Tweed River Entrance Sand Bypassing Project

Kirra Reef Marine Biota Monitoring 2012

Prepared for:

NSW Department of Primary Industries, Catchment and Land Division

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Summary

The NSW Department of Primary Industries Catchment and Lands Division (NSW DPI) commissioned frc environmental on behalf of the Tweed River Entrance Sand Bypassing Project (TRESBP) to monitor the condition and biodiversity of benthic assemblages at Kirra Reef, and to assess the impacts of the project on those assemblages. The purpose of the TRESBP is to maintain a navigable entrance to the Tweed River, and to provide a continuing supply of sand to the southern Gold Coast beaches that is consistent with the natural rate of longshore drift. This report discusses the results of ecological monitoring of the benthic fauna, flora, and fish of Kirra Reef, completed in July 2012.

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 February 2001. The methods used in the July 2012 survey (i.e. surveys of benthic cover and fish abundance), were those developed for the Stage I survey completed in 1995, and have been used in the subsequent surveys in 1996, 2001, 2003, 2004, 2005 and 2010.

Impacts of the Sand Bypassing System on Kirra Reef

During the early years of the TRESBP operation, large amounts of sand were deposited on the southern Gold Coast beaches. This was done to provide a 'catch up' quantity of sand to the badly eroded beaches, reduce the Tweed River entrance bar and clear a sand trap in the vicinity of the sand collection jetty to increase the efficiency of the bypassing system. During the initial period of increased deposition, the volume of sand delivered exceeded the amount that was transported north through natural sand transport mechanisms. This resulted in a large volume of sand being deposited on the southern beaches, and wave action and tidal currents redistributed some of this sand over Kirra Reef. This resulted in smothering and a decline in the areal extent of Kirra Reef. The project EIS predicted that the impact associated with the gradual accumulation of sand around the base of Kirra Reef was unavoidable.

Since the delivery of large quantities of sand was completed in 2005, the volume of sand delivered by the project has declined, and now matches the natural rate of northward sand transport more closely. However, 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 between 2005 and 2010.

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, which is directly correlated with the

migration of sand further to the north. As predicted in the project EIS, the extent of the reef uncovered in the northern section now closely approximates that recorded before the Tweed River training walls were extended. However, in 2012, the eastern and inner western parts of the reef remained buried due to their close proximity to the shoreline.

Changes to the Ecological Condition of Kirra Reef

The Project's EIS did not consider the ecological consequences of both the reduced areal extent and increased wave energy (a consequence of decreased depth of the reef habitat available) that would occur as a result of the accretion of sand around the base of the rock outcrops at Kirra Reef. However, once sand transport became more consistent with the natural supply, it was expected that the benthic flora and fauna assemblages of the reef would return to a condition consistent with the historical reef extent and natural sand transport patterns (and associated coastal fluctuations, wave action, sedimentation and water quality) that were observed in the vicinity of the reef prior to the development of the Tweed River training walls.

Since monitoring began, the greatest change to the ecological assemblages on Kirra Reef has been due to the loss of large areas of rocky reef, caused by burial of the rock by sand. The loss of reef habitat has reduced the area of hard substratum available for colonisation and consequently the overall abundance (cover) of benthic sessile assemblages. The redistribution of sand also resulted in small scale changes to the distribution and cover of the benthic assemblages on the remaining reef over time, through complex interactions between physical disturbance (i.e. increased burial, sedimentation, wave action, and abrasion), food availability, competition, and local weather and sea conditions.

In July 2012, the diversity of assemblages increased relative to that found in February 2010, as did the cover of macroalgae (though it remained well below the peak of 60% cover recorded in January 2001), which is most likely due to the reduction of physical disturbance from sand burial and abrasion, as sand levels reduced during this period. Nevertheless, the benthic assemblage on Kirra Reef exhibited signs of ongoing stress from physical disturbance such as storm and wave disturbance, physical abrasion and burial by sand; including reduced cover of macroalgae, hard coral and soft coral relative to times when the level of sand was much lower. Physical disturbance from sand burial, sand abrasion and the action of storm waves appear to keep the benthic assemblages on Kirra Reef in a state of early succession; however, the diversity of benthic assemblages is predicted to increase if the extent of reef remains the same or increases, and physical disturbance remains relatively benign.

In July 2012, a diverse assemblage of fish was also found on Kirra Reef. As fish are mobile, they can move more easily to areas that are less disturbed or that exhibit more suitable conditions. While the composition of the assemblage differed from previous survey events, the differences are more likely due to the effects of seasonal changes in water temperature and the effects of prevailing conditions at the time of the survey, rather than any substantial effect of the bypassing project.

Despite some impacts from the TRESBP, overall the composition of the flora and fauna assemblages on Kirra Reef was more similar to that found at nearby Palm Beach Reef than in previous years. Kirra Reef therefore continues to provide habitat to a range of flora and fauna, and provides important marine ecological functions and services in the region.

Impacts of Storms & Seasonality on Kirra Reef

The large quantities of sand that were initially delivered by the project caused a substantial shallowing of the nearshore area around the reef. This increase in bed levels was responsible for increasing the incidence of wave disturbance and sand scouring around the reef, which negatively impacted on the benthic fauna and flora found growing there.

As the delivery of sand through the bypassing project now matches the natural rate of northern longshore sand transport, short-term and seasonal changes in the areal extent of the reef are more likely the result of the action of storm waves and currents shifting sand offshore, than a discrete impact of the sand bypassing activity. It was noted that shorter-term fluctuations that result from storms or changes in the coastal sand supply, would have been a component of the natural range of ecological conditions observed prior to the development of the training walls.

The proximity of the reef to the coast means that the benthic assemblages will continue to be affected by sand abrasion, wave disturbance and sand smothering; however, having greater balance between the delivery of sand through the project and the natural movement of sand on and offshore, is likely to result in better ecological outcomes for the benthic assemblages found on Kirra Reef and greater consistency in the extent of reef habitat that is uncovered.

Long-term Impact of the Sand Bypassing System on Kirra Reef

In July 2012, Kirra Reef covered approximately 45 to 50% (3700 m^2) of the area present in 1995 (i.e. prior to the operation of the TRESBP). This is largely due to the reduction in the inner western and eastern sections of the reef, predicted to occur in the EIS.

We expect that the area of reef uncovered will continue to change due to seasonal shifts in sand delivery and storms; however, the diversity of flora and fauna assemblages on Kirra Reef should increase gradually over time, especially if the extent of the rocky reef that remains uncovered is consistent or increases over time to become more similar with that found prior to development of the training walls. In this scenario, it is expected that that newly exposed areas of Kirra Reef in 2012 that were dominated by turf algae, would be colonised by other organisms including macroalgae, sponges, ascidians and potentially hard and soft coral over time.

Ongoing monitoring will provide insight into the rate of ‘recovery’ of communities. It is recommended that monitoring is repeated in early 2013 (February or March, when previous surveys have been undertaken) to confirm the results of the July 2012 survey and account for seasonal differences. Based on the results of this survey, recommendations could be made regarding the frequency of future monitoring.

