0.055	
CIN vs CIS		0.44	0.697		1.71	0.151	1.01	0.372	1.80	0.173	
CIN vs PB		5.67	**0.008**		21.59	**0.002**	16.30	**0.001**	7.52	**0.003**	
CIS vs PB		1.61	0.156		6.05	**0.003**	7.38	**0.003**	23.52	**0.001**	
CIS vs PBBR		2.01	0.096		0.35	0.754			4.48	**0.001**	
CIW vs PBBR		3.04	**0.042**		0.18	0.864			2.14	0.104	
CIN vs PBBR		6.03	**0.001**		1.66	0.155			6.03	**0.001**	
PB vs PBBR		5.35	**0.001**		4.78	**0.014**			0.87	0.420	

Table D.5 SIMPER of the differences in the average coverage of algae among pairs of reefs on horizontal surfaces

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Kirra	Palm Beach	Average dissimilarity = 63.5		
Turf	25.1	80.2	43.6	2.25	68.6
Sargassum sp	16.3	0.0	11.0	0.80	17.3
ACA	7.4	0.2	5.3	1.11	8.3
	Kirra	Palm Beach Bait	Average dissimilarity = 57.0		
Turf	25.1	47.1	29.8	1.55	52.2
Sargassum sp	16.3	0.0	14.8	0.80	25.9
ACA	7.4	0.0	7.4	1.06	12.9
	Kirra	Cook Is. West	Average dissimilarity = 57.8		
Turf	25.1	49.7	25.5	1.56	44.2
Sargassum sp	16.3	0.0	12.0	0.81	20.8
ACA	7.4	4.4	5.6	1.13	9.7
Dictyota sp	1.5	5.7	4.6	0.84	8.0
Padina sp	0.6	5.0	4.2	0.75	7.3
Coralline Algae	0.1	2.8	2.4	0.61	4.1
	Kirra	Cook Is. North	Average dissimilarity = 56.4		
Turf	25.1	60.8	31.6	1.75	56.0
Sargassum sp	16.3	0.0	11.7	0.80	20.7
ACA	7.4	7.1	6.0	1.16	10.6
Coralline Algae	0.1	3.9	3.2	0.78	5.6
	Kirra	Cook Is. South	Average dissimilarity = 59.7		
Turf	25.1	55.1	30.5	1.64	51.1
Sargassum sp	16.3	0.0	12.7	0.80	21.2
ACA	7.4	1.3	6.1	1.06	10.2
Coralline Algae	0.1	7.2	6.0	0.80	10.1
	Cook Is. West	Cook Is. North	Average dissimilarity = 30.2		
Turf	49.7	60.8	12.9	1.30	42.6
ACA	4.4	7.1	4.7	1.12	15.5
Dictyota sp	5.7	0.5	3.8	0.83	12.7
Padina sp	5.0	0.1	3.5	0.75	11.5
Coralline Algae	2.8	3.9	3.2	0.93	10.7
	Cook Is. West	Cook Is. South	Average dissimilarity = 33.22		
Turf	49.7	55.1	14.5	1.17	43.7
Coralline Algae	2.8	7.2	5.3	0.89	15.9
Dictyota sp	5.7	0.6	4.3	0.81	13.0
Padina sp	5.0	0.1	3.7	0.73	11.2
ACA	4.4	1.3	3.4	0.84	10.1
	Cook Is. North	Cook Is. South	Average dissimilarity = 26.3		

Turf	60.8	55.1	14.0	1.04	53.4
Coralline Algae	3.9	7.2	5.2	0.93	19.7
ACA	7.1	1.3	5.1	1.04	19.2
	Cook Is. West	Palm Beach	Average dissimilarity = 34.2		
Turf	49.7	80.2	20.9	1.85	61.2
Dictyota sp	5.7	0.0	3.7	0.83	10.7
Padina sp	5.0	0.0	3.3	0.74	9.5
ACA	4.4	0.2	2.8	0.84	8.2
Coralline Algae	2.8	0.6	2.0	0.68	5.7
	Cook Is. North	Palm Beach	Average dissimilarity = 22.0		
Turf	60.8	80.2	13.9	1.29	63.0
ACA	7.1	0.2	4.5	1.07	20.4
Coralline Algae	3.9	0.6	2.5	0.84	11.3
	Cook Is. South	Palm Beach	Average dissimilarity = 26.3		
Turf	55.1	80.2	19.6	1.20	74.6
Coralline Algae	7.2	0.6	4.6	0.82	17.6
	Cook Is. West	Palm Beach Bait	Average dissimilarity = 35.6		
Turf	49.7	47.1	17.8	1.21	50.0
Dictyota sp	5.7	0.0	4.8	0.82	13.4
Padina sp	5.0	0.0	4.3	0.73	12.0
ACA	4.4	0.0	3.7	0.82	10.3
Coralline Algae	2.8	0.0	2.4	0.60	6.8
	Cook Is. North	Palm Beach Bait	Average dissimilarity = 31.1		
Turf	60.8	47.1	19.8	1.15	63.8
ACA	7.1	0.0	5.9	1.03	19.0
Coralline Algae	3.9	0.0	3.3	0.78	10.5
	Cook Is. South	Palm Beach Bait	Average dissimilarity = 31.2		
Turf	55.1	47.1	21.7	1.15	69.5
Coralline Algae	7.2	0.0	6.3	0.81	20.0
ACA	1.3	0.0	1.2	0.37	3.8
	Palm Beach	Palm Beach Bait	Average dissimilarity = 30.4		
Turf	80.2	47.1	28.7	1.38	94.5

ACA = Articulate Coralline Algae

Table D.6 PERMANOVA of the difference in the composition of sessile invertebrate assemblages among reefs in 2020

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	12359	**1.95**	**0.041**
Reef	5	62817	**6.72**	**0.001**
Site (Reef)	12	9456	**2.76**	**0.001**
Orientation x Reef	4	17562	**2.78**	**0.001**
Orientation x Site (Reef)	10	6327	**1.85**	**0.001**
Error	462	3426		
Pairwise Tests	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
KR vs PB	**3.29**	**0.001**	**4.84**	**0.001**
KR vs PBBR	1.43	0.142	No test	
KR vs CIW	**2.53**	**0.004**	**4.28**	**0.001**
KR vs CIS	**5.93**	**0.001**	**6.68**	**0.001**
KR vs CIN	**3.38**	**0.001**	**3.54**	**0.001**
CIW vs CIN	**1.97**	**0.009**	**2.31**	**0.007**
CIW vs CIS	**2.60**	**0.003**	**4.16**	**0.001**
CIW vs PB	**2.36**	**0.004**	**2.76**	**0.001**
CIN vs CIS	**2.10**	**0.006**	1.18	0.245
CIN vs PB	**3.53**	**0.001**	**2.06**	**0.017**
CIS vs PB	**6.09**	**0.001**	**4.38**	**0.001**
CIS vs PBBR	**6.19**	**0.001**		
CIW vs PBBR	**2.72**	**0.002**		
CIN vs PBBR	**3.81**	**0.001**		
PB vs PBBR	**4.17**	**0.001**		
d) Horizontal vs Vertical	t Value	P (MC)		
KR	**3.81**	**0.001**		
PB	1.15	0.333		
CIW	**1.82**	**0.049**		
CIN	0.98	0.486		
CIS	**1.89**	**0.032**		

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 D.7 PERMANOVA of the difference in the taxonomic richness of sessile invertebrates among reefs in 2020

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	46.08	**15.08**	**0.007**
Reef	5	224.10	**19.78**	**0.002**
Site (Reef)	12	11.48	**3.19**	**0.001**
Orientation x Reef	4	114.64	**37.52**	**0.001**
Orientation x Site (Reef)	10	3.06	0.85	0.572
Error	462	3.59		
Pairwise Tests	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
KR vs PB	0.73	0.515	**6.33**	**0.002**
KR vs PBBR	2.53	0.067		
KR vs CIW	**2.95**	**0.047**	**8.36**	**0.001**
KR vs CIS	2.31	0.077	**6.77**	**0.004**
KR vs CIN	0.10	0.924	**6.86**	**0.002**
CIW vs CIN	**3.40**	**0.038**	2.80	0.055
CIW vs CIS	**4.78**	**0.010**	**3.64**	**0.018**
CIW vs PB	**4.19**	**0.014**	**3.14**	**0.029**
CIN vs CIS	2.55	0.069	0.58	0.58
CIN vs PB	0.89	0.444	0.58	0.593
CIS vs PB	2.30	0.094	0.10	0.921
CIS vs PBBR	0.34	0.745		
CIW vs PBBR	**5.35**	**0.006**		
CIN vs PBBR	**3.08**	**0.036**		
PB vs PBBR	**3.04**	**0.037**		
d) Horizontal vs Vertical	t Value	P (MC)		
KR	**15.94**	**0.006**		
PB	0.05	0.966		
CIW	1.48	0.292		
CIN	0.31	0.765		
CIS	3.71	0.079		

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 D.8 PERMANOVA of the difference in the coverage of sessile invertebrates among reefs in 2020

