# Kirra Reef Biota Monitoring 2017

## Tweed River Entrance
## Sand Bypassing Project

*Prepared for:*

**Coastal Infrastructure Unit**
**NSW Department of Industry – Crown Lands**

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# Summary

Kirra Reef has intrinsic ecological and conservation value, and is both a highly visible and iconic fishing and diving site on the southern Gold Coast. The extent and biodiversity of Kirra Reef varies naturally with the northerly longshore transport of sand and episodic storm events. Over the last 55 years, Kirra Reef has been subject to changes in the rate of longshore drift and the intensity of wave action resulting from coastal management strategies, including the extension of the Tweed River training walls, installation of groynes, beach nourishment and the Tweed River Entrance Sand Bypassing Project (TRESBP). Rapid population growth and urban development has also increased pressure on reef ecosystems in the region, through sediment and nutrient runoff, habitat loss, boating and anchoring impacts, waste disposal, overfishing, aquarium trade collection and climate change.

The TRESBP was established in 1995 as a joint initiative of the New South Wales and Queensland Governments to improve and maintain navigation conditions at the Tweed River entrance and to provide a continuing supply of sand to the southern Gold Coast beaches consistent with the natural rate of longshore drift. Ongoing monitoring of Kirra Reef is required under *the Environmental Management System (EMS) Sub-Plan B14 Kirra Reef Management Plan*, prepared by the TRESBP in January 2010. This report discusses the results of ecological monitoring of benthic and fish communities at Kirra Reef in May 2017, and compares the results to previous monitoring done in 1995, 1996, 2001, 2003, 2004, 2005, 2010, 2012, 2014, 2015 and 2016.

**Benthic Communities**

There are clear differences in benthic community assemblages at Kirra Reef and the comparative reefs at Cook Island West and Cook Island East. Kirra Reef had a higher cover of the large brown alga *Sargassum* sp. and ascidians and a lower cover of turf algae and hard corals than the comparative Cook Island reefs.

The benthic assemblage at Kirra Reef has varied over time, however macroalgae have dominated in all surveys. Following the commencement of stage 2 of the TRESBP in 2001, the cover of macroalgae dramatically decreased, likely a result of the direct and indirect affects of 'catch-up' sand delivery. Most of Kirra Reef was buried by sand between 2006 and 2008. Since 2008, sand volumes delivered by the TRESBP have been consistent with natural rate of longshore drift, and macroalgae cover has increased between 2010 and 2016. In 2017, macroalgae cover was lower than in 2016, which may be a result of recent sand accretion around the reef and / or storm-driven wave events.

The cover of soft and hard coral at Kirra Reef is naturally low and characteristic of shallow inshore reefs. Since the emergence of a large area of reef from sand burial in 2009, both soft coral and hard coral have had a very low presence (<0.2% cover) or been absent. The extremely low cover / lack of corals since this time may indicate the community is subject to frequent disturbance from shifting sands and wave action preventing recruitment and / or growth.

**Fish Communities**

The fish assemblages at Kirra Reef differed to those at the comparative Cook Island West and Cook Island North reefs. As in previous years, large schools of yellowtail were observed at Kirra Reef, along with striped sea pike, mado, black tipped bullseye and stripey. These species were on average more abundant at Kirra Reef than at the Cook Island reefs (Kirra Reef appears to have a concentrating effect). In contrast, eastern pomfred and ring-tailed surgeon were more common at the Cook Island reefs than at Kirra Reef. Differences in fish assemblages between reefs are likely to be due to a combination of factors, including differences in topography, benthic communities influencing food availability, and fishing activity at Kirra Reef compared to the protected Cook Island reefs.

**Reef Area**

The greatest change to the ecological condition of Kirra Reef since the commencement of TRESBP has been burial of large areas of hard substrate that support benthic flora and fauna. In particular the delivery of large sand volumes during the stage 1 TRESBP (1995 to 1998) and the initial operation of the sand bypass system (2001 to 2008) resulted in a significant increase in the beach width at Kirra, with wave action and tidal currents redistributing sand over Kirra Reef. This was predicted in the project's Environmental Impact Statement (EIS) in 1997, and in 2001 the EMS predicted that the extent of Kirra Reef would return to conditions prior to 1962 when the extension of the Tweed River training walls depleted sand supplies to the area. Overall, the extent of Kirra Reef has remained relatively constant for the last five years, during a period where the delivery of sand by the TRESBP has mimicked natural rates of longshore drift, and in which storm activity has been moderate. Whilst a period of increased storm activity may allow the extent of Kirra Reef to expand through increased exposure of rock substrate, it is unlikely that the reef will exhibit a significantly greater extent than at present over the long-term.

**Future Monitoring**

No comparative site used to date in this monitoring program has provided an 'ideal match'. Kirra Reef is unique in the region, being completely surrounded by mobile sand.

It is likely that the ‘rocks’ (such as Manta Bommie) off the north-eastern tip of Stradbroke Island may serve as better comparative sites.

# Glossary

| | |
|---|---|
| AHD | Australian Height Datum |
| ANOSIM | Analysis of Similarities |
| BRUVS | Baited Remote Underwater Video Station |
| CPCe | Coral Point Cover with Excel extensions |
| df | Degrees Freedom |
| DO | Dissolved Oxygen |
| EC | Electrical Conductivity |
| EIS | Environmental Impact Statement |
| EMS | Environmental Management System |
| EPBC | Environment Protection and Biodiversity Conservation |
| F | F- ratio, the statistic used to test whether means are statistically different |
| GIS | Geographic Information Software |
| IPO | Interdecadal Pacific Oscillation |
| maxN | Maximum Number of individuals in given timeframe |
| MS effect | Mean Square value, calculated by dividing sum-of-squares by degrees of freedom |
| nMDS | non-Metric Multidimensional Scaling |
| NSW | New South Wales |
| NTU | Nephelometric Turbidity Units |
| p | p value, the calculated probability of a statistically significant difference |
| PERMANOVA | Permutational Multivariate Analysis Of Variance |
| ROV | Remotely Operated Vehicle |
| SE | Standard Error |
| SIMPER | Similarity Percentage |
| SST | Sea Surface Temperature |
| STDev | Standard Deviation |
| t | t-statistic, the ratio of departure of the hypothesized value from its standard error |
| TRESBP | Tweed River Entrance Sand Bypassing Project |

# 1 Introduction

## 1.1 The Kirra Reef Biota Monitoring Program

Kirra Reef is the collective name given to the complex of rocky outcrops located a few hundred metres offshore of Kirra Beach, at approximately -5 m Australian Height Datum (AHD) and within the influence of wave action. The reef is naturally subject to shifting sands and storm events that intermittently cover and uncover parts of the reef (TRESBP 2015). The exposed extent of Kirra Reef also varies due to anthropogenic changes to the coastal environment that have included the extension of the Tweed River training walls in 1964 and the commencement of the Tweed River Entrance Sand Bypassing Project (TRESBP) in 2001 (WorleyParsons 2009). Rapid population growth and urban development has also increased pressure on reef ecosystems in the region, through sediment and nutrient runoff, habitat loss, boating and anchoring impacts, waste disposal, overfishing, aquarium trade collection and climate change (Loder et al. 2013)

Ongoing monitoring of Kirra Reef is required under *the Environmental Management System (EMS) Sub-Plan B14 Kirra Reef Management Plan*, prepared by the TRESBP in Jaunuary 2010. Under *EMS Sub-Plan B14 Kirra Reef Management Plan*, if the area of exposed reef on aerial photographs is smaller than the range of areas shown on aerial photographs from 1962 to 1965, then monitoring of marine biota of Kirra Reef is triggered.

Kirra Reef has intrinsic ecological and conservation value, and is both a highly visible and iconic fishing and diving site on the southern Gold Coast. The Kirra Reef Biota Monitoring Program contributes to an understanding of how the sand bypassing system directly impacts Kirra Reef, and also to how the placement of sand interacts with a range of natural factors that influence the physical extent of the reef, its biodiversity, and the abundances of its biota.

## 1.2 History of the Tweed River Entrance Sand Bypassing Project

The TRESBP was established in 1995 as a joint initiative of the New South Wales (NSW) and Queensland Governments to improve and maintain navigation conditions at the Tweed River entrance and to provide a continuing supply of sand to the southern Gold Coast beaches consistent with the natural rate of longshore drift. The project was carried out in two stages:

- Stage 1: Initial dredging and nourishment works (April 1995 to May 1998), and

- Stage 2: Implementation of a sand bypassing system to maintain the improvements achieved during Stage 1 (from May 2001 onwards).

During Stage 1, approximately three million cubic metres ($m^3$) of clean marine sand (with less than 3% fines) were dredged from the Tweed River entrance. Most of the sand was delivered to -10 m mean water depth extending from Point Danger to North Kirra, with approximately 600 000 $m^3$ of sand being placed on the upper beaches from Rainbow Bay to North Kirra. From April 2000 to February 2001, additional dredging activities were undertaken to maintain a clear navigation channel at the Tweed River entrance. Prior to the establishment of the permanent sand bypassing system a further 480 000 $m^3$ of clean marine sand was placed in near-shore areas from Point Danger to Coolangatta Beach.

Stage 2 commissioning trials commenced in March 2001 and full-scale operation of the sand bypassing system commenced in May 2001. Since this time, approximately 8.7 million $m^3$ of pumped sand and 2.1 million $m^3$ of dredged sand (derived from dredging of the Tweed River mouth) have been deposited along the southern Gold Coast beaches. Most of the sand delivered through pumping and dredging has been placed in the primary placement area, south-east of Snapper Rocks. Sand from the pumping system is also periodically discharged from outlets at Duranbah Beach, and occasionally at Snapper Rocks West, Greenmount and Kirra. The outlet at Kirra Beach has not been used since December 2003. A placement exclusion zone was established around Kirra Reef extending a minimum of 100 m from the reef edge (1995 extent) to prevent placement of sand in close proximity to the reef (Lawson et al. 2001).

During the early operation years (from 2001 to 2008) of stage 2 of the TRESBP, relatively high quantities of sand were delivered to the southern Gold Coast beaches to:

- nourish the severely eroded southern Gold Coast beaches
- reduce the Tweed Entrance Bar, and
- clear a sand-trap in the vicinity of the pumping jetty to improve the efficiently of the sand bypass system.

These project objectives were achieved, and the quantity of sand delivered since 2008 has been more consistent with the natural movement of sand along the coast (average natural net longshore sand drift is estimated to be 500 000 $m^3$ per year in a northward direction). In 2016, a total of 461 502 $m^3$ was pumped through the sand bypassing system, with the majority placed at Snapper Rocks East (442 869 $m^3$) and the remainder placed at Duranbah (18 633 $m^3$). From January to April 2017 an additional 142 472 $m^3$ of sand was pumped through the system to Snapper Rocks East.

Dredging to clear the Tweed River entrance and maintain a navigatable entrance channel is also undertaken as required, with dredged sand also supplementing the sand bypassing system. Dredging campaigns typically remove between 100 000 $m^3$ and 200 000 $m^3$ of sand from the Tweed River channel and mouth, and place sand between Duranbah and Snapper Rocks to provide nearshore nourishment. Between 2008 and 2015, there was only one small dredging campaign (200 $m^3$ of dredged material in 2011). However, in 2016, 41 943 $m^3$ of sand was dredged and placed at Duranbah and between January and April 2017, 57 125 $m^3$ of sand was dredged and placed at Snapper Rocks East and Duranbah.

## 1.3 Past Monitoring – Events and Insights

frc environmental completed a baseline assessment of Kirra Reef in April and June 1995 (Fisheries Research Consultants 1995a). Subsequent ecological monitoring of the reef on behalf of TRESBP have been completed in February 1996, January 2001, May 2003, March 2004, February 2005, February 2010, July 2012, April 2014, March 2015 and July 2016 (Fisheries Research Consultants 1996; frc environmental 2001; 2003; 2004; 2005a; 2010). The current survey was completed in May 2017.

### *Comparison with Predictions Made in the Project's EIS*

The current extent of Kirra Reef is broadly in accordance with predictions made in the EIS. Initial 'catch-up' bypassing and dredge placement of sand (between 2001 and 2008) resulted in the burial of Kirra Reef. Subsequent sand delivery (since 2008) more closely reflected natural patterns of long-shore sand transport, allowing the reef to gradually re-emerge.

Since monitoring commenced, the greatest change to the floral and faunal assemblages of Kirra Reef has been due to the burial of rocky substrate. The coincident shallowing of the waters surrounding the reef and consequent increase in wave action (and likely sediment deposition) has also influenced floral and faunal community structure.

The diversity of fishes associated with Kirra Reef is broadly similar to that recorded prior to the commencement of sand bypassing in 1995.

Kirra Reef therefore continues to provide habitat for a range of flora and fauna, and provides important marine ecological functions and services in the region.

***The Influence of Storm-driven Waves***

The extent of the reef has been relatively stable since 2013. Whilst the benthic assemblage of Kirra Reef exhibits signs of ongoing ecological stress (as exemplified by a typically low percentage cover of hard and soft corals) from storm-driven waves, physical abrasion and burial by sand, this is both natural and characteristic of shallow, wave exposed inshore reefs surrounded by sand.

## 1.4 This Report

This report presents results of the survey of benthic macrophytes, benthic macroinvertebrates and fishes at Kirra Reef and at comparative sites at Cook Island, in May 2017.

The 2017 monitoring event has focused on:

- the quantitative description of benthic community at Kirra Reef.
- the description of biodiversity at Kirra Reef, both through species lists of macroalgae, benthic invertebrates and fishes.
- comparing observed changes in biodiversity, cover and abundance with abiotic factors including water temperature and wave conditions; and
- assessing the impacts of sand placement through the comparison of data acquired from Kirra Reef with that acquired from Cook Island.

# 2 Scope of the 2017 Monitoring Event and Methods Used

## 2.1 Scope

The proposed scope of the 2017 monitoring event was to:

- update the program's understanding of: the influence of abiotic environmental factors, recreational fishing and diving activity at Kirra Reef, and species of conservation significance and invasive species;
- acquire fresh data from a single monitoring event at Kirra Reef and comparative sites[1]; and
- develop a report in compliance with the requirements of the Environmental Management System.

## 2.2 Experimental Design

The 2017 monitoring event (experimental) design comprised:

- Benthic Biota
  - three sites: Kirra Reef and reefs at two comparative sites at Cook Island North and Cook Island West;
  - forty five randomly placed 'virtual quadrats' from each site[2] (supplemented by focused diver searches).
- Fishes
  - three sites: Kirra Reef and reefs at two comparative sites at Cook Island North and Cook Island West;
  - three baited remote underwater video stations at each site (supplemented by video transects and diver observations / searches)

The survey was conducted at Kirra Reef and Cook Island North on the 16 May 2017, and at Cook Island West on the 17 May 2017 (Map A1).

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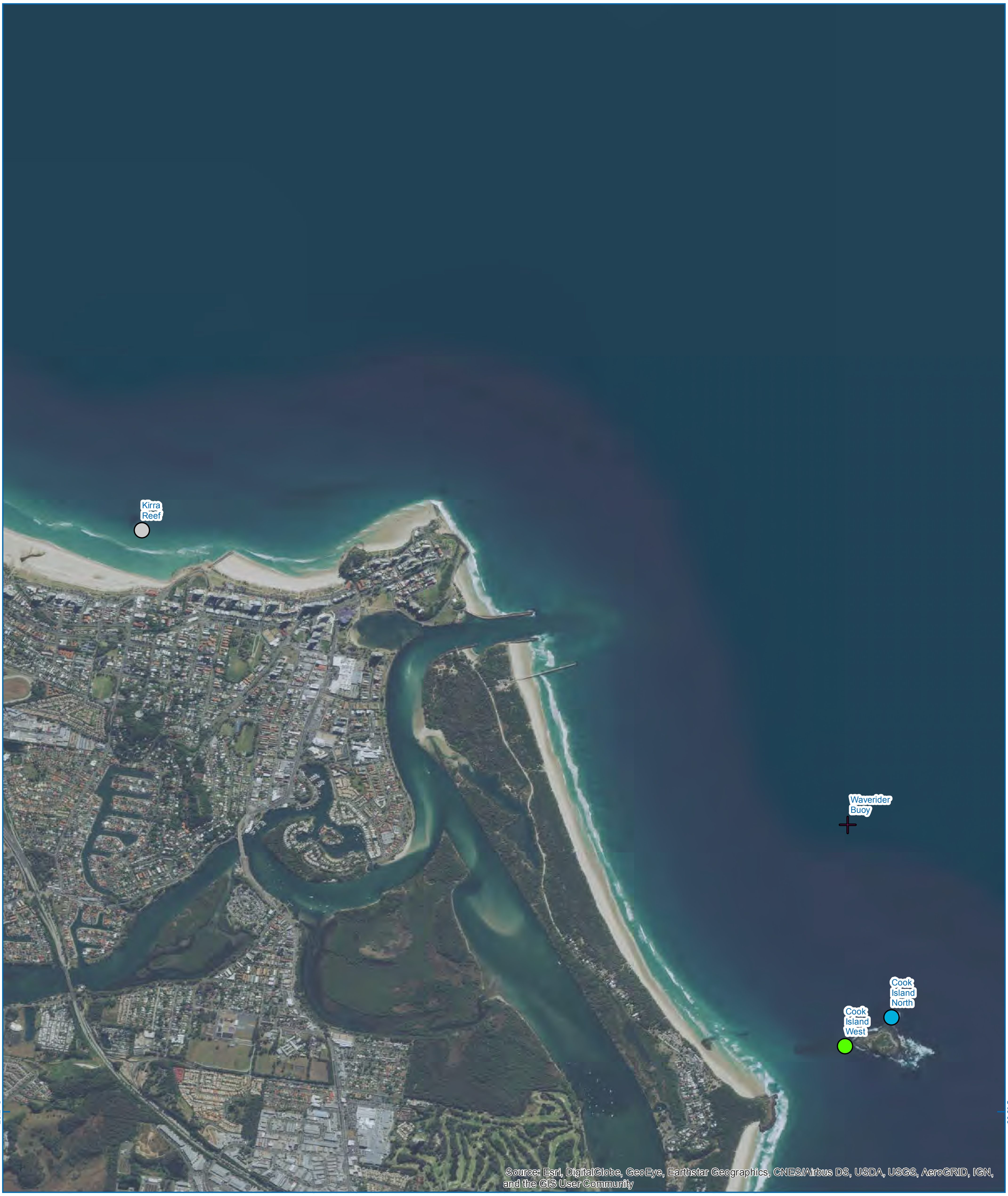
1 Sea conditions on 17 May prevented the acquisition of data from Kingscliff Reef. A second comparative site was established at Cook Island.

2 An additional 15 randomly placed 'virtual quadrats' were to be derived from areas of Kirra Reef recently uncovered. However, a thorough search of the reef by divers failed to reveal any recently uncovered substrate (sand is currently accreting around the reef).



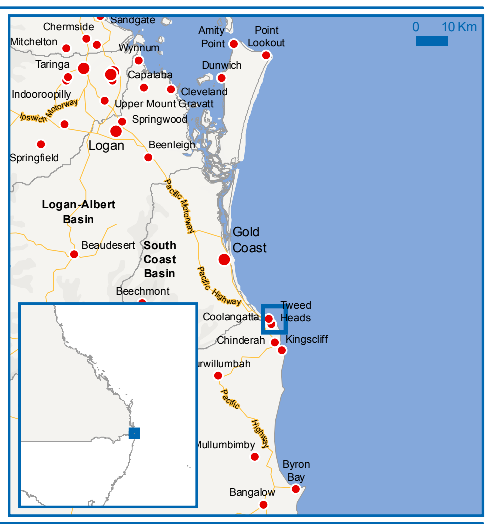

## Kirra Reef Biota Monitoring 2017

Map 1:
Location of survey sites and
Waverider Buoy for 2017 Monitoring

**LEGEND**

**Survey sites and Waverider Buoy**

- Kirra Reef
- Cook Island North
- Cook Island West
- Waverider Buoy





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**SOURCES**



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## 2.3 Collection of Data

### Benthic Biota

In May 2017, benthic biota was surveyed using a remotely operated vehicle (ROV) equipped with high-definition digital stills and video cameras, video lighting and laser scaling, augmented by an accredited scientific diver who focused on (Figure 1 and Figure 2):

- *in situ* species identification; and
- searching for cryptic and invasive species.

### Fishes

ROV-acquired video imaging, baited remote underwater video stations (BRUVS) and diver searches, were the basis for developing an understanding of fish community structure and relative abundances.

Figure 1

ROV above Kirra Reef in 2017


Figure 2

Scientific diver at Kirra Reef in 2017

**Abiotic Factors**

Sea condition, wind strength and direction, Secchi depth, temperature, turbidity, salinity and the concentration of dissolved oxygen were recorded *in situ* at each site, whilst wave height, wave direction and sea surface temperature data was sourced from the Tweed Heads Waverider Buoy data base (DSITI 2017), to provide a record of physical conditions at the time of, and leading up-to the monitoring event.

## 2.4 Data Management and Analyses

**Benthic Biota**

Coral Point Count with Excel extensions (CPCe) (Kohler & Gill 2006) was used to generate a matrix of 50[3] randomly distributed points for each 0.5m x 0.5m 'virtual quadrat' derived from the high definition digital imagery. The substrate type, and identity of macroalgae and invertebrate fauna were determined by an experienced reef ecologist for each point (referencing the species list compiled from *in-situ* observations and collected specimens). Percentage cover / abundance of key taxa was calculated for each reef.

A one factor permutational multivariate analysis of variance (PERMANOVA) was used to examine differences in the composition of benthic assemblages in 2017, with reefs (Cook Island Reef West, Cook Island Reef North and Kirra Reef, fixed factor) as the factor. To examine differences in benthic communities at Kirra Reef (only) through time, a one factor PERMANOVA was used, with time as the factor. For temporal comparisons at Kirra Reef, data was aggregated into the taxonomic categories used prior to 2016 (FRC 2015).

[3] 50 points were considered statistically appropriate considering the typically small size of sessile fauna encountered.

Prior to analyses, data was square-root transformed to down-weight the dominance of highly abundant species, converted to a Bray Curtis distance matrix, and tested for significance using 9999 permutations, where possible. Non-metric multidimensional scaling (nMDS) ordinations were used to visually represent the variation in the composition of assemblages between reefs, for each survey. Taxa that contributed to the differences in assemblages among sites were identified using the similarity percentages (SIMPER) routine. Post-hoc pairwise tests were used on significant terms to determine the source and magnitude of differences. The magnitude of difference between reefs was assessed using pairwise tests following analyses of similarity (ANOSIM), where differences were greater where the $R$ value is closer to 1.

Average data for each reef was used to generate the K-dominance curves to examine the difference diversity (richness and evenness) of benthic faunal assemblages between reefs.

### Fishes

All BRUVS digital imagery was analysed by the same observer and the maxN was recorded for each species, with maxN defined as the highest number of individuals of a given species recorded within a single video frame throughout each 60 minute deployment (Pearson & Stevens 2015).

One-way PERMANOVA were used to assess similarities between sites in 2017 (with the factor being sites), with the differences visually displayed as nMDS ordinations. SIMPER was used to identify taxa contributing to dissimilarities between reefs. Post-hoc pairwise tests were used on significant terms to determine the source and magnitude of differences. Prior to analyses, data was square-root transformed to down-weight the dominance of highly abundant species, converted to a Bray Curtis distance matrix, and tested for significance using 9999 permutations, where possible.

Kirra Reef and the comparative reefs were also compared to surrounding reefs, including inshore continental shelf reefs near Kingscliff and the Southport seaway (Pearson & Stevens 2015) as well as reefs in Moreton Bay (Johnson 2010).

### Abiotic Factors

The historical dataset of biota on the reef was analysed with respect to other historical datasets relating to:

- wave height
- satellite imagery
- weather data including wind strength and direction, and
- sand release.

### Temporal Changes in the Extent of Exposed Reef

Historical data on the extent of Kirra Reef was sourced from previous Kirra Reef Biota Monitoring program reports (Ecosure 2016; frc environmental 2015) and other available literature. As in previous years the extent of exposed reef in 2017 was calculated from a rectified aerial image (nearmap 2017) using Geographic Information Software (ESRI 2014).

# 3 Results

## 3.1 Benthic Assemblages in 2017

The composition of benthic fauna and flora differed between reefs (Table 3.1; Table 3.2; and Figure 2 to Figure 6). However, Cook Island West and Cook Island North were more similar to each other than to Kirra Reef (Figure 3). Kirra Reef had (SIMPER analyses; Appendix A):

- more brown macroalgae (Phaeophyta) of the genus *Sargassum* than both Cook Island West and Cook Island North (Figure 7)
- less red algae (Rhodophyta) cover than at Cook Island North (Figure 8)
- less hard coral compared to both Cook Island reefs (Figure 9 Figure 10)
- more ascidians than both Cook Island reefs (Figure 11), and
- less turf algae than both Cook Island reefs (Figure 12).

In general, the benthic assemblages at Kirra Reef had a higher evenness (abundance of different species was similar) compared to Cook Island West and Cook Island North, illustrated by a shallow gradient slope representing ranked abundances of taxa (Figure 13).