1 Introduction

frc environmental was commissioned by the NSW Department of Primary Industries Catchment and Lands Division (NSW DPI) on behalf of the Tweed River Entrance Sand Bypassing Project (TRESBP) to monitor the condition, abundance and biodiversity of floral and faunal communities at Kirra Reef. This report presents results of the survey of benthic flora and macro-invertebrate fauna, and fish at sites on Kirra Reef and at comparative sites on Palm Beach Reef, in July 2012.

The current condition of Kirra Reef was compared with the condition of nearby Palm Beach Reef in July 2012, and with changes to the reef community over time with previous assessments of Kirra Reef in 1995, 1996, 2001, 2003, 2004, 2005 and 2010 (frc environmental 2010).

1.1 Historical Context of Monitoring

Kirra Beach receives indirect sand nourishment as part of the Tweed River Entrance Sand Bypassing Project (TRESBP). The purpose of the TRESBP is to maintain a navigable entrance to the Tweed River, and to provide a continuing supply of sand to the southern Gold Coast beaches that is consistent with the natural rate of longshore drift.

frc environmental completed a baseline assessment of Kirra Reef in 1995 (Fisheries Research Consultants 1995b; a), and has undertaken six subsequent ecological monitoring surveys of the reef on behalf of TRESBP since 1996 (Fisheries Research Consultants 1996; frc environmental 2001; 2003; 2004; 2005; 2010). Kirra Reef is the collective name given to the complex of rocky outcrops located offshore of Kirra Beach, in water depths between 3 and 7 m. The ongoing monitoring of Kirra Reef meets the requirements of the Environmental Management System (EMS) Sub-Plan B14 Kirra Reef Management Plan, prepared by the TRESBP in February 2001. It also incorporates additional monitoring activities implemented by TRESBP in August 2004.

Under Sub-Plan B14, 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 the marine biota of Kirra Reef is required. Interpretation of aerial photographs taken in August 2002 indicated there had been substantial changes to the reef since 1965. Loss of reef area continued for some years, with aerial photographs from November 2003 showing the inner northern reef and entire eastern reef covered by sand (Figure 1.2). The area of the outer northern reef was also greatly reduced (Figure 1.2). In April 2004 the extent of the outer northern reef was further reduced, although a small outcrop of eastern reef had been uncovered (Figure 1.2). By early 2006, the area of exposed reef had been reduced to 100 m^2. As a consequence of the extensive burial of the reef, ecological surveys were postponed between 2006 and 2010. Between 2006 and 2010, visual inspections of the reef were completed in place of full ecological surveys, by dive teams from Gilbert Diving and Gold Coast City Council.

By February 2010, the area of Kirra Reef had increased again and ecological surveys recommenced. In July 2012, analysis of aerial photos indicated that the exposed section of Kirra Reef has increased in extent since the previous survey in 2010; although, the reef was still 50% smaller than recorded in 1962 and 1995 before the sand bypassing project began (Figure 1.2) (Boswood & Murray 1997). The survey in July 2012 was therefore commissioned to assess changes in the ecological communities.

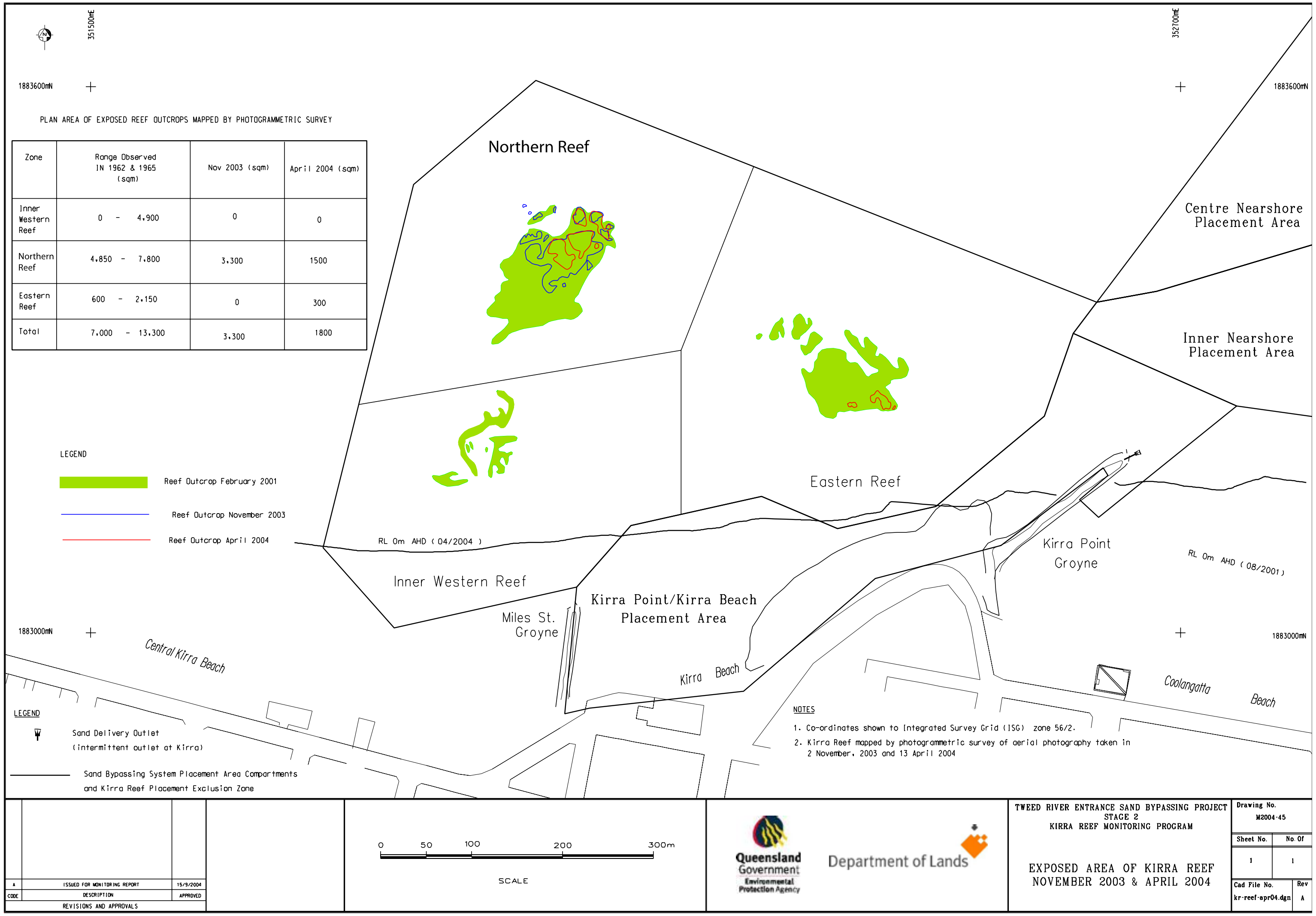
1.2 Sand Nourishment History

Initial sand nourishment works (Stage 1 of the TRESBP) involved two sub-stages: Stage 1A from April 1995 to August 1996, and Stage 1B from September 1997 to May 1998. These sub-stages delivered about three million cubic metres (m^3) of clean marine sand (with less than 3% fines) out to 10 metres mean water depth, including approximately 600,000 m^3 of clean marine sand placed on the upper beaches during Stage 1A activities.