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)
Orientation	1	679	**8.31**	**0.018**
Reef	5	10834	**35.70**	**0.001**
Site (Reef)	12	305	1.58	0.092
Orientation x Reef	4	8078	**98.79**	**0.001**
Orientation x Site (Reef)	10	82	0.42	0.941
Error	462	193		
Pairwise Tests	b) Horizontal		c) Vertical	
	t Value	P (MC)	t Value	P (MC)
KR vs PB	2.04	0.107	**13.11**	**0.001**
KR vs PBBR	1.45	0.214		
KR vs CIW	**4.41**	**0.010**	**13.06**	**0.001**
KR vs CIS	**4.69**	**0.010**	**11.87**	**0.001**
KR vs CIN	0.44	0.677	**10.05**	**0.001**
CIW vs CIN	**6.05**	**0.002**	2.52	0.066
CIW vs CIS	**12.70**	**0.001**	**5.62**	**0.007**
CIW vs PB	**4.68**	**0.016**	1.99	0.101
CIN vs CIS	**5.61**	**0.004**	1.31	0.259
CIN vs PB	**3.69**	**0.021**	1.23	0.277
CIS vs PB	**15.16**	**0.001**	**5.42**	**0.011**
CIS vs PBBR	2.27	0.079		
CIW vs PBBR	**5.54**	**0.005**		
CIN vs PBBR	1.25	0.296		
PB vs PBBR	**3.60**	**0.021**		
d) Horizontal vs Vertical	t Value	P (MC)		
KR	**28.38**	**0.002**		
PB	1.49	0.269		
CIW	0.86	0.495		
CIN	**8.27**	**0.02**		
CIS	**10.62**	**0.007**		

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 D.9 SIMPER of the differences in the average coverage of sessile invertebrate taxonomic groups among pairs of reefs on horizontal surfaces

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	Kirra Reef	Palm Beach	Average dissimilarity = 86.9		
Polycarpa procera	6.7	1.9	18.3	1.0	21.1
Pyura stolonifera	4.9	0.5	12.1	0.8	13.9
Spheciospongia confoederata	1.0	3.5	10.0	0.7	11.4
Heteractis sp.	3.3	1.5	9.9	0.6	11.4
Haliclona sp. 2	2.5	1.0	8.7	0.8	10.0
Cnemidocarpa stolonifera	1.1	0.7	4.6	0.7	5.3
Oceanapia sp.	0.0	1.3	4.3	0.6	4.9
Desmapsamma sp. 1	0.8	0.0	2.1	0.4	2.4
Spheciospongia sp. 4	0.0	0.6	2.1	0.4	2.4
Dendronephyta sp. 3	0.2	0.7	1.6	0.2	1.8
Cladeiella sp. 2	0.0	0.5	1.3	0.2	1.5
Dysidea sp. 3	0.0	0.4	1.2	0.3	1.4
Spheciospongia sp. 3	0.0	0.3	1.1	0.3	1.3
Spheciospongia montiformis	0.0	0.4	1.0	0.1	1.2
Encrusting sponge sp. 5	0.1	0.2	1.0	0.3	1.1
	Kirra Reef	Bait Reef	Average dissimilarity = 82.1		
Polycarpa procera	6.7	10.1	23.2	1.2	28.2
Pyura stolonifera	4.9	5.8	16.0	1.0	19.5
Haliclona sp. 2	2.5	0.1	6.7	0.7	8.2
Cnemidocarpa stolonifera	1.1	2.5	6.0	0.7	7.3
Heteractis sp.1	3.3	0.0	5.8	0.4	7.0
Cribrochalina sp. 2	0.0	2.4	5.6	0.6	6.8
Polycarpa sp. 1	0.0	1.8	3.9	0.6	4.8
Spheciospongia confoederata	1.0	1.0	3.2	0.5	3.8
Stelletta sp.	0.0	1.2	2.8	0.5	3.4
Desmapsamma sp. 1	0.8	0.0	1.8	0.3	2.2
	Kirra Reef	Cook Is. West	Average dissimilarity = 97.1		
Polycarpa procera	6.7	0.1	27.2	1.0	28.1
Pyura stolonifera	4.9	0.2	15.8	0.8	16.2
Haliclona sp. 2	2.5	0.0	12.3	0.7	12.6
Heteractis sp. 1	3.3	0.0	9.1	0.5	9.4
Cnemidocarpa stolonifera	1.1	0.5	6.5	0.6	6.7
Turbinaria mesenterina	0.0	1.0	3.3	0.3	3.4
Cladeiella sp. 2	0.0	1.2	3.2	0.3	3.3
Desmapsamma sp. 1	0.8	0.0	3.0	0.4	3.1
Spheciospongia montiformis	0.0	0.9	2.8	0.3	2.9
Spheciospongia confoederata	1.0	0.0	2.6	0.3	2.7
Oceanapia sp.	0.0	0.5	1.9	0.3	2.0
	Kirra Reef	Cook Is. North	Average dissimilarity = 92.5		
Polycarpa procera	6.7	0.0	15.3	0.9	16.6
Pyura stolonifera	4.9	3.7	14.1	1.0	15.2
Heteractis sp.	3.3	1.0	8.1	0.6	8.7
Haliclona sp. 2	2.5	0.0	6.8	0.7	7.3
Turbinaria mesenterina	0.0	2.2	5.1	0.4	5.5
Pocillipora damincornis	0.0	1.3	3.3	0.4	3.6
Cnemidocarpa stolonifera	1.1	0.0	3.0	0.6	3.2
Acanthastrea sp. 2	0.0	1.9	2.9	0.2	3.1
Cladeiella sp. 2	0.0	2.0	2.8	0.2	3.0
Dendronephyta sp. 3	0.2	1.0	2.7	0.4	2.9

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Spheciospongia confoederata	1.0	0.3	2.5	0.4	2.7
Acropora hyacinthis	0.0	1.1	2.3	0.3	2.5
Stelletta sp.	0.0	0.6	1.9	0.4	2.1
Desmapsamma sp. 1	0.8	0.0	1.8	0.4	2.0
Unknown Zooanthid	0.0	0.9	1.8	0.2	1.9
Paragoniastrea australensis	0.0	0.6	1.8	0.3	1.9
Palythoa caesia	0.0	0.6	1.6	0.4	1.7
Acropora sp. 1	0.0	0.7	1.4	0.2	1.5
Lobophyllia sp. 1	0.0	0.8	1.3	0.2	1.5
Platygyra lamellina	0.0	0.5	1.3	0.2	1.4
Acanthastrea bowerbanki	0.0	0.5	1.3	0.3	1.4
Spheciospongia sp. 4	0.0	0.4	1.2	0.3	1.3
	Kirra Reef	Cook Is. South	Average dissimilarity = 99.0		
Polycarpa procera	6.7	0.0	11.8	0.9	11.9
Turbinaria mesenterina	0.0	7.9	11.7	0.6	11.8
Pyura stolonifera	4.9	0.5	8.1	0.8	8.2
Discosoma sp. 1	0.0	4.5	6.7	0.5	6.7
Cladeiella sp. 1	0.0	2.4	5.7	0.4	5.8
Heteractis sp.	3.3	0.3	5.1	0.4	5.1
Haliclona sp. 2	2.5	0.0	5.1	0.7	5.1
Pocillopora aliciae	0.0	2.0	4.3	0.6	4.4
Acanthastrea bowerbanki	0.0	2.2	4.0	0.4	4.0
Acropora solitaryensis	0.0	1.8	3.0	0.3	3.1
Paragoniastrea australensis	0.0	1.4	2.9	0.5	2.9
Acropora sp. 1	0.0	1.9	2.8	0.4	2.8
Spheciospongia confoederata	1.0	0.7	2.6	0.3	2.6
Lobophyton sp. 2	0.0	1.0	2.2	0.4	2.3
Cnemidocarpa stolonifera	1.1	0.1	2.2	0.6	2.3
Favites sp.	0.0	1.2	2.1	0.3	2.2
Spheciospongia sp. 4	0.0	0.9	1.9	0.4	1.9
Platygyra lamellina	0.0	1.1	1.8	0.3	1.8
Desmapsamma sp. 1	0.8	0.0	1.4	0.3	1.4
Porites sp. 2	0.0	0.7	1.3	0.3	1.3
Sarconphton sp. 1	0.0	0.6	1.2	0.3	1.3
Pocillipora damincornis	0.0	0.6	1.2	0.4	1.2
Lobophyton sp. 3	0.0	0.6	1.2	0.3	1.2
	Cook Is. West	Cook Is. North	Average dissimilarity = 97.6		
Pyura stolonifera	0.2	3.7	16.6	0.8	17.0
Turbinaria mesenterina	1.0	2.2	10.0	0.5	10.2
Cladeiella sp. 2	1.2	2.0	6.3	0.3	6.4
Heteractis sp.	0.0	1.0	5.9	0.4	6.0
Pocillipora damincornis	0.0	1.3	5.0	0.4	5.1
Paragoniastrea australensis	0.5	0.6	4.3	0.4	4.4
Spheciospongia montiformis	0.9	0.2	4.0	0.3	4.0
Acanthastrea sp. 2	0.0	1.9	3.7	0.3	3.7
Dendronephyta sp. 3	0.0	1.0	3.4	0.4	3.5
Acropora hyacinthis	0.0	1.1	3.3	0.3	3.4
Stelletta sp.	0.0	0.6	3.0	0.4	3.1
Palythoa caesia	0.0	0.6	2.6	0.4	2.6
Acanthastrea bowerbanki	0.2	0.5	2.4	0.3	2.5
Unknown Zooanthid	0.0	0.9	2.4	0.2	2.4
Cnemidocarpa stolonifera	0.5	0.0	2.2	0.4	2.3