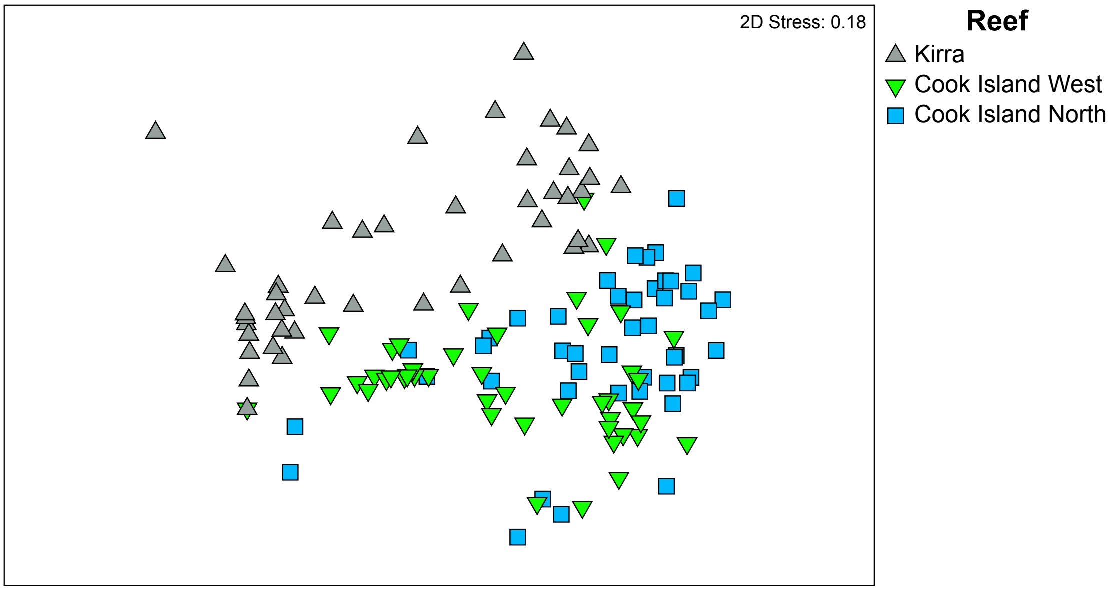



Figure 3 nMDS plot of benthic invertebrate communities at Kirra, Cook Island West and Cook Island North reefs during the 2017 survey.

Table 3.1 PERMANOVA results for differences in the composition of benthic assemblages between reefs. Bold p values denote significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 36648 | 18.422 | **0.0001** |
| Residual | 132 | 1989.4 | | |

[a] p values based on Monte Carlo simulations

Table 3.2 Results of pairwise comparisons between reefs following PERMANOVA. Bold p values denote significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 2.9044 | **0.0001** | 9932 | **0.0001** |
| Cook Island North, Kirra Reef | 5.1463 | **0.0001** | 9941 | **0.0001** |
| Cook Island West, Kirra Reef | 4.3288 | **0.0001** | 9946 | **0.0001** |

[a] p values based on Monte Carlo simulations

Table 3.3 Results of pairwise comparisons between reefs following ANOSIM analyses (Global R = 0.321; p = 0.001). Bold p values denote significance at p<0.05.

| Groups | R value | Significance Level | Actual permutations |
|---|---|---|---|
| Cook Island North, Cook Island West | 0.179 | **0.001** | 999 |
| Cook Island North, Kirra Reef | 0.452 | **0.001** | 999 |
| Cook Island West, Kirra Reef | 0.324 | **0.001** | 999 |

[a] R-values closer to 1 are more different, with R-values of 0 indicating no difference.

Figure 4

Typical ROV image of benthic community at Kirra Reef, showing *Sargassum*, sponges and areas of bare sand.

Figure 5

Typical ROV image of benthic community at Cook Island North, showing a mix of hard coral, turf and red algae.

Figure 6

Typical ROV image of benthic community at Cook Island West, with a mix of hard coral and turf algae.

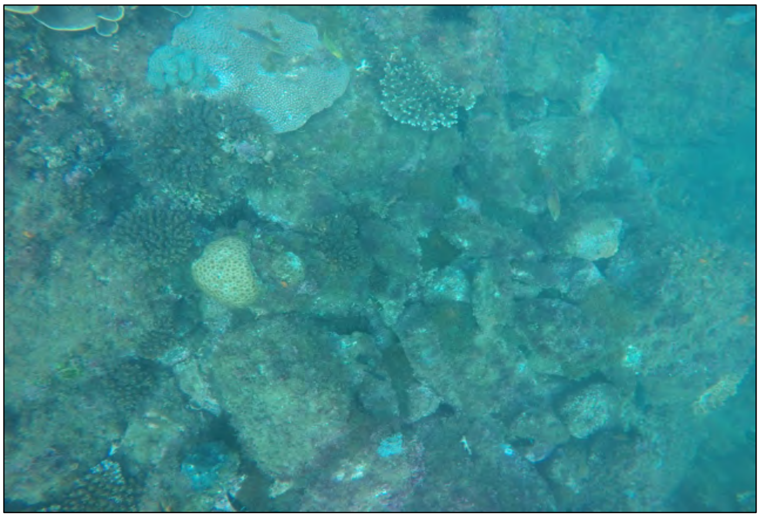


Figure 7

Diver at Kirra Reef in an area dominated by *Sargassum*.

Figure 8

An assemblage of red algae (Rhodophyta) at Kirra Reef.

Figure 9

Colony of hard coral (*Turbinaria* sp.) at Cook Island North.

Figure 10

Colonies of the soft coral *Dendronepthya* sp. amongst tunicates and small sponges.

Figure 11

An assemblage of benthic invertebrates dominated by ascidians at Kirra Reef.

Figure 12

Turf algae at Kirra Reef within a sandy and macroalgae dominated area.

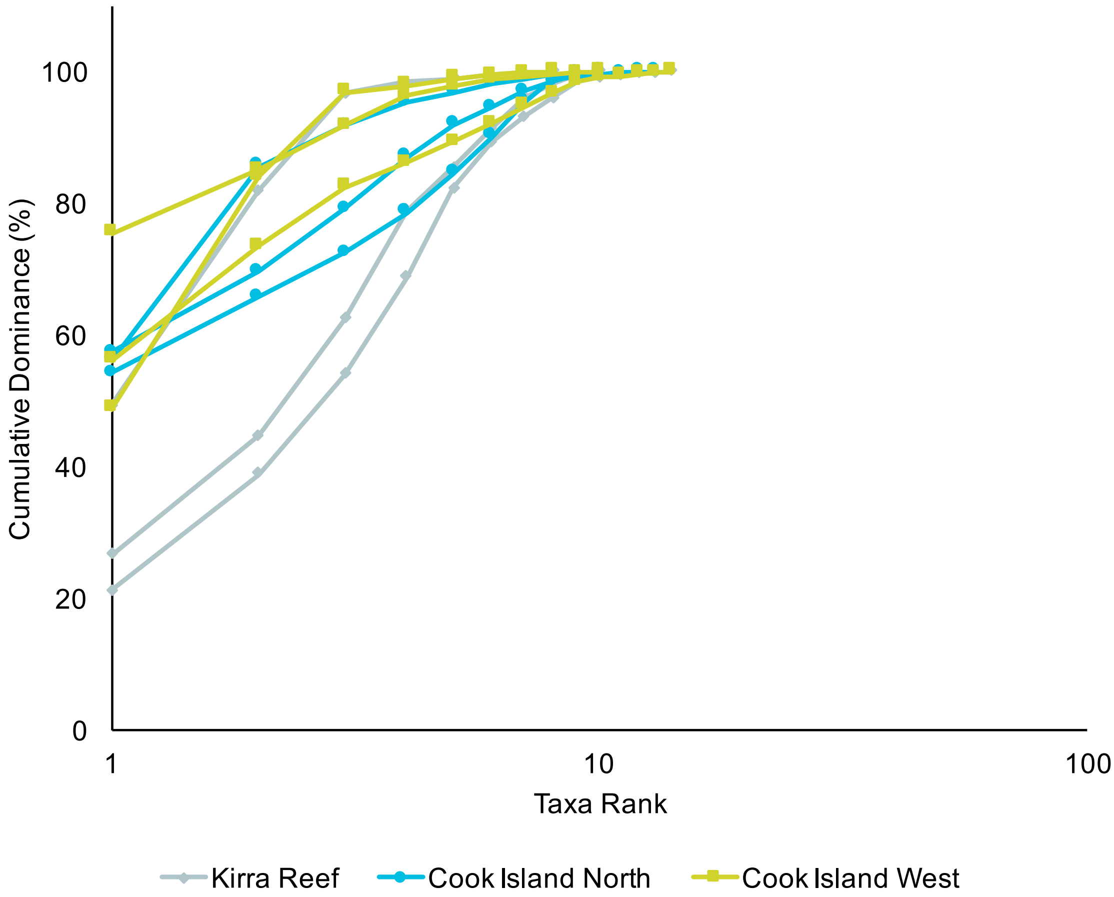



Figure 13 k-dominance of benthic assemblages at Kirra and Cook Island Reefs in 2017.

### Turf and Macroalgae

In 2017, as in previous surveys, the brown macroalgae, *Sargassum* sp. (Figure 15), dominated benthic assemblages at Kirra Reef (Ecosure 2016; frc environmental 2015). The cover of *Sargassum* was significantly higher at Kirra Reef than at both Cook Island reefs, which had a similar cover (Figure 14; Appendix A). Other brown algae had a low cover and were not significantly different between reefs (Appendix A). This included *Zonaria* sp. and *Padina* sp. from the family Dictyotaceae.

Red algae of the family Galaxauraceae, typical of temperate reefs, was significantly more common and approximately five time more abundant at Cook Island North compared to both Cook Island West and Kirra Reef (Table 3.3; Appendix A). Whereas, the cover of the red algae of the family Rhodomelaceae, was significantly higher at Kirra Reef than at both Cook Island reefs, which had a similar cover (Figure 14; Appendix A). A number of species of branching coralline algae are also common (though never dominant) at each location surveyed (Figures 8, 14 and 17).

The cover of green algae (Chlorophtya) was low and similar at all reefs ($p > 0.05$; Figure 14; and, Appendix A). Green algae included *Chlorodesmis* sp. (Figure 16), *Halimeda discoidea* (Figure 17) and *Caulerpa racemosa* (Figure 18), present in small isolated patches.

The cover of turf algae (comprised of brown, red and green algae) was much lower at Kirra Reef than at the Cook Island reefs, which had a similar cover (Figure 14; Appendix A).

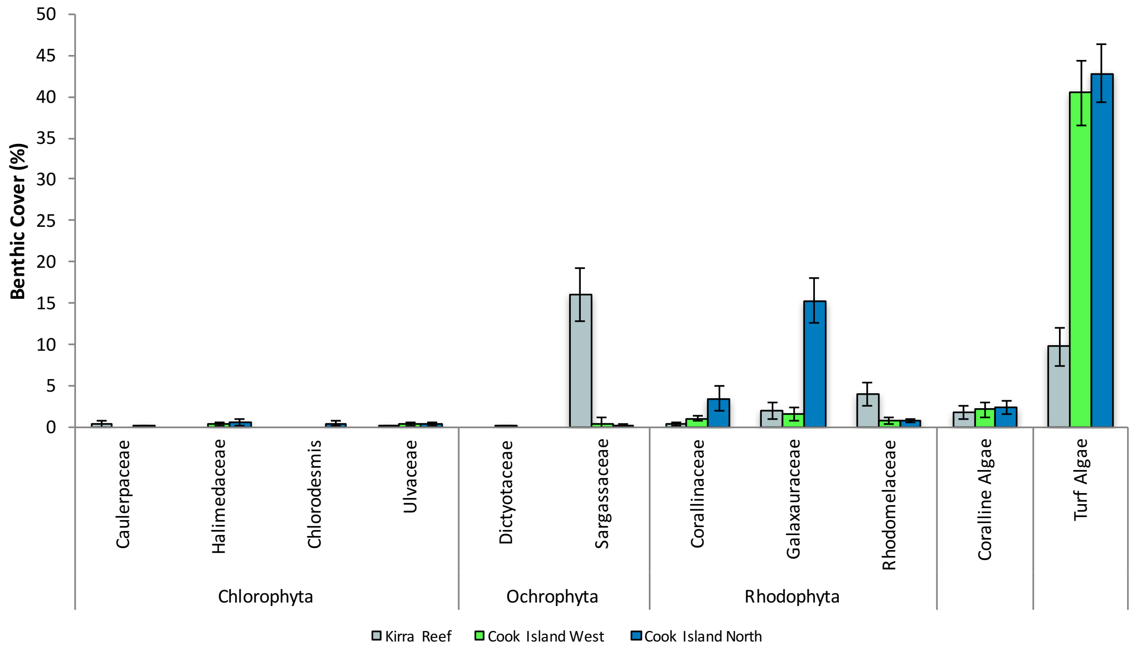



Figure 14 Benthic cover (%, ± standard error) of turf and macroalgae during the 2017 survey.

Figure 15

The brown algae *Sargassum* sp. at Kirra Reef.

Figure 16

The green algae *Chlorodesmis* sp. at Cook Island North.

Figure 17

The green algae *Halimeda discoidea* within an assemblage of red algae at Cook Island North.

Figure 18

*Caulerpa racemosa* at Cook Island North.

### Benthic Invertebrates: Ascidians, Corals, Sponges and Crinoids

Large variation in the presence and cover of several benthic groups was evident between the reefs at Cook Island and Kirra Reef. Kirra Reef had a statistically high percentage of ascidians (Figure 20) covering the substrate (mean cover 16%) than both Cook Island reefs, which had a similar cover of less than 3% (Figure 19; Appendix A).

Conversely, hard corals were not recorded at Kirra Reef in 2017, but covered almost 11% of substrate at both Cook Island reefs (Figure 19; Appendix A). Soft coral was recorded at Kirra Reef, but colonies were uncommon, covering approximately 0.1 percent of the available substrate (Figure 19, Figure 21 and Figure 22). There was a similarly low abundance of soft coral at both Cook Island reefs (Figure 19; Appendix A).

The cover of sponges was similar at Kirra Reef and Cook Island North (Figure 23), while Cook Island West had less than one percent cover (Figure 19; Appendix A). The mean cover of feather stars (Crinoidea) was highest at Kirra Reef, with the cover statistically higher to Cook Island North, but not statistically different to Cook Island West (Figure 19 and Figure 24).

Other groups such as bivalves, echinoderms and polychaetes were detected in very low percentages and were not statistically different between reefs (Figure 19 and Appendix A).

At each reef, but particularly at the Cook Island reefs, a diverse range of less common invertebrate taxa were recorded, including sea urchins (Figure 25), anemones (Figure 26) and nudibranchs (Figure 27).

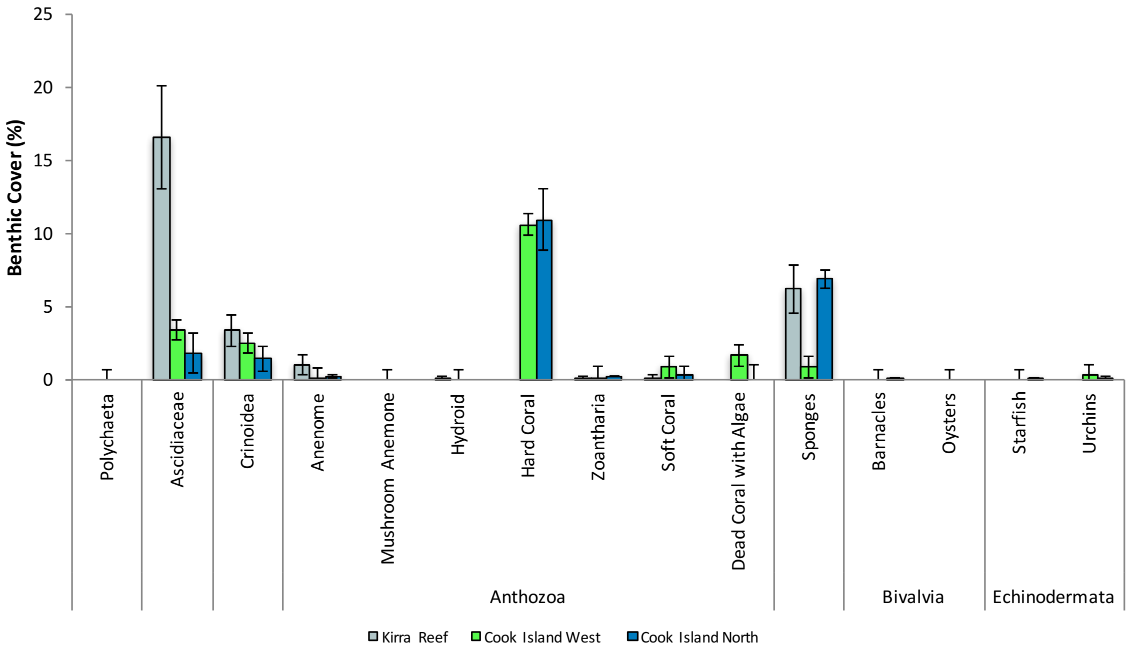



Figure 19 Cover of benthic assemblages other than macroalgae (%, ± standard error) during the 2017 survey.

Figure 20

A colony of ascidians below black crinoids at Kirra Reef.

Figure 21

A colony of soft coral (*Carijoa* sp.) at Kirra Reef.

Figure 22

The soft coral *Sarcophyton* sp. at Cook Island West.

Figure 23

A sponge (Order Demospongiae) at Kirra Reef.

Figure 24

Crinoids (*Cenolia* sp., Order Crinoidea) Cook Island West.

Figure 25

Sea urchin and anemone at Cook Island West.

Figure 26

Anemonefish (*Amphiprion akindynos* sp.) and anemone at Cook Island West.

Figure 27

Nudibranch (*Chromodoris* sp.) at Cook Island West.

## 3.2 Changes in Benthic Communities at Kirra Reef Over Time

As in previous years, benthic assemblages at Kirra Reef appeared to show some overlap through time (Figure 28). However, there was a significant difference in benthic communities at Kirra Reef between years, with post-hoc tests indicating most years to be different to each other (Table 3.4; Appendix A). Differences between years were largely attributed to the cover of macroalgae, turf algae, ascidians, sponges and soft coral (SIMPER, Appendix A).

Table 3.4 One-way PERMANOVA Results for the comparison of benthic communities at Kirra Reef over all surveys.

| Factor | df | MS effect | Pseudo-F | p (perm) |
|---|---|---|---|---|
| **Main test** | | | | |
| Years | 12 | 29767 | 35.748 | **0.0001** |
| Residual | 583 | 832.69 | | |

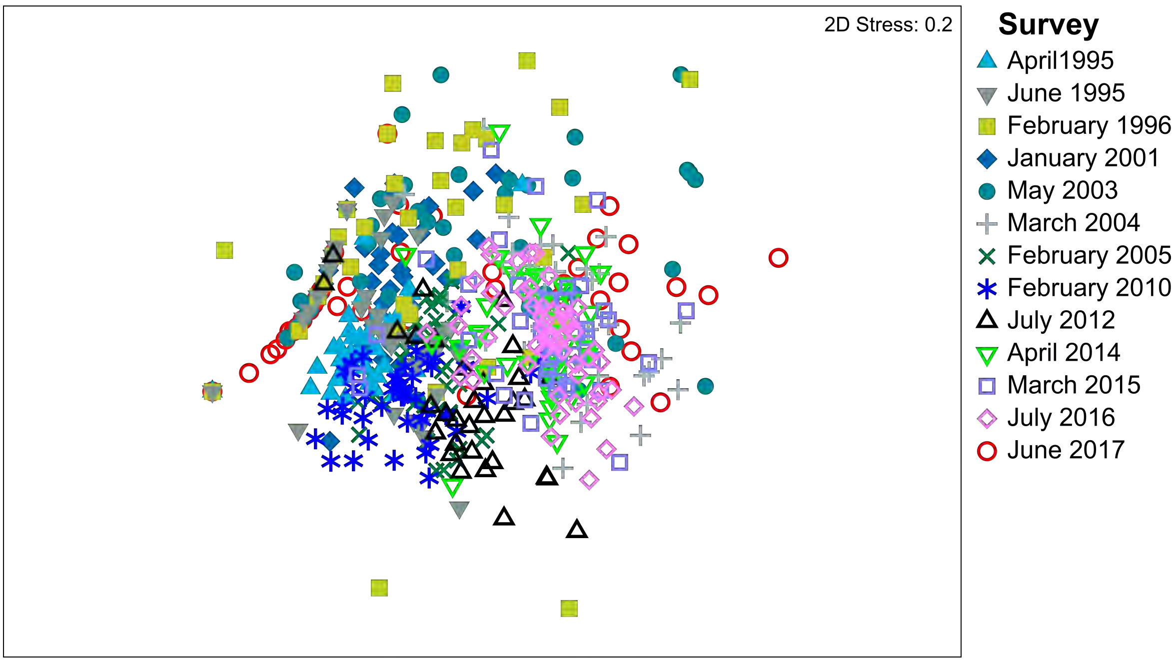



Figure 28 Multi-dimensional scale plot of benthic cover at Kirra Reef in all surveys.

### Turf and Macroalgae

The cover of macroalgae at Kirra Reef has changed between years, and reached its peak in 2001 (Figure 29), when the cover was significantly higher than all other sampling years (Appendix A). Cover of macroalgae decreased between 2001 and 2003, likely as a result of the large sand volumes placed in the area during stage 2 of the TRESBP. Since 2008, sand volumes have been more consistent with natural sand supply rates, and macroalgae cover has shown an increasing trend between 2010 and 2016, following the emergence of Kirra Reef from almost complete sand burial between 2006 and 2009. In 2017, macroalgae cover was significantly lower than in 2016 coincident with the recent accretion of sand around the reef (frc environmental, pers. obs). However, in 2017 macroalgal cover was similar to that recorded in April 1995 prior to TRESBP, and in 2003, 2004, 2012, 2014 and 2015 (Figure 29; Appendix A).

The cover of turf algae in the 2017 survey was significantly lower than recorded in recent years, and similar to that recorded in April 1995, 1996, 2001 and 2003 (Figure 29; Appendix A).

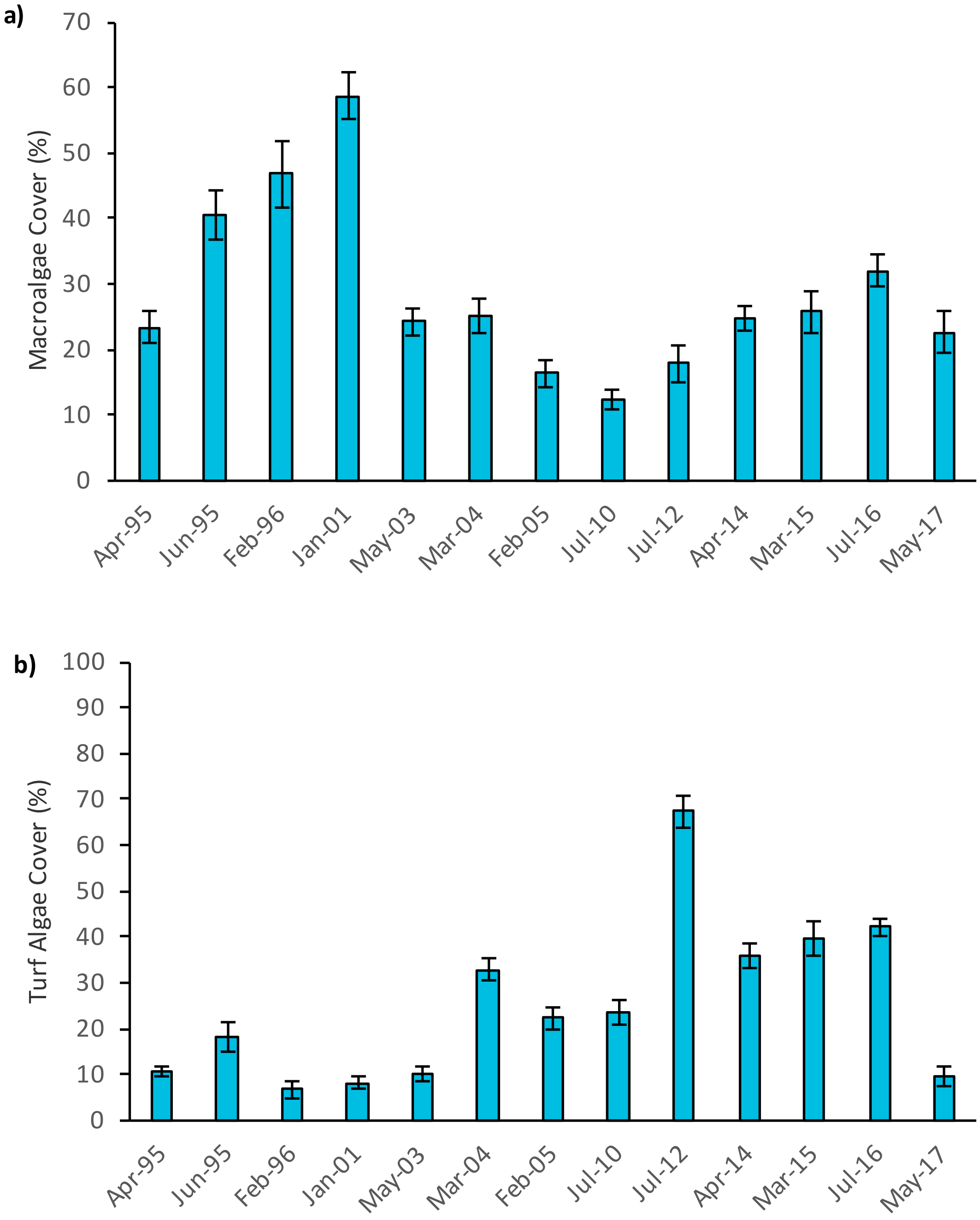



Figure 29 Mean cover of macroalgae and turf algae (± standard error) at Kirra Reef in all surveys

**Benthic Invertebrates: Corals, Sponges and Ascidians**

In 1995 and 1996, prior to and during stage 1 of the TRESBP, soft coral cover ranged between 0.7% and 9.7%, and hard coral cover ranged between 0% and 2.3%. In 2001 when stage 2 of the TRESBP commenced, no soft or hard coral was recorded at Kirra Reef. Between 2003 and 2005, soft coral cover ranged between 0.6% and 5.8%, and hard coral cover ranged between 0% and 1.7%. The reef was largely buried in sand between 2006 and 2009, and since surveys recommenced in 2010, both soft coral and hard coral have been absent or in very low cover (<0.2% cover). The extremely low cover of both hard and soft corals recorded since 2010 is likely to reflect frequent disturbance and prolonged periods of elevated turbidity associated with shifting sands and wave action inhibiting both recruitment and growth.

The cover of sponges at both Kirra Reef has varied significantly among years, being relatively high in 1996, 2003 and 2004, and lowest in 1995, 2001, 2010 and 2012 (Figure 30; Appendix A). Since 2012, the cover of sponges has varied but has always been statistically higher than that of 2010 and lower than that of 1996, 2003 and 2004 (Figure 30; Appendix A).