Prior to the establishment of the permanent sand bypassing system, additional dredging activities were undertaken to maintain a clear navigation channel at the Tweed River entrance, resulting in approximately 480,000 m^3 of clean marine sand being placed in nearshore areas from Point Danger to Coolangatta Beach (from April 2000 to February 2001).

Operation of the TRESBP commenced in May 2001. Since that time approximately 5.9 million m^3 of pumped sand and 1.4 million m^3 of dredged sand (derived from dredging of the Tweed River mouth) has 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. Wave and current action has transported the sand around Snapper Rocks, nourishing beaches further to the north. Sand is also discharged from outlets at Duranbah Beach and occasionally at Snapper Rocks West. There is an outlet at Kirra, however this has not been used since December 2003. Accumulation of sand on Kirra Reef has occurred through sand transport by waves and currents along the seabed, rather than by direct depositional smothering (Hyder Consulting Pty Ltd et al. 1997).

To provide much needed sand nourishment to the severely eroded southern Gold Coast beaches, reduce the Tweed Entrance Bar and to clear a sand trap in the vicinity of the jetty to improve the efficiently of the sand bypass system, relatively high quantities of sand were delivered to the southern Gold Coast beaches during the early operational years of the TRESBP. These project objectives were achieved, and the quantity of sand delivered since 2005 has been more consistent with the natural quantity of sand movement along the coast.



Zone	Range Observed IN 1962 & 1965 (sqm)	Nov 2003 (sqm)	April 2004 (sqm)
Inner Western Reef	0 - 4,900	0	0
Northern Reef	4,850 - 7,800	3,300	1500
Eastern Reef	600 - 2,150	0	300
Total	7,000 - 13,300	3,300	1800

Figure 1.1 Extent of Kirra Reef in 2001, 2003 and 2004.

Figure 1.2 Extent of Kirra Reef in 1995, 2001, 2010 and 2012.

1.3 Faunal and Floral Characteristics of the Survey Region

The subtidal rocky reefs of the Gold Coast region comprise remnants of highly eroded volcanic substratum that are isolated from each other by wide, variable expanses of soft sediment (Edwards & Smith 2005). They support assemblages of benthic fauna and flora, and fish that are indicative of a transition between the tropical waters of the Great Barrier Reef and the temperate waters characteristic of the mid-New South Wales coast (Done 1982; Cannon et al. 1987). These communities are dominated by macroalgae and sessile benthic invertebrates, and are broadly similar to areas of comparable topography to the north (Inner Gneerings offshore from Mooloolaba and offshore of Moreton Bay) and to the south, for example at Julian Rocks offshore of Byron Bay (Fisheries Research Consultants 1991; Harriott et al. 1999; Edwards & Smith 2005; Baronio & Butcher 2008; Fellegara 2008; Schlacher-Hoenlinger et al. 2009).

The fish fauna of the Gold Coast region is similar to that recorded at Flat and Shag Rocks offshore of Moreton Bay, Julian Rocks and the Solitary Islands, offshore of Coffs Harbour and to a lesser extent to the ex-HMAS Brisbane near Mooloolaba (Robinson & Pollard 1982; Parker 1995; Parker 1999; Edwards & Smith 2005; Malcolm et al. 2009; Schlacher-Hoenlinger et al. 2009). The smaller inshore reefs of the Gold Coast region typically support a lower abundance, richness and diversity of reef fish (Edwards & Smith 2005; frc environmental 2005).

Kirra Reef

In July 2012, Kirra Reef covered an area of 3700 m^2 predominantly in a single area of the northern section of the reef. The rocky outcrops rose between 1 and 2 m above the clean mobile sand. Several outcrops were found to extend to more than 2 m above the seafloor.

The benthic assemblages have previously been characterised by a high cover of macroalgae and a moderate cover of sessile benthic invertebrates, including a few hard corals (Edwards & Smith 2005; frc environmental 2005). Macroalgae covers the majority of the reef substrate with crinoids (feather stars), ascidians (sea squirts), and sponges, typically the most abundant benthic fauna, whilst anemones, soft corals and urchins are present in low numbers (Fisheries Research Consultants 1995b; a; 1996; frc environmental 2003; 2004; Edwards & Smith 2005; frc environmental 2005). The composition of benthic assemblages at Kirra Reef was broadly similar to that described from adjacent rocky reefs, including Palm Beach Reef (Hollingsworth 1975; Edwards & Smith 2005), and also those of the southern QLD and northern NSW bioregions (refer Harriott et al. 1999; Baronio & Butcher 2008; Fellegara 2008; Schlacher-Hoenlinger et al. 2009).

Changes in the height of sand around the base of rocky outcrops appears to be a major factor influencing the cover of benthic flora and fauna, periodically resulting in a bare zone on rocks within 0.8 to 1 m of the seafloor. Exposure to wave driven sand scouring and smothering is an important factor influencing the distribution and abundance of sessile species (Kay & Keough 1981; McGuinness 1987). Outcrops on the eastern side of the reef complex, where wave action and sand abrasion are greatest, have historically supported a lower abundance of benthic fauna than outcrops on the northwest side (Fisheries Research Consultants 1995b; a; 1996; frc environmental 2003; 2004; 2005; 2010).

Strong wave action results in sustained abrasion of the dominant brown macroalgae (*Sargassum flavicans* & *Ecklonia radiata*), which caused the fronds to break apart. The continual re-suspension of algal fragments (commonly referred to as 'cornflakes') can dramatically reduce water clarity and visibility. In contrast to previous surveys, algal fragments were largely absent in July 2012, which could be due to long periods of relatively benign physical conditions.

Palm Beach Reef

Palm Beach Reef is an extensive rocky reef, lying between the mouths of Tallebudgera Creek to the north and Currumbin Creek to the south. The inner section of the reef is approximately 400 metres off the beach, and lies in 9 to 12 metres of water. Palm Beach Reef lies in slightly deeper water than Kirra Reef, is much larger and has greater topographical relief.

Sessile invertebrates, including sponges, corals and ascidians, dominate the benthic assemblage of Palm Beach Reef (Edwards & Smith 2005; frc environmental 2005; Reef Check 2010). The cover of ascidians, sponges and other invertebrates at Palm Beach Reef has historically been similar to that recorded from the outer sections of Kirra Reef. However, the cover of macroalgae has consistently been lower on Palm Beach Reef than on Kirra Reef. The proximity of Palm Beach Reef to two creek mouths, and the absence of strong currents in the area, typically results in a high level of turbidity. A factor that together with greater depth and the high abundance of grazing species such as urchins, is likely to contribute to reduced cover of macroalgae on Palm Beach.