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Spheciospongia sp. 4	0.0	0.4	2.1	0.3	2.1
Platygyra lamellina	0.0	0.5	2.0	0.2	2.1
Acropora sp. 1	0.0	0.7	1.9	0.2	2.0
Goniopora sp.	0.1	0.6	1.8	0.3	1.9
Lobophyllia sp. 1	0.0	0.8	1.7	0.2	1.8
Oceanapia sp	0.5	0.0	1.6	0.3	1.7
Sarconphton sp. 1	0.3	0.1	1.5	0.3	1.6
Cladeiella sp. 1	0.1	0.3	1.3	0.3	1.3
	Cook Is. West	Cook Is. South	Average dissimilarity = 97.5		
Turbinaria mesenterina	1.0	7.9	16.3	0.7	16.7
Discosoma sp. 1	0.0	4.5	8.5	0.6	8.7
Cladeiella sp. 1	0.1	2.4	8.4	0.5	8.6
Pocillopora aliciae	0.0	2.0	6.3	0.6	6.4
Acanthastrea bowerbanki	0.2	2.2	5.6	0.4	5.7
Paragoniastrea australensis	0.5	1.4	4.9	0.6	5.0
Acropora solitaryensis	0.0	1.8	4.1	0.3	4.2
Acropora sp. 1	0.0	1.9	3.5	0.4	3.6
Lobophyton sp. 2	0.0	1.0	3.2	0.4	3.3
Cladeiella sp. 2	1.2	0.7	3.1	0.4	3.2
Favites sp.	0.0	1.2	2.8	0.3	2.9
Spheciospongia sp. 4	0.0	0.9	2.7	0.4	2.7
Platygyra lamellina	0.0	1.1	2.4	0.3	2.4
Sarconphton sp. 1	0.3	0.6	2.2	0.4	2.3
Spheciospongia montiformis	0.9	0.0	1.8	0.3	1.9
Porites sp. 2	0.0	0.7	1.7	0.3	1.8
Pyura stolonifera	0.2	0.5	1.7	0.5	1.7
Pocillipora damincornis	0.0	0.6	1.6	0.4	1.6
Lobophyton sp. 3	0.0	0.6	1.6	0.3	1.6
Leptoclinides sp. 1	0.0	0.5	1.6	0.2	1.6
Cnemidocarpa stolonifera	0.5	0.1	1.5	0.5	1.6
Spheciospongia confoederata	0.0	0.7	1.5	0.2	1.5
Protopalythoa sp.	0.0	0.5	1.5	0.5	1.5
	Cook Is. North	Cook Is. South	Average dissimilarity = 94.3		
Turbinaria mesenterina	2.2	7.9	13.0	0.7	13.8
Pyura stolonifera	3.7	0.5	7.1	0.9	7.5
Discosoma sp. 1	0.0	4.5	6.5	0.5	6.9
Cladeiella sp. 1	0.3	2.4	5.6	0.5	6.0
Acanthastrea bowerbanki	0.5	2.2	4.4	0.5	4.6
Pocillopora aliciae	0.2	2.0	4.3	0.6	4.5
Acropora sp. 1	0.7	1.9	3.7	0.4	3.9
Paragoniastrea australensis	0.6	1.4	3.5	0.6	3.8
Acropora solitaryensis	0.2	1.8	3.2	0.4	3.4
Acanthastrea sp. 2	1.9	0.4	3.1	0.3	3.3
Pocillipora damincornis	1.3	0.6	3.1	0.5	3.3
Cladeiella sp. 2	2.0	0.7	3.1	0.3	3.3
Platygyra lamellina	0.5	1.1	2.5	0.4	2.7
Heteractis sp.	1.0	0.3	2.5	0.5	2.6
Spheciospongia sp. 4	0.4	0.9	2.3	0.5	2.5
Acropora hyacinthis	1.1	0.3	2.2	0.4	2.3
Unknown Zooanthid	0.9	0.7	2.2	0.3	2.3
Lobophyton sp. 2	0.0	1.0	2.1	0.4	2.3
Favites sp.	0.0	1.2	2.1	0.3	2.2
Dendronephyta sp. 3	1.0	0.0	1.8	0.4	1.9

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Spheciospongia confoederata	0.3	0.7	1.7	0.2	1.8
Sarconphton sp. 1	0.1	0.6	1.4	0.4	1.5
Palythoa caesia	0.6	0.1	1.3	0.5	1.3
Stelletta sp.	0.6	0.0	1.3	0.4	1.3
Porites sp. 2	0.0	0.7	1.2	0.3	1.3
Species	Cook Is. West	Palm Beach	Average dissimilarity = 96.4		
Spheciospongia confoederata	0.0	3.5	13.7	0.7	14.2
Polycarpa procera	0.1	1.9	9.0	0.5	9.3
Oceanapia sp.	0.5	1.3	8.3	0.7	8.6
Heteractis sp.	0.0	1.5	7.7	0.5	8.0
Cnemidocarpa stolonifera	0.5	0.7	6.3	0.5	6.5
Haliclona sp. 2	0.0	1.0	6.0	0.5	6.2
Cladeiella sp. 2	1.2	0.5	5.4	0.4	5.6
Turbinaria mesenterina	1.0	0.2	5.1	0.3	5.3
Pyura stolonifera	0.2	0.5	4.7	0.4	4.8
Spheciospongia montiformis	0.9	0.4	4.4	0.4	4.6
Spheciospongia sp. 4	0.0	0.6	3.5	0.4	3.7
Paragoniastrea australensis	0.5	0.2	2.9	0.3	3.1
Spheciospongia sp. 3	0.0	0.3	2.4	0.2	2.5
Sarconphton sp. 1	0.3	0.2	2.3	0.3	2.4
Dysidea sp. 3	0.0	0.4	2.0	0.4	2.0
Iotrochota sp. 1	0.1	0.3	1.5	0.4	1.5
encrusting porifera sp. 5	0.0	0.2	1.5	0.2	1.5
Dendronephyta sp. 3	0.0	0.7	1.4	0.2	1.5
	Cook Is. North	Palm Beach	Average dissimilarity = 94.7		
Pyura stolonifera	3.7	0.5	10.9	0.9	11.6
Spheciospongia confoederata	0.3	3.5	8.7	0.7	9.2
Heteractis sp.	1.0	1.5	6.4	0.6	6.7
Turbinaria mesenterina	2.2	0.2	6.1	0.4	6.5
Polycarpa procera	0.0	1.9	5.1	0.5	5.4
Cladeiella sp. 2	2.0	0.5	4.1	0.3	4.4
Oceanapia sp	0.0	1.3	3.9	0.6	4.1
Pocillipora damincornis	1.3	0.1	3.7	0.4	3.9
Dendronephyta sp. 3	1.0	0.7	3.6	0.4	3.8
Acanthastrea sp. 2	1.9	0.0	3.1	0.3	3.3
Haliclona sp. 2	0.0	1.0	3.0	0.5	3.1
Spheciospongia sp. 4	0.4	0.6	2.9	0.5	3.0
Acropora hyacinthis	1.1	0.0	2.5	0.3	2.6
Paragoniastrea australensis	0.6	0.2	2.4	0.3	2.6
Zooanthid	0.9	0.2	2.4	0.3	2.5
Stelletta sp.	0.6	0.1	2.3	0.5	2.4
Cnemidocarpa stolonifera	0.0	0.7	2.2	0.5	2.3
Spheciospongia montiformis	0.2	0.4	1.9	0.2	2.0
Palythoa caesia	0.6	0.1	1.8	0.4	1.9
Acropora sp. 1	0.7	0.0	1.5	0.2	1.6
Lobophyllia sp. 1	0.8	0.0	1.4	0.2	1.5
Platygyra lamellina	0.5	0.0	1.4	0.2	1.5
Acanthastrea bowerbanki	0.5	0.0	1.4	0.3	1.5
Goniopora sp.	0.6	0.0	1.2	0.2	1.3
Dysidea sp. 3	0.0	0.4	1.2	0.3	1.2

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Spheciospongia sp. 3	0.1	0.3	1.1	0.3	1.2
Species	Cook Is. South	Palm Beach	Average dissimilarity = 97.9		
Turbinaria mesenterina	7.9	0.2	12.7	0.7	12.9
Spheciospongia confoederata	0.7	3.5	7.4	0.6	7.6
Discosoma sp. 1	4.5	0.0	7.1	0.5	7.3
Cladeiella sp. 1	2.4	0.0	6.2	0.5	6.3
Pocillopora aliciae	2.0	0.0	4.7	0.6	4.8
Acanthastrea bowerbanki	2.2	0.0	4.3	0.4	4.3
Polycarpa procera	0.0	1.9	3.9	0.5	4.0
Heteractis sp.	0.3	1.5	3.6	0.6	3.7
Paragoniastrea australensis	1.4	0.2	3.4	0.6	3.5
Acropora solitaryensis	1.8	0.0	3.3	0.3	3.3
Spheciospongia sp. 4	0.9	0.6	2.9	0.5	3.0
Acropora sp. 1	1.9	0.0	2.9	0.4	3.0
Oceanapia sp.	0.1	1.3	2.9	0.6	3.0
Lobophyton sp. 2	1.0	0.0	2.4	0.4	2.5
Favites sp.	1.2	0.0	2.3	0.3	2.3
Haliclona sp. 2	0.0	1.0	2.2	0.5	2.2
Platygyra lamellina	1.1	0.0	1.9	0.3	2.0
Pyura stolonifera	0.5	0.5	1.8	0.6	1.9
Cladeiella sp. 2	0.7	0.5	1.7	0.3	1.8
Sarconphton sp. 1	0.6	0.2	1.7	0.4	1.7
Cnemidocarpa stolonifera	0.1	0.7	1.6	0.5	1.7
Porites sp. 2	0.7	0.0	1.4	0.3	1.4
Pocillipora damincornis	0.6	0.1	1.4	0.4	1.4
Zooanthid	0.7	0.2	1.3	0.3	1.3
Lobophyton sp. 3	0.6	0.0	1.3	0.3	1.3
Leptoclinides sp. 1	0.5	0.0	1.2	0.2	1.2
Protopalythoa sp.	0.5	0.0	1.1	0.5	1.1
Species	Cook Is. West	Palm Beach Bait Reef	Average dissimilarity = 96.6		
Pyura stolonifera	0.2	5.8	23.2	1.0	24.0
Polycarpa procera	0.1	10.1	18.4	0.8	19.0
Cnemidocarpa stolonifera	0.5	2.5	9.8	0.7	10.2
Cribrochalina sp. 2	0.0	2.4	8.5	0.6	8.8
Polycarpa sp. 1	0.0	1.8	6.2	0.6	6.4
Stelletta sp.	0.0	1.2	4.2	0.5	4.3
Turbinaria mesenterina	1.0	0.0	3.0	0.3	3.1
Cladeiella sp. 2	1.2	0.0	3.0	0.3	3.1
Spheciospongia montiformis	0.9	0.0	2.6	0.3	2.7
Spheciospongia confoederata	0.0	1.0	2.3	0.4	2.4
Oceanapia sp.	0.5	0.0	1.8	0.3	1.8
Didemnum sp. 1	0.0	0.4	1.7	0.3	1.8
Paragoniastrea australensis	0.5	0.0	1.7	0.2	1.7
encrusting porifera sp. 5	0.0	0.4	1.2	0.3	1.2
	Cook Is. North	Palm Beach Bait Reef	Average dissimilarity = 89.5		
Polycarpa procera	0.0	10.1	13.8	0.7	15.4
Pyura stolonifera	3.7	5.8	13.1	1.0	14.6
Cnemidocarpa stolonifera	0.0	2.5	5.5	0.8	6.1
Cribrochalina sp. 2	0.0	2.4	5.3	0.6	5.9
Turbinaria mesenterina	2.2	0.0	4.7	0.4	5.2