The cover of ascidians has also varied significantly among years. There were no or a very low cover of ascidians recorded in 1995 and 1996. The cover of ascidians in 2017 was similar to that recorded in 2005, 2014 and 2015.

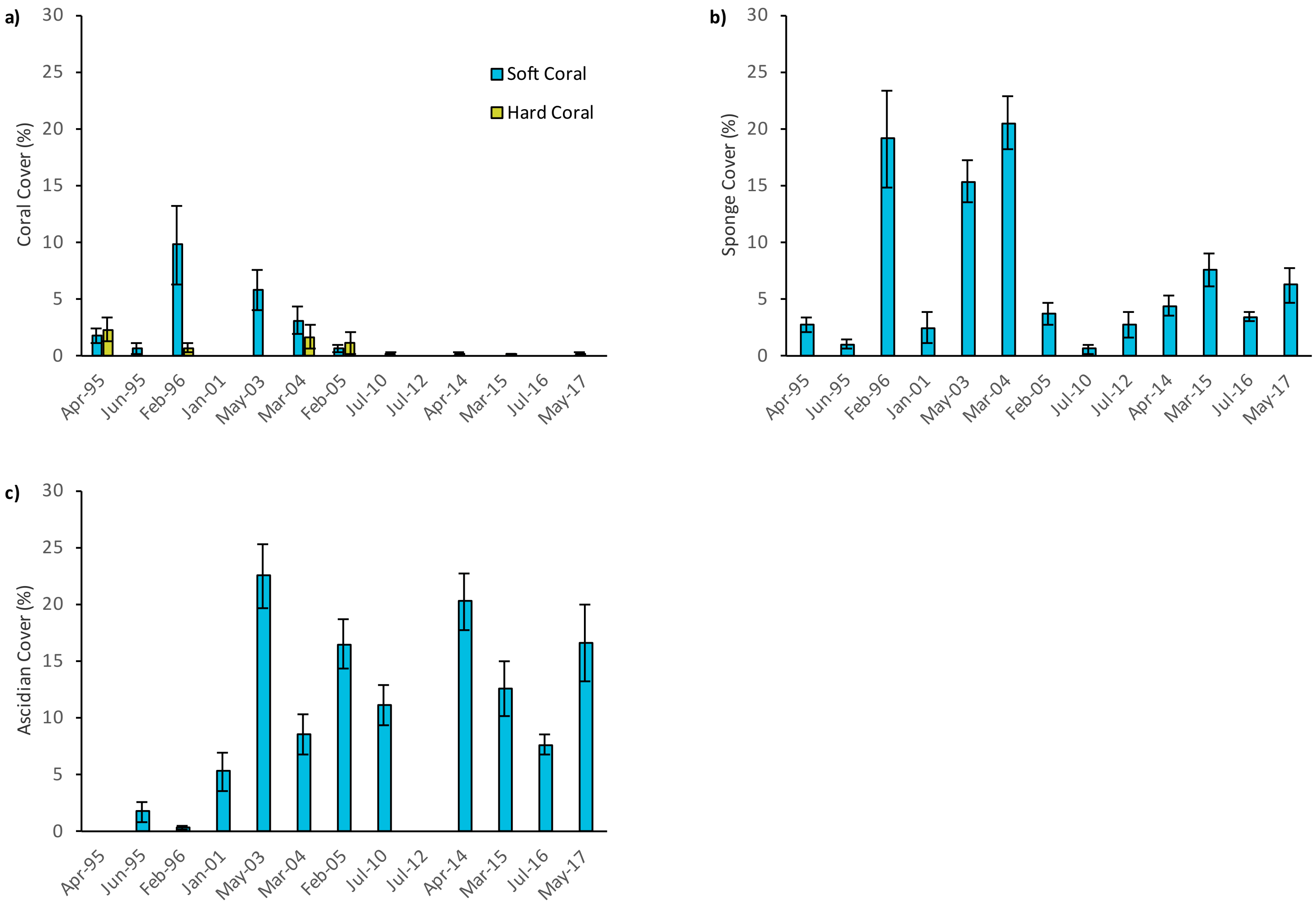



Figure 30 Mean cover of benthic communities (± standard error) at Kirra Reef in all surveys

Table 3.5 One-way PERMANOVA results for the differences in the cover of benthic taxa at Kirra Reef between surveys from 1995 to 2017. Bold p values denote significance at p <0.05.

| Benthic Taxa | Factor | df | MS effect | Pseudo-F | p (perm) |
|---|---|---|---|---|---|
| **Macroalgae** | Survey | 12 | 4063.4 | 7.1443 | **0.001** |
| | error | 583 | 568.76 | | |
| **Turf Algae** | Survey | 12 | 21951 | 36.607 | **0.001** |
| | error | 583 | 599.64 | | |
| **Soft Coral** | Survey | 12 | 1910.8 | 7.0155 | **0.001** |
| | error | 583 | 272.37 | | |
| **Hard Coral** | Survey | 12 | 492.3 | 4.6049 | **0.001** |
| | error | 583 | 106.91 | | |
| **Sponges** | Survey | 12 | 11665 | 15.032 | **0.001** |
| | error | 583 | 775.98 | | |
| **Ascidians** | Survey | 12 | 20558 | 28.799 | **0.001** |
| | error | 583 | 713.87 | | |

## 3.3 Fish Assemblages in 2017

### Species Richness and Evenness

A total of 76 species of fish representing 37 families were observed during the surveys at Kirra and Cook Island reefs (Appendix B1). Of these, 71 species were bony fish, and five species were cartilaginous fish (i.e. sharks and rays). Damselfishes (Pomacentridae) and wrasses (Labridae, Figure 31) were the most species-rich families, with fifteen and twelve species, respectively. Both Kirra Reef and Cook Island West supported 52 species, with 44 species observed at Cook Island North.

Figure 31 Yellow moon wrasse (*Thalassoma lutescens*).

Whilst sixteen species of fish were new to the monitoring program these were mostly observed at the Cook Island sites. These species included three species of shark and large, predatory fish like Maori grouper and snapper. The new species recorded in May 2017 were the:

- blindshark (*Brachaelurus waddi*) at Cook Island North
- spotted wobbegong (*Orectolobus maculatus*) at Cook Island North and West
- brown-banded bambooshark (*Chiloscyllium punctatum*) at Kirra Reef (Figure 32)
- striated surgeonfish (*Acanthurus striatus*) at Kirra Reef
- Sydney cardinalfish (*Apogon limenus*) at Cook Island West
- blueblotch butterflyfish (*Chaetodon plebeius*) at Cook Island West
- black-spotted goby (*Istigobius nigroocellatus*) at Cook Island West)
- cigar wrasse (*Cheilio inermis*) at Cook Island West
- bird wrasse (*Gomphosus varius*) at Cook Island West
- spangled emperor (*Lethrinus nebulosus*) at Cook Island West
- Abbott's moray eel (*Gymnothorax eurostus*) at Cook Island West
- highfin moray eel (*Gymnothorax pseudothyrsoideus*) at Kirra Reef
- brown puller (*Chromis hypsilepis*) at Cook Island North and West
- double-spotted queenfish (*Scomberoides lysan*) at Cook Island North (Figure 35)
- Maori grouper (*Epinephelus undulatostriatus*) at all sites, and
- snapper (*Pagus auratus*) at Cook Island West.

The majority of species observed at the three reefs were not at either extreme of their distribution range (Table 3.6), indicating that the reefs surveyed support an assemblage of typical sub-tropical species. Nevertheless, Kirra Reef had the slightly more species with a typically tropical distribution (i.e. the species are at the southern extreme end of their range). In contrast, the reef at Cook Island North had a higher number of species with a typically temperate distribution, indicating that these species are at the northern extreme of their range.

The overwhelming majority of fish species at all three reefs were typically reef associated (e.g. sand perch, Figure 33, sweetlip, Figure 34, Table 3.6), with only a small number of species (three at all sites) being classed as pelagic.

While both Kirra Reef and Cook Island West had a higher number of species, there was also a slight difference in the number of species that dominated the fish community with fewer species being more dominant at Cook Island West, indicated by a steeper k-dominance curve (Figure 36). Kirra Reef and Cook Island North were dominated by fewer species.

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 observed.

Table 3.6 Number of species observed at Kirra and Cook Island Reefs in 2017 depending on their typical range and life style.

| | Kirra Reef | Cook Island North | Cook Island West |
|---|---|---|---|
| **Range**[a] | | | |
| Temperate (TE) | 11 | 13 | 11 |
| Tropical (TR) | 11 | 6 | 10 |
| Tropical / Temperate (TR/TE) | 30 | 25 | 31 |
| **Total** | 52 | 44 | 52 |
| | **Kirra Reef** | **Cook Island North** | **Cook Island West** |
| **Life style**[b] | | | |
| Pelagic (P) | 3 | 3 | 3 |
| Reef associated (R) | 48 | 41 | 48 |
| Reef / Pelagic (R/P) | 1 | 0 | 0 |
| **Total** | 52 | 44 | 52 |

[a] Ranges have been derived from the Australian Museum's OZCAM mapping, https://australianmuseum.net.au/ and Johnson, J. W. "Annotated checklist of the fishes of Moreton Bay, Queensland, Australia." Memoirs Queensland Museum 43.2 (1999): 709-762.

[b] Life styles and substrate associations were sourced from fishbase.org

Figure 32

BRUV image of a brownbanded bamboo shark (*Chiloscyllium punctatum*) at Kirra Reef.

Figure 33

Sand perch (*Parapercis sp.*) on reef substrate at Cook Island West.

Figure 34

Gold-spot sweetlip (*Plectorhinchus flavomaculatus*) at Cook Island West.

Figure 35

A school of double-spotted queenfish (*Scomberoides lysan)* at Cook Island West.

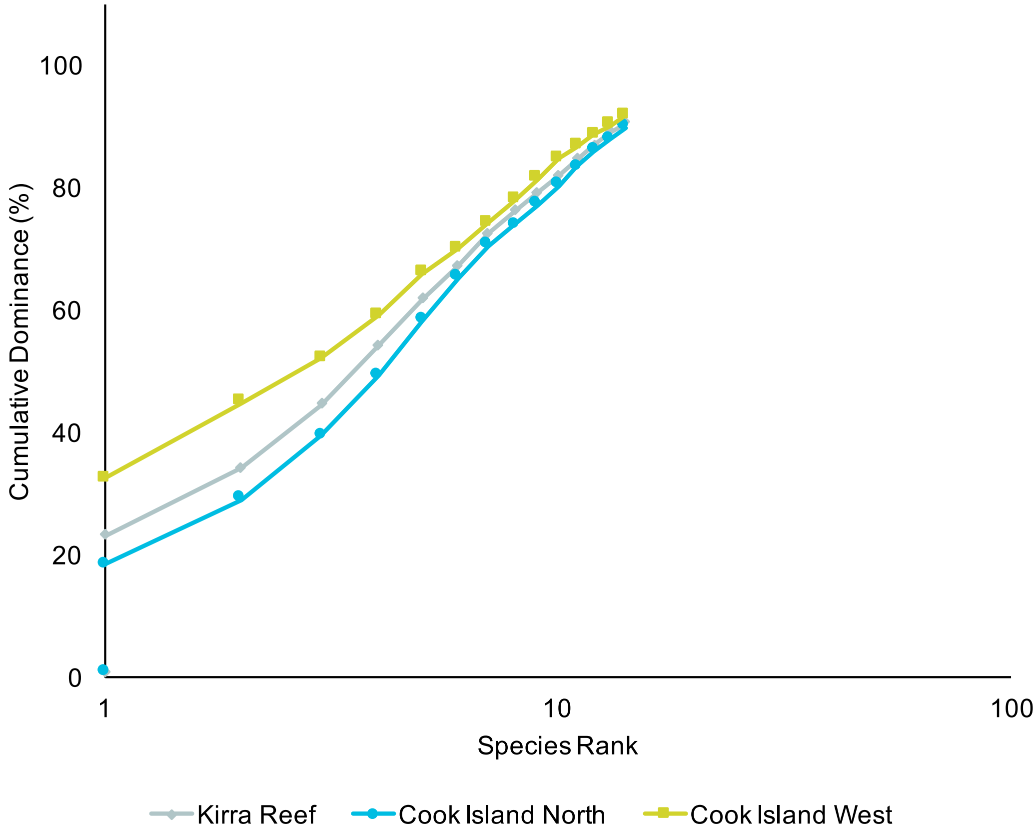



Figure 36 k-dominance curves for fish assemblages at Kirra and Cook Island Reefs 2017

### Abundance and Trophic Levels

The abundance of fish from different trophic levels varied across all reefs, with Kirra Reef having a higher total abundance (sum of maxN values) of fish (256) compared to Cook Island West (182) and Cook Island North (193). Kirra Reef supported a larger number of omnivorous and carnivorous fish (e.g. ornate wobbegong Figure 37) than the Cook Island sites, but had a lower number of planktivorous fish than Cook Island (Figure 38). The abundances of herbivores, omnivores with herbivorous tendencies and corallivores at Kirra Reef and Cook Island West are similar, indicating that these reefs are able to support fish with similar trophic status.

Figure 37 Ornate wobbegong (*Orectolobus ornatus*).

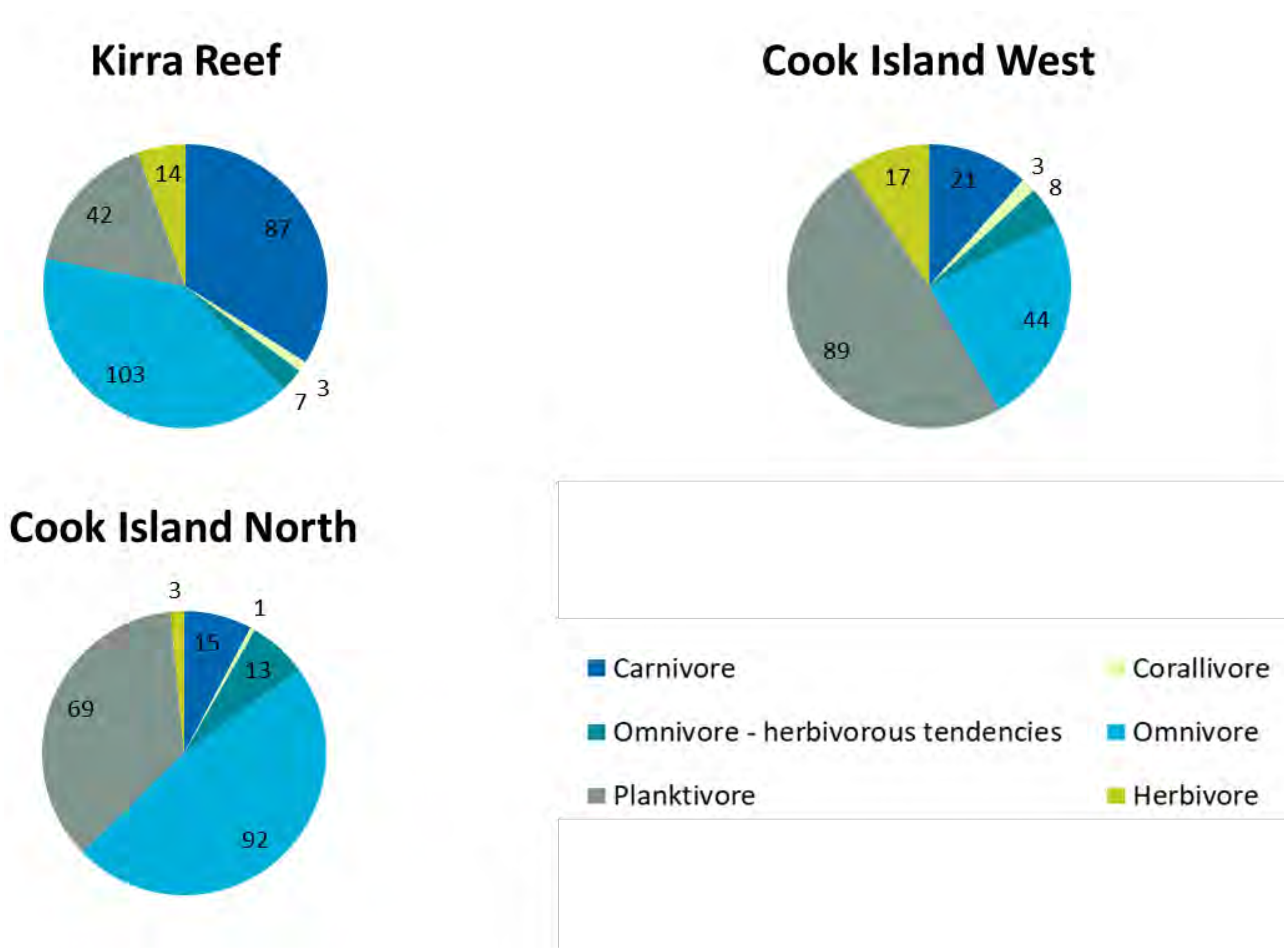



Figure 38 Abundance of fish of different trophic levels using summed maxN values

The number of species of different trophic levels were also similar between Kirra Reef and the reefs at Cook Island, whilst a lower number of carnivorous species and the most herbivorous species were observed at Cook Island North (Figure 39).

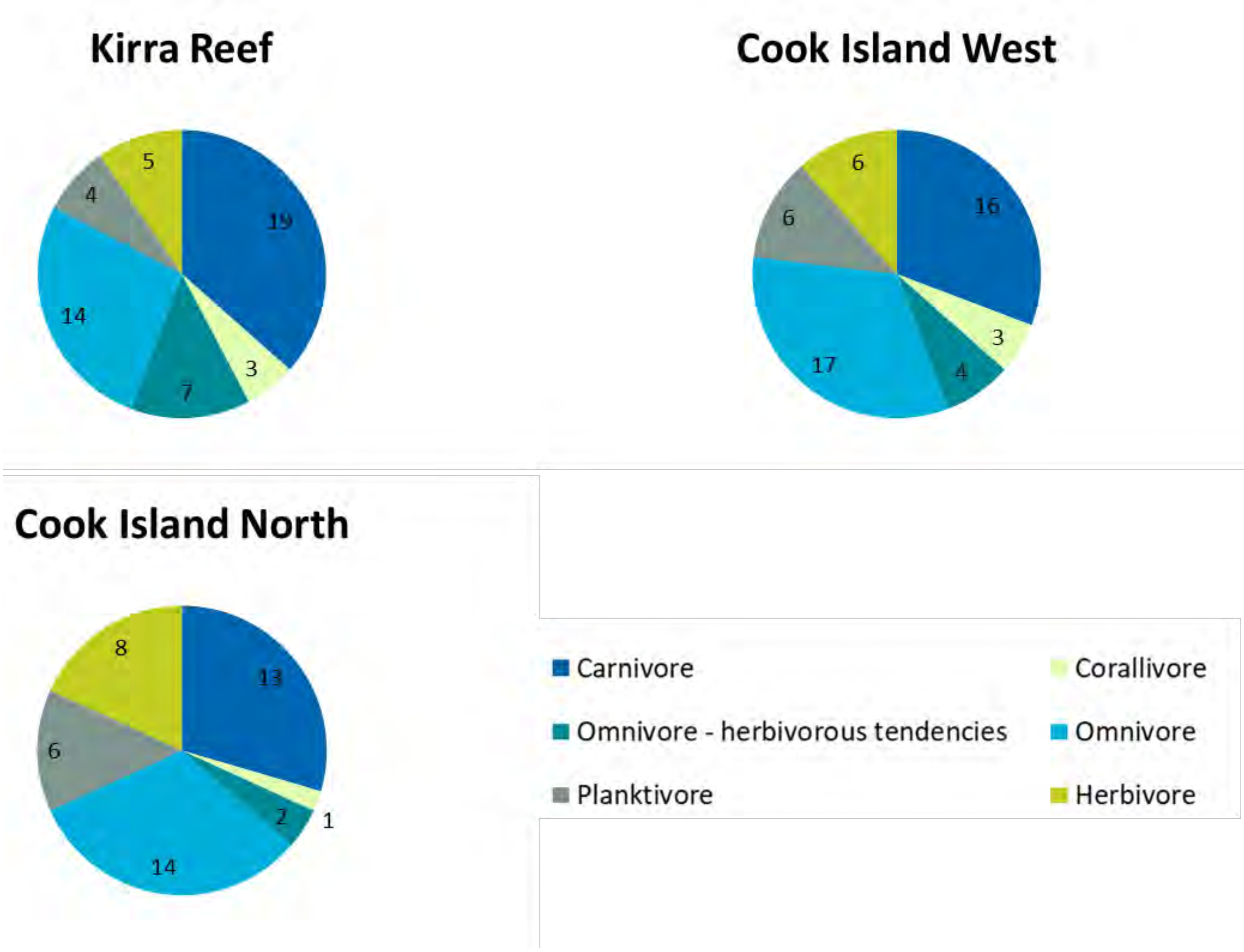



Figure 39 Fish species of different trophic levels at Kirra and Cook Island reefs.

### Fish assemblages at Kirra and Cook Island Reefs

Fish assemblages at Kirra Reef were significantly different to those at the Cook Island West and Cook Island North (Table 3.7, Table 3.8, Table 3.9; Figure 40). Conversely, there was no significant difference between the two Cook Island reefs (Table 3.8; Figure 40). Significant differences between Kirra Reef and the Cook Island reefs were largely attributed to yellowtail, eastern pomfred, sweep and black tipped bullseye (SIMPER, Appendix A).

As in previous years, large schools of yellowtail (*Trachurus novazelandiae*) were observed at Kirra Reef (Figure 41)(Ecosure 2016; frc environmental 2015), along with striped sea pike (*Sphyraena obtusata*), mado (*Atypichtys strigatus*, Figure 42), black tipped bullseye (*Pempheris affinis*) and stripey (*Microcanthus strigatus,* Figure 43). These species were on average more abundant at Kirra Reef than at the Cook Island reefs (Appendix A). In contrast, eastern pomfred (*Schuettea sclaripinnis,* Figure 44) and ring-tailed surgeon (*Acanthurus blochii*) were more common at the Cook Island reefs than at Kirra Reef.


Figure 40 Multi-dimensional scale plot of fish assemblages at Kirra and Cook Island reefs in the 2017 survey.

Table 3.7 PERMANOVA results for differences in the composition of fish assemblages between reefs. Bold p values denote significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 6165.6 | 3.7749 | **0.0004** |
| Residual | 15 | 1633.3 | | |

[a] p values based on Monte Carlo simulations

Table 3.8 Results of pairwise comparisons between reefs following PERMANOVA. Bold p values denote significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 2.2862 | **0.0018** | 462 | **0.0028** |
| Cook Island North, Kirra Reef | 2.31 | **0.0027** | 462 | **0.0023** |
| Cook Island West, Kirra Reef | 1.023 | 0.4328 | 462 | 0.3885 |

[a] p values based on Monte Carlo simulations

Table 3.9 One-way analysis of similarities (ANOSIM) of fish assemblages at Kirra and Cook Island reefs using all survey methods. Bold p values denote significance at p<0.05.

| | Test statistic (*R*) | Significance (*p*) | Possible permutations |
|---|---|---|---|
| **Main Test** | | | |
| Between Reefs | 0.489 | **0.0001** | 2858856 |
| **Pairwise tests** | | | |
| Kirra Reef, Cook Island West | 0.733 | **0.002** | 462 |
| Kirra Reef, Cook Island North | 0.75 | **0.002** | 462 |
| Cook Island West, North | -0.026 | 0.593 | 462 |

Figure 41

Yellowtail (*T. novazelandiae*) schooling over Kirra Reef.

Figure 42

Mado (*Atypichtys strigatus*) along the reef edge at Kirra Reef.

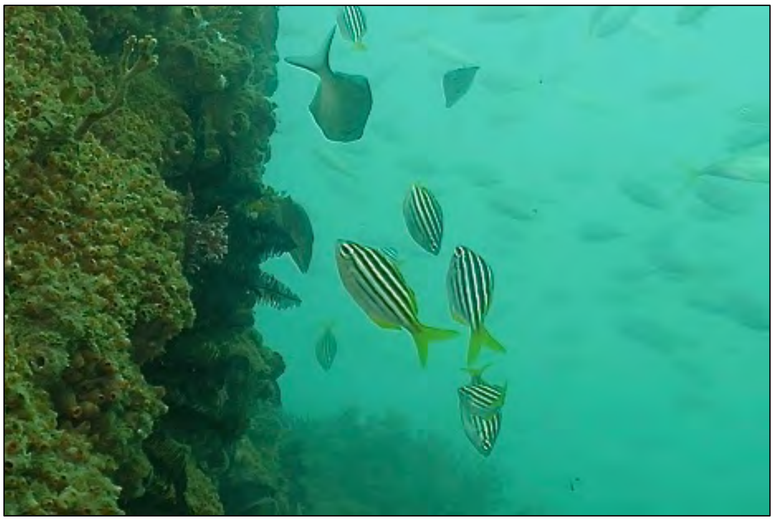


Figure 43

Stripey (*Microcanthus strigatus*, foreground) and Mado at Cook Island North.

Figure 44

A school of eastern pomfred (*Schuettea sclaripinnis*) at Cook Island West.

## 3.4 Abiotic Factors

**In-Situ Water Quality and Weather Conditions**

Water quality measured at the Kirra and Cook Island reefs in the 2017 survey was typical of shallow coastal seas on the Australian east coast during winter, with clear water at all three sites and on both days (Table 3.10), with no obvious stratification of temperature, pH, dissolved oxygen or electrical conductivity (Appendix D). Turbidity was highest at the surface and decreased significantly with depth (Appendix D). There was no significant variation in water quality parameters between sites. The water temperatures were around 22°C - within the typical range of variation for this time of year (Ecosure 2016). The wind strength and direction during the survey was typical of the time of year, with prevailing winds from the south and east.

Table 3.10 Abiotic conditions during the surveys at Kirra and Cook Island Reefs in May 2017.

| | Kirra Reef | Cook Island North | Cook Island West |
|---|---|---|---|
| | **16 May 2017** | **16 May 2017** | **17 May 2017** |
| **Sea conditions** | seas below 1 m | seas below 1 m | seas up to 1.3 m |
| **Temperature (°C at 0.5m)** | 22.1 | 22.2 | 21.9 |
| **Wind strength (km/h)** | 7 | 12 | 9 |
| **Wind direction** | SSW | ENE | SSW |
| **Secchi Depth (m)** | 6.2 | 9 | 7[a] |

[a] Secchi depth at Cook Island West was not measured, but estimated instead.