2 Methods

The methods used in the July 2012 survey were developed for the Stage I survey completed in 1995, and used for subsequent surveys in the 1996, 2001, 2003, 2004, 2005 and 2010 surveys (following the requirements of the ToR). Data was collected from the potentially impacted Kirra Reef, and comparative Palm Beach Reef further north (Figure 2.1).

The aim of this survey was to assess the effect of the sand bypass project (and subsequent increases in sand load) on the nature and magnitude of change in the cover of floral and faunal, assemblage structure, and the abundance of selected invertebrates.

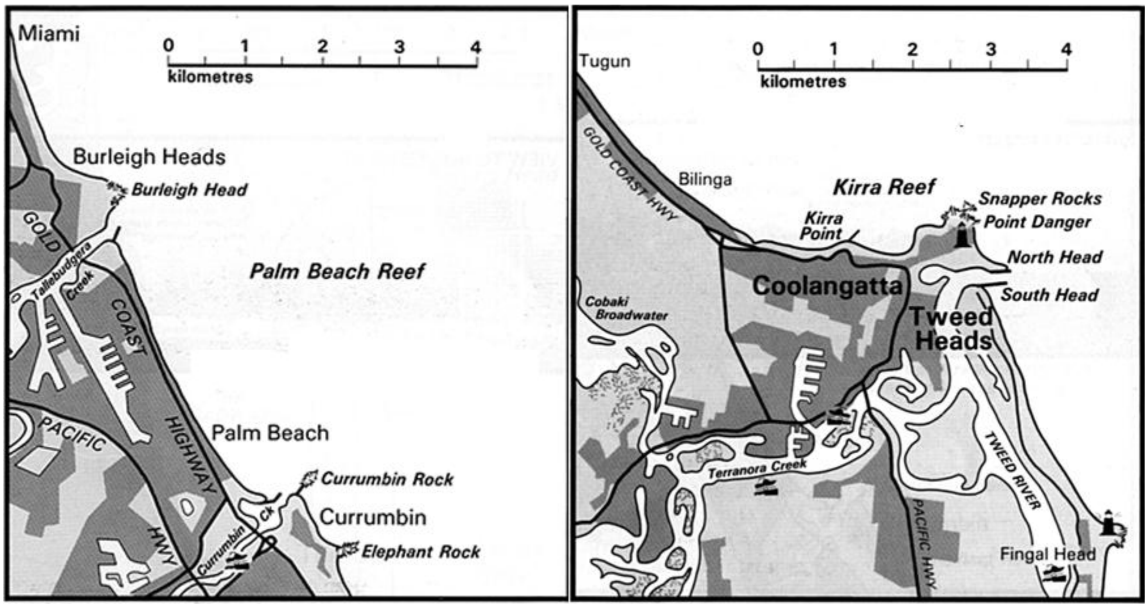


Figure 2.1 Location of (a) Palm Beach Reef and (b) Kirra Reef

2.1 Benthic Flora and Macroinvertebrates

The number of sites surveyed has varied over time as a result of the fluctuating level of sand surrounding Kirra Reef. A historical recount of sites surveyed can be found in frc environmental 2010.

In July 2012, emergent outcrops were found in the northern section of Kirra Reef. Therefore, it was not possible to examine outer and inner reef locations separately or eastern from northern sections. In the eastern section there was a small emergent outcrop (1 m^2) surrounded by sand in approximately 2 m of water. This outcrop was covered by macroalgae (Figure 2.2). The majority of the reef was largely exposed to a similar level of wave action and sediment deposition and was within a depth range of 5 to 8 m. Only three sites were surveyed (KRN1, KRN2, KRO3) in July 2012, due to the extent of available reef habitat compared with previous surveys (3,700 m^2) (Figure 2.3 and Figure 2.4). The area of reef was determined using ESRI ArcGIS based on a rectified satellite image taken in August 2012 (Near maps 2012). Three comparative sites were also surveyed at Palm Beach Reef in a similar depth of water (9 to 12 m) and similar spatial arrangement.

Figure 2.2

Small exposed outcrop in the eastern section of Kirra Reef.

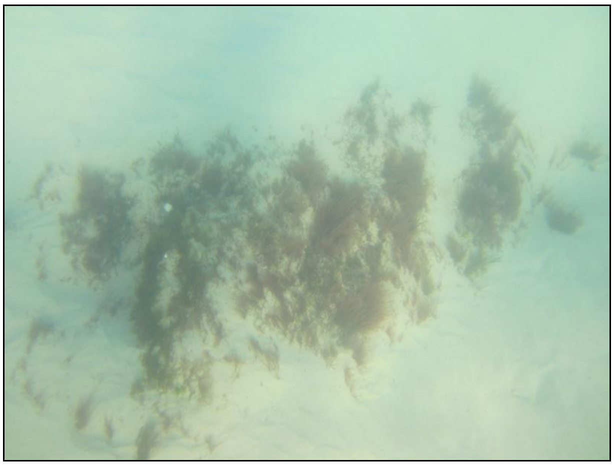


Figure 2.3

Diver surveying benthic assemblages at Kirra Reef in July 2012.

At each site, benthic assemblages were surveyed in fifteen 0.25 m^2 quadrats, and the cover of benthic macroalgae, turf algae, sponges, ascidians, hard corals and soft corals were assessed visually. The number of large ascidians (*Pyura stolonifera*), crinoids (feather stars), barnacles, urchins, tubeworms, polychaetes, hydroids, zoanthids and cowries was also noted. These are the same taxonomic groups recorded in the 1995, 1996, 2001, 2003, 2004, 2005 and 2010 surveys. The dominant species of macroalgae were also recorded, and notes were made on the apparent health of each taxonomic group.