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Polycarpa sp. 1	0.0	1.8	3.7	0.6	4.1
Stelletta sp.	0.6	1.2	3.6	0.6	4.0
Pocillipora damincornis	1.3	0.0	3.0	0.4	3.4
Heteractis sp.	1.0	0.0	3.0	0.4	3.3
Acanthastrea sp. 2	1.9	0.0	2.7	0.2	3.0
Cladeiella sp. 2	2.0	0.0	2.6	0.2	2.9
Spheciospongia confoederata	0.3	1.0	2.2	0.5	2.5
Dendronephyta sp. 3	1.0	0.0	2.2	0.4	2.4
Acropora hyacinthis	1.1	0.0	2.1	0.3	2.4
Zooanthid	0.9	0.0	1.6	0.2	1.8
Paragoniastrea australensis	0.6	0.0	1.6	0.3	1.8
Palythoa caesia	0.6	0.0	1.4	0.4	1.6
Spheciospongia sp. 4	0.4	0.2	1.4	0.3	1.5
Acropora sp. 1	0.7	0.0	1.3	0.1	1.5
Lobophyllia sp. 1	0.8	0.0	1.3	0.2	1.4
Platygyra lamellina	0.5	0.0	1.2	0.2	1.3
Acanthastrea bowerbanki	0.5	0.0	1.2	0.2	1.3
Goniopora sp.	0.6	0.0	1.0	0.2	1.2
Didemnum sp. 1	0.0	0.4	0.9	0.4	1.0
encrusting porifera sp. 5	0.0	0.4	0.8	0.3	0.9
	Cook Is. South	Palm Beach Bait Reef	Average dissimilarity = 98.6		
Polycarpa procera	0.0	10.1	11.7	0.7	11.9
Turbinaria mesenterina	7.9	0.0	10.9	0.6	11.1
Pyura stolonifera	0.5	5.8	9.9	1.0	10.0
Discosoma sp. 1	4.5	0.0	6.2	0.5	6.3
Cladeiella sp. 1	2.4	0.0	5.2	0.4	5.3
Cnemidocarpa stolonifera	0.1	2.5	4.2	0.9	4.3
Cribrochalina sp. 2	0.0	2.4	4.1	0.6	4.2
Pocillopora aliciae	2.0	0.0	4.0	0.6	4.0
Acanthastrea bowerbanki	2.2	0.0	3.7	0.4	3.7
Polycarpa sp. 1	0.0	1.8	2.9	0.6	2.9
Acropora solitaryensis	1.8	0.0	2.8	0.3	2.9
Paragoniastrea australensis	1.4	0.0	2.7	0.5	2.7
Acropora sp. 1	1.9	0.0	2.6	0.4	2.6
Spheciospongia confoederata	0.7	1.0	2.4	0.3	2.4
Lobophyton sp. 2	1.0	0.0	2.1	0.4	2.1
Stelletta sp.	0.0	1.2	2.0	0.5	2.0
Favites sp.	1.2	0.0	2.0	0.3	2.0
Spheciospongia sp. 4	0.9	0.2	1.9	0.4	2.0
Platygyra lamellina	1.1	0.0	1.7	0.3	1.7
Porites sp. 2	0.7	0.0	1.2	0.3	1.2
Sarconphton sp. 1	0.6	0.0	1.2	0.3	1.2
Pocillipora damincornis	0.6	0.0	1.1	0.4	1.1
Lobophyton sp. 3	0.6	0.0	1.1	0.3	1.1
Leptoclinides sp. 1	0.5	0.0	1.0	0.2	1.0
Protopalythoa sp.	0.5	0.0	0.9	0.5	0.9
	Palm Beach	Palm Beach Bait Reef	Average dissimilarity = 91.8		
Polycarpa procera	1.9	10.1	17.8	0.9	19.4
Pyura stolonifera	0.5	5.8	15.1	1.0	16.5
Spheciospongia confoederata	3.5	1.0	8.8	0.7	9.6
Cnemidocarpa stolonifera	0.7	2.5	6.7	0.8	7.2
Cribrochalina sp. 2	0.0	2.4	6.1	0.6	6.6

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
Heteractis sp.	1.5	0.0	4.3	0.5	4.7
Polycarpa sp. 1	0.0	1.8	4.3	0.6	4.7
Oceanapia sp.	1.3	0.0	3.9	0.5	4.2
Stelletta sp.	0.1	1.2	3.2	0.5	3.5
Haliclona sp. 2	1.0	0.1	3.1	0.5	3.4
Spheciospongia sp. 4	0.6	0.2	2.2	0.4	2.3
Encrusting porifera sp. 5	0.2	0.4	1.6	0.4	1.7
Cladeiella sp. 2	0.5	0.0	1.2	0.2	1.3
Dysidea sp. 3	0.4	0.0	1.1	0.3	1.2
Didemnum sp. 1	0.0	0.4	1.1	0.4	1.2
Spheciospongia sp. 3	0.3	0.0	1.1	0.2	1.1
Dendronephyta sp. 3	0.7	0.0	1.0	0.2	1.1
Spheciospongia montiformis	0.4	0.0	1.0	0.1	1.0

Table D.10 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 %
	Cook Is. West	Cook Is. North	Average dissimilarity = 96.1		
Polycarpa procera	4.2	0.3	15.1	0.8	15.7
Heteractis sp.	0.1	2.1	8.5	0.6	8.9
Pyura stolonifera	1.0	1.4	7.9	0.7	8.3
Turbinaria mesenterina	0.4	2.4	7.4	0.5	7.7
Pocillopora aliciae	0.0	1.5	7.0	0.4	7.3
Cladiella sp. 2	0.1	0.9	3.6	0.3	3.7
Spheciospongia sp. 4	0.0	0.9	3.4	0.3	3.5
Platygyra lamellina	0.1	0.9	2.9	0.2	3.0
Stelletta sp.	0.0	0.7	2.8	0.5	2.9
Spheciospongia sp. 3	0.0	0.3	2.8	0.3	2.9
Cnemidocarpa stolonifera	0.6	0.0	2.7	0.5	2.9
Acanthastrea bowerbanki	0.1	0.5	2.6	0.3	2.7
Pocillopora damicornis	0.0	0.8	2.6	0.3	2.7
Spheciospongia confoederata	0.1	0.5	2.5	0.3	2.6
Iotrochota sp. 1	0.6	0.1	2.1	0.3	2.2
Paragoniastrea australensis	0.1	0.4	2.1	0.4	2.1
Spheciospongia montiformis	0.4	0.0	1.9	0.2	1.9
Goniopora sp.	0.0	0.3	1.8	0.3	1.9
Acropora solitaryensis	0.0	0.5	1.5	0.2	1.5
Plumularia sp. 1	0.0	0.1	1.4	0.2	1.5
Spheciospongia sp. 6	0.0	0.3	1.1	0.2	1.2
Dysidea sp. 3	0.1	0.1	1.0	0.3	1.1
Xenia sp. 1	0.3	0.0	1.0	0.3	1.0
Spheciospongia papillosa	0.0	0.3	0.9	0.2	1.0
Palythoa caesia	0.0	0.2	0.9	0.2	0.9
	Cook Is. West	Cook Is. South	Average dissimilarity = 97.5		
Polycarpa procera	4.2	0.1	14.2	0.7	14.6
Paragoniastrea australensis	0.1	3.3	12.6	0.7	12.9
Turbinaria mesenterina	0.4	2.6	8.6	0.5	8.8
Discosoma sp. 1	0.0	3.0	7.8	0.4	8.0
Porites sp. 2	0.0	1.7	6.0	0.5	6.2
Pyura stolonifera	1.0	0.5	5.7	0.5	5.9
Cladiella sp. 1	0.1	0.9	3.5	0.4	3.6
Sarcophyton sp. 1	0.1	0.9	2.9	0.3	3.0
Iotrochota sp. 1	0.6	0.3	2.8	0.3	2.9