### Wave Height and Direction

Wave height and direction from the Waverider buoy 1.6 km offshore of the Tweed River entrance was first incorporated in the Kirra Reef Biota Monitoring Program in 2016 (Ecosure 2016). Analysis of a historical dataset showed the greatest proportion of wave heights in the 1 and 2 m categories and a consistent wave direction from north east to south east (Ecosure 2016).

In the months preceding the 2017 monitoring event from June 2016 to April 2017 (Figure 45), the wave height and direction followed this general pattern:

- waves occurred with a higher frequency from E to SE
- wave heights were mostly up to 2 m high, and
- waves larger than 3 m were rare.

Overall, the mean wave height at the waverider buoy was below 1 m and from slightly east-south-east (Table 3.11). Variation in wave direction ranged from 17 to 35 degrees.

When analysed individually for each month, the month of June 2016 was by far the most distinct in terms of wave height, with waves of over 6 m coming from due east, due to an East Coast Low on the 4$^{th}$ and 5$^{th}$ of June 2016. A period of waves to 3 m occurred between February and April 2017 (Figure 46).

The calmest conditions, in terms of wave height, occurred at and near Kirra Reef in July 2016 during the last monitoring event (Ecosure 2016) and in the autumn and summer months of October 2016 to January 2017, with wave heights rarely exceeding 2 m (Figure 46).

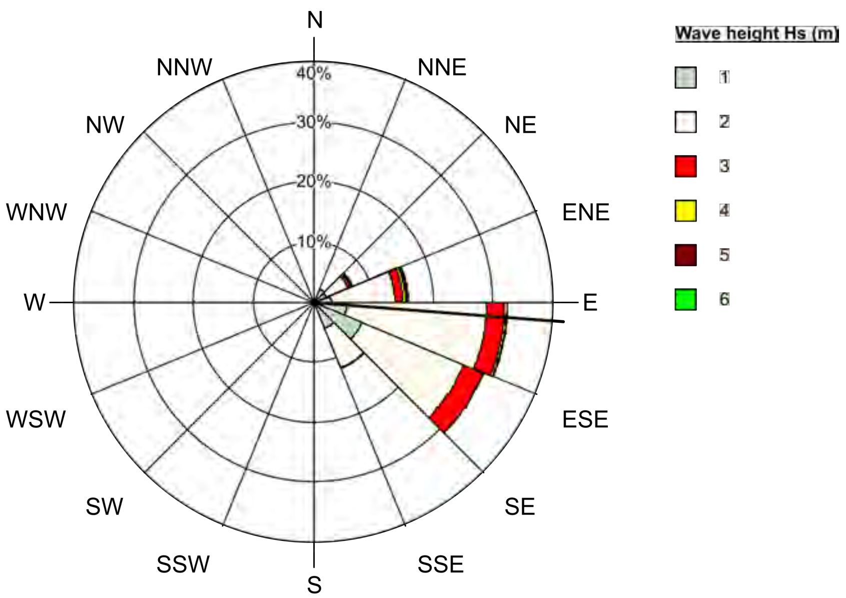



Figure 45 Rose plot showing the height in metres and cardinal direction of waves for the time between June 2016 and April 2017.

Table 3.11 Wave height, direction and circular variation

| Year | Season | Month | Mean Wave Direction | Mean Wave Height (m) | Circular StDev |
|---|---|---|---|---|---|
| **2016** | **Winter** | **June** | 99.029° | 0.924 | 22.812° |
| | | **July** | 106.484° | 0.908 | 25.208° |
| | | **August** | 106.107° | 0.95 | 18.318° |
| | **Spring** | **September** | 93.619° | 0.832 | 34.73° |
| | | **October** | 96.047° | 0.805 | 37.76° |
| | | **November** | 94.55° | 0.824 | 35.68° |
| | **Summer** | **December** | 77.412° | 0.923 | 22.901° |
| **2017** | | **January** | 97.881° | 0.891 | 27.534° |
| | | **February** | 87.817° | 0.946 | 19.163° |
| | **Autumn** | **March** | 91.705° | 0.924 | 22.765° |
| | | **April** | 97.824° | 0.957 | 17.074° |
| | | **Overall** | **95.395°** | **0.889** | **27.744°** |

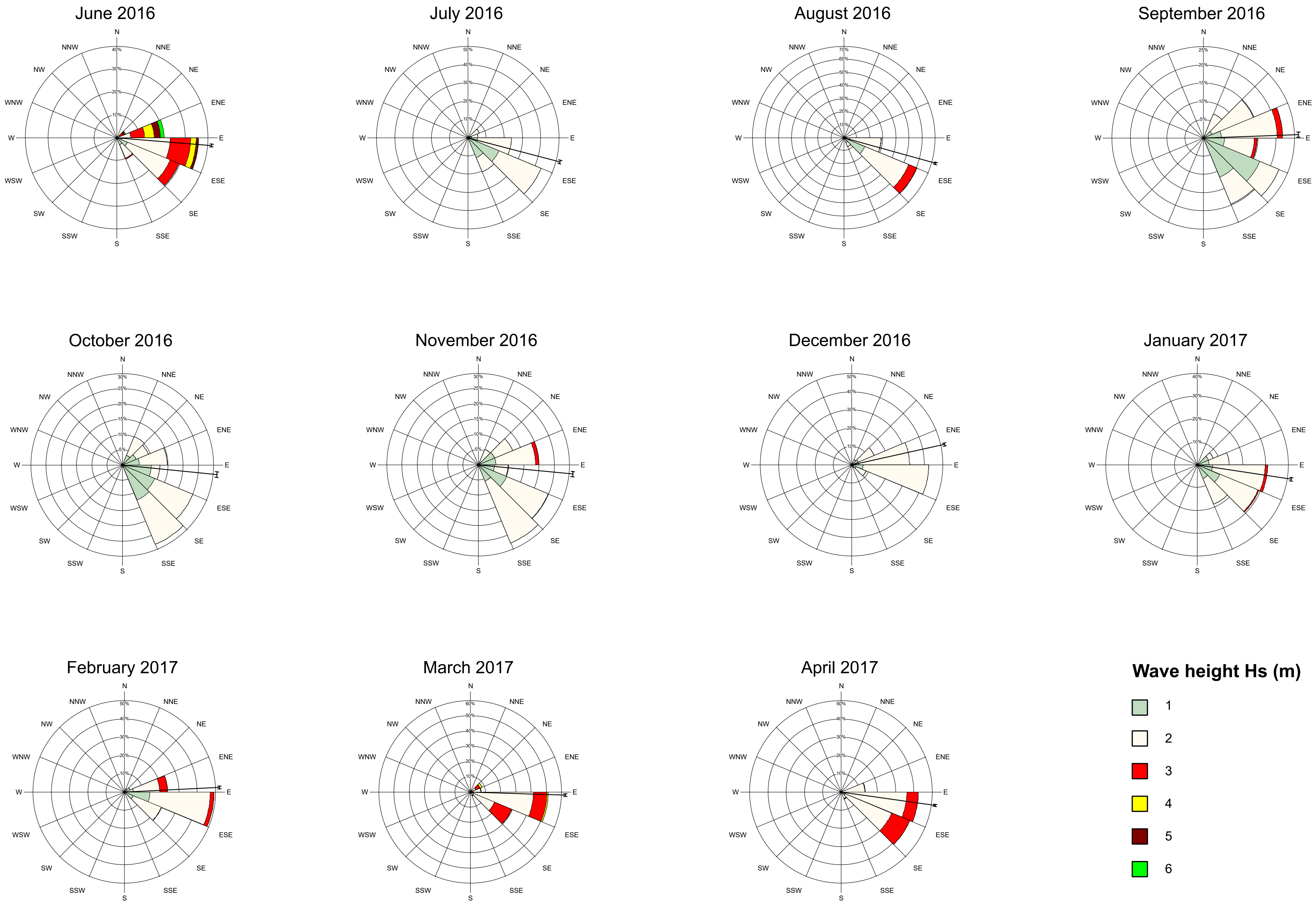



Figure 46 Rose plots showing the height in metres and cardinal directions of waves measured at the Tweed Heads Waverider Buoy between June 2016 and April 2017.

### Sea Surface Temperature

The sea surface temperature (SST) measured at the waverider buoy was also incorporated into the Kirra Reef Biota Monitoring Program in 2016 (ecosure 2016). Changes in average SST over a period of 15 years was minimal, with no distinct increase or decrease. The only notable exceptions were the years of 2010 and 2013, with atypically high and low SST measured at the waverider buoy, respectively (Ecosure 2016). Historically, variation in SST is highest in the summer months, with the highest temperatures typically occurring in February and March and the lowest around July and August. In the months prior to the 2017 monitoring program, the SST followed this general pattern with the average SST ranging from 19.98 to 26.35 degrees Celsius (Figure 47). Variation in SST was highest in March (Figure 47).

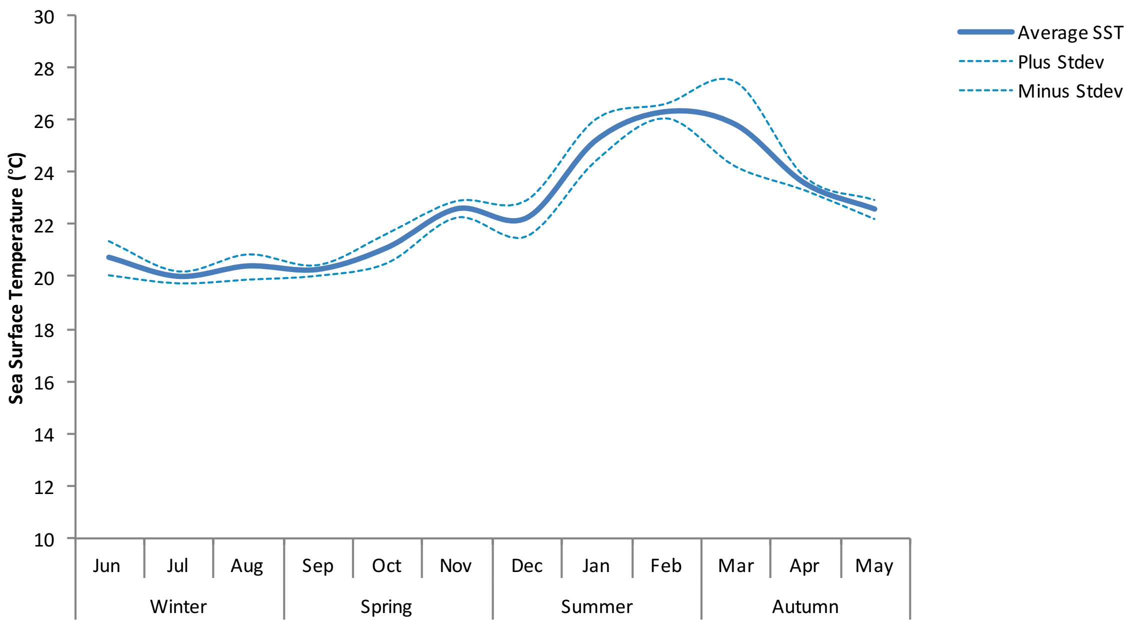



Figure 47 Sea Surface Temperatures (SST, in °C) measured at the Tweed Heads Waverider Buoy between June 2016 and April 2017.

## 3.5 Temporal Changes in the Extent of Exposed Reef

The area of exposed reef has changed substantively over the course of the last 9 decades, since aerial images of the reef first became available (Figure 52). Three major outcrops of reef (north, south and east) have been exposed and covered with sand at various times as a result of sand movements in the area.

### Natural Sand Movement Pre-1960s

Prior to 1960 (Figure 48), Kirra Reef was partially covered by sand, which varied naturally with the natural long-shore drift of sand and wave energy. Partial coverage of the reef was normal under natural sand supply rates, with the movement of large sand shoals likely to have covered the eastern and southern reefs at times (WorleyParsons 2009). Sand supply in the area during this time was largely uninterrupted and sand movements were episodic, with large amounts of sand transported during major storm events.

Gold Coast major storm events correlate with the Interdecadal Pacific Oscillation (IPO). Between the 1920s and 1940s, the IPO was positive indicating calmer, drier periods with less frequent and less extreme cyclones. The IPO was negative in the late 1940s and 1950s, indicating stormy periods during this time, although relatively few tropical cyclones and east coast lows were recorded during this time (Callaghan & Helman 2008). The only major coastal structure in the area pre-1960 was the original Tweed River training walls built in the mid 1890s and they were not of sufficient length to substantially interrupt sand supply (WorleyParsons 2009).

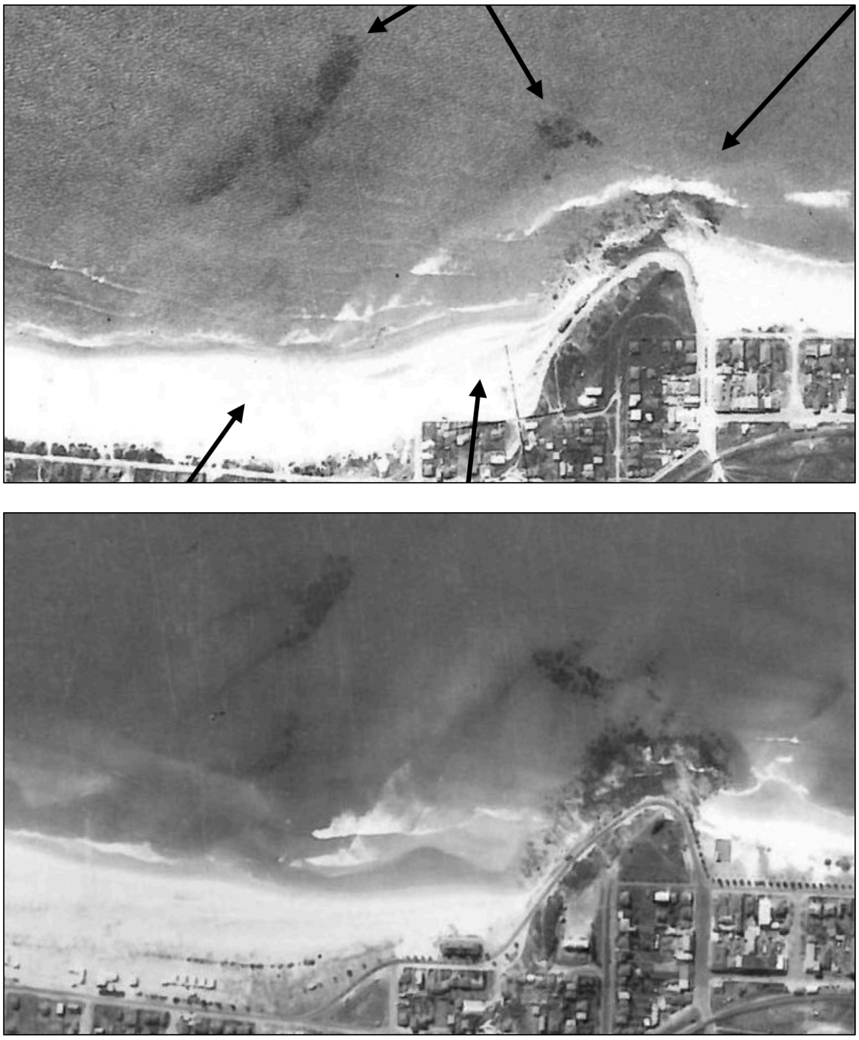


Figure 48 Aerial photos for Kirra Reef in 1930 (top) and 1946 (bottom). Source TRESBP 2017.

**Sand Depletion - 1960s to Mid-1980s**

Following the extension of the Tweed River training walls by 380m between 1962 and 1965, Kirra Reef became increasingly exposed due to a depleted sand supply. It was also a period of negative IPO, and in 1967 a series of successive high intensity east coast lows and cyclones occurred in the area. Kirra Beach suffered major beach erosion and hard groyne structures were installed, including Kirra Point groyne construction in 1972 and Miles Street groyne in 1974. Beach nourishment (0.765$Mm^3$) also occurred at Kirra Beach in 1974-75. However, the lack of sand supply resulted in Kirra Reef being perennially exposed during this period (Figure 49).

Figure 49 Aerial photos for Kirra Reef in 1965 (top), 1977 (middle) and 1982 (bottom). Source TRESBP 2017 (top) and Worley Parsons 2009 (middle and bottom).

**Sand Accretion - Mid-1980s to 2001**

Beach nourishment works in the mid to late 1980s (Figure 50), along with the commencement of stage 1 of the TRESBP in 1995 resulted in an accumulation of sand during this time. There were relatively few major storms events, with the IPO positive since the 1980s. The extent of Kirra Reef exposed, decreased as sand accumulated around it, but a relatively large area remained uncovered. Kirra Point and Miles Street groynes were both shortened by 30 m in 1996.

Figure 50 Aerial photos for Kirra Reef in 1987 (top) and 1999 (bottom). Source TRESBP 2017.

### Sand Excess - 2001 to 2008

During the early years of stage 2 of the TRESBP (from 2001 to 2008), relatively high quantities of sand were delivered to the southern Gold Coast beaches as a ‘catch-up’. As predicted in the EIS, an inherent result of TRESBP was the reduction in area of Kirra Reef (Figure 51). Loss of reef continued for some years, and by early 2006, the area of exposed reef had been reduced to <100 $m^2$, and was almost completely covered in 2007 and 2008. The small area of reef remaining was in the northern section, with the southern and eastern sections covered. As a consequence of the extensive burial of the reef, simple visual inspections of the reef were undertaken in place of full ecological surveys between 2006 and 2010[4].

Figure 51 Aerial photos for Kirra Reef in 2002 (top) and 2008 (bottom). Source TRESBP 2017.

4 Underwater visual inspections were completed by Gilbert Diving and Gold Coast City Council from 2006 to 2010. May 2009 event was ranked third highest wave event recorded with a maximum significant wave height of Hsig = 5.6 metres.

**Mimicking Natural Sand Supply - 2008 to 2017**

Since 2008, sand delivery through the TRESBP has been more consistent with the natural movement of sand along the coast. There was a substantial lag between the reduction in sand delivery and transport of the sand further north, due to a period of calmer than usual conditions with reduced storm activity from the north-east. As such, dispersion of sand from Kirra Beach and reduction in the sand levels around the reef was slower than predicted. In May 2009, a series of storms moved approximately 200 000 $m^3$ of sand from Kirra Beach to the north. This, along with the removal of approximately 140 000 $m^3$ of sand from the Kirra Beach intertidal zone, again uncovered parts of Kirra Reef (TRESBP 2015).

Between February 2010 and July 2012, there was a large (50%) increase in the area of exposed rock in the northern section of Kirra Reef. In late 2013, Kirra Point groyne was reinstated by 30 m to its original constructed length, and while this was done with the expectation that the beach bar would move seaward, it has had little effect on reef exposure. The reef has been relatively stable since 2012, with relatively[5] minor changes (< 25%) in reef area. The width of Kirra Beach generally correlates with the exposure of Kirra Beach, with a wide width corresponding to low reefal area and the eastern and southern sections becoming buried (Hyder Consulting 1997). The southern section of the reef has not been exposed for more than fifteen years, and while the eastern section had several instances of being exposed by shifting sand, it has also remained mostly covered. In February 2017, Kirra Reef reached an extent of approximately 3 263 $m^2$ (Figure 52, Table 3.12), marginally smaller than approximately 12 months earlier (Ecosure 2016).

The aerial extent of Kirra Reef was slightly larger (132 $m^2$) in May 2017 than February 2017. Small areas of reef appear to be more exposed in the north east section of the reef and covered in the southeast section of the reef. This may be from shifting sands resulting from Cyclone Debbie that occurred on the Gold Coast in late March 2017.

Overall, the area extent of Kirra Reef has remained relatively constant for the last five years during a period in which sand bypass rates have mimicked the rate of natural sand transport and storm conditions have been moderate.

5 A 25% change in reef area is considered relatively minor given the error associated with accurately calculating the area from aerial images and given Kirra Reef is in an area of active sand movement and transportation and thus is naturally subject to large changes reef area from shifting sands.

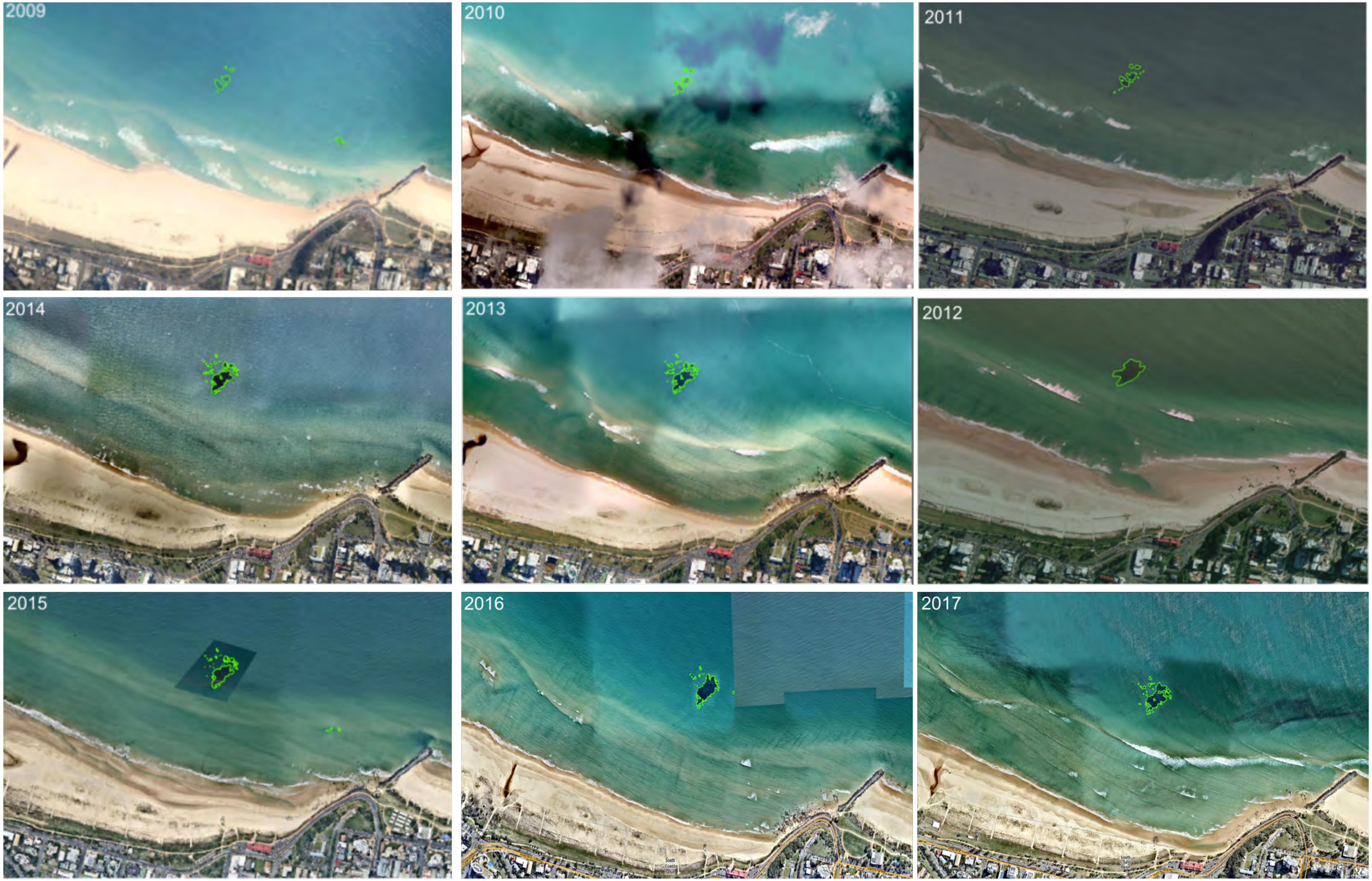



Figure 52 Extent of Kirra Reef between 2009 to 2017.