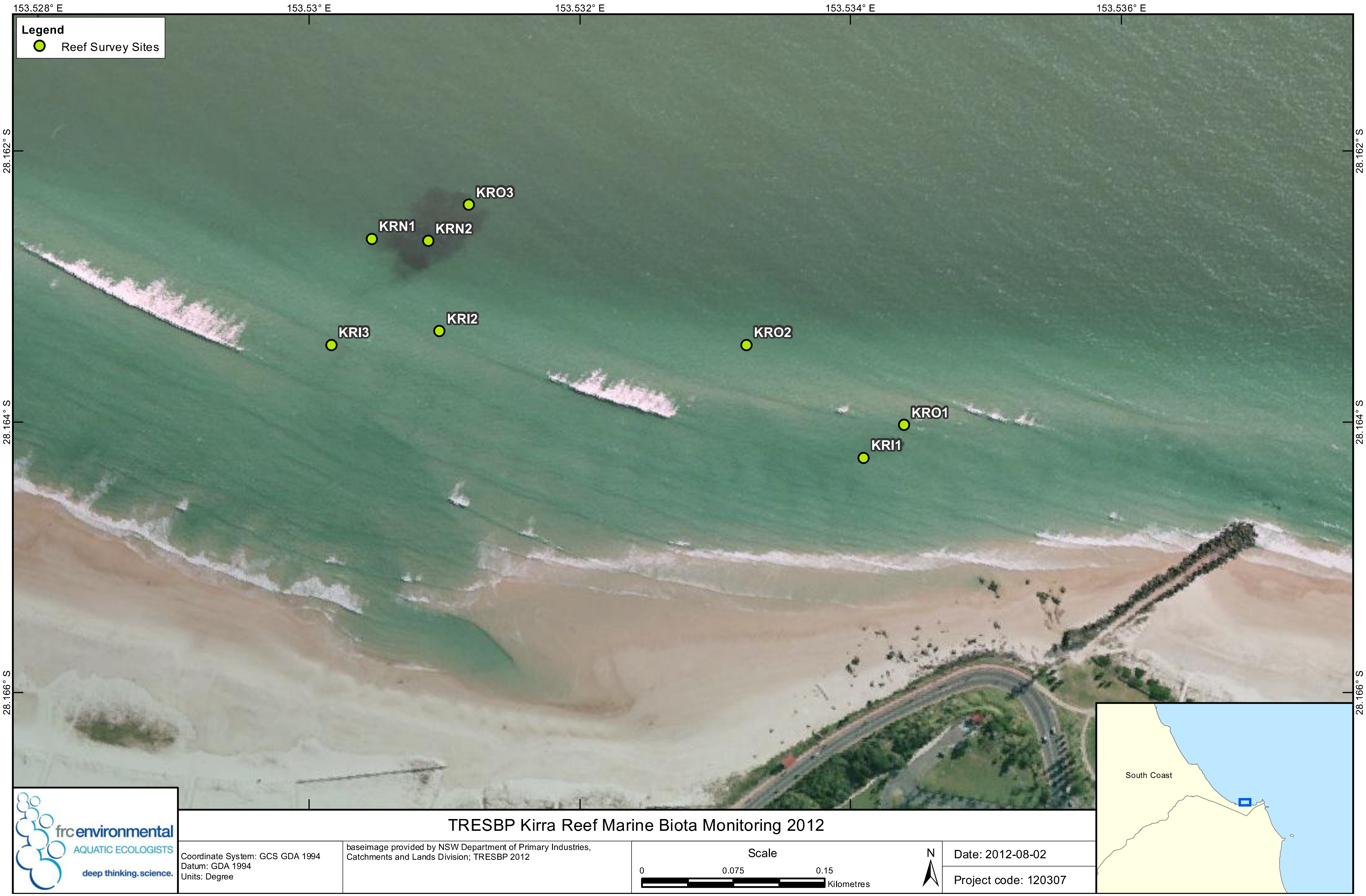


Figure 2.4 Monitoring sites at Kirra Reef.

2.2 Fish

The species richness and relative abundance of fish at Kirra Reef and Palm Beach Reef were assessed using a combination of underwater visual census (UVC) and video surveys. The combination of these techniques represents the most cost-effective and efficient means of obtaining data on the structure of fish assemblages in different habitats (Murphy & Jenkins 2010). These approaches were the same as used in the 1995, 1996, 2001, 2003, 2004, 2005 and 2010 surveys. Continuity in the make up of the dive team over the years of monitoring has ensured a high degree of accuracy and precision in fish identification, and in estimating their relative abundance.

2.3 Data Analysis

Due to the limited number of sites sampled, the comparison of the composition of benthic assemblages (cover of each benthic group such as macroalgae, turf algae, corals, sponges and ascidians) over time was restricted to sites KRN1, KRN2 and KRO3 on Kirra Reef and the three comparative sites at Palm Beach Reef. The analyses completed in 2012 incorporated the data from all previous surveys.

Permutational multivariate analysis of variance (PERMANOVA) was used to determine differences in the composition (cover of benthic fauna and taxonomic group) of benthic assemblages between Kirra Reef and Palm Beach Reef over time. This was a new analysis undertaken for the first time in 2012. PERMANOVA is analogous to multivariate analysis of variance (MANOVA); however, rather than using F-tables to derive statistical significance, PERMANOVA uses permutational methods, which require fewer assumptions to be met (Anderson 2001; Anderson et al. 2008). This analysis enables an examination of changes in the community as a whole, which can be more informative than looking at individual components in isolation. In this case, PERMANOVA was used to examine changes in the comparison of benthic assemblages over time.

A three factor PERMANOVA was used to examine differences in the composition of benthic assemblages, with survey (fixed factor), locations (Palm Beach Reef and Kirra Reef, fixed factor) and sites (nested in locations and a random factor) as the factors. Untransformed data was converted to a Euclidean distance matrix and tested for significance using 9999 permutations where possible. Variation in the multivariate dispersion among locations over time (analogous to a test for heterogeneous variances in ANOVA) was tested using the PERMDISP routine in PRIMER 6+ (Anderson et al. 2008). Non-metric multidimensional scaling (nMDS) ordinations were used to visually represent the variation in the composition of assemblages between reefs, separately for each survey.

PERMANOVA can also be used to examine single variables, analogous to ANOVA, except it does not have the same restrictive assumptions that ANOVA has (Anderson et al. 2008). This is because unlike ANOVA, PERMANOVA uses a permutation method to assess significance, which has fewer data assumptions than ANOVA and allows a more accurate assessment of unbalanced experimental designs or where biological data is not normally distributed. Therefore in 2012, separate univariate PERMANOVAs (rather than ANOVAs) were used to compare differences in the cover of macroalgae, turf algae and the abundance of crinoids and the ascidian *Pyura stolonifera*. These univariate analyses were completed using the design described above (Anderson et al. 2008).

Further information on the use and interpretation of PERMANOVA and other analyses used in this report is provided in Appendix A.

3 Results

3.1 Cover of Benthic Assemblages

The composition of benthic fauna and flora (% cover and type combined) at Kirra Reef and Palm Beach Reef changed between surveys, with the magnitude of difference between reefs varying over time (Table 3.1 to Table 3.3). While there were substantial differences in the composition of the benthic assemblages between the two reefs in 1995 to 2005 (Figure 3.1 and Table 3.2), these assemblages have become more similar in 2010 and 2012 as indicated by the substantial reduction in ANOSIM R-values (Figure 3.2, Table 3.2 and Table 3.3). In 2012, the main difference in the composition of benthic assemblages between Kirra and Palm Beach reefs was due to increased cover of macroalgae and reduced cover of soft corals, hard corals and ascidians at Kirra Reef (Table 3.3).

Table 3.1 PERMANOVA results for multivariate differences in the composition of benthic assemblages between surveys and locations.

Factor	**df**	**MS effect**	**Pseudo-F**	**p (perm)**
location	1	316600	45.09	0.108
survey	7	44981	9.97	0.001
site (location)	4	6965	6.57	0.001
location x survey	7	27126	6.01	0.001
site (location) x survey	27	4480	4.23	0.001
error	763	1060		

Shading denotes significance at $p < 0.05$

Table 3.2 Pairwise ANOSIM results for differences in assemblage composition between reefs for each survey.