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Cnemidocarpa stolonifera	0.6	0.0	2.7	0.4	2.7
Spheciospongia sp. 4	0.0	0.6	2.5	0.4	2.5
Acanthastrea bowerbanki	0.1	0.7	2.4	0.3	2.4
Pocillopora aliciae	0.0	0.8	2.3	0.4	2.4
Spheciospongia montiformis	0.4	0.0	1.8	0.2	1.9
Chondropsis sp. 2	0.0	0.2	1.6	0.2	1.6
Spheciospongia confoederata	0.1	0.4	1.5	0.3	1.5
Agelas sp. 1	0.1	0.2	1.3	0.3	1.3
Protopalythoa sp.	0.0	0.2	1.3	0.2	1.3
Echinopora	0.1	0.3	1.3	0.2	1.3
Goniopora sp.	0.0	0.5	1.2	0.2	1.3
Cladiella sp. 2	0.1	0.2	1.2	0.2	1.2
Batzella sp. 1	0.0	0.4	1.1	0.2	1.1
Dysidea sp. 3	0.1	0.1	1.1	0.2	1.1
encrusting porifera sp. 2	0.0	0.1	1.0	0.1	1.0
	Cook Is. North	Cook Is. South	Average dissimilarity = 94.7		
Turbinaria mesenterina	2.4	2.6	10.3	0.6	10.8
Paragoniastrea australensis	0.4	3.3	9.8	0.7	10.4
Discosoma sp. 1	0.0	3.0	6.4	0.4	6.7
Pocillopora aliciae	1.5	0.8	6.2	0.5	6.5
Heteractis sp.	2.1	0.1	6.0	0.5	6.3
Pyura stolonifera	1.4	0.5	5.3	0.6	5.6
Porites sp. 2	0.0	1.7	4.5	0.5	4.7
Spheciospongia sp. 4	0.9	0.6	4.0	0.4	4.2
Acanthastrea bowerbanki	0.5	0.7	3.1	0.3	3.3
Cladiella sp. 2	0.9	0.2	2.6	0.3	2.8
Cladiella sp. 1	0.0	0.9	2.4	0.4	2.5
Pocillopora damicornis	0.8	0.2	2.3	0.4	2.4
Spheciospongia sp. 3	0.3	0.2	2.2	0.3	2.3
Spheciospongia confoederata	0.5	0.4	2.2	0.3	2.3
Sarcophyton sp. 1	0.0	0.9	2.2	0.3	2.3
Goniopora sp.	0.3	0.5	2.2	0.3	2.3
Stelletta sp.	0.7	0.1	2.0	0.4	2.1
Platygyra lamellina	0.9	0.0	2.0	0.2	2.1
Batzella sp. 1	0.1	0.4	1.2	0.3	1.3
Polycarpa procera	0.3	0.1	1.1	0.3	1.2
Acropora solitaryensis	0.5	0.0	1.1	0.2	1.2
Chondropsis sp. 2	0.0	0.2	1.1	0.2	1.1

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Iotrochota sp. 1	0.1	0.3	1.0	0.3	1.1
Micromussa lordhowensis	0.1	0.2	0.9	0.3	0.9
Protopalythoa sp.	0.0	0.2	0.9	0.3	0.9
Spheciospongia sp. 6	0.3	0.0	0.8	0.2	0.9
Plumularia sp. 1	0.1	0.0	0.8	0.2	0.8
encrusting porifera sp. 4	0.0	0.2	0.8	0.2	0.8
Spheciospongia papillosa	0.3	0.0	0.8	0.2	0.8
	Cook Is. West	Kirra Reef	Average dissimilarity = 88.1		
Polycarpa procera	4.2	13.1	18.3	1.2	20.8
Herdmania momus	0.0	10.3	14.8	1.0	16.8
Pyura stolonifera	1.0	6.7	11.1	0.7	12.6
Spheciospongia confoederata	0.1	2.6	4.2	0.5	4.8
Cribrochalina sp. 2	0.0	2.4	4.1	0.5	4.7
Heteractis sp.	0.1	2.5	4.0	0.7	4.5
Cnemidocarpa stolonifera	0.6	2.2	3.4	0.9	3.8
Dendronephtya sp. 2	0.0	2.5	3.3	0.4	3.8
Polycarpa sp. 1	0.0	2.1	3.0	0.8	3.4
Haliclona sp. 2	0.0	1.8	2.9	0.6	3.3
Cribrochalina sp. 1	0.0	1.3	2.0	0.5	2.3
Amphibalanus sp.	0.0	1.1	1.6	0.5	1.9
encrusting porifera sp. 5	0.0	1.0	1.6	0.6	1.8
Iotrochota sp. 1	0.6	0.3	1.3	0.3	1.4
Pallusia julinea	0.0	0.7	1.1	0.5	1.2
Xenia sp. 1	0.3	0.2	0.9	0.3	1.0
Spheciospongia montiformis	0.4	0.0	0.8	0.2	0.9
Callyspongia sp. 2	0.0	0.5	0.7	0.5	0.8
Turbinaria mesenterina	0.4	0.1	0.6	0.3	0.7
	Cook Is. North	Kirra Reef	Average dissimilarity = 94.6		
Polycarpa procera	0.3	13.1	17.6	1.3	18.6
Herdmania momus	0.0	10.3	13.3	1.0	14.1
Pyura stolonifera	1.4	6.7	9.3	0.7	9.9
Heteractis sp.	2.1	2.5	5.0	0.7	5.3
Spheciospongia confoederata	0.5	2.6	4.1	0.6	4.3
Cribrochalina sp. 2	0.0	2.4	3.6	0.5	3.8
Turbinaria mesenterina	2.4	0.1	3.1	0.4	3.2
Dendronephtya sp. 2	0.0	2.5	3.0	0.4	3.2
Cnemidocarpa stolonifera	0.0	2.2	2.9	1.0	3.1
Polycarpa sp. 1	0.0	2.1	2.7	0.8	2.8

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Haliclona sp. 2	0.1	1.8	2.6	0.6	2.8
Pocillopora aliciae	1.5	0.0	2.4	0.4	2.5
Cribrochalina sp. 1	0.0	1.3	1.8	0.5	1.9
encrusting porifera sp. 5	0.1	1.0	1.5	0.6	1.6
Amphibalanus sp.	0.0	1.1	1.5	0.5	1.6
Spheciospongia sp. 4	0.9	0.0	1.2	0.3	1.3
Cladiella sp. 2	0.9	0.0	1.2	0.2	1.3
Platygyra lamellina	0.9	0.0	1.1	0.2	1.2
Stelletta sp.	0.7	0.1	1.1	0.5	1.1
Pocillopora damicornis	0.8	0.0	1.0	0.3	1.1
Pallusia julinea	0.0	0.7	0.9	0.5	1.0
Acanthastrea bowerbanki	0.5	0.0	0.8	0.2	0.9
Spheciospongia sp. 3	0.3	0.0	0.6	0.2	0.7
Acropora solitaryensis	0.5	0.0	0.6	0.2	0.7
Paragoniastrea australensis	0.4	0.0	0.6	0.3	0.6
Spheciospongia sp. 6	0.3	0.1	0.6	0.2	0.6
Callyspongia sp. 2	0.0	0.5	0.6	0.5	0.6
Entacmaea sp. 2	0.1	0.1	0.6	0.2	0.6
	Cook Is. South	Kirra Reef	Average dissimilarity = 98.2		
Polycarpa procera	0.1	13.1	17.2	1.2	17.5
Herdmania momus	0.0	10.3	12.8	1.0	13.1
Pyura stolonifera	0.5	6.7	9.2	0.7	9.4
Paragoniastrea australensis	3.3	0.0	4.7	0.6	4.8
Spheciospongia confoederata	0.4	2.6	3.8	0.6	3.8
Discosoma sp. 1	3.0	0.0	3.5	0.4	3.6
Cribrochalina sp. 2	0.0	2.4	3.5	0.5	3.6
Turbinaria mesenterina	2.6	0.1	3.5	0.4	3.5
Heteractis sp.	0.1	2.5	3.4	0.6	3.4
Dendronephtya sp. 2	0.0	2.5	2.9	0.4	3.0
Cnemidocarpa stolonifera	0.0	2.2	2.8	1.0	2.9
Polycarpa sp. 1	0.0	2.1	2.6	0.8	2.6
Haliclona sp. 2	0.0	1.8	2.5	0.6	2.5
Porites sp. 2	1.7	0.0	2.3	0.4	2.4
Cribrochalina sp. 1	0.0	1.3	1.8	0.5	1.8
Amphibalanus sp.	0.0	1.1	1.4	0.5	1.5
encrusting porifera sp. 5	0.0	1.0	1.4	0.6	1.4
Cladiella sp. 1	0.9	0.0	1.2	0.4	1.2
Sarcophyton sp. 1	0.9	0.0	1.2	0.2	1.2