Table 3.12 Approximate extent of Kirra Reef since 1930 (some years are missing as data is not available)

| Date | | Area ($m^2$) | | | | Source of Image |
|---|---|---|---|---|---|---|
| | | Northern Section | Southern Section | Eastern Section | Total | |
| Feb | 2017 | 3 263 | 0 | 0 | 3 263 | Nearmap |
| May | 2016 | 3 326 | 0 | 0 | 3 326 | Nearmap[4] |
| Mar | 2015 | 2 672 | 0 | 116 | 2 788 | Rectified image, NSW Trade & Investment |
| Apr | 2014 | 2 920 | 0 | 0 | 2 920 | Nearmap |
| Jun | 2013 | 2 801 | 0 | 0 | 2 801 | Nearmap |
| May | 2013 | 3 539 | 0 | 0 | 3 539 | Nearmap |
| Aug | 2012 | 3 700 | 0 | 0 | 3 700 | Nearmap |
| Nov | 2011 | 1 044 | 0 | 0 | 1 044 | NSW DPI, Catchment and Land Division |
| May | 2010 | 965 | 0 | 0 | 965 | Nearmap |
| Nov | 2009 | 868 | 0 | 141 | 1 009 | Nearmap |
| Apr | 2004 | 1 578 | 0 | 273 | 1 851 | Department of Land and Water Conservation |
| Nov | 2003 | 3 369 | 0 | 0 | 3 369 | Department of Land and Water Conservation |
| Aug | 2002 | 8 442 | 0 | 73 | 8 515 | Department of Infrastructure Planning & Natural Resources |
| Feb | 2001 | 11 194 | 2 156 | 7 048 | 20 398 | Department of Infrastructure Planning & Natural Resources |
| Oct | 1996 | 3 435 | 3 491 | 8 959 | 15 885 | Rectified image from Boswood and Murray 1997 [2] |
| | 1995 | 9 090 | 11 998 | 19 725 | 40 813 | NSW DPI, Catchment and Land Division |
| Nov | 1989 | 9 528 | 6 660 | 20 077 | 36 265 | Rectified image, Boswood and Murray 1997 [2] |
| Nov | 1974 | 6 078 | - | - | > 6 078 | Rectified image, Boswood and Murray 1997 [2] |
| Feb | 1972 | 5 480 | 0 | 16 631 | 22 111 | Rectified image, Boswood and Murray 1997 [2] |
| Oct | 1962 [1] | - | 3 841 | 742 | > 4 583 | Rectified image, Boswood and Murray 1997 [2] |
| Nov | 1935 | 1694 | - | 1 656 | > 3 350 | Rectified image, Boswood and Murray 1997 [2] |
| Sep | 1930 | 5016 [3] | - | 1 047 | > 6 063 | Rectified image, Boswood and Murray 1997 [2] |

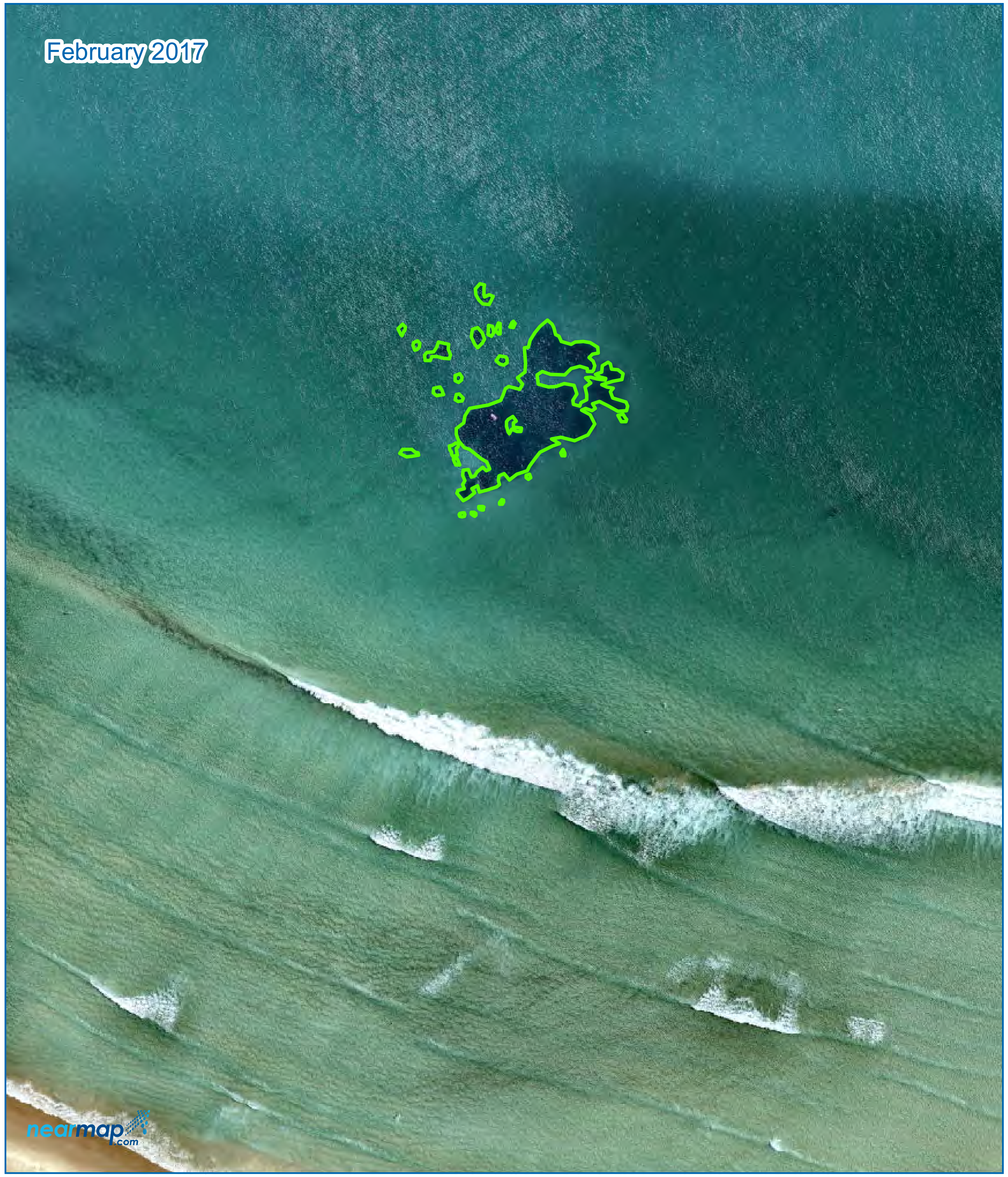
[1] Area of Kirra Reef between 1962 and 1965 ranged from 4 850 to 7 800 in the northern reef; 0 to 4 900 in the southern reef; and 600 to 2 150 in the eastern reef, with a total range between 7 000 and 13 300 (Department of Land and Water Conservation, photogrammetric analysis).

[2] Area of reef extent is the outside limit of major clusters of reef as viewed from the 1:6000 and 1:12000 photographs. It does not exactly correspond to the area of exposed rocky reef outcrop and indeed may overestimates it as it includes sandy areas between rock outcrops and may also include areas of sand near the rocky reef covered by debris, seaweed or shadow.

[3] Owing to flight height and clarity, the actual area for 1930 may be much less than this figure.

[4] Area from 2016 Ecosure report

- Images not clear enough to calculate extent.



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## Kirra Reef Biota Monitoring 2017

### Map 2: Extent of Kirra Reef in February and May 2017

**SOURCES**



Document Path: Y:\Projects\2017\170402_NSW_Kirra_Reef_Biota_Monitoring\Mapping\Workspaces\170402_Kirra_area_2017_CB_17-06-27.mxd

**LEGEND**

**Reef Extend and Survey Site**

- February 2017
- May 2017

**Road Network**

- Highway
- Main Road
- Local Road
- Track

N

**SCALE**

0 0.05 0.1
Kilometres

Scale: 1:2,500 @ A3

**PROJECTION**
Coordinate System: GCS GDA 1994
Datum: GDA 1994
Units: Degree

**DATE**
2017-09-21

**DRAWN BY**
CB

**VERSION**
01

# 4 Discussion

The benthic assemblages of Kirra Reef are characterised by a high cover of macroalgae and a moderate cover of sessile benthic invertebrates, at times including few soft and hard corals (Edwards & Smith 2005; frc environmental 2005b). The benthic assemblage at Kirra Reef has experienced significant change over time, due to storms and changes in sand supply.

## 4.1 Changes in Biodiversity and Cover at Kirra Reef

### Turf and Macroalgae

Macroalgae cover continues to dominate communities at Kirra Reef, with a higher cover of *Sargassum* sp. compared to the Cook Island reefs. The abundance of *Sargassum* sp. is likely to be indirectly influenced by sand supply, with elevated seabed levels contributing to increased wave energy and abrasive suspended sand particles.

Following the commencement of stage 2 of the TRESBP in 2001, the cover of macroalgae dramatically decreased, likely a result of the 'catch-up' sand delivery and the burial of reef habitat. Since 2008, sand volumes have been more consistent with natural sand supply rates, and macroalgae cover increased between 2010 and 2016. In 2017, macroalgae cover was lower than in 2016, which may be a result of the recent accretion of sand around the reef (frc environmental, pers. obs) and / or from the waves generated by cyclone Debbie in March of 2017.

Turf algae can out-compete other species, often thriving under harsh conditions (nutrient pollution, sedimentation and ocean acidification) (Harris 2015). However, the cover of turf algae commonly exhibits extreme temporal variability (Mumby 2009). Macroalgal communities are also known to have a competitive advantage following disturbance, but also experience seasonal changes due to abiotic conditions (Clifton & Clifton 1999), disturbances and propagule supply and recruitment (Vroom et al. 2003). Grazing by fish has also been linked to reduced macroalgal cover and can be seasonal with grazing peaking in the warmer months (Duran et al. 2016). The cover of macroalgae has varied between 18 and 32% over the past 15 years likely in response to a combination of these factors. The cover of macroalgae in 2017 was similar to that of the 1995 baseline monitoring (23%), but lower than that recorded in 2016. The cover of turf algae was also lower in 2017 than in recent years.

### Benthic Invertebrates

There was higher cover of sponges and ascidians recorded in 2017 than in 2016. The higher cover of sessile benthic organisms is likely related to the lower cover of macroalgae and turf algae, which can affect recruitment and survival due to fronds 'sweeping' the substrate with wave action, killing new recruits (McCook et al. 2001).

The percent cover of hard and soft corals at Kirra Reef continues to be very low. Small colonies of hard coral were recorded in 2016 (Ecosure 2016); however, they were not observed in 2017 and may have decreased as a result of sediment deposition. Soft coral colonies at Kirra Reef are typically smaller than at either reef at Cook Island, indicating that Kirra Reef is subject to more frequent disturbances.

Overall, the reefs at Cook Island were dominated by less taxa of benthic invertebrates than at Kirra Reef. More diverse but less dominant assemblages are indicative of disruptions by abiotic factors (e.g. wave disturbance and sand coverage) that prevent the establishment of a few dominant groups (frc environmental 2015). At Kirra Reef, taxa typical of being able to rapidly colonise recently uncovered and disturbed substrate, such as ascidians and macroalgae (Mumby 2009; McCook et al. 2001) are more common than longer lived taxa such as soft and hard corals.

### Fishes

The distribution of fish trophic guilds varied between sites, with Kirra Reef dominated by omnivores and carnivores, while both of the Cook Island reefs were dominated by omnivores and planktivores. At all sites, corallivores and omnivores with herbivorous tendencies were the least abundant guilds. Previously, planktivores were the most dominant guild at both Kirra Reef and Cook Island (Ecosure 2016). Many studies have identified that a large abundance of herbivorous fish correlates to a reduced cover of macroalgae (Green & Bellwood 2009); however, the low abundance of herbivorous fish at all sites indicates that the decreases in macroalgae cover is more likely influenced by abiotic factors.

Kirra Reef and Cook Island are located within the biogeographic overlap between southern temperate and northern tropical oceans. At Kirra Reef, 11 species were considered to be temperate species whilst another 11 were considered to be tropical species. These 22 species were at the extreme end of their known ranges, while the remaining 30 species were considered to be tropical / temperate.

**The Cook Island Marine Sanctuary and Kirra Reef**

The Cook Island Marine Sanctuary includes 78 hectares extending from the mean high water mark out to a 500 m radius from the survey marker on Cook Island (NSW DPI 2017). The area around Cook Island is considered to be a ‘no take’ zone where fishing by all methods is prohibited (although we suspect this is occassionally breached). Studies have shown that no take zones can be effective in increasing herbivore density and diversity (Gilby & Stevens 2014; McClanahan 2014), which can lead to increased macroalgae herbivory and the potential for coral growth (Stockwell et al. 2009; Rasher et al. 2013). Analyses from the 2017 monitoring event indicate that the no take zone has no obvious impact on the species richness of herbivorous and carnivorous fishes, although studies from the Great Barrier Reef show the importance of no-take zones for the recruitment of large predatory species (Harrison et al. 2012). However, fish species commonly targeted by recreational anglers were notably more abundant at the Cook Island reefs compared to Kirra Reef (Table B1). These included:

- black spot snapper (*Lutjanus fulviflamma*),
- spangled emperor (*Lethrinus nebulosus*),
- maori grouper (*Epinephelus undulatostriatus*),
- double-spotted queenfish (*Scomberoides lysan*),
- blue groper (*Achoerodus gouldii*),
- snapper (*Pagrus auratus*), and
- yellow-fin bream (*Acanthapagrus australis,* Figure 53).

Discarded fishing line litters Kirra Reef, whilst no such impact was observed at the reefs at Cook Island, where line fishing is prohibited. No impact of SCUBA diving and / or snorkelling (e.g. overturned corals or benthic fauna damaged by fins) was observed at any of the 3 reefs surveyed.

No comparative site used to date in this monitoring program has provided an ‘ideal match’. Palm Beach Reef is representative of a deeper and more offshore environment, Kingscliff Reef is subject to greater wave intensity than Kirra Reef, and the reefs of Cook Island are more sheltered from wave action than Kirra Reef. Kirra Reef is unique in the region, being completely surrounded by mobile sand. It is likely that the ‘rocks’ (such as Manta Bommie) off the north-eastern tip of Stradbroke Island may serve as better comparative sites.

Figure 53 Yellow-fin bream (*Acanthapagrus australis)* at Cook Island West.

## 4.2 The Influence of the Sand Bypassing Program

The greatest change to the ecological condition of Kirra Reef since the commencement of TRESBP has been the burial of large areas of hard substrate that support benthic flora and fauna. In particular, the delivery of large sand volumes during the stage 1 TRESBP (1995 to 1998) and the initial operation of the sand bypass system (2001 to 2008) resulted in a significant increase in the beach width at Kirra, with wave action and tidal currents redistributing sand over Kirra Reef. This was predicted in the projects EIS.

It has been predicted that the extent of Kirra Reef will return to conditions prior to 1962 when the Tweed River training walls were extended. Overall, the areal extent of Kirra Reef has remained relatively constant for the last five years during a time of natural sand transportation rate via the TRESBP and relatively calm storm conditions.

## 4.3 The Influence of Storms and Wave Action

Exposure to wave action, sand scouring and smothering are important factors influencing the distribution and abundance of sessile species on rocky reefs (Kay & Keough 1981;

McGuinness 1987). Change in the height of sand levels around the base of Kirra Reef appears to be the major factor influencing the abundance (cover) of benthic flora and fauna, periodically resulting in bare stratum. Outcrops on the eastern section of the reef, where wave action and likely sand abrasion are greatest, have historically supported a lower abundance of benthic fauna than outcrops on the northern section (Fisheries Research Consultants 1995c; b; frc environmental 2003; 2004; 2005b; 2010; Fisheries Research Consultants 1996).

### 4.4 Species of Conservation Significance

Fourteen threatened (critically endangered, endangered or vulnerable) and twenty one migratory fish, marine reptiles or marine mammals protected by the Commonwealth EPBC Act were listed as potentially occurring at Kirra Reef using the Protected Matters Search Tool (Appendix E). Threatened species that may occur from time to time in the vicinity of Kirra Reef include:

- black rockcod, listed as vulnerable[6]
- humpback whale and southern right whale, listed as threatened and migratory
- green turtle, loggerhead turtle and hawksbill turtle, listed as threatened and migratory marine
- grey nurse shark, listed as critically endangered
- great white shark, listed as vulnerable and migratory
- Indo-Pacific humpback dolphin, listed as migratory, and
- manta ray, listed as migratory.

Of these, the black rock cod and green and hawksbill turtles are most likely to occur from time to time at Kirra Reef. However, the (potential) extent of Kirra Reef is such that it does represent critical habitat for these species.

### 4.5 Invasive Species

Four pest species have previously been recorded within the Brisbane, Gold Coast and Northern NSW region:

[6] Although there are very few records from Queensland

- marine pill bug (*Sphaeroma walkeri*)
- hydroid (*Halecium delicatulum*)
- hydroid (*Obelia dichotoma*), and
- sea lettuce (*Ulva fasciata*).

There are over 200 marine pests recorded from Australian waters, and 27 marine pests identified in Queensland.

No marine pest species were recorded during the May 2017 monitoring event. However, the highly disturbed nature of Kirra Reef makes the reef vulnerable to colonisation by these and other invasive species.

# 5 Conclusion

Kirra Reef is a rocky outcrop with locally unique characteristics. The extent of rocky substrate fluctuates with the rate of longshore sand drift and storm activity.

Brown macroalgae are the dominant epi-flora, whilst a diverse assemblage of temperate and tropical epi fauna remain in a near-constant flux Hard and soft coral cover is typically very low.

Large schools of yellowtail dominate fish communities, with striped sea pike, mado, black tipped bullseye and stripey also relatively common.

The commencement of TRESBP resulted in the burial of large areas of rocky substrate. However, the extent of Kirra Reef has remained relatively constant for the last five years, during a period where the delivery of sand by the TRESBP has mimicked natural rates of longshore drift, and in which storm activity has been moderate.

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# Appendix A Detailed Statistical Analyses

## Benthic Assemblages at Kirra and Cook Island Reefs in 2017

Table A1 Similarity percentage analysis (SIMPER) of dissimilarity of benthic assemblages at Kirra and Cook Island reefs. Benthic taxa contributing up to and including 90% cumulative dissimilarity are shown. Data for SIMPER analysis has been derived from square-root transformed abundance (percent coverage) data.

| Genus | Average Abundance | Average Abundance | Contrib% | Cum.% |
|---|---|---|---|---|
| | Kirra Reef | Cook Island West | | |
| **Kirra Reef versus Cook Island West, Average dissimilarity = 76.59** | | | | |
| Sand | 3.99 | 3.5 | 16.89 | 16.89 |
| Turf Algae | 1.97 | 5.98 | 16.33 | 33.22 |
| Sargassaceae | 3.06 | 0.13 | 10.82 | 44.04 |
| Ascidiaceae | 2.82 | 1.02 | 10.48 | 54.52 |
| Rock | 1.42 | 1.48 | 7.51 | 62.03 |
| Scleractinia | 0 | 1.99 | 6.83 | 68.86 |
| Demospongiae | 1.58 | 0.23 | 5.64 | 74.5 |
| Crinoidea | 1.01 | 0.73 | 5.09 | 79.59 |
| Rhodomelaceae | 1.05 | 0.28 | 3.88 | 83.47 |
| Crustose Coralline Algae | 0.65 | 0.59 | 3.51 | 86.97 |
| Galaxauraceae | 0.49 | 0.48 | 3.1 | 90.08 |

| | Kirra Reef | Cook Island North | | |
|---|---|---|---|---|
| **Kirra Reef versus Cook Island North, Average dissimilarity = 79.36** | | | | |
| Turf Algae | 1.97 | 6.08 | 16.17 | 16.17 |
| Sand | 3.99 | 1.01 | 14.73 | 30.9 |
| Sargassaceae | 3.06 | 0.05 | 10.46 | 41.36 |
| Galaxauraceae | 0.49 | 2.75 | 9.6 | 50.96 |
| Ascidiaceae | 2.82 | 0.85 | 8.38 | 59.34 |
| Demospongiae | 1.58 | 1.83 | 6.74 | 66.08 |
| Scleractinia | 0 | 2.08 | 6.45 | 72.53 |
| Rock | 1.42 | 0.99 | 6.14 | 78.68 |
| Rhodomelaceae | 1.05 | 0.23 | 3.65 | 82.32 |
| Crinoidea | 1.01 | 0.41 | 3.37 | 85.69 |
| Crustose Coralline Algae | 0.65 | 0.77 | 3.25 | 88.95 |
| Corallinaceae | 0.15 | 0.77 | 2.75 | 91.7 |

| | Cook Island West | Cook Island North | | |
|---|---|---|---|---|
| **Cook Island West versus Cook Island North, Average dissimilarity = 61.9** | | | | |
| Sand | 3.5 | 1.01 | 14.81 | 14.81 |
| Scleractinia | 1.99 | 2.08 | 11.71 | 26.52 |
| Turf Algae | 5.98 | 6.08 | 11.32 | 37.85 |
| Galaxauraceae | 0.48 | 2.75 | 11.21 | 49.06 |
| Demospongiae | 0.23 | 1.83 | 8.09 | 57.16 |
| Rock | 1.48 | 0.99 | 8.09 | 65.25 |
| Ascidiaceae | 1.02 | 0.85 | 5.61 | 70.86 |
| Crustose Coralline Algae | 0.59 | 0.77 | 5.22 | 76.07 |
| Corallinaceae | 0.3 | 0.77 | 4.37 | 80.45 |
| Crinoidea | 0.73 | 0.41 | 4.33 | 84.78 |
| Rhodomelaceae | 0.28 | 0.23 | 1.98 | 86.77 |
| Fish | 0.13 | 0.31 | 1.74 | 88.5 |
| Dead Coral with Algae | 0.36 | 0 | 1.53 | 90.03 |

Table A2 PERMANOVA results for differences in Sargassaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 27630 | 62.644 | **0.0001** |
| Residual | 132 | 441.06 | | |

[a] p values based on Monte Carlo simulations

Table A3 Results of pairwise comparisons for Sargassaceae between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)a |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 0.53787 | 0.7477 | 4 | 0.6047 |
| Cook Island North, Kirra Reef | 8.4728 | **0.0001** | 9939 | **0.0001** |
| Cook Island West, Kirra Reef | 8.014 | **0.0001** | 9922 | **0.0001** |

[a] p values based on Monte Carlo simulations

Table A4 PERMANOVA results for differences in turf algae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 25591 | 36.863 | **0.0001** |
| Residual | 132 | 694.24 | | |

[a] p values based on Monte Carlo simulations

Table A5 Results of pairwise comparisons for turf algae between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 0.63441 | 0.6495 | 9943 | 0.6256 |
| Cook Island North, Kirra Reef | 6.5524 | **0.0001** | 9942 | **0.0001** |
| Cook Island West, Kirra Reef | 7.1447 | **0.0001** | 9937 | **0.0001** |

[a] p values based on Monte Carlo simulations

Table A6 PERMANOVA results for differences in Rhodomelaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 2795 | 6.0573 | **0.0033** |
| Residual | 132 | 461.43 | | |

[a] p values based on Monte Carlo simulations

Table A7 Results of pairwise comparisons for Rhodomelaceae between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 0.37068 | 0.7478 | 60 | 0.7454 |
| Cook Island North, Kirra Reef | 2.9119 | **0.0048** | 5456 | **0.0027** |
| Cook Island West, Kirra Reef | 2.5828 | **0.0095** | 4413 | **0.0117** |

[a] p values based on Monte Carlo simulations

Table A8 PERMANOVA results for differences in Galaxauraceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 12754 | 17.104 | **0.0033** |
| Residual | 132 | 745.69 | | |

[a] p values based on Monte Carlo simulations

Table A9 Results of pairwise comparisons for Galaxauraceae between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 4.6069 | **0.0001** | 9918 | **0.0001** |
| Cook Island North, Kirra Reef | 4.6939 | **0.0001** | 9909 | **0.0001** |
| Cook Island West, Kirra Reef | 0.23743 | 0.9165 | 1460 | 0.8949 |

[a] p values based on Monte Carlo simulations

Table A10 PERMANOVA results for differences in Dictyotaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 61.588 | 2.0168 | 0.1354 |
| Residual | 132 | 30.538 | | |

[a] p values based on Monte Carlo simulations

Table A11 PERMANOVA results for differences in coralline algae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 263.23 | 0.43614 | 0.6617 |
| Residual | 132 | 603.54 | | |

[a] p values based on Monte Carlo simulations

Table A12 PERMANOVA results for differences in Corallinaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 1104.9 | 2.8185 | 0.0563 |
| Residual | 132 | 392.02 | | |

[a] p values based on Monte Carlo simulations

Table A13 PERMANOVA results for differences in Ulvaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 39.677 | 0.37006 | 0.6991 |
| Residual | 132 | 107.22 | | |

[a] p values based on Monte Carlo simulations

Table A14 PERMANOVA results for differences in Chlorodesmis at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 180.67 | 2.9972 | 0.0538 |
| Residual | 132 | 60.279 | | |

[a] p values based on Monte Carlo simulations

Table A15 PERMANOVA results for differences in Halimedaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 154.05 | 1.3492 | 0.2604 |
| Residual | 132 | 114.18 | | |

[a] p values based on Monte Carlo simulations

Table A16 PERMANOVA results for differences in Caulerpaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 69.584 | 1.0206 | 0.3708 |
| Residual | 132 | 68.181 | | |

[a] p values based on Monte Carlo simulations

Table A17 PERMANOVA results for differences in Hard Coral at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 12849 | 15.921 | **0.0001** |
| Residual | 132 | 807.04 | | |

[a] p values based on Monte Carlo simulations

Table A18 Results of pairwise comparisons for Hard Coral between reefs following PERMANOVA. Bold p values denotes significance at $p<0.05$.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 0.28464 | 0.8735 | 9929 | 0.8623 |
| Cook Island North, Kirra Reef | 5.8304 | **0.0001** | 9530 | **0.0001** |
| Cook Island West, Kirra Reef | 5.4359 | **0.0001** | 9454 | **0.0001** |

[a] p values based on Monte Carlo simulations

Table A19 PERMANOVA results for differences in Ascidians at Kirra and Cook Island reefs. Bold p values denotes significance at $p<0.05$.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 5912.2 | 6.6929 | **0.0009** |
| Residual | 132 | 883.34 | | |

[a] p values based on Monte Carlo simulations

Table A20 Results of pairwise comparisons for Ascidians between reefs following PERMANOVA. Bold p values denotes significance at $p<0.05$.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 3.55E-01 | 0.8002 | 7966 | 0.802 |
| Cook Island North, Kirra Reef | 3.1343 | **0.0011** | 9943 | **0.0014** |
| Cook Island West, Kirra Reef | 2.8334 | **0.0043** | 9938 | **0.004** |

[a] p values based on Monte Carlo simulations

Table A21 PERMANOVA results for differences in Sponges at Kirra and Cook Island reefs. Bold p values denotes significance at $p<0.05$.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 11178 | 1.57E+01 | **0.0001** |
| Residual | 132 | 713.1 | | |

[a] p values based on Monte Carlo simulations

Table A22 Results of pairwise comparisons for Sponges between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 5.86E+00 | **0.0001** | 9715 | **0.0001** |
| Cook Island North, Kirra Reef | 9.31E-01 | 0.3643 | 9941 | 0.3579 |
| Cook Island West, Kirra Reef | 4.57E+00 | **0.0001** | 9696 | **0.0001** |

[a] p values based on Monte Carlo simulations

Table A23 PERMANOVA results for differences in Crinoids at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 1667.2 | 2.6724 | 0.0704 |
| Residual | 132 | 623.85 | | |

[a] p values based on Monte Carlo simulations

Table A24 PERMANOVA results for differences in Sand at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 11112 | 8.5326 | **0.0003** |
| Residual | 132 | 1302.3 | | |

[a] p values based on Monte Carlo simulations

Table A25 Results of pairwise comparisons for Sand between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 3.28E+00 | **0.0011** | 9895 | **0.0018** |
| Cook Island North, Kirra Reef | 4.1089 | **0.0001** | 9905 | **0.0001** |
| Cook Island West, Kirra Reef | 0.71747 | 0.4818 | 9910 | 0.4917 |