Survey	**1995**	**1996**	**2001**	**2003**	**2004**	**2005**	**2010**	**2012**
ANOSIM R statistic	0.514	0.738	0.813	0.511	0.421	0.849	0.237	0.247
p value	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Shading denotes significance at $p < 0.05$

Table 3.3 PERMANOVA post hoc pairwise results for the differences between locations in each survey events, for the assemblage composition and cover of selected benthic groups.

Year	Assemblage Composition		Macroalgae		Turf Algae		Soft Corals		Hard Corals		Sponges		Ascidians	
	t	p (MC) [a]	t	p (MC) [a]	t	p (MC) [a]	t	p (MC) [a]	t	p (MC) [a]	t	p (MC) [a]	t	p (MC)[a]
1995	5.02	0.0001	5.74	0.0040	2.86	0.0468	7.79	0.0014	0.96	0.3960	4.40	0.0106	2.28	0.0855
1996	3.70	0.0002	2.59	0.0569	12.01	0.0002	0.11	0.9166	5.41	0.0062	1.15	0.3222	1.86	0.1316
2001	3.87	0.0044	6.75	0.0067	3.70	0.0337	0.84	0.4794	–	–	2.50	0.0887	2.58	0.0828
2003	2.66	0.0039	4.59	0.0097	10.15	0.0003	3.75	0.0227	1.66	0.1769	0.24	0.8218	2.23	0.0882
2004	3.78	0.0002	7.01	0.0016	5.97	0.0045	0.50	0.6446	7.65	0.0013	0.78	0.4739	2.12	0.1010
2005	6.77	0.0003	2.95	0.0393	9.27	0.0007	2.26	0.0809	0.49	0.6431	4.73	0.0105	1.22	0.2891
2010	2.49	0.0020	2.81	0.0473	0.89	0.4211	8.86	0.0008	1.54	0.1962	3.45	0.0238	0.86	0.4350
2012	2.12	0.0254	3.88	0.0186	1.25	0.2806	19.83	0.0001	2.83	0.0440	1.97	0.1118	4.48	0.0110

Shading denotes significance at $p < 0.05$

[a] p values based on Monte Carlo tests

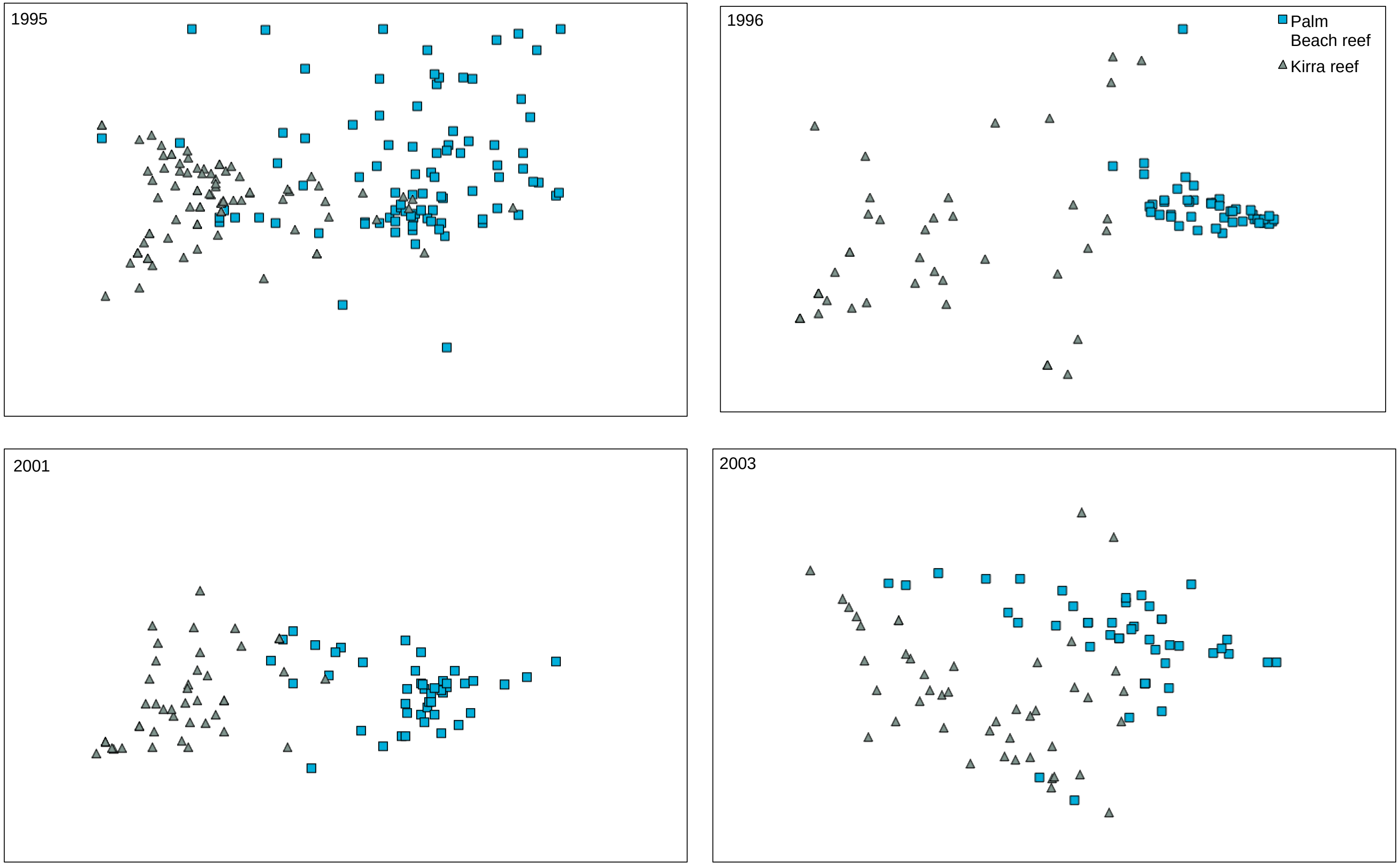


Figure 3.1 Multi-dimensional scaling plot of benthic cover in the 1995, 1996, 2001 and 2003 surveys.