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Pocillopora aliciae	0.8	0.0	1.0	0.4	1.0
Spheciospongia sp. 4	0.6	0.0	0.9	0.3	1.0
Pallusia julinea	0.0	0.7	0.9	0.5	0.9
Acanthastrea bowerbanki	0.7	0.0	0.9	0.3	0.9
Iotrochota sp. 1	0.3	0.3	0.8	0.4	0.8
Goniopora sp.	0.5	0.0	0.6	0.2	0.6
Callyspongia sp. 2	0.0	0.5	0.6	0.5	0.6
Entacmaea sp. 2	0.1	0.1	0.6	0.2	0.6
Dysidea sp. 2	0.1	0.3	0.5	0.2	0.5
Batzella sp. 1	0.4	0.0	0.5	0.2	0.5
	Cook Is. West	Palm Beach	Average dissimilarity = 93.2		
Polycarpa procera	4.2	0.7	17.4	0.8	18.7
Spheciospongia confoederata	0.1	2.5	11.1	0.7	11.9
Cnemidocarpa stolonifera	0.6	1.2	7.5	0.6	8.1
Pyura stolonifera	1.0	0.6	6.4	0.6	6.9
Oceanapia sp.	0.1	1.2	5.8	0.6	6.3
Heteractis sp.	0.1	0.6	3.6	0.5	3.9
Sarcophyton sp. 1	0.1	0.5	3.2	0.4	3.5
Cladiella sp. 1	0.1	0.5	2.9	0.3	3.1
Spheciospongia montiformis	0.4	0.1	2.6	0.3	2.8
Turbinaria mesenterina	0.4	0.2	2.2	0.3	2.4
Stelletta sp.	0.0	0.5	2.1	0.4	2.3
Iotrochota sp. 1	0.6	0.0	2.1	0.3	2.2
Dysidea sp. 3	0.1	0.2	2.1	0.3	2.2
Spheciospongia sp. 3	0.0	0.5	1.7	0.2	1.8
Cladiella sp. 2	0.1	0.2	1.6	0.3	1.7
Acanthastrea bowerbanki	0.1	0.3	1.5	0.3	1.6
Paragoniastrea australensis	0.1	0.2	1.4	0.3	1.5
Xenia sp. 1	0.3	0.0	1.2	0.3	1.3
Acanthella sp. 1	0.0	0.4	1.2	0.2	1.3
Hyattella sp. 2	0.0	0.2	1.2	0.2	1.3
Porites sp. 2	0.0	0.4	1.1	0.2	1.2
Cladiella sp. 3	0.0	0.1	1.0	0.1	1.1
Haliclona sp. 2	0.0	0.2	0.8	0.3	0.9
Acanthella sp. 1	0.0	0.1	0.8	0.1	0.9
Tedania sp.	0.0	0.1	0.8	0.1	0.9
Agelas sp. 1	0.1	0.0	0.8	0.2	0.8
	Cook Is. North	Palm Beach	Average dissimilarity = 95.1		

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Spheciospongia confoederata	0.5	2.5	8.9	0.7	9.4
Heteractis sp.	2.1	0.6	7.7	0.6	8.1
Turbinaria mesenterina	2.4	0.2	6.3	0.5	6.6
Pyura stolonifera	1.4	0.6	6.1	0.7	6.4
Pocillopora aliciae	1.5	0.0	5.6	0.4	5.9
Oceanapia sp.	0.1	1.2	4.2	0.6	4.5
Cnemidocarpa stolonifera	0.0	1.2	4.2	0.5	4.4
Polycarpa procera	0.3	0.7	3.7	0.5	3.9
Stelletta sp.	0.7	0.5	3.2	0.6	3.4
Cladiella sp. 2	0.9	0.2	3.1	0.3	3.3
Spheciospongia sp. 3	0.3	0.5	3.1	0.3	3.2
Spheciospongia sp. 4	0.9	0.1	2.8	0.3	3.0
Acanthastrea bowerbanki	0.5	0.3	2.7	0.3	2.8
Platygyra lamellina	0.9	0.0	2.2	0.2	2.3
Sarcophyton sp. 1	0.0	0.5	2.1	0.4	2.2
Pocillopora damicornis	0.8	0.0	2.1	0.3	2.2
Paragoniastrea australensis	0.4	0.2	1.9	0.4	2.0
Cladiella sp. 1	0.0	0.5	1.7	0.3	1.8
Goniopora sp.	0.3	0.0	1.4	0.3	1.5
Acropora solitaryensis	0.5	0.0	1.3	0.2	1.3
Plumularia sp. 1	0.1	0.1	1.2	0.2	1.3
Dysidea sp. 3	0.1	0.2	1.1	0.3	1.2
Acanthella sp. 1	0.0	0.4	1.0	0.2	1.0
Spheciospongia sp. 6	0.3	0.0	0.9	0.2	1.0
Porites sp. 2	0.0	0.4	0.9	0.2	0.9
Hyattella sp. 2	0.0	0.2	0.9	0.2	0.9
Spheciospongia papillosa	0.3	0.0	0.8	0.2	0.9
Haliclona sp. 2	0.1	0.2	0.8	0.3	0.9
Palythoa caesia	0.2	0.0	0.7	0.2	0.8
Cladiella sp. 3	0.0	0.1	0.7	0.1	0.7
encrusting porifera sp. 5	0.1	0.1	0.6	0.2	0.6
Batzella sp. 1	0.1	0.1	0.6	0.3	0.6
Micromussa lordhowensis	0.1	0.0	0.6	0.2	0.6
Acanthella sp.1	0.0	0.1	0.5	0.1	0.5
Acropora sp. 1	0.1	0.0	0.5	0.2	0.5
	Cook Is. South	Palm Beach	Average dissimilarity = 96.9		
Paragoniastrea australensis	3.3	0.2	10.5	0.7	10.8
Spheciospongia confoederata	0.4	2.5	8.1	0.7	8.4

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Turbinaria mesenterina	2.6	0.2	7.3	0.5	7.5
Discosoma sp. 1	3.0	0.0	6.8	0.4	7.0
Porites sp. 2	1.7	0.4	5.6	0.5	5.8
Cnemidocarpa stolonifera	0.0	1.2	4.0	0.5	4.2
Sarcophyton sp. 1	0.9	0.5	4.0	0.4	4.1
Oceanapia sp.	0.1	1.2	3.9	0.6	4.1
Pyura stolonifera	0.5	0.6	3.9	0.5	4.0
Cladiella sp. 1	0.9	0.5	3.8	0.5	3.9
Polycarpa procera	0.1	0.7	2.9	0.4	3.0
Acanthastrea bowerbanki	0.7	0.3	2.6	0.3	2.7
Heteractis sp.	0.1	0.6	2.2	0.4	2.3
Spheciospongia sp. 4	0.6	0.1	2.1	0.4	2.2
Pocillopora aliciae	0.8	0.0	2.0	0.4	2.1
Spheciospongia sp. 3	0.2	0.5	1.9	0.3	2.0
Stelletta sp.	0.1	0.5	1.5	0.4	1.5
Chondropsis sp. 2	0.2	0.1	1.5	0.2	1.5
Batzella sp. 1	0.4	0.1	1.1	0.3	1.2
Goniopora sp.	0.5	0.0	1.1	0.2	1.1
Dysidea sp. 3	0.1	0.2	1.1	0.3	1.1
Cladiella sp. 2	0.2	0.2	1.1	0.3	1.1
Iotrochota sp. 1	0.3	0.0	0.9	0.2	1.0
Acanthella sp. 1	0.0	0.4	0.9	0.2	1.0
Aplysilla sulfurea	0.2	0.1	0.9	0.3	0.9
Protopalythoa sp.	0.2	0.0	0.9	0.2	0.9
Hyattella sp. 2	0.0	0.2	0.8	0.2	0.8
encrusting porifera sp. 4	0.2	0.0	0.8	0.2	0.8
Agelas sp. 1	0.2	0.0	0.8	0.3	0.8
Echinopora	0.3	0.0	0.7	0.2	0.7
Pocillopora damicornis	0.2	0.0	0.7	0.3	0.7
encrusting porifera sp. 2	0.1	0.0	0.7	0.1	0.7
Cladiella sp. 3	0.0	0.1	0.6	0.1	0.7
	Kirra Reef	Palm Beach	Average dissimilarity = 92.6		
Polycarpa procera	13.1	0.7	17.9	1.2	19.3
Herdmania momus	10.3	0.0	13.8	1.0	14.9
Pyura stolonifera	6.7	0.6	10.1	0.7	10.9
Spheciospongia confoederata	2.6	2.5	5.9	0.8	6.4
Heteractis sp.	2.5	0.6	4.0	0.7	4.3
Cribrochalina sp. 2	2.4	0.0	3.8	0.5	4.1

Taxonomic Group	Average Abundance		Average dissimilarity	Diss/SD	Contrib %
Cnemidocarpa stolonifera	2.2	1.2	3.6	0.9	3.9
Dendronephtya sp. 2	2.5	0.0	3.1	0.4	3.4
Haliclona sp. 2	1.8	0.2	2.8	0.6	3.0
Polycarpa sp. 1	2.1	0.0	2.8	0.8	3.0
Cribrochalina sp. 1	1.3	0.0	1.9	0.5	2.1
Oceanapia sp.	0.0	1.2	1.9	0.6	2.0
encrusting porifera sp. 5	1.0	0.1	1.5	0.6	1.7
Amphibalanus sp.	1.1	0.0	1.5	0.5	1.7
Pallusia julinea	0.7	0.0	1.0	0.5	1.1
Sarcophyton sp. 1	0.0	0.5	0.9	0.3	1.0
Stelletta sp.	0.1	0.5	0.8	0.4	0.9
Callyspongia sp. 2	0.5	0.1	0.8	0.5	0.8
Cladiella sp. 1	0.0	0.5	0.7	0.3	0.8
Haliclona sp. 1	0.4	0.1	0.7	0.3	0.7
Spheciospongia sp. 3	0.0	0.5	0.7	0.2	0.7
Dysidea sp. 3	0.2	0.2	0.6	0.3	0.6
Desmapsamma sp. 1	0.4	0.0	0.6	0.4	0.6
Acanthella sp. 1	0.1	0.4	0.6	0.2	0.6
Xenia sp. 1	0.2	0.0	0.5	0.2	0.5
Hyattella sp. 2	0.1	0.2	0.5	0.2	0.5
Porites sp. 2	0.0	0.4	0.5	0.1	0.5
Acanthastrea bowerbanki	0.0	0.3	0.5	0.2	0.5