[a] p values based on Monte Carlo simulations

Table A26 PERMANOVA results for differences in Rock at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 2404.9 | 2.731 | 0.0602 |
| Residual | 132 | 880.6 | | |

[a] p values based on Monte Carlo simulations

Table A27 PERMANOVA results for differences in Soft Coral at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 87.908 | 0.58276 | 0.5381 |
| Residual | 132 | 150.85 | | |

[a] p values based on Monte Carlo simulations

Table A28 PERMANOVA results for differences in Alariaceae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 0 | Denominator is 0 | - |
| Residual | 132 | 0 | | - |

[a] p values based on Monte Carlo simulations

Table A29 PERMANOVA results for differences in Bare Ground at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 0 | Denominator is 0 | - |
| Residual | 132 | 0 | | - |

[a] p values based on Monte Carlo simulations

Table A30 PERMANOVA results for differences in Rubble at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 145.86 | 0.71014 | 0.5068 |
| Residual | 132 | 205.4 | | |

[a] p values based on Monte Carlo simulations

Table A31 PERMANOVA results for differences in Anemone at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 192.38 | 1.1306 | 0.3156 |
| Residual | 132 | 170.16 | | |

[a] p values based on Monte Carlo simulations

Table A32 PERMANOVA results for differences in Barnacles at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 18.519 | 1 | 1 |
| Residual | 132 | 18.519 | | |

[a] p values based on Monte Carlo simulations

Table A33 PERMANOVA results for differences in Hydroids at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 22.449 | 1 | 1 |
| Residual | 132 | 22.449 | | |

[a] p values based on Monte Carlo simulations

Table A34 PERMANOVA results for differences in Mushroom Anemone at Kirra and Cook Island reefs. Bold p values denotes significance at $p<0.05$.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 0 | Denominator is 0 | - |
| Residual | 132 | 0 | | - |

[a] p values based on Monte Carlo simulations

Table A35 PERMANOVA results for differences in Other groups at Kirra and Cook Island reefs. Bold p values denotes significance at $p<0.05$.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 0.35979 | 6.05E-03 | 1 |
| Residual | 132 | 59.486 | | |

[a] p values based on Monte Carlo simulations

Table A36 PERMANOVA results for differences in Oysters at Kirra and Cook Island reefs. Bold p values denotes significance at $p<0.05$.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 0 | Denominator is 0 | - |
| Residual | 132 | 0 | | - |

[a] p values based on Monte Carlo simulations

Table A37 PERMANOVA results for differences in Polychaetes at Kirra and Cook Island reefs. Bold p values denotes significance at $p<0.05$.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 0 | Denominator is 0 | - |
| Residual | 132 | 0 | | - |

[a] p values based on Monte Carlo simulations

Table A38 PERMANOVA results for differences in Starfish at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 51.138 | 2.05E+00 | 0.3316 |
| Residual | 132 | 24.988 | | |

[a] p values based on Monte Carlo simulations

Table A39 PERMANOVA results for differences in Urchins at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 314.84 | 3.88E+00 | **0.0309** |
| Residual | 132 | 81.159 | | |

[a] p values based on Monte Carlo simulations

Table A40 Results of pairwise comparisons for Urchins between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | p (perm) | Unique permutations | p (MC)[a] |
|---|---|---|---|---|
| Cook Island North, Cook Island West | 1.74E+00 | 0.1367 | 8 | 0.0868 |
| Cook Island North, Kirra Reef | 1.00E+00 | 1 | 1 | 0.3136 |
| Cook Island West, Kirra Reef | 2.33E+00 | 0.0542 | 6 | **0.0222** |

[a] p values based on Monte Carlo simulations

Table A41 PERMANOVA results for differences in Zoanthids at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 2 | 57.791 | 6.32E-01 | 0.6208 |
| Residual | 132 | 91.461 | | |

[a] p values based on Monte Carlo simulations

## Temporal Comparisons of Benthic Groups at Kirra Reef

Table A42 PERMANOVA results for differences in macroalgae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 12 | 4063.4 | 7.1443 | **0.001** |
| Residual | 583 | 568.76 | | |

[a] p values based on Monte Carlo simulations

Table A43 Results of pairwise comparisons for macroalgae between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2001, 2003 | 4.5232 | **0.001** | 995 |
| 2001, 2004 | 4.4511 | **0.001** | 997 |
| 2001, 2005 | 6.3794 | **0.001** | 999 |
| 2001, 2010 | 7.9816 | **0.001** | 998 |
| 2001, 2012 | 6.3733 | **0.001** | 999 |
| 2001, 2014 | 5.5648 | **0.001** | 999 |
| 2001, 2015 | 4.7568 | **0.001** | 999 |
| 2001, 2016 | 3.7387 | **0.001** | 999 |
| 2001, 2017 | 5.0867 | **0.001** | 999 |
| 2001, A1995 | 5.9719 | **0.001** | 998 |
| 2001, F1996 | 2.569 | **0.006** | 998 |
| 2001, J1995 | 2.5537 | **0.004** | 998 |
| 2003, 2004 | 0.48703 | 0.705 | 999 |
| 2003, 2005 | 1.2196 | 0.22 | 999 |
| 2003, 2010 | 1.9853 | **0.036** | 999 |
| 2003, 2012 | 1.4209 | 0.152 | 998 |
| 2003, 2014 | 2.07 | **0.03** | 997 |
| 2003, 2015 | 1.4009 | 0.172 | 999 |
| 2003, 2016 | 1.9971 | **0.04** | 999 |
| 2003, 2017 | 0.43632 | 0.784 | 997 |
| 2003, A1995 | 1.7542 | 0.06 | 998 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2003, F1996 | 1.6577 | 0.096 | 999 |
| 2003, J1995 | 2.0947 | **0.027** | 999 |
| 2004, 2005 | 1.519 | 0.111 | 997 |
| 2004, 2010 | 2.2877 | **0.008** | 998 |
| 2004, 2012 | 1.819 | 0.053 | 999 |
| 2004, 2014 | 1.6006 | 0.096 | 998 |
| 2004, 2015 | 0.91873 | 0.372 | 999 |
| 2004, 2016 | 1.5591 | 0.128 | 999 |
| 2004, 2017 | 0.61084 | 0.627 | 999 |
| 2004, A1995 | 1.314 | 0.192 | 999 |
| 2004, F1996 | 1.6139 | 0.094 | 999 |
| 2004, J1995 | 1.8225 | **0.046** | 999 |
| 2005, 2010 | 0.74951 | 0.523 | 998 |
| 2005, 2012 | 0.51977 | 0.718 | 995 |
| 2005, 2014 | 3.0467 | **0.001** | 997 |
| 2005, 2015 | 2.3418 | **0.012** | 999 |
| 2005, 2016 | 3.3065 | **0.002** | 997 |
| 2005, 2017 | 0.89265 | 0.422 | 997 |
| 2005, A1995 | 2.4314 | **0.009** | 998 |
| 2005, F1996 | 2.8868 | **0.003** | 998 |
| 2005, J1995 | 3.4265 | **0.001** | 999 |
| 2010, 2012 | 0.86128 | 0.452 | 999 |
| 2010, 2014 | 3.983 | **0.001** | 999 |
| 2010, 2015 | 3.1549 | **0.001** | 998 |
| 2010, 2016 | 4.2767 | **0.001** | 999 |
| 2010, 2017 | 1.635 | 0.082 | 999 |
| 2010, A1995 | 3.202 | **0.001** | 999 |
| 2010, F1996 | 3.7141 | **0.001** | 999 |
| 2010, J1995 | 4.3871 | **0.001** | 999 |
| 2012, 2014 | 3.4278 | **0.001** | 999 |
| 2012, 2015 | 2.7145 | **0.007** | 999 |
| 2012, 2016 | 3.6233 | **0.001** | 999 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2012, 2017 | 1.2089 | 0.244 | 998 |
| 2012, A1995 | 2.8573 | **0.001** | 999 |
| 2012, F1996 | 2.9765 | **0.002** | 999 |
| 2012, J1995 | 3.624 | **0.001** | 999 |
| 2014, 2015 | 0.70804 | 0.576 | 999 |
| 2014, 2016 | 1.2291 | 0.228 | 999 |
| 2014, 2017 | 2.1081 | **0.032** | 996 |
| 2014, A1995 | 0.81357 | 0.516 | 999 |
| 2014, F1996 | 2.4119 | **0.008** | 995 |
| 2014, J1995 | 1.9911 | **0.04** | 999 |
| 2015, 2016 | 1.0447 | 0.321 | 998 |
| 2015, 2017 | 1.4375 | 0.144 | 999 |
| 2015, A1995 | 0.67758 | 0.645 | 998 |
| 2015, F1996 | 1.9365 | **0.043** | 998 |
| 2015, J1995 | 1.6869 | 0.074 | 998 |
| 2016, 2017 | 2.23 | **0.012** | 997 |
| 2016, A1995 | 1.6929 | 0.067 | 999 |
| 2016, F1996 | 1.5997 | 0.106 | 998 |
| 2016, J1995 | 0.86364 | 0.435 | 999 |
| 2017, A1995 | 1.6466 | 0.087 | 998 |
| 2017, F1996 | 2.0428 | **0.036** | 999 |
| 2017, J1995 | 2.4179 | **0.01** | 998 |
| A1995, F1996 | 2.5318 | **0.006** | 999 |
| A1995, J1995 | 2.351 | **0.01** | 999 |
| F1996, J1995 | 0.99897 | 0.365 | 998 |

Table A44 PERMANOVA results for differences in turf algae at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 12 | 21951 | 36.607 | **0.001** |
| Residual | 583 | 599.64 | | |

[a] p values based on Monte Carlo simulations

Table A45 Results of pairwise comparisons for turf algae between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2017, 2001 | 0.84835 | 0.403 | 997 |
| 2017, 2003 | 0.71683 | 0.496 | 999 |
| 2017, 2004 | 6.9378 | **0.001** | 999 |
| 2017, 2005 | 6.8019 | **0.001** | 998 |
| 2017, A1995 | 5.2456 | **0.001** | 999 |
| 2017, F1996 | 1.3074 | 0.203 | 999 |
| 2017, J1995 | 1.6602 | 0.083 | 997 |
| 2017, 2010 | 6.6506 | **0.001** | 999 |
| 2017, 2012 | 8.4064 | **0.001** | 999 |
| 2017, 2014 | 7.0439 | **0.001** | 999 |
| 2017, 2015 | 6.5743 | **0.001** | 996 |
| 2017, 2016 | 9.7917 | **0.001** | 997 |
| 2001, 2003 | 1.5727 | 0.118 | 953 |
| 2001, 2004 | 6.5119 | **0.001** | 998 |
| 2001, 2005 | 6.1926 | **0.001** | 996 |
| 2001, A1995 | 4.424 | **0.001** | 885 |
| 2001, F1996 | 2.1382 | 0.035 | 903 |
| 2001, J1995 | 1.2819 | 0.213 | 996 |
| 2001, 2010 | 6.0473 | **0.001** | 998 |
| 2001, 2012 | 8.28 | **0.001** | 999 |
| 2001, 2014 | 6.6506 | **0.001** | 999 |
| 2001, 2015 | 6.2055 | **0.001** | 998 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2001, 2016 | 9.4911 | **0.001** | 999 |
| 2003, 2004 | 7.7516 | **0.001** | 992 |
| 2003, 2005 | 7.7389 | **0.001** | 999 |
| 2003, A1995 | 6.1897 | **0.001** | 973 |
| 2003, F1996 | 0.65415 | 0.519 | 955 |
| 2003, J1995 | 2.2878 | **0.02** | 993 |
| 2003, 2010 | 7.5696 | **0.001** | 999 |
| 2003, 2012 | 9.0826 | **0.001** | 996 |
| 2003, 2014 | 7.8397 | **0.001** | 999 |
| 2003, 2015 | 7.3137 | **0.001** | 999 |
| 2003, 2016 | 10.748 | **0.001** | 998 |
| 2004, 2005 | 2.6967 | **0.004** | 996 |
| 2004, A1995 | 5.7493 | **0.001** | 998 |
| 2004, F1996 | 9.0888 | **0.001** | 998 |
| 2004, J1995 | 4.6353 | **0.001** | 998 |
| 2004, 2010 | 2.4821 | **0.006** | 999 |
| 2004, 2012 | 3.9856 | **0.001** | 999 |
| 2004, 2014 | 0.42865 | 0.764 | 998 |
| 2004, 2015 | 0.78937 | 0.519 | 999 |
| 2004, 2016 | 2.6859 | **0.004** | 998 |
| 2005, A1995 | 4.1666 | **0.001** | 996 |
| 2005, F1996 | 9.1497 | **0.001** | 997 |
| 2005, J1995 | 4.4618 | **0.001** | 998 |
| 2005, 2010 | 0.21458 | 0.915 | 998 |
| 2005, 2012 | 7.2097 | **0.001** | 999 |
| 2005, 2014 | 3.1381 | **0.001** | 997 |
| 2005, 2015 | 3.0945 | **0.001** | 999 |
| 2005, 2016 | 7.4761 | **0.001** | 995 |
| A1995, F1996 | 7.3222 | **0.001** | 942 |
| A1995, J1995 | 3.4043 | **0.002** | 998 |
| A1995, 2010 | 3.9959 | **0.001** | 997 |
| A1995, 2012 | 9.7738 | **0.001** | 997 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| A1995, 2014 | 6.1051 | **0.001** | 999 |
| A1995, 2015 | 5.5956 | **0.001** | 999 |
| A1995, 2016 | 11.624 | **0.001** | 999 |
| F1996, J1995 | 2.9853 | **0.005** | 993 |
| F1996, 2010 | 8.9374 | **0.001** | 999 |
| F1996, 2012 | 10.53 | **0.001** | 997 |
| F1996, 2014 | 9.1786 | **0.001** | 999 |
| F1996, 2015 | 8.5342 | **0.001** | 998 |
| F1996, 2016 | 12.661 | **0.001** | 997 |
| J1995, 2010 | 4.3429 | **0.001** | 998 |
| J1995, 2012 | 6.1293 | **0.001** | 998 |
| J1995, 2014 | 4.7463 | **0.001** | 998 |
| J1995, 2015 | 4.4011 | **0.001** | 999 |
| J1995, 2016 | 6.8834 | **0.001** | 999 |
| 2010, 2012 | 6.8077 | **0.001** | 998 |
| 2010, 2014 | 2.9086 | **0.002** | 999 |
| 2010, 2015 | 2.887 | **0.001** | 999 |
| 2010, 2016 | 6.7884 | **0.001** | 999 |
| 2012, 2014 | 3.5164 | **0.001** | 999 |
| 2012, 2015 | 2.9196 | **0.001** | 998 |
| 2012, 2016 | 3.6501 | **0.001** | 998 |
| 2014, 2015 | 0.5059 | 0.717 | 999 |
| 2014, 2016 | 2.1329 | **0.019** | 999 |
| 2015, 2016 | 2.0127 | 0.022 | 997 |

Table A46 PERMANOVA results for differences in hard coral at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 12 | 492.3 | 4.6049 | **0.001** |
| Residual | 583 | 106.91 | | |

[a] p values based on Monte Carlo simulations

Table A47 Results of pairwise comparisons for hard coral between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2017, 2001 | - | | |
| 2017, 2003 | - | | |
| 2017, 2004 | 1.7118 | 0.225 | 4 |
| 2017, 2005 | 1.4005 | 0.472 | 2 |
| 2017, A1995 | 3.1993 | **0.001** | 27 |
| 2017, F1996 | 1.7728 | 0.25 | 2 |
| 2017, J1995 | - | | |
| 2017, 2010 | 1 | 1 | 1 |
| 2017, 2012 | - | | |
| 2017, 2014 | - | | |
| 2017, 2015 | 1 | 1 | 1 |
| 2017, 2016 | - | | |
| 2001, 2003 | - | | |
| 2001, 2004 | 1.7118 | 0.235 | 4 |
| 2001, 2005 | 1.4005 | 0.493 | 2 |
| 2001, A1995 | 3.1993 | **0.001** | 27 |
| 2001, F1996 | 1.7728 | 0.249 | 2 |
| 2001, J1995 | - | | |
| 2001, 2010 | 1 | 1 | 1 |
| 2001, 2012 | - | | |
| 2001, 2014 | - | | |
| 2001, 2015 | 1 | 1 | 1 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2001, 2016 | - | | |
| 2003, 2004 | 1.7118 | 0.241 | 4 |
| 2003, 2005 | 1.4005 | 0.499 | 2 |
| 2003, A1995 | 3.1993 | **0.004** | 28 |
| 2003, F1996 | 1.7728 | 0.269 | 2 |
| 2003, J1995 | - | | |
| 2003, 2010 | 1 | 1 | 1 |
| 2003, 2012 | - | | |
| 2003, 2014 | - | | |
| 2003, 2015 | 1 | 1 | 1 |
| 2003, 2016 | - | | |
| 2004, 2005 | 0.41558 | 0.8 | 12 |
| 2004, A1995 | 1.6324 | 0.125 | 101 |
| 2004, F1996 | 0.25067 | 0.789 | 16 |
| 2004, J1995 | 1.7118 | 0.239 | 4 |
| 2004, 2010 | 1.1739 | 0.376 | 6 |
| 2004, 2012 | 1.7118 | 0.243 | 4 |
| 2004, 2014 | 1.7118 | 0.228 | 4 |
| 2004, 2015 | 1.3289 | 0.256 | 8 |
| 2004, 2016 | 1.9119 | 0.099 | 8 |
| 2005, A1995 | 2.0419 | 0.041 | 75 |
| 2005, F1996 | 0.40231 | 1 | 5 |
| 2005, J1995 | 1.4005 | 0.474 | 2 |
| 2005, 2010 | 0.79401 | 0.488 | 4 |
| 2005, 2012 | 1.4005 | 0.504 | 2 |
| 2005, 2014 | 1.4005 | 0.469 | 2 |
| 2005, 2015 | 0.96585 | 0.481 | 4 |
| 2005, 2016 | 1.5643 | 0.2 | 4 |
| A1995, F1996 | 1.7286 | 0.11 | 63 |
| A1995, J1995 | 3.1993 | **0.003** | 28 |
| A1995, 2010 | 2.7305 | **0.008** | 30 |
| A1995, 2012 | 3.1993 | **0.004** | 28 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| A1995, 2014 | 3.1993 | **0.004** | 28 |
| A1995, 2015 | 2.8621 | **0.004** | 51 |
| A1995, 2016 | 3.5733 | **0.002** | 51 |
| F1996, J1995 | 1.7728 | 0.25 | 2 |
| F1996, 2010 | 1.1343 | 0.25 | 4 |
| F1996, 2012 | 1.7728 | 0.251 | 2 |
| F1996, 2014 | 1.7728 | 0.211 | 2 |
| F1996, 2015 | 1.3044 | 0.272 | 4 |
| F1996, 2016 | 1.9801 | 0.094 | 4 |
| J1995, 2010 | 1 | 1 | 1 |
| J1995, 2012 | - | | |
| J1995, 2014 | - | | |
| J1995, 2015 | 1 | 1 | 1 |
| J1995, 2016 | - | | |
| 2010, 2012 | 1 | 1 | 1 |
| 2010, 2014 | 1 | 1 | 1 |
| 2010, 2015 | 0.21678 | 1 | 2 |
| 2010, 2016 | 1.1169 | 0.452 | 2 |
| 2012, 2014 | - | | |
| 2012, 2015 | 1 | 1 | 1 |
| 2012, 2016 | - | | |
| 2014, 2015 | 1 | 1 | 1 |
| 2014, 2016 | - | | |
| 2015, 2016 | 1.1169 | 0.438 | 2 |

- Denominator is 0

Table A48 PERMANOVA results for differences in soft coral at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)[a] |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 12 | 1910.8 | 7.0155 | **0.001** |
| Residual | 583 | 272.37 | | |

[a] p values based on Monte Carlo simulations

Table A49 Results of pairwise comparisons for soft coral between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2017, 2001 | 1 | 1 | 1 |
| 2017, 2003 | 2.6141 | **0.005** | 107 |
| 2017, 2004 | 3.0031 | **0.005** | 76 |
| 2017, 2005 | 1.0471 | 0.355 | 6 |
| 2017, A1995 | 2.7386 | **0.007** | 46 |
| 2017, F1996 | 3.4328 | **0.001** | 511 |
| 2017, J1995 | 1.0238 | 0.477 | 6 |
| 2017, 2010 | 1 | 1 | 1 |
| 2017, 2012 | 1 | 1 | 1 |
| 2017, 2014 | 5.59E-02 | 1 | 2 |
| 2017, 2015 | 1 | 1 | 1 |
| 2017, 2016 | 1.1169 | 0.425 | 2 |
| 2001, 2003 | 3.0099 | **0.003** | 54 |
| 2001, 2004 | 3.4609 | **0.002** | 40 |
| 2001, 2005 | 1.7631 | 0.247 | 3 |
| 2001, A1995 | 3.2571 | **0.003** | 24 |
| 2001, F1996 | 3.7915 | **0.001** | 349 |
| 2001, J1995 | 1.7321 | 0.221 | 3 |
| 2001, 2010 | - | | |
| 2001, 2012 | - | | |
| 2001, 2014 | 1 | 1 | 1 |
| 2001, 2015 | - | | |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2001, 2016 | - | | |
| 2003, 2004 | 0.50246 | 0.638 | 498 |
| 2003, 2005 | 1.8759 | 0.062 | 163 |
| 2003, A1995 | 0.66151 | 0.562 | 484 |
| 2003, F1996 | 0.89239 | 0.392 | 915 |
| 2003, J1995 | 1.8781 | 0.055 | 190 |
| 2003, 2010 | 3.0099 | **0.005** | 54 |
| 2003, 2012 | 3.0099 | **0.005** | 54 |
| 2003, 2014 | 2.6457 | **0.006** | 108 |
| 2003, 2015 | 3.0099 | **0.006** | 54 |
| 2003, 2016 | 3.3618 | **0.001** | 106 |
| 2004, 2005 | 2.1618 | 0.043 | 60 |
| 2004, A1995 | 0.46313 | 0.667 | 158 |
| 2004, F1996 | 0.88481 | 0.383 | 683 |
| 2004, J1995 | 2.1698 | **0.018** | 84 |
| 2004, 2010 | 3.4609 | **0.001** | 41 |
| 2004, 2012 | 3.4609 | **0.001** | 40 |
| 2004, 2014 | 3.0366 | **0.004** | 52 |
| 2004, 2015 | 3.4609 | **0.001** | 40 |
| 2004, 2016 | 3.8655 | **0.001** | 72 |
| 2005, A1995 | 1.8217 | 0.098 | 38 |
| 2005, F1996 | 2.7394 | **0.003** | 489 |
| 2005, J1995 | 3.47E-02 | 1 | 12 |
| 2005, 2010 | 1.7631 | 0.259 | 3 |
| 2005, 2012 | 1.7631 | 0.243 | 3 |
| 2005, 2014 | 1.0907 | 0.372 | 5 |
| 2005, 2015 | 1.7631 | 0.237 | 3 |
| 2005, 2016 | 1.9693 | 0.087 | 6 |
| A1995, F1996 | 1.3196 | 0.168 | 738 |
| A1995, J1995 | 1.8329 | 0.08 | 57 |
| A1995, 2010 | 3.2571 | **0.002** | 24 |
| A1995, 2012 | 3.2571 | **0.003** | 24 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| A1995, 2014 | 2.7745 | **0.008** | 28 |
| A1995, 2015 | 3.2571 | **0.003** | 24 |
| A1995, 2016 | 3.638 | **0.001** | 45 |
| F1996, J1995 | 2.7417 | **0.004** | 488 |
| F1996, 2010 | 3.7915 | **0.001** | 356 |
| F1996, 2012 | 3.7915 | **0.001** | 345 |
| F1996, 2014 | 3.4618 | **0.001** | 424 |
| F1996, 2015 | 3.7915 | **0.001** | 361 |
| F1996, 2016 | 4.2349 | **0.001** | 507 |
| J1995, 2010 | 1.7321 | 0.258 | 3 |
| J1995, 2012 | 1.7321 | 0.234 | 3 |
| J1995, 2014 | 1.0674 | 0.497 | 4 |
| J1995, 2015 | 1.7321 | 0.237 | 3 |
| J1995, 2016 | 1.9347 | 0.089 | 6 |
| 2010, 2012 | - | | |
| 2010, 2014 | 1 | 1 | 1 |
| 2010, 2015 | - | | |
| 2010, 2016 | - | | |
| 2012, 2014 | 1 | 1 | 1 |
| 2012, 2015 | - | | |
| 2012, 2016 | - | | |
| 2014, 2015 | 1 | 1 | 1 |
| 2014, 2016 | 1.1169 | 0.444 | 2 |
| 2015, 2016 | - | | |

- Denominator is 0

Table A50 PERMANOVA results for differences in sponges at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)a |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 12 | 11665 | 15.032 | **0.001** |
| Residual | 583 | 775.98 | | |