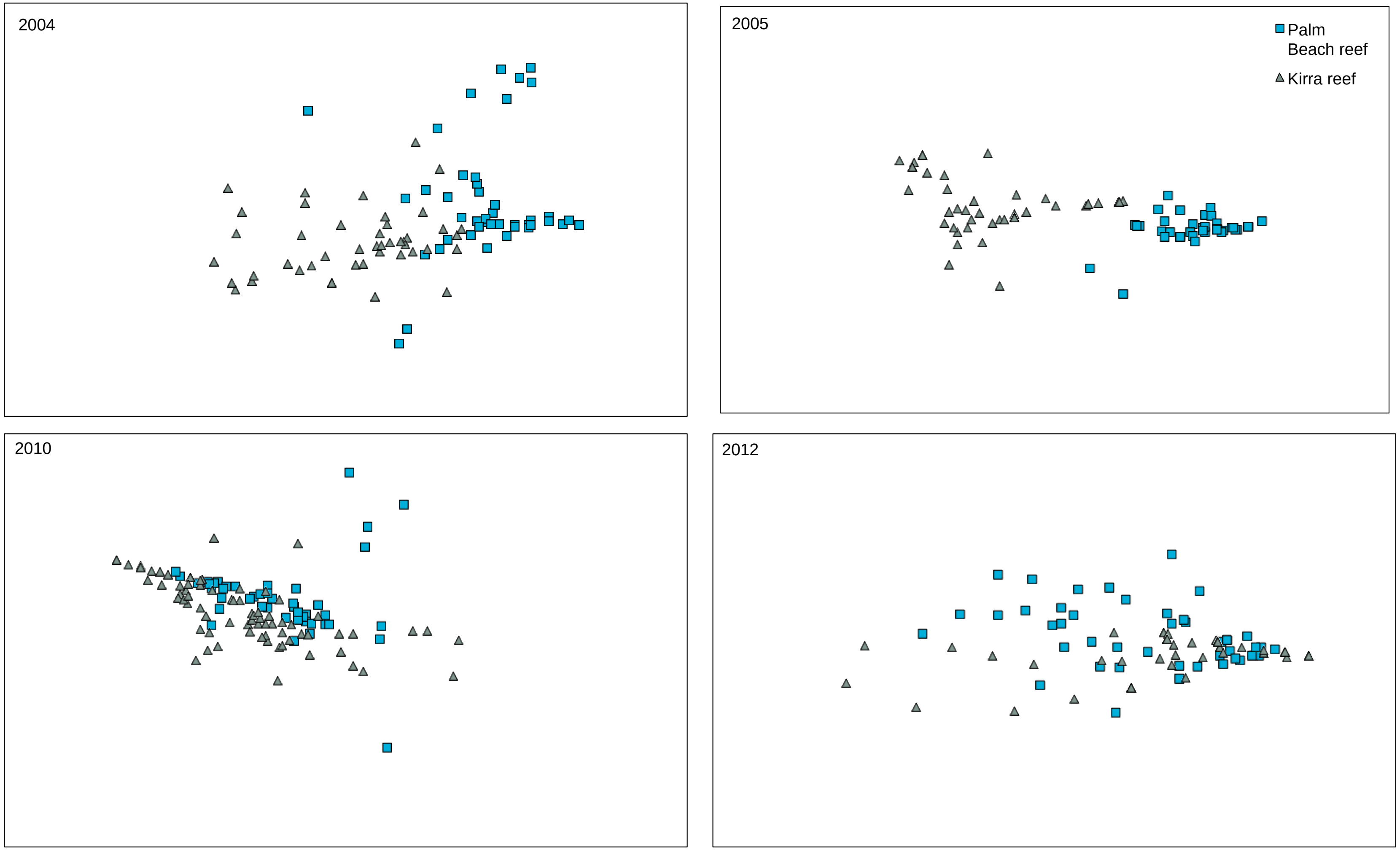


Figure 3.2 Multi-dimensional scale plot of benthic cover in the 2004, 2005, 2010 and 2012 surveys.

3.2 Benthic Algae

Macroalgae

In July 2012, as in previous surveys, the macroalgae *Sargassum* sp., dominated the benthic assemblages at all sites at Kirra Reef, covering up to 18% of the available surface area on the reef (Figure 3.3). Other species present included:

- *Dictyopteris arostichoides*
- *Dilophus intermedius*
- *Zonaria* sp.
- *Laurencia brongniartic*
- *Amphiroa anceps*
- *Caulerpa lentillifera*, and
- *Halimeda discoidea*.

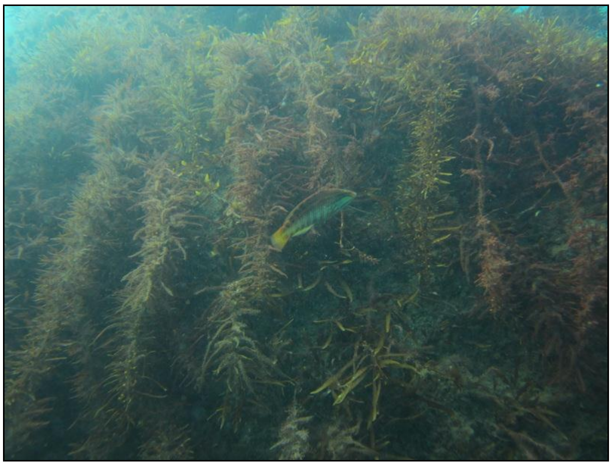
The mean cover of macroalgae at Kirra Reef has declined substantially over time, with the greatest magnitude of decline recorded between January 2001 and May 2003. In surveys prior to May 2003, *Sargassum* sp. formed dense carpets over the rocky substrate, covering up to 58% of the available surface area on the reef. There was a distinct decline in the cover of macroalgae between January 2001 and May 2003, which appears strongly correlated with the decrease in reef area during that time. In July 2012 the cover of macroalgae was 18%, an increase from the 12% recorded in February 2010 (Figure 3.4). In contrast, the cover of macroalgae on Palm Beach Reef was consistently lower than Kirra Reef, generally being less than 5% of the available surface area.

The macroalgae species recorded at Palm Beach Reef, included:

- *Amphiroa anceps*
- *Laurencia brongniartic*
- *Chlorodesmis major*, and
- *Zonaria* sp..

Figure 3.3

Sargassum sp. dominated the macroalgal communities of Kirra Reef in July 2012.