Table D.11 Comparisons of sessile assemblages on horizontal surfaces among reefs and survey periods (2016 to 2020)

a) PERMANOVA Source	df	MS	Pseudo-F	P(perm)	
Survey	4	132420	**122.88**	**0.001**	
Reef	6	37646	**34.94**	**0.001**	
Survey x Reef	11	17816	**16.53**	**0.001**	
Error	995	1077.6			
Pairwise Tests	b) 2016	c) 2017	d) 2018	e) 2019	f) 2020
	t Value	t Value	t Value	t Value	t Value
KR vs PB	10.4***		6.2***	4.8***	8.6***
KR vs PBBR					5.2***
KR vs CIW		5.7***	3.5***	4.6***	4.0***
KR vs CIS					6.7***
KR vs CIN	5.4***	4.6***	4.6***	4.5***	6.0***
CIW vs CIN		2.2***	1.7*	1.2	4.0***
CIW vs CIS					4.8***
CIW vs PB			3.5***	5.3***	6.9***
CIN vs CIS					3.2***
CIN vs PB			4.1***	5.7***	6.3***
CIS vs PB	4.6***				7.4***
KR vs KC	4.2***			2.0*	
PB vs KC	8.0***			4.7***	
KC vs CIN	3.6***		4.3***		
KC vs CIW				4.4***	
CIN vs PBBR					5.5***
PB vs PBBR					6.4***
CIW vs PBBR					5.4***
CIS vs PBBR					6.1***
g) Pairwise comparison within reefs over time	Kirra	Palm Beach	Cook Island North	Cook Island West	
2016 vs 2017	**4.67*** **		**2.02*** **		
2017 vs 2018	**3.37*** **		**5.88*** **	**5.41*** **	
2018 vs 2019	**4.92*** **	**6.51*** **	**5.76*** **	**4.47*** **	
2019 vs 2020	**5.56*** **	**10.31*** **	**12.20*** **	**9.58*** **	

Significance level: * p < 0.05, **p < 0.01, *** p = 0.001

Table D.12 SIMPER differences in sessile assemblages at Kirra Reef among survey periods (2016 to 2020)

Taxonomic Group	Average Abundance		Average Dissimilarity	Diss/SD	Contrib%
	2016	2017	Average dissimilarity = 60.9		
Turf Algae	41.8	9.7	24.4	1.6	40.1
Macroalgae	38.6	22.3	17.7	1.3	29.1
Ascidian	7.2	16.6	10.2	1.0	16.7
Sponge	3.4	6.2	4.4	0.9	7.2
Coralline Algae	1.3	2.2	1.7	0.6	2.8
Anemone	0.9	1.1	1.1	0.5	1.8
Hydroid	1.0	0.1	0.7	0.3	1.2
Polychaete	0.7	0.0	0.5	0.2	0.8
Oyster	0.1	0.0	0.1	0.2	0.1
Soft Coral	0.0	0.1	0.1	0.2	0.1
Zoanthid	0.0	0.1	0.1	0.2	0.1
	2017	2018	Average dissimilarity = 67.4		
Turf Algae	9.7	28.6	19.1	1.1	28.3
Macroalgae	22.3	24.8	16.3	1.1	24.2
Ascidian	16.6	17.6	15.5	1.0	23.0
Coralline Algae	2.2	16.0	11.2	1.0	16.6
Sponge	6.2	0.0	3.7	0.6	5.5
Anemone	1.1	0.5	0.9	0.4	1.4
Hard coral	0.0	0.5	0.4	0.3	0.6
Soft Coral	0.1	0.1	0.2	0.2	0.2
Hydroid	0.1	0.0	0.1	0.2	0.1
Zoanthid	0.1	0.0	0.1	0.2	0.1
	2018	2019	Average dissimilarity = 59.5		
Ascidian	17.6	41.5	19.1	1.4	32.1
Macroalgae	24.8	35.7	14.2	1.4	24.0
Turf Algae	28.6	11.1	13.1	1.3	22.0
Coralline Algae	16.0	0.1	8.7	1.2	14.6
Anemone	0.5	4.0	2.3	0.6	3.9
Sponge	0.0	2.8	1.5	0.7	2.6
Hard coral	0.5	0.0	0.3	0.3	0.5
Soft Coral	0.1	0.1	0.1	0.3	0.2
Zoanthid	0.0	0.2	0.1	0.3	0.2
	2019	2020	Average dissimilarity = 56.7		
Ascidian	41.5	12.8	17.0	1.4	30.1
Macroalgae	35.7	28.3	14.5	1.5	25.6
Turf Algae	11.1	35.6	14.1	1.5	24.9
Coralline Algae	0.1	9.0	4.7	1.1	8.3
Anemone	4.0	3.5	3.4	0.7	5.9
Sponge	2.8	4.7	2.6	1.0	4.6
Soft Coral	0.1	0.2	0.2	0.3	0.3
Zoanthid	0.2	0.0	0.1	0.3	0.2
Hydroid	0.0	0.1	0.0	0.2	0.0
Hard coral	0.0	0.1	0.0	0.2	0.0

Appendix E July 2020 Fish Species List

Table E.1 Fish species recorded in July 2020 survey, not recorded in previous surveys

Scientific Name	Common name	Reef Recorded at
Acanthuridae		
Acanthurus grammoptilus	inshore surgeonfish	Bait Reef, Cook island West, Cook island North, Kirra Reef, Palm beach reef
Naso brachycentron	humpback unicornfish	Cook Island North
Naso tonganus	humpnose unicornfish	Cook Island North, Cook Island West
Zebrasoma velifer	sailfin tang	Cook Island North
Balistidae		
Pseudobalistes fuscus	yellowspotted triggerfish	Cook Island West
Blenniidae		
Meiacanthus lineatus	lined fangblenny	Cook Island North, Kirra reef
Plagiotremus rhinorhynchose	piano fangblenny	Kirra Reef
Carangidae		
Scomberoides lysan	lesser queenfish	Cook Island North
Cirrhitidae		
Cirrhiichthys aprinus	blotched hawkfish	Kirra Reef
Dasyatidae		
Taeniura meyeni	blotched fantail ray	Kirra Reef
Fistularia		
Fistularia commersonii	smooth flutemouth	Cook Island North
Labridae		
Anampses femininus	bluetail wrasse	Cook Island South
Bodianus perditio	goldspot pigfish	Cook Island North
Choerodon schoenleinii	blackspot tuskfish	Cook Island West, Palm Beach Reef
Coris dorsomacula	pinklined wrasse	Cook Island West
Halichoeres margaritaceus	pearly wrasse	Cook Island North
Hemigymnus fasciatus	fiveband wrasse	Cook Island North
Hologymnosus doliatus	pastel slender wrasse	Cook Island West
Stethojulis interrupta	brokenline wrasse	Cook Island West, Kirra Reef
Mullidae		
Mulloidichthys flavolineatus	yellowstripe goatfish	Cook Island West, Palm Beach Reef
Nemipteridae		

Scientific Name	Common name	Reef Recorded at
Scolopsis bilineata	two-lined monocle bream	Cook Island South
Scolopsis monogramma	rainbow monocle bream	Palm Beach Reef
Pinguipedidae		
Parapercis stricticeps	whitestreak grubfish	Cook Island West
Pomacanthidae		
Pomacanthus semicirculatus	*Blue Angelfish*	Cook Island North
Pomacentridae		
Abudefduf septemfasciatus	banded sergeant	Cook Island North
Pomacentrus nagasakiensis	blue-scribbled damsel	Cook Island South
Pomacentrus wardi	Ward's damsel	Cook Island North, Cook Island South, Palm Beach Reef
Tetraodontidae		
Arothron meleagris	whitespotted puffer	Cook Island West

Table E.2 Fish species (summed MaxN values) at Palm Beach Bait Reef, Cook Island Reef (West, North and South), Kirra Reef and Palm Beach Reef recorded during the 2020 survey.

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Acanthuridae									
Acanthurus grammoptilus	inshore surgeonfish	H	R	1	25	16		4	4
Acanthurus nigrofuscus	dusky surgeonfish	H	R					1	
Acanthurus pyroferus	mimic surgeonfish	D	R					1	
Acanthurus sp. 1[11]	surgeonfish	H	R		4	10	1	1	
Acanthurus sp. Unidentified[12]	surgeonfish		R		2	32		4	3
Naso brachycentron	humpback unicornfish	H	R			1			
Naso tonganus	humpnose unicornfish	H	R		1				
Naso unicornis	bluespine unicornfish	H	R			8			
Prionurus microlepidotus	australian sawtail	H	R		14				
Zebrasoma velifer	sailfin tang	H	R			1			
Apogonidae									
Ostorhinchus cookii	Cook's cardinalfish	CA	R				1		1
Balistidae									
Balistidae sp.[13]	triggerfish		R		1				1
Balistoides conspicillum	clown triggerfish	CA	R			1			

[11] This species is either *Acanthurus nigroris* (Greyhead surgeonfish) or *Acanthurus nigrofuscus* (Dusky Surgeonfish) however, these two species are indistinguishable using the RUV method.

[12] These records are of fish that were swimming in the distance or in conditions of low visibility, the Acanthuridae Family has a distinguishable body shape however because of conditions, identifying them further into species was not possible.