[a] p values based on Monte Carlo simulations

Table A51 Results of pairwise comparisons for sponges between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2017, 2001 | 3.2045 | **0.002** | 997 |
| 2017, 2003 | 1.5814 | 0.108 | 998 |
| 2017, 2004 | 4.8567 | **0.001** | 998 |
| 2017, 2005 | 1.1005 | 0.26 | 997 |
| 2017, A1995 | 1.4535 | 0.126 | 998 |
| 2017, F1996 | 1.6541 | 0.089 | 998 |
| 2017, J1995 | 3.4886 | **0.001** | 994 |
| 2017, 2010 | 4.6645 | **0.001** | 998 |
| 2017, 2012 | 2.9547 | **0.007** | 998 |
| 2017, 2014 | 0.33022 | 0.833 | 997 |
| 2017, 2015 | 2.0318 | **0.044** | 996 |
| 2017, 2016 | 1.6972 | 0.091 | 999 |
| 2001, 2003 | 4.2439 | **0.001** | 976 |
| 2001, 2004 | 9.0001 | **0.001** | 987 |
| 2001, 2005 | 2.095 | 0.051 | 363 |
| 2001, A1995 | 1.8262 | 0.081 | 148 |
| 2001, F1996 | 4.4134 | **0.001** | 984 |
| 2001, J1995 | 0.33665 | 0.818 | 44 |
| 2001, 2010 | 1.373 | 0.155 | 78 |
| 2001, 2012 | 0.23274 | 0.934 | 383 |
| 2001, 2014 | 2.9464 | **0.006** | 461 |
| 2001, 2015 | 5.6959 | **0.001** | 824 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2001, 2016 | 5.5019 | **0.001** | 999 |
| 2003, 2004 | 3.0633 | **0.003** | 995 |
| 2003, 2005 | 2.4561 | 0.018 | 991 |
| 2003, A1995 | 2.8131 | **0.006** | 985 |
| 2003, F1996 | 0.23103 | 0.903 | 998 |
| 2003, J1995 | 4.5685 | **0.001** | 975 |
| 2003, 2010 | 5.5601 | **0.001** | 965 |
| 2003, 2012 | 4.0084 | **0.001** | 984 |
| 2003, 2014 | 1.8693 | 0.053 | 996 |
| 2003, 2015 | 1.5357 | 0.118 | 998 |
| 2003, 2016 | 2.4962 | **0.008** | 999 |
| 2004, 2005 | 6.1901 | **0.001** | 990 |
| 2004, A1995 | 6.7311 | **0.001** | 989 |
| 2004, F1996 | 2.8956 | **0.005** | 996 |
| 2004, J1995 | 9.6283 | **0.001** | 981 |
| 2004, 2010 | 11.497 | **0.001** | 991 |
| 2004, 2012 | 8.5986 | **0.001** | 994 |
| 2004, 2014 | 5.2805 | **0.001** | 996 |
| 2004, 2015 | 3.1702 | **0.004** | 998 |
| 2004, 2016 | 5.3498 | **0.001** | 999 |
| 2005, A1995 | 0.35343 | 0.741 | 358 |
| 2005, F1996 | 2.5788 | **0.013** | 988 |
| 2005, J1995 | 2.3433 | 0.024 | 230 |
| 2005, 2010 | 3.5084 | **0.003** | 335 |
| 2005, 2012 | 1.8573 | 0.07 | 735 |
| 2005, 2014 | 0.81306 | 0.419 | 629 |
| 2005, 2015 | 3.2349 | **0.003** | 879 |
| 2005, 2016 | 2.7996 | **0.007** | 999 |
| A1995, F1996 | 2.9395 | **0.004** | 988 |
| A1995, J1995 | 2.0523 | 0.043 | 84 |
| A1995, 2010 | 3.2605 | **0.002** | 141 |
| A1995, 2012 | 1.592 | 0.103 | 445 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| A1995, 2014 | 1.1563 | 0.239 | 446 |
| A1995, 2015 | 3.6489 | **0.001** | 811 |
| A1995, 2016 | 3.1706 | **0.001** | 998 |
| F1996, J1995 | 4.7386 | **0.001** | 977 |
| F1996, 2010 | 5.7526 | **0.001** | 993 |
| F1996, 2012 | 4.1744 | **0.001** | 995 |
| F1996, 2014 | 1.9582 | 0.054 | 998 |
| F1996, 2015 | 1.3924 | 0.164 | 997 |
| F1996, 2016 | 2.4181 | **0.014** | 998 |
| J1995, 2010 | 1.2688 | 0.276 | 39 |
| J1995, 2012 | 0.52718 | 0.605 | 213 |
| J1995, 2014 | 3.2192 | **0.001** | 340 |
| J1995, 2015 | 6.0981 | **0.001** | 712 |
| J1995, 2016 | 5.8791 | **0.001** | 996 |
| 2010, 2012 | 1.5947 | 0.095 | 160 |
| 2010, 2014 | 4.4183 | **0.001** | 476 |
| 2010, 2015 | 7.5971 | **0.001** | 844 |
| 2010, 2016 | 7.613 | **0.001** | 998 |
| 2012, 2014 | 2.698 | **0.011** | 814 |
| 2012, 2015 | 5.3837 | **0.001** | 975 |
| 2012, 2016 | 5.1675 | **0.001** | 997 |
| 2014, 2015 | 2.3601 | **0.01** | 933 |
| 2014, 2016 | 1.9144 | 0.057 | 998 |
| 2015, 2016 | 1.6614 | 0.085 | 998 |

Table A52 PERMANOVA results for differences in ascidians at Kirra and Cook Island reefs. Bold p values denotes significance at p<0.05.

| Factor | df | MS effect | Pseudo-F | p (MC)a |
|---|---|---|---|---|
| **Main test** | | | | |
| Reef | 12 | 20558 | 28.799 | **0.001** |
| Residual | 583 | 713.87 | | |

[a] p values based on Monte Carlo simulations

Table A53 Results of pairwise comparisons for ascidians between reefs following PERMANOVA. Bold p values denotes significance at p<0.05.

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2017, 2001 | 2.6605 | 0.005 | 999 |
| 2017, 2003 | 0.58772 | 0.6 | 999 |
| 2017, 2004 | 0.88595 | 0.371 | 999 |
| 2017, 2005 | 3.2942 | **0.001** | 999 |
| 2017, A1995 | 6.9466 | **0.001** | 998 |
| 2017, F1996 | 5.6632 | **0.001** | 996 |
| 2017, J1995 | 4.7863 | **0.001** | 997 |
| 2017, 2010 | 1.3104 | 0.2 | 998 |
| 2017, 2012 | 6.9466 | **0.001** | 999 |
| 2017, 2014 | 3.116 | **0.004** | 999 |
| 2017, 2015 | 1.1048 | 0.265 | 999 |
| 2017, 2016 | 1.8183 | 0.067 | 999 |
| 2001, 2003 | 2.9481 | **0.004** | 997 |
| 2001, 2004 | 2.0095 | 0.052 | 811 |
| 2001, 2005 | 6.8743 | **0.001** | 986 |
| 2001, A1995 | 4.2752 | **0.001** | 255 |
| 2001, F1996 | 2.8758 | **0.007** | 803 |
| 2001, J1995 | 2.0775 | **0.046** | 622 |
| 2001, 2010 | 3.9593 | **0.001** | 998 |
| 2001, 2012 | 4.2752 | **0.001** | 256 |
| 2001, 2014 | 6.5864 | **0.001** | 993 |
| 2001, 2015 | 3.6476 | **0.001** | 982 |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| 2001, 2016 | 4.3329 | **0.001** | 998 |
| 2003, 2004 | 1.4213 | 0.15 | 997 |
| 2003, 2005 | 3.1933 | **0.005** | 999 |
| 2003, A1995 | 6.9261 | **0.001** | 977 |
| 2003, F1996 | 5.7839 | **0.001** | 997 |
| 2003, J1995 | 4.938 | **0.001** | 997 |
| 2003, 2010 | 1.6301 | 0.088 | 998 |
| 2003, 2012 | 6.9261 | **0.001** | 978 |
| 2003, 2014 | 2.9185 | **0.008** | 998 |
| 2003, 2015 | 1.4833 | 0.135 | 999 |
| 2003, 2016 | 2.2958 | **0.022** | 998 |
| 2004, 2005 | 4.1836 | **0.001** | 989 |
| 2004, A1995 | 6.5628 | **0.001** | 324 |
| 2004, F1996 | 5.1203 | **0.001** | 866 |
| 2004, J1995 | 4.2271 | **0.001** | 709 |
| 2004, 2010 | 1.7593 | 0.067 | 996 |
| 2004, 2012 | 6.5628 | **0.001** | 329 |
| 2004, 2014 | 4.0623 | **0.001** | 993 |
| 2004, 2015 | 1.5018 | 0.128 | 992 |
| 2004, 2016 | 1.9832 | **0.046** | 998 |
| 2005, A1995 | 17.132 | **0.001** | 974 |
| 2005, F1996 | 13.226 | **0.001** | 999 |
| 2005, J1995 | 10.876 | **0.001** | 983 |
| 2005, 2010 | 2.3971 | **0.019** | 998 |
| 2005, 2012 | 17.132 | **0.001** | 971 |
| 2005, 2014 | 0.68916 | 0.619 | 998 |
| 2005, 2015 | 2.6263 | **0.007** | 996 |
| 2005, 2016 | 3.0747 | **0.003** | 999 |
| A1995, F1996 | 2.5725 | **0.024** | 10 |
| A1995, J1995 | 2.5227 | **0.029** | 16 |
| A1995, 2010 | 9.8323 | **0.001** | 998 |
| A1995, 2012 | - | | |

| Groups | t | P(perm) | Unique permutations |
|---|---|---|---|
| A1995, 2014 | 15.113 | **0.001** | 984 |
| A1995, 2015 | 9.1834 | **0.001** | 962 |
| A1995, 2016 | 10.85 | **0.001** | 999 |
| F1996, J1995 | 0.86422 | 0.45 | 261 |
| F1996, 2010 | 7.8795 | **0.001** | 999 |
| F1996, 2012 | 2.5725 | **0.04** | 10 |
| F1996, 2014 | 12.106 | **0.001** | 999 |
| F1996, 2015 | 7.3656 | **0.001** | 993 |
| F1996, 2016 | 8.6277 | **0.001** | 997 |
| J1995, 2010 | 6.6604 | **0.001** | 999 |
| J1995, 2012 | 2.5227 | **0.018** | 16 |
| J1995, 2014 | 10.159 | **0.001** | 992 |
| J1995, 2015 | 6.2322 | **0.001** | 990 |
| J1995, 2016 | 7.3104 | **0.001** | 998 |
| 2010, 2012 | 9.8323 | **0.001** | 999 |
| 2010, 2014 | 2.4368 | **0.016** | 999 |
| 2010, 2015 | 0.26562 | 0.9 | 999 |
| 2010, 2016 | 0.70083 | 0.51 | 998 |
| 2012, 2014 | 15.113 | **0.001** | 986 |
| 2012, 2015 | 9.1834 | **0.001** | 963 |
| 2012, 2016 | 10.85 | **0.001** | 999 |
| 2014, 2015 | 2.6337 | **0.006** | 996 |
| 2014, 2016 | 3.2307 | **0.002** | 998 |
| 2015, 2016 | 0.70877 | 0.534 | 999 |

- Denominator is 0

Table A54 Similarity percentage analysis (SIMPER) of dissimilarity of fish assemblages at Kirra and Cook Island reefs. The relative contribution (Contrib.%) of fish species up to 50% cumulative dissimilarity (Cum.%) is shown. Data for SIMPER analysis has been derived from square-root transformed maxN values (combined for all survey methods).

| **Trophic level** | **Species** | **Common name** | **Average Abundance** | | **Contrib%** | **Cum.%** |
|---|---|---|---|---|---|---|
| | | | **Kirra Reef** | **Cook Island West** | | |
| **Kirra Reef versus Cook Island West, Average dissimilarity = 74.15%** | | | | | | |
| CA | *Trachurus novaezelandiae* | yellowtail | 4.75 | 0 | 11.04 | 11.04 |
| P | *Schuettea scalaripinnis* | eastern pomfred | 1.69 | 4.97 | 8.77 | 19.81 |
| P | *Scorpis lineolata* | sweep | 2.63 | 0.33 | 5.55 | 25.36 |
| O | *Pempheris affinis* | black tipped bullseye | 2.38 | 0.47 | 5.32 | 30.67 |
| CA | *Sphyraena obtusata* | striped sea pike | 1.86 | 0 | 4.01 | 34.69 |
| O | *Microcanthus strigatus* | stripey | 2.04 | 0.33 | 3.84 | 38.52 |
| O | *Atypichthys strigatus* | mado | 2.37 | 0.9 | 3.72 | 42.24 |
| O | *Pempheris sp* | bullseye | 0.17 | 1.43 | 3.33 | 45.57 |
| O | *Monodactylus argenteus* | silver batfish | 0 | 1.42 | 3.05 | 48.62 |
| O | *Pseudolabrus guentheri* | Gunther’s wrasse | 1.81 | 1.63 | 2.19 | 50.81 |

| Trophic level | Species | Common name | Average Abundance | | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| | | | **Kirra Reef** | **Cook Island North** | | |
| **Kirra Reef versus Cook Island North, Average dissimilarity = 74.71%** | | | | | | |
| CA | *Trachurus novaezelandiae* | yellowtail | 4.75 | 0 | 11.27 | 11.27 |
| P | *Schuettea scalaripinnis* | eastern pomfred | 1.69 | 4.83 | 9.5 | 20.77 |
| P | *Scorpis lineolata* | sweep | 2.63 | 0.4 | 5.53 | 26.3 |
| O | *Pempheris affinis* | black tipped bullseye | 2.38 | 0 | 4.93 | 31.23 |
| O | *Atypichthys strigatus* | mado | 2.37 | 0.87 | 4.29 | 35.52 |
| CA | *Sphyraena obtusata* | striped sea pike | 1.86 | 0 | 4.1 | 39.62 |
| O | *Microcanthus strigatus* | stripey | 2.04 | 0.5 | 3.58 | 43.2 |
| O | *Pseudolabrus guentheri* | Gunther's wrasse | 1.81 | 1.31 | 2.41 | 45.61 |
| H | *Acanthurus blochii* | ring-tailed surgeon | 0.93 | 1.67 | 2.14 | 47.75 |
| P | *Dascyllus trimaculatus* | domino puller | 0.64 | 0.87 | 1.96 | 49.71 |
| O | *Thalassoma lutescens* | yellow moon wrasse | 0.24 | 0.9 | 1.88 | 51.59 |

| Trophic level | Species | Common name | Average Abundance | | Contrib% | Cum.% |
|---|---|---|---|---|---|---|
| | | | Cook Island West | Cook Island North | | |
| **Cook Island West versus Cook Island North, Average dissimilarity = 57.67%** | | | | | | |
| P | *Schuettea scalaripinnis* | eastern pomfred | 4.97 | 4.83 | 13.33 | 13.33 |
| O | *Pempheris sp* | bullseye | 1.43 | 0 | 4.9 | 18.23 |
| O | *Monodactylus argenteus* | silver batfish | 1.42 | 0.79 | 3.93 | 22.15 |
| H | *Acanthurus blochii* | ring-tailed surgeon | 0.74 | 1.67 | 3.35 | 25.5 |
| O | *Atypichthys strigatus* | mado | 0.9 | 0.87 | 3.24 | 28.74 |
| P | *Dascyllus trimaculatus* | domino puller | 0.47 | 0.87 | 3.16 | 31.9 |
| CA | *Rhabdosargus sarba* | tarwhine | 0.74 | 1.24 | 2.9 | 34.8 |
| O-HT | *Parma unifasciata* | girdled scalyfin | 0.86 | 0.17 | 2.76 | 37.56 |
| O | *Abudefduf vaigiensis* | seargant major | 0.57 | 0.98 | 2.7 | 40.26 |
| O | *Amphiprion akindynos* | Barrier Reef anemonefish | 0.4 | 0.86 | 2.63 | 42.89 |
| H | *Prionurus microlepidotus* | sawtail surgeon | 0.17 | 0.79 | 2.51 | 45.4 |
| O | *Thalassoma lutescens* | yellow moon wrasse | 0.62 | 0.9 | 2.3 | 47.7 |
| O | *Labroides dimidiatus* | cleaner wrasse | 0.9 | 0.91 | 2.25 | 49.95 |
| CA | *Lutjanus fulviflamma* | black-spot snapper | 0.4 | 0.57 | 2.13 | 52.08 |

# Appendix B Abundance of fish species at Kirra and Cook Island Reefs in 2017

Table B1 Fish species at Kirra and Cook Island Reef recorded during the 2017 survey. Key to abbreviations: Trophic Level: **H** = herbivore, **P** = planktivore, **CA** = carnivore, **C** = Corallivore, **O** = omnivore, **O-HT** = omnivore with herbivorous tendencies; Reef/Pelagic: **R** = reef associated or benthic, **P** = pelagic, **R/P** = bentho-pelagic; Range: **TR** = found generally in tropical and subtropical waters, Kirra and Cook Island Reefs at south end of range, **TE** = found generally in temperate and subtropical waters, Kirra and Cook Island Reefs at north end of range; **TR/TE** = found throughout tropic and temperate waters, Kirra and Cook Island Reefs are not in extreme range.

| | | | | | | maxN | | | relative abundance | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scientific Name** | **Common Name** | **Trophic Level** | **Reef / Pelagic** | **Range** | **Kirra Reef** | **Cook Island North** | **Cook Island West** | **Kirra Reef** | **Cook Island North** | **Cook Island West** |
| **Acanthuridae** | | | | | | | | | | |
| *Acanthurus blochii* | ring-tailed surgeon | H | R | TR | 3 | 2 | 12 | * | * | ** |
| *Acanthurus xanthopterus* | yellowfin surgeon | H | R | TR | 1 | 0 | 0 | * | | |
| *Prionurus microlepidotus* | sawtail surgeon | H | R | TR/TE | 0 | 1 | 3 | | * | * |
| *Acanthurus olivaceus* | orange-band surgeon | H | R | TR | 1 | 0 | 1 | * | | * |
| *Acanthurus striatus* | striated surgeonfish | H | R | TR | 2 | 0 | 0 | * | | |
| *Naso sp.* | unicornfish | P | R | TR/TE | 2 | 0 | 1 | * | | * |
| **Apogonidae**[x] | | | | | 0 | 0 | 0 | | | |
| *Apogon limenus*[x] | Sydney cardinalfish | CA | R | TR/TE | | | 1 | | | * |
| *Apogon sp.*[x] | cardinalfish | CA | R | TR/TE | 1 | | | * | | |
| **Balistidae** | | | | | 0 | 0 | 0 | | | |
| *Balistidae spp* | triggerfish | CA | R | TR/TE | 0 | 0 | 1 | | | * |
| **Blennidae** | | | | | 0 | 0 | 0 | | | |
| *Plagiotremus tapeinosoma* | hit and run blenny | CA | R | TR/TE | 0 | 1 | 0 | | * | |
| **Brachaeluridae** | | | | | 0 | 0 | 0 | | | |
| *Brachaelurus waddi* | blindshark | CA | R | TE | 0 | 1 | 0 | | * | |
| **Carangidae** | | | | | 0 | 0 | 0 | | | |
| *Caranax sp.* | trevally | CA | P | TR/TE | 0 | 1 | 1 | | * | * |
| *Trachurus novaezelandiae* | yellowtail | CA | P | TE | 38 | 0 | 0 | *** | | |
| **Chaetodontidae** | | | | | 0 | 0 | 0 | | | |
| *Chaetodon auriga* | threadfin butterfly fish | C | R | TR/TE | 1 | 0 | 0 | * | | |
| *Chaetodon citrinellus* | citron butterfly fish | C | R | TR | 1 | 0 | 0 | * | | |
| *Chaetodon flavirostris* | dusky butterfly fish | C | R | TR/TE | 0 | 0 | 1 | | | * |
| *Chaetodon plebeius* | blueblotch butterflyfish | C | R | TR | 0 | 0 | 1 | | | * |
| *Chaetodon guentheri* | Gunther's butterflyfish | C | R | TE | 0 | 1 | 0 | | * | |
| *Chaetodon kleinii* | brown butterflyfish | C | R | TR/TE | 1 | 0 | 1 | * | | * |

| Scientific Name | Common Name | Trophic Level | Reef / Pelagic | Range | maxN | | | relative abundance | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kirra Reef | Cook Island North | Cook Island West | Kirra Reef | Cook Island North | Cook Island West |
| **Cheilodactylidae** | | | | | 0 | 0 | 0 | | | |
| *Cheilodactylus fuscus* | red morwong | CA | R | TE | 2 | 0 | 0 | * | | |
| *Cheilodactylus vestitus* | crested morwong | CA | R | TE | 1 | 0 | 0 | * | | |
| **Cirrhitidae** | | | | | 0 | 0 | 0 | | | |
| *Cirrhitichthys falco*[x] | coral hawkfish | CA | R | TR/TE | | | 1 | | | * |
| *Cirrhitichthys sp.* | hawkfish | CA | R | TR/TE | 0 | 0 | 1 | | | * |
| **Dasyatidae** | | | | | 0 | 0 | 0 | | | |
| *Dasyatis kuhlii* | blue-spotted maskray | CA | R | TR/TE | 1 | 0 | 0 | * | | |
| **Diodontidae** | | | | | 0 | 0 | 0 | | | |
| *Diodon hystrix* | black-spotted porcupine fish | CA | R | TR/TE | 1 | 0 | 0 | * | | |
| **Enoplosidae** | | | | | 0 | 0 | 0 | | | |
| *Enoplosus armatus*[x] | old wife | CA | R | TE | 1 | 0 | 0 | * | | |
| **Gobiidae**[x] | | | | | | | | | | |
| *Istigobius nigroocellatus*[x] | black-spotted goby | O | R | TR | | | 1 | | | * |
| **Haemulidae** | | | | | 0 | 0 | 0 | | | |
| *Plectorhinchus flavomaculatus* | gold-spotted sweetlip | CA | R | TR/TE | 1 | 1 | 2 | * | * | * |
| *Plectorhinchus spp* | sweetlip | CA | R | TR/TE | 1 | 0 | 0 | * | | |
| **Hemiscylliidae** | | | | | 0 | 0 | 0 | | | |
| *Chiloscyllium punctatum* | brownbanded bamboo shark | CA | R | TR | 1 | 0 | 0 | * | | |
| **Labridae** | | | | | 0 | 0 | 0 | | | |
| *Achoerodus gouldii* | blue groper | O | R | TE | 0 | 1 | 1 | | * | * |
| *Cheilio inermis* | cigar wrasse | O | R | TR/TE | 0 | 0 | 1 | | | * |
| *Gomphosus varius* | bird wrasse | O | R | TR | 0 | 0 | 1 | | | * |
| *Halichoeres sp.* | striped wrasse | O | R | TR/TE | 1 | 0 | 1 | * | | * |
| *Labroides dimidiatus* | cleaner wrasse | O | R | TR/TE | 1 | 2 | 6 | * | * | ** |
| *Notolabrus gymnogenis* | crimson-banded wrasse | O | R | TE | 1 | 1 | 0 | * | * | |
| *Notolabrus sp.* | wrasse | O | R | TR/TE | 0 | 1 | 1 | | * | * |
| *Pseudolabrus guentheri* | Gunther's Wrasse | O | R | TR | 8 | 7 | 3 | ** | ** | * |
| *Thalasoma jansenii* | Jansen’s wrasse | O | R | TR | 2 | 0 | 1 | * | | * |
| *Thalasoma spp* | wrasse | O | R | TR/TE | 1 | 0 | 0 | * | | |
| *Thalassoma lunare* | moon wrasse | O | R | TR/TE | 2 | 2 | 3 | * | * | * |

| Scientific Name | Common Name | Trophic Level | Reef / Pelagic | Range | maxN | | | relative abundance | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kirra Reef | Cook Island North | Cook Island West | Kirra Reef | Cook Island North | Cook Island West |
| *Thalassoma lutescens* | yellow moon wrasse | O | R | TR/TE | 2 | 3 | 2 | * | * | * |
| **Lethrinidae** | | | | | 0 | 0 | 0 | | | |
| *Lethrinus nebulosus* | spangled emperor | CA | R | TR/TE | 0 | 0 | 1 | | | * |
| **Lutjanidae** | | | | | 0 | 0 | 0 | | | |
| *Lutjanus fulviflamma* | black-spot snapper | CA | R | TR | 1 | 2 | 2 | * | * | * |
| **Microcanthidae** | | | | | 0 | 0 | 0 | | | |
| *Atypichthys strigatus* | mado | O | R | TE | 23 | 4 | 8 | *** | * | ** |
| *Microcanthus strigatus* | stripey | O | R | TE | 8 | 1 | 1 | ** | * | * |
| **Monodactylidae** | | | | | 0 | 0 | 0 | | | |
| *Monodactylus argenteus* | silver batfish | O | P | TR/TE | 0 | 7 | 4 | | ** | * |
| *Schuettea scalaripinnis* | eastern pomfred | P | P | TE | 15 | 52 | 75 | ** | *** | *** |
| **Mullidae** | | | | | 0 | 0 | 0 | | | |
| *Parupeneus signatus* | black spot goat fish | CA | R | TR/TE | 0 | 1 | 0 | | * | |
| **Muraenidae** | | | | | 0 | 0 | 0 | | | |
| *Gymnothorax eurostus* | Abbott's moray eel | CA | R | TR/TE | 0 | 0 | 1 | | | * |
| *Gymnothorax sp.* | moray eel | CA | R | TR/TE | 0 | 1 | 0 | | * | |
| *Gymnothorax pseudothyrsoideus* | highfin moray | CA | R | TR/TE | 1 | 0 | 0 | * | | |
| **Myliobatididae** | | | | | 0 | 0 | 0 | | | |
| *Aetobatus narinari* | white-spotted eagle ray | CA | R/P | TR/TE | 1 | 0 | 0 | * | | |
| **Orectolobidae** | | | | | 0 | 0 | 0 | | | |
| *Orectolobus ornatus* | ornate wobbegong | CA | R | TR/TE | 1 | 1 | 1 | * | * | * |
| *Orectolobus maculatus* | spotted wobbegong | CA | R | TE | 0 | 1 | 1 | | * | * |
| **Pempheridae** | | | | | 0 | 0 | 0 | | | |
| *Pempheris affinis* | black tipped bullseye | O | R | TE | 51 | 8 | 0 | *** | ** | |
| *Pempheris sp* | bullseye | O | R | TR/TE | 1 | 51 | 0 | * | *** | |
| **Pinguipedidae** | | | | | 0 | 0 | 0 | | | |
| *Parapercis sp* | sandperch | CA | R | TR/TE | 0 | 0 | 1 | | | * |
| **Pomacanthidae** | | | | | 0 | 0 | 0 | | | |
| *Centropyge bicolor*[x] | bicolor angelfish | H | R | TR | | | 1 | | | * |
| *Centropyge tibicen* | keyhole angelfish | H | R | TR/TE | 2 | 0 | 0 | * | | |
| **Pomacentridae** | | | | | 0 | 0 | 0 | | | |
| *Abudefduf vaigiensis* | sergeant major | O | R | TR/TE | 1 | 2 | 6 | - | * | ** |