[13] These records are of fish that were swimming in the distance or in conditions of low visibility, the Balistidae Family has a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Psudobalistes fuscus	yellowspotted triggerfish	CA	R		1				
Sufflamen chrysopterum	eye-stripe triggerfish	CA	R		2	1		1	1
Sufflamen fraenatum	bridled triggerfish	CA	R		2				
Blenniidae									
Blenniidae sp. 1[14]	blenny 1	CA	R					1	
Blenniidae sp. 2[15]	blenny 2	CA	R					1	
Meiacanthus lineatus	lined fangblenny	CA	R			1		1	
Plagiotremus rhinorhynchose	piano fangblenny	CA	R					4	
Carangidae									
Carangoides sp. Unidentified[16]	trevally	CA	P		1			1	
Scomberoides lysan	lesser queenfish	CA	R/P			2			
Trachurus novaezelandiae	yellowtail scad	P	P	300	2	2		400	100
Chaetodontidae									
Chaetodon auriga	threadfin butterflyfish	C	R			1			
Chaetodon citrinellus	citron butterflyfish	C	R		5	2		1	
Chaetodon kleinii	klein's butterflyfish	C	R		3			2	1
Chaetodon lineolatus	lined butterflyfish	C	R		2	1		1	1
Heniochus sp.	bannerfish	CA	R						1
Cirrhiichthys aprinus	blotched hawkfish	CA	R					1	
Cirrhitichthys falco	dwarf hawkfish	CA	R		1				

[14] This species were unable to be identified further using the RUV method, as Blenniidae species are small and all share very similar features

[15] This species were unable to be identified further using the RUV method, as Blenniidae species are small and all share very similar features

[16] These records are of fish that were swimming in the distance or in conditions of low visibility, the Carangidae Family has a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Dasyatidae									
Taeniura meyeni	blotched fantail ray	CA	R					1	
Diodontidae									
Dicotylichthys punctulatus	threebar porcupinefish	CA	R	1	1			1	1
Diodon sp.[17]	porcupinefish	CA	R			1			
Enoplosidae									
Enoplosus armatus	old wife	CA	R			2		2	
Ephippidae									
Platax teria	roundface batfish	O	R			13			
Fistularia									
Fistularia commersonii	smooth flutemouth	CA	R			3			
Haemulidae									
Plectorhinchus flavomaculatus	goldspotted sweetlips	CA	R		2	1			1
Plectorhinchus picus	dotted sweetlips	CA	R		1				
Labridae									
Achoerodus viridis	eastern blue grouper	O	R		2	3			1
Anampses caeruleopuncatatus	diamond wrasse	O	R			1			
Anampses femininus	bluetail wrasse	O	R				1		
Anampses neoguinaicus	blackback wrasse	O	R			1			
Bodianus perditio	goldspot pigfish	O	R			1			
Cheilio inermis	sharpnose wrasse	O	R					1	

[17] These records are of fish that were swimming in the distance or in conditions of low visibility, the Diodontidae Family has a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible.

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Chlorus sp.[18]	parrotfish	H	R			1			
Choerodon graphicus	graphic tuskfish	CA	R						1
Choerodon schoenleinii	blackspot tuskfish	CA	R		1				1
Coris dorsomacula	pinklined wrasse	O	R		3				
Gomphosus varius	birdnose wrasse	O	R			1			
Halichoeres hortulanus	checkerboard wrasse	O	R			1			
Halichoeres margaritaceus	pearly wrasse	O	R			1			
Hemigymnus fasciatus	fiveband wrasse	O	R			1			
Hologymnosus doliatus	pastel slender wrasse	O	R		1				
Labridae sp. Unidentified[19]	labridae sp. unidentified		R		2	4		1	1
Labroides dimidiatus	common cleaner fish	O	R		1	1	1	3	
Notolabrus gymnogenis	crimsonband wrasse	O	R		2	1	1	1	1
Pseudolabrus guentheri	gÜnther's wrasse	O	R	1	3	3	3	4	2
Stethojulis bandanensis	redspot wrasse	O	R			1			
Stethojulis interrupta	brokenline wrasse	O	R		1			2	
Thalassoma lunare	moon wrasse	CA	R			1			
Thalassoma lutescens	green moon wrasse	O	R		6	30	1	1	2
Thalassoma nigrofasciatum	blackbarred wrasse	O	R		1	5			
Latridae									

[18] These records are of fish that were swimming in the distance or in conditions of low visibility, species in the genus *Chlorus* have a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible.

[19] These records are of fish that have characteristics similar to a variety of species in Labridae, they are unable to be identified further using the RUV method.

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Goniistius vestitus	crested morwong	CA	R		5	1		1	
Morwong fuscus	red morwong	CA	R		1	1	1		
Lutjanidae									
Lutjanus fulviflamma	blackspot snapper	CA	R					1	2
Lutjanus russellii	moses' snapper	CA	R					1	1
Microcanthidae									
Atypichthys strigatus	mado	O	R			3		11	1
Microcanthus strigatus	stripey	O	R		5	47	1	5	4
Monacanthidae									
Meuschenia sp. Unidentified[20]	leatherjacket	O	R		3				
Monacanthus chinensis	fanbellied leatherjacket	O	R		1			2	2
Paraluteres prionurus	backsaddle filefish	O	R		1				
Monodactylidae									
Schuettea scalaripinnis	eastern pomfred	P	P			150		4	
Mullidae									
Mulloidichthys flavolineatus	yellowstipe goatfish	CA	P		3				2
Mulloidichthys vanicolensis	goldstripe goatfish	CA	P		1				1
Parupeneus multifasciatus	banded goatfish	CA	P		2	1	1	1	1
Parupeneus sp. Unidentified[21]	goatfish	CA	P			1			1

[20] This species was unable to be identified further due to the RUV methodology, the limited visibility and the dramatic variation between individuals in this Family

[21] These records are of fish that were swimming in the distance or in conditions of low visibility, the Mullidae Family has a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Parupeneus spilurus	backsaddle goatfish	CA	P		7	4	1	9	4
Myliobatidae									
Aetobatus ocellatus	whitespotted eagle ray	CA	R/P	1				1	1
Nemipteridae									
Scolopsis bilineata	two-line monocle bream	CA	R				1		
Scolopsis monogramma	rainbow monocle bream	CA	R						1
Orectolobidae									
Orectolobus maculatus	spotted wobbegong	CA	R		1	1		1	
Pempheridae									
Pempheris affinis	blacktip bullseye	CA	R			50			
Pinguipedidae									
Parapercis sp.[22]	grubfish	CA	R		1				
Parapercis stricticeps	whitestreak grubfish	CA	R		1				
Pomacanthidae									
Centropyge tibicen	keyhole angelfish	H	R		1		1		
Pomacanthus semicirculatus	blue angelfish	O	R			1			
Pomacentridae									
Abudefduf bengalensis	bengal sergeant	O	R		1	5		1	1
Abudefduf septemfasciatus	banded sergeant	O	R			1			
Abudefduf vaigiensis	indo-pacific sergeant	O	R		25	7			

[22] The fish in the genus *Parapercis* have similar characteristics which were not able to be distinguished using the RUV method.

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Abudefduf whitleyi	whitley's sergeant	O	R			3			
Amphiprion akindynos	barrier reef anemonefish	O	R		1	1		3	
Chromis margaritifer	whitetail puller	P	R			3			
Dascyllus trimaculatus	threespot humbug	O - HT	R		1	3			
Parma oligolepis	bigscale scalyfin	O - HT	R				2	2	
Parma unifasciata	girdled scalyfin	O - HT	R		2	3		1	1
Pomacentrus bankanensis	speckled damselfish	O - HT	R		1	1			
Pomacentrus coelestis	neon damselfish	O - HT	R				3	1	
Pomacentrus nagasakiensis	blue-scribbled damselfish	O	R				1		
Pomacentrus sp. Unidentified[23]	damselfish		R		2	2	1		2
Pomacentrus wardi	ward's damselfish	H	R			8	2		1
Stegastes apicalis	yellowtip gregory	H	R			1			
Stegastes gascoynei	coral sea damselfish	O - HT	R			2	1	1	
Scorpaendiae									
Scorpaena sp. [24]	scorpionfish	CA	R				1		
Scorpididae									
Scorpis lineolata	silver sweep	P	R		2			6	6
Serranidae									
Diploprion bifasciatum	barred soapfish	CA	R		1	1	1		
Siganidae									

[23] These records are of fish that were swimming in the distance or in conditions of low visibility, the Pomacentridae Family has a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible.

[24] This record is of a fish in the genus *Scorpaena,* however due to the similarity of the characteristics within this genus, the fish was unable to be identified further using the RUV method

Scientific Name	Common Name	Functional Group	Habitat	Palm Beach Bait Reef	Cook Island West	Cook Island North	Cook Island South	Kirra Reef	Palm Beach Reef
Siganus spinus	scribbled rabbitfish	H	R		1	2			
Sparidae									
Acanthopagrus australis[25]	yellowfin bream	CA	R	10	35	10			7
Sphyraenidae									
Sphyraena obtusata	striped barracuda	CA	R/P					1	
Tetraodontidae									
Arothron hispidus	stars-and-stripes puffer	O	R		1				1
Arothron meleagris	whitespotted puffer	O	R		1				
Arothron nigropuncatus	blackspotted puffer	O	R						2
Arothron stellatus	starry puffer	O	R						1
Canthigaster bennetti	blackspot toby	O	R		2				
Canthigaster valentini	blacksaddle toby	O	R		1				1
Tetradontidae sp. Unidentified[26]	puffer	O	R		1				1
Zanclidae									
Zanclus cornutus	moorish idol	CA	R		7	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

[25] This species is either *Acanthopagrus australis* (Yellowfin Bream) or *Rhabdosargus sarba* (Tarwhine). Using the RUV method, confidently distinguishing between these two species is not possible.

[26] These records are of fish that were swimming in the distance or in conditions of low visibility, the Tetradontidae Family has a distinguishable body shape and swimming style however because of conditions, identifying them further into species was not possible