| Scientific Name | Common Name | Trophic Level | Reef / Pelagic | Range | maxN | | | relative abundance | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kirra Reef | Cook Island North | Cook Island West | Kirra Reef | Cook Island North | Cook Island West |
| *Abudefduf spp* | | O | R | TR/TE | 0 | 0 | 1 | | | * |
| *Amphiprion akindynos* | Barrier Reef anemonefish | O | R | TR/TE | 1 | 2 | 3 | - | * | * |
| *Chromis chrysura* | robust puller | P | R | TR | 1 | 2 | 2 | - | * | * |
| *Chromis hypsilepis* | brown puller | P | R | TE | 0 | 1 | 1 | | * | * |
| *Chromis spp* | damselfish | P | R | TR/TE | 0 | 1 | 0 | | * | |
| *Chrysiptera sp.* | demoiselle | P | R | TR/TE | 0 | 1 | 0 | | * | |
| *Dascyllus spp* | damselfish | P | R | TR/TE | 0 | 3 | 0 | | * | |
| *Dascyllus trimaculatus* | domino puller | P | R | TR/TE | 2 | 8 | 8 | - | ** | ** |
| *Parma oligolepis* | large-scaled parma | O-HT | R | TR/TE | 2 | 3 | 2 | - | * | * |
| *Parma unifasciata* | girdled scalyfin | O-HT | R | TE | 0 | 3 | 1 | | * | * |
| *Pomacentrus coelestis* | neon damsel | O-HT | R | TR/TE | 2 | 2 | 2 | - | * | * |
| *Stegastes gascoynei* | coral sea gregory | O-HT | R | TR/TE | 0 | 1 | 2 | | * | * |
| *Stegastes apicalis* | australian gregory | O-HT | R | TR/TE | 1 | 1 | 1 | - | * | * |
| *Stegastes sp.* | damsel | O-HT | R | TR/TE | 2 | 3 | 0 | - | * | |
| *Scorpaendiae* | | | | | 0 | 0 | 0 | | | |
| *Scorpaena cardinalis*[x] | red scorpionfish | CA | R | TE | 0 | 0 | 1 | | | * |
| **Scombridae** | | | | | 0 | 0 | 0 | | | |
| *Scomberoides lysan*[x] | double-spotted queenfish | CA | R | TR | | 1 | | | * | |
| **Scorpididae** | | | | | 0 | 0 | 0 | | | |
| *Scorpis lineolata* | sweep | P | R | TE | 22 | 1 | 2 | *** | * | * |
| **Serranidae** | | | | | 0 | 0 | 0 | | | |
| *Epinephelus undulatostriatus* | maori grouper | CA | R | TR/TE | 1 | 1 | 2 | * | * | * |
| **Siganidae** | | | | | 0 | 0 | 0 | | | |
| *Siganus fuscescens* | black rabbit fish | H | R | TR/TE | 2 | 0 | 0 | * | | |
| *Siganus sp* | rabbit fish | H | R | TR/TE | 3 | 0 | 0 | * | | |
| **Sparidae** | | | | | 0 | 0 | 0 | | | |
| *Acanthopagrus australis* | yellow fin bream | CA | R | TR | 1 | 1 | 0 | * | * | |
| *Pagrus auratus* | snapper | CA | R | TE | 0 | 0 | 1 | | | * |
| *Rhabdosargus sarba* | tarwhine | CA | R | TE | 5 | 2 | 4 | * | * | * |
| ***Sphyraenidae*** | | | | | 0 | 0 | 0 | | | |
| *Sphyraena obtusata* | striped sea pike | CA | R | TR/TE | 28 | 0 | 0 | *** | | |

| Scientific Name | Common Name | Trophic Level | Reef / Pelagic | Range | maxN | | | relative abundance | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Kirra Reef | Cook Island North | Cook Island West | Kirra Reef | Cook Island North | Cook Island West |
| **Tetraodontidae** | | | | | 0 | 0 | 0 | | | |
| *Canthigaster valentini* | black-saddled toby | O-HT | R | TR/TE | 0 | 0 | 1 | | | * |
| **Zanclidae** | | | | | 0 | 0 | 0 | | | |
| *Zanclus cornutus* | moorish idol | CA | R | TR/TE | 1 | 0 | 0 | * | | |

[x] Fish species only observed by scientific diver

References for trophic levels, benthic/pelagic lifestyles and range:

OZCAM mapping from https://australianmuseum.net.au/

fishbase.org

Johnson, J. W. "Annotated checklist of the fishes of Moreton Bay, Queensland, Australia." MEMOIRS-QUEENSLAND MUSEUM 43.2 (1999): 709-762.

# Appendix C Cover of benthic communities at Kirra and Cook Island Reefs 2017

Table C1 Percentage cover of benthic communities using CPCe

| | | Kirra Reef | | Cook Island North | | Cook Island West | |
|---|---|---|---|---|---|---|---|
| **Taxa** | | **Mean** | **SE** | **Mean** | **SE** | **Mean** | **SE** |
| **Polychaeta** | | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| **Ascidiaceae** | | 16.6 | 3.52 | 1.8 | 1.37 | 3.4 | 1.37 |
| **Crinoidea** | | 3.4 | 1.11 | 1.4 | 0.84 | 2.5 | 0.72 |
| **Anthozoa** | **Anenome** | 1.1 | 0.69 | 0.3 | 0.09 | 0.1 | 0.16 |
| | **Mushroom Anemone** | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| | **Hydroid** | 0.1 | 0.15 | 0.0 | 0.00 | 0.0 | 0.00 |
| | **Hard Coral** | 0.0 | 0.00 | 10.9 | 2.12 | 10.6 | 2.90 |
| | **Zoantharia** | 0.1 | 0.10 | 0.2 | 0.00 | 0.2 | 0.22 |
| | **Soft Coral** | 0.1 | 0.16 | 0.3 | 0.62 | 0.9 | 0.22 |
| | **Dead Coral with Algae** | 0.0 | 0.00 | 0.0 | 1.00 | 1.7 | 0.00 |
| **Sponges** | | 6.2 | 1.66 | 6.9 | 0.63 | 0.9 | 1.35 |
| **Bivalvia** | **Barnacles** | 0.0 | 0.00 | 0.1 | 0.00 | 0.0 | 0.09 |
| | **Oysters** | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| **Echinodermata** | **Starfish** | 0.0 | 0.00 | 0.1 | 0.00 | 0.0 | 0.06 |
| | **Feather stars** | 3.4 | 0.00 | 1.4 | 0.14 | 2.5 | 0.04 |
| | **Urchins** | 0.0 | 0.34 | 0.0 | 0.00 | 0.3 | 0.04 |
| **Chlorophyta** | **Caulerpaceae** | 0.4 | 0.00 | 0.1 | 0.13 | 0.0 | 0.38 |
| | **Halimedaceae** | 0.0 | 0.00 | 0.5 | 0.00 | 0.4 | 0.26 |
| | **Chlorodesmis** | 0.0 | 0.05 | 0.4 | 0.27 | 0.0 | 0.23 |
| | **Ulvaceae** | 0.0 | 0.00 | 0.3 | 0.10 | 0.4 | 0.00 |
| **Ochrophyta** | **Dictyotaceae** | 0.0 | 0.00 | 0.0 | 0.00 | 0.1 | 0.00 |
| | **Alariaceae** | 0.0 | 3.30 | 0.0 | 0.81 | 0.0 | 0.13 |
| | **Sargassaceae** | 16.0 | 0.18 | 0.1 | 0.24 | 0.4 | 1.51 |
| **Rhodophyta** | **Corallinaceae** | 0.4 | 1.08 | 3.4 | 0.80 | 1.0 | 2.73 |
| | **Galaxauraceae** | 2.0 | 1.32 | 15.2 | 0.44 | 1.6 | 0.16 |
| | **Rhodomelaceae** | 4.0 | 0.78 | 0.7 | 0.93 | 0.8 | 0.76 |
| **Coralline Algae** | | 1.8 | 2.5 | 2.30 | 2.5 | 3.91 | 3.1 |
| **Turf Algae** | | 9.7 | 0.14 | 42.8 | 0.16 | 40.5 | 0.33 |
| **Other** | **Fish** | 0.2 | 0.10 | 0.8 | 0.09 | 0.3 | 0.13 |
| | **Unidentified Fauna** | 0.1 | 0.00 | 0.1 | 0.00 | 0.1 | 0.00 |
| | **Bare Ground** | 0.0 | 1.77 | 0.0 | 1.08 | 0.0 | 2.13 |
| | **Rock** | 6.5 | 0.00 | 4.8 | 0.75 | 4.6 | 0.25 |
| | **Rubble** | 1.0 | 5.44 | 0.5 | 4.88 | 0.3 | 2.31 |
| | **Sand** | 30.4 | 0.38 | 5.7 | 0.00 | 26.8 | 0.06 |
| | **Shadow** | 0.5 | 0.00 | 0.1 | 0.00 | 0.0 | 0.00 |

# Appendix D Abiotic Factors

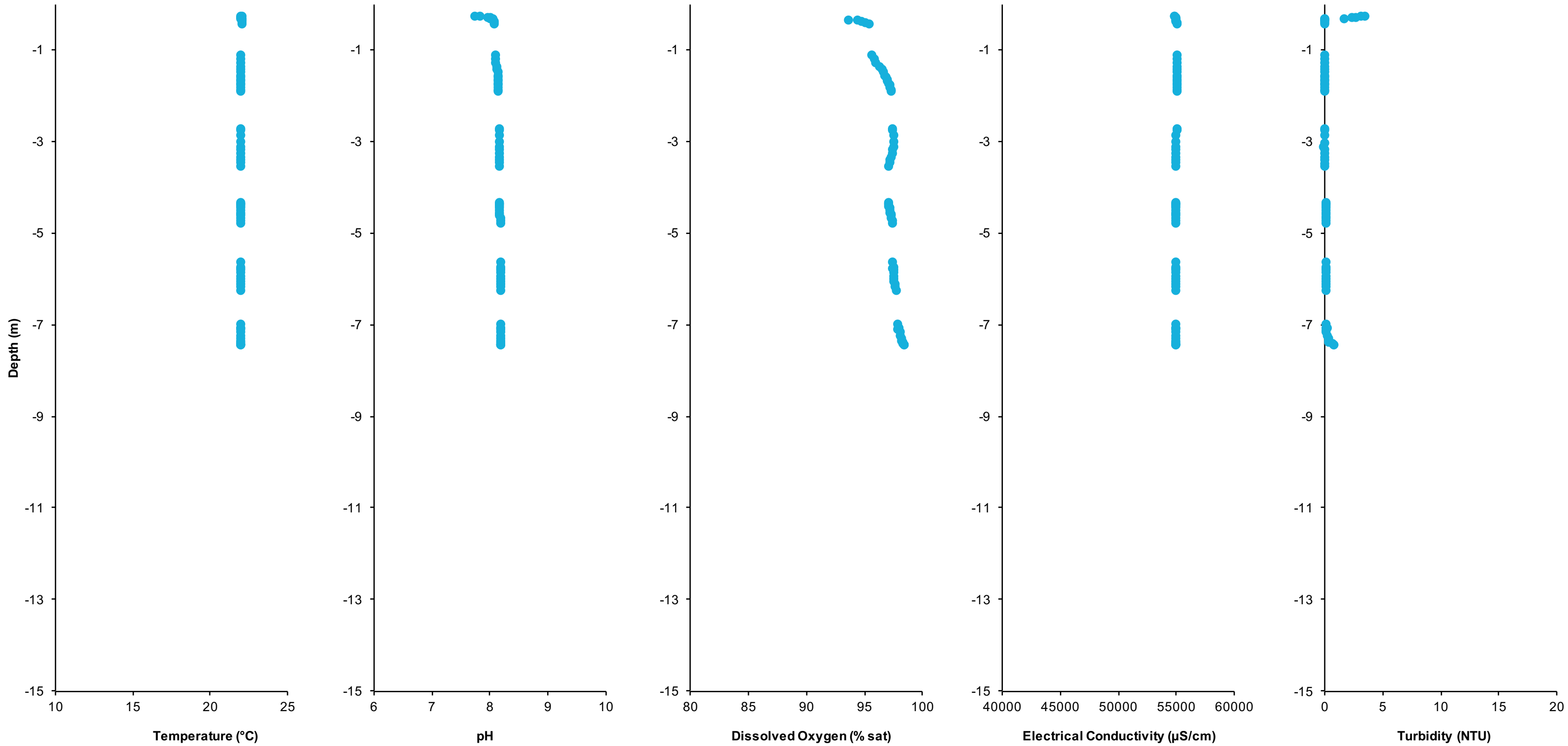


Figure 54 Water quality measured in situ at Kirra reef on 16 May 2017.

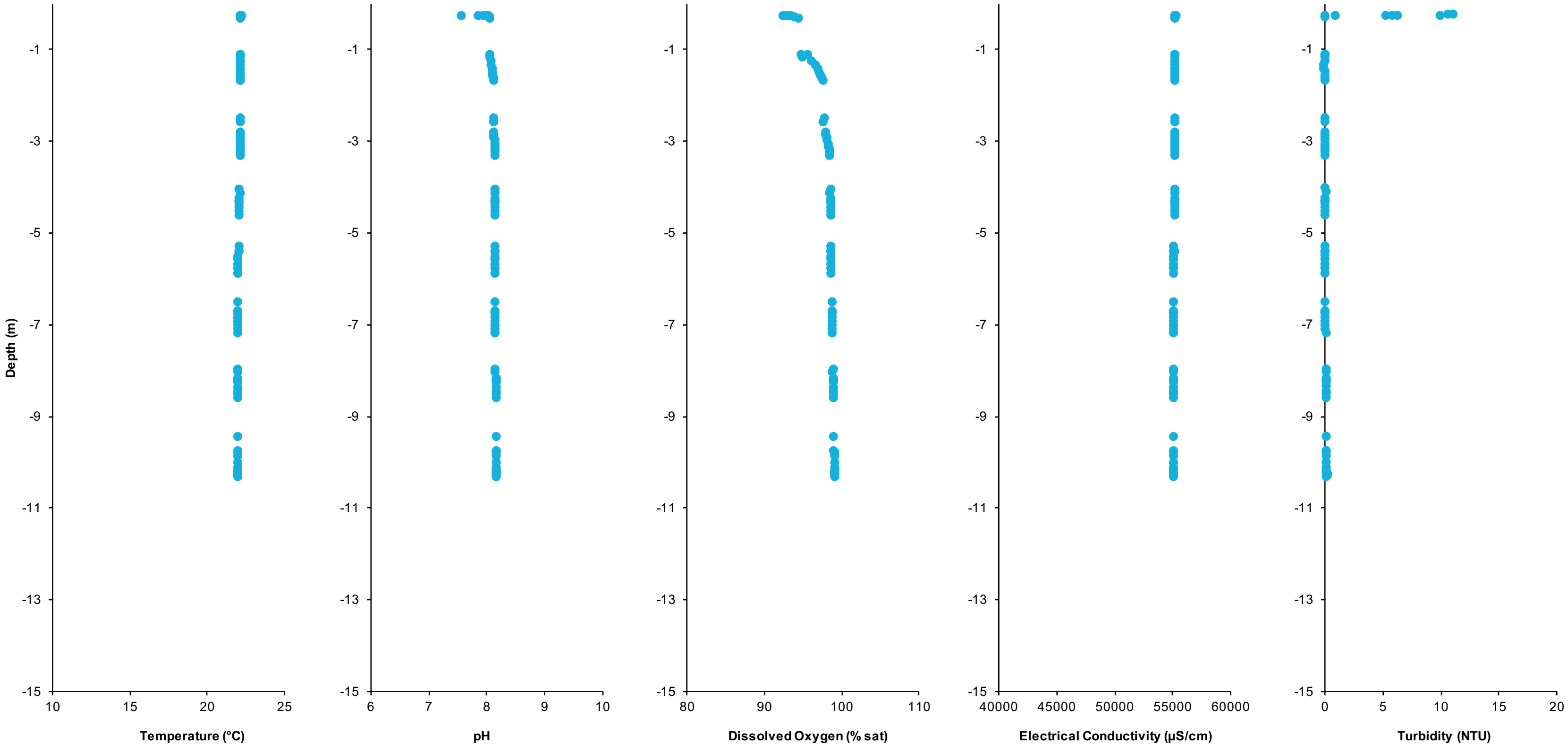


Figure 55 Water quality measured in-situ at Cook Island North on 16 May 2017.

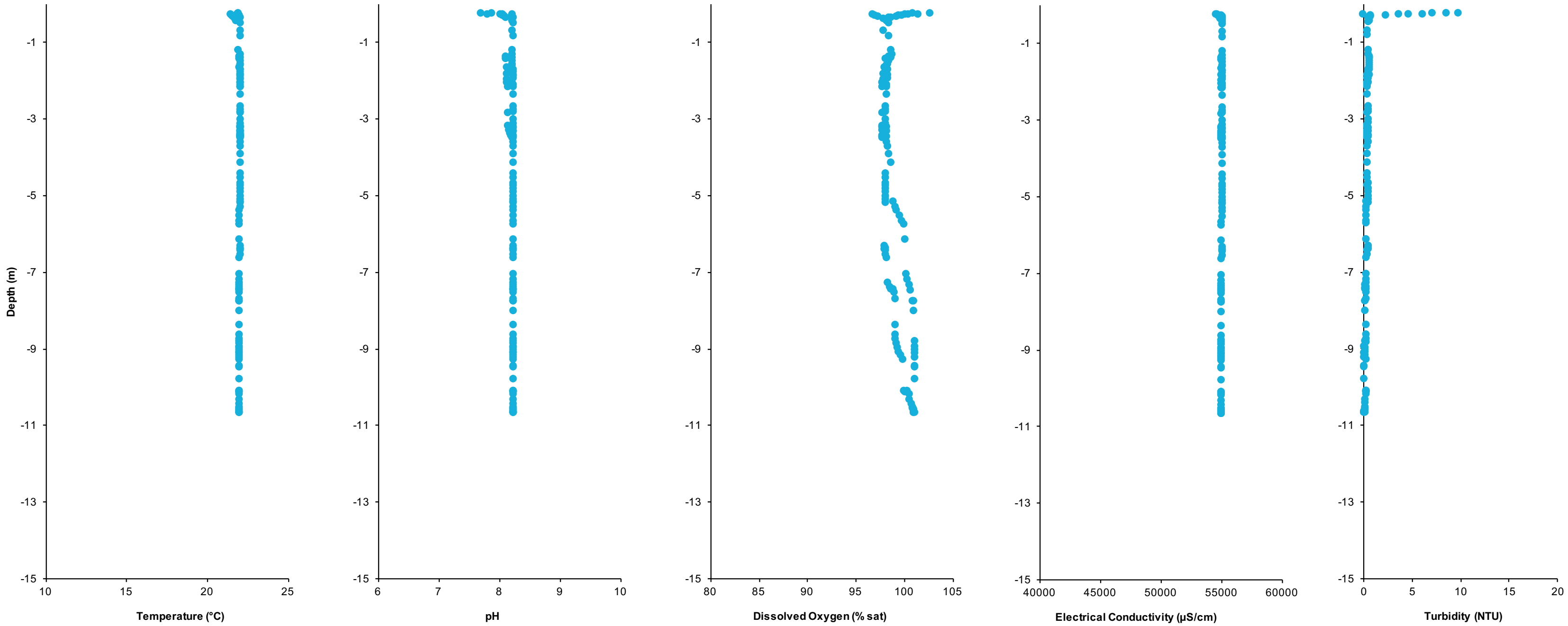


Figure 56 Water quality measured in-situ at Cook Island West on 17 May 2017.

# Appendix E Protected Matters Search

The Protected Matters Search Tool was used to assist in determining whether any marine MNES were likely to occur in the study area of Kirra Reef with a 1 km buffer zone. This search area was considered to include all marine areas that are within the likely extent of potential impact of the TRESBP, in order to adequately identify all marine MNES that could potentially be impacted by the TRESBP.

The following MNES relevant to marine ecology[7] were listed in this search:

- World Heritage Properties – none
- National Heritage Places – none
- Wetlands of International Importance – none
- Great Barrier Reef Marine Park – none
- Commonwealth Marine Areas – none
- Listed Threatened Ecological Communities – none
- Listed Threatened Species – 14
- Listed Migratory Species – 21

Other matters listed in the search results included 109 listed marine species and 14 whales and other cetaceans. The EPBC Act only protects these species in Commonwealth Marine Areas. The closest Commonwealth Marine Area is three nautical miles offshore. The TRESBP will not have a significant impact on Commonwealth Marine Areas and thus species listed only as ‘marine species’ or ‘whales and other cetaceans’ are not considered further in this report. However, species that are also listed as ‘migratory’ or ‘threatened’ are also protected in state waters (i.e. coastal waters to three nautical miles and other waters under Queensland jurisdiction) under the EPBC Act.

There are no World Heritage Properties, National Heritage Places, Wetlands of International Importance, listed threatened ecological communities, Commonwealth Lands, Commonwealth Heritage Places, Commonwealth Reserves or critical habitats in the vicinity of Kirra Reef. Likewise, the Great Barrier Reef Marine Park is approximately 400 km north of the proposed project and will not be affected. The Temperate East

[7] Fifty-seven threatened species (29 birds, 1 frog, 9 terrestrial mammals, 1 snail, 15 plants 1 lizard and 1 snake); 48 migratory species (22 migratory wetland birds, 20 migratory marine birds and 6 terrestrial birds) and 60 marine species (all birds) were also listed in the Protected Matters Search Tools and are not assessed in this report.

Marine Bioregional Plan (Commonwealth of Australia 2012) has been prepared under section 176 of the EPBC Act for Commonwealth Marine Area (which extend from 3 to 200 nautical miles from the coastline). The Commonwealth Marine Area is approximately 5 km east of Kirra Reef, and will not be affected by TRESBP.

**Listed Threatened Marine Species**

Fourteen threatened (critically endangered, endangered or vulnerable) fish, marine reptiles or marine mammals were listed as potentially occurring within 1 km of the proposed action using the Protected Matters Search Tool. The likelihood that these species are present in the area of Kirra Reef was assessed using the criteria in Table E1. The list of species is shown in Table E2.

Table E1 Criteria used to assess the likelihood of occurrence of species.

| **Likelihood of Occurrence** | **Definition** |
|---|---|
| low | The species is considered to have a low likelihood of occurring in the area potentially impacted by the proposed action, or occurrence is infrequent and transient. Existing database records are considered historic, invalid or based on predictive habitat modelling. The habitat does not exist for the species, or the species is considered locally extinct. Despite a low likelihood based on the above criteria, the species cannot be totally ruled out of occurring in the potentially impacted area. |
| moderate | There is habitat for the species; however, it is either marginal or not particularly abundant. The species is known from the wider region. |
| high | The species is known to occur in the potentially impacted area, and there is core habitat in this area. |

Table E2 Threatened marine species listed on the protected matters search tool as potentially occurring within 1 km of Kirra Reef, and their likelihood of occurrence in this area.

| Species | Common Name | EPBC Act Threatened Status | Likelihood of Occurrence |
|---|---|---|---|
| **Mammals** | | | |
| *Balaenoptera musculus* | blue whale | E | low |
| *Eubalaena australis* | southern right whale | E | low |
| *Megaptera novaeangliae* | humpback whale | V | moderate |
| **Reptiles** | | | |
| *Caretta caretta* | Loggerhead Turtle | E | moderate to high |
| *Chelonia mydas* | green turtle | V | moderate to high |
| *Dermochelys coriacea* | leatherback turtle | E | low |
| *Eretmochelys imbricata* | hawksbill turtle | V | moderate |
| *Lepidochelys olivacea* | olive ridley turtle | E | low |
| *Natator depressus* | flatback turtle | V | low |
| **Fish and Sharks** | | | |
| *Epinephelus daemelii* | black rockcod | V | low |
| *Carcharias taurus* | grey nurse shark | CE | moderate |
| *Carcharodon carcharias* | great white shark | V | moderate |
| *Pristis zijsron* | green sawfish | V | low |
| *Rhincodon typus* | whale shark | V | low |

CE Critically Endangered
E endangered
V vulnerable

### Listed Migratory Marine Species

Twenty-one migratory marine species were listed as potentially occurring within 1 km of Kirra Reef using the Protected Matters Search Tool. Of these, 12 species are also listed as threatened species.

The likelihood of occurrence of each listed marine migratory species near Kirra Reef is shown in Table E3.

Table E3 Migratory marine species listed as potentially occurring within 1 km of Kirra Reef on the protected matters search tool, and their likelihood of occurrence in the area.

| Species | Common Name | EPBC Act Threatened Status | Likelihood of Occurrence |
|---|---|---|---|
| **Mammals** | | | |
| *Balaenoptera edeni* | Bryde's whale | - | low |
| Balaenoptera musculus | blue whale | E | low |
| *Eubalaena australis* | southern right whale | E | low |
| *Megaptera novaeangliae* | humpback whale | V | moderate |
| *Orcaella heinsohni* (previously known as *Orcaella brevirostris)* | Australian snubfin dolphin | – | low |
| *Sousa chinensis* | Indo-Pacific humpback dolphin | – | moderate |
| *Dugong dugon* | dugong | - | low |
| *Lagenorhynchus obscurus* | dusky dolphin | - | low |
| *Orcinus orca* | killer whale | - | low |
| **Reptiles** | | | |
| *Caretta caretta* | loggerhead turtle | E | moderate to high |
| *Chelonia mydas* | green turtle | V | moderate to high |
| *Dermochelys coriacea* | leatherback turtle | E | low |
| *Eretmochelys imbricata* | hawksbill turtle | V | moderate |
| *Lepidochelys olivacea* | olive ridley turtle | E | low |
| *Natator depressus* | flatback turtle | V | low |
| **Fish and Sharks** | | | |
| *Pristis zijsron* | green sawfish | V | low |
| *Rhincodon typus* | whale shark | V | low |
| *Carcharodon carcharias* | great white shark | V | moderate |

| Species | Common Name | EPBC Act Threatened Status | Likelihood of Occurrence |
|---|---|---|---|
| *Lamna nasus* | mackerel shark | – | low |
| **Rays** | | | |
| *Manta birostris* | giant manta ray | – | low |
| *Manta alfredi* | Reef Manta Ray, | | moderate |

Source: (DoTE 2014)

E endangered

V vulnerable