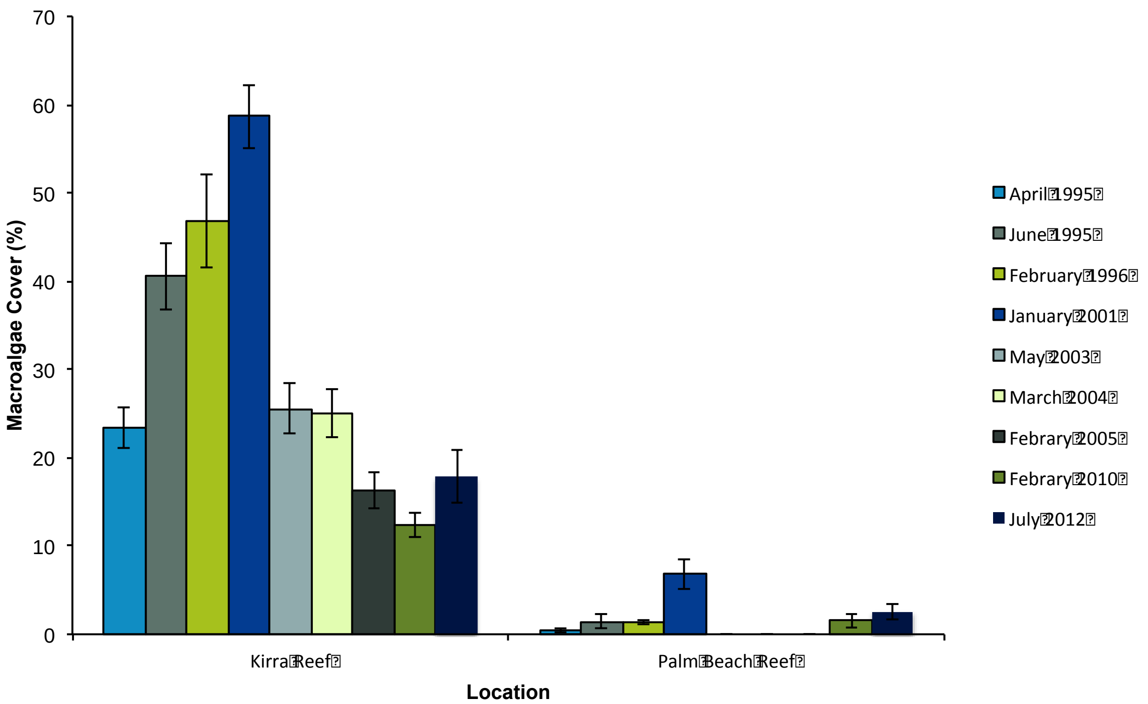


Figure 3.4 Mean cover of macroalgae (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.4 Univariate PERMANOVA results for differences in the cover of macroalgae between surveys and location.

Factor	df	MS effect	Pseudo-F	p (perm)
location	1	146250	44.98	0.0344
survey	7	7180	6.15	0.0002
site (location)	4	3225	16.63	0.0001
location x survey	7	5009	4.29	0.0023
site (location) x survey	27	1160	5.98	0.0001
error	763	194		

Shading denotes significance at $p < 0.05$

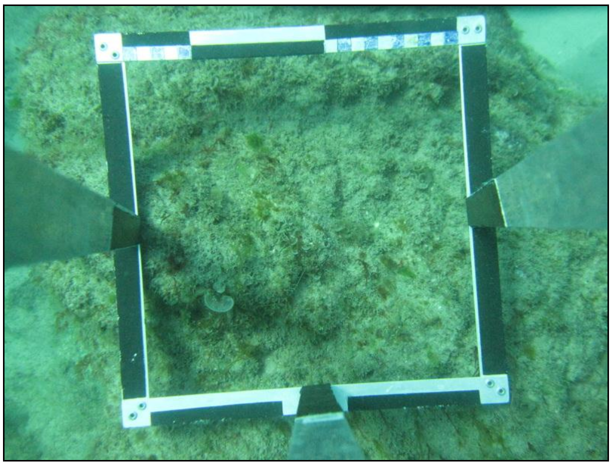
Turf Algae

The mean cover of turf algae at both Kirra Reef and Palm Beach Reef has varied considerably between surveys, between reefs and between sites (Table 3.5). Both Kirra and Palm Beach reefs showed major increases in turf algae percent cover from 2010 to 2012. The cover of turf algae is typically lower at Kirra Reef than at Palm Beach Reef. However, in July 2012, turf algae covered more than 67% of the available surface area of Kirra Reef, which is much higher than previously recorded (Figure 3.5 and Figure 3.6). The cover of turf algae at Palm Beach Reef also varied from more than 65% in February 1996 and 2005, to just 17% in February 2010 (Figure 3.5 and Figure 3.6). In July 2012, the cover of turf algae at Palm Beach Reef was 50% of the available surface area.

Increased cover of turf algae is typically related to good light conditions, high concentrations of nutrients and low numbers of grazing species such as fish and sea urchins, and perhaps reflects a more physically robust growth form suited to high wave energy environments (than foliose macro-algae).

Figure 3.5

Areas of Kirra Reef that support little macroalgae but have a high cover of turf algae (July 2012).



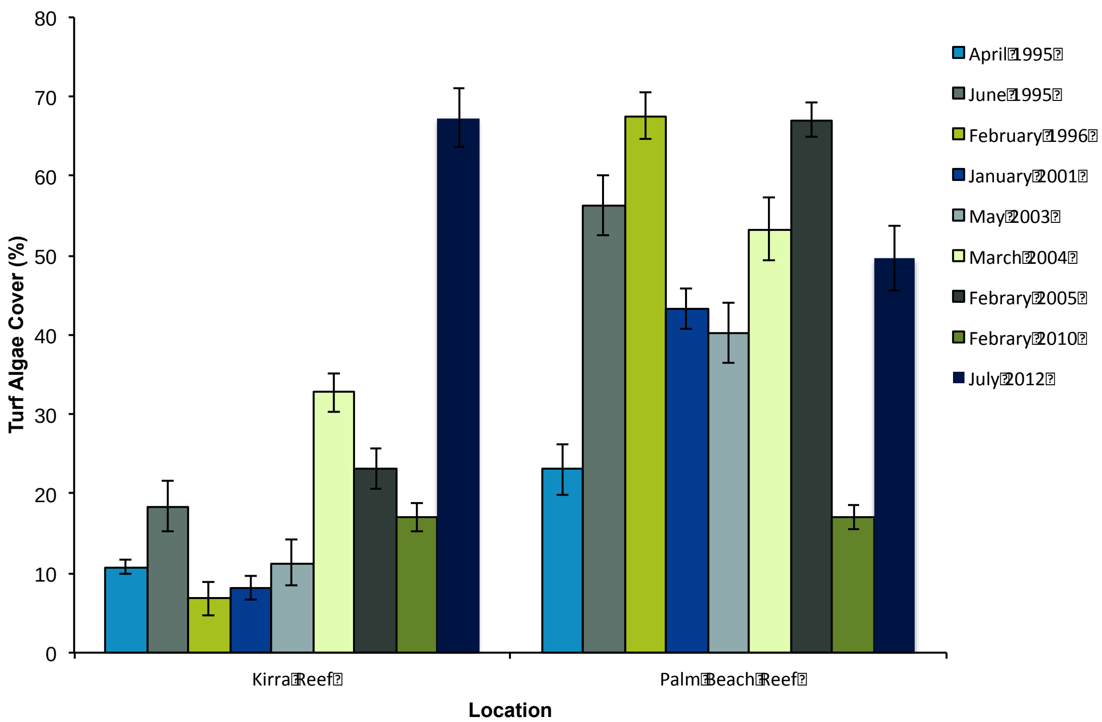


Figure 3.6 Mean cover of turf algae (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.5 PERMANOVA results for differences in the cover of turf algae between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
location	1	111190	53.22	0.1007
survey	7	16451	11.92	0.0001
site (location)	4	2073	5.79	0.0003
location x survey	7	14548	10.54	0.0001
site (location) x survey	27	1371	3.83	0.0001
error	763	358		

Shading denotes significance at p <0.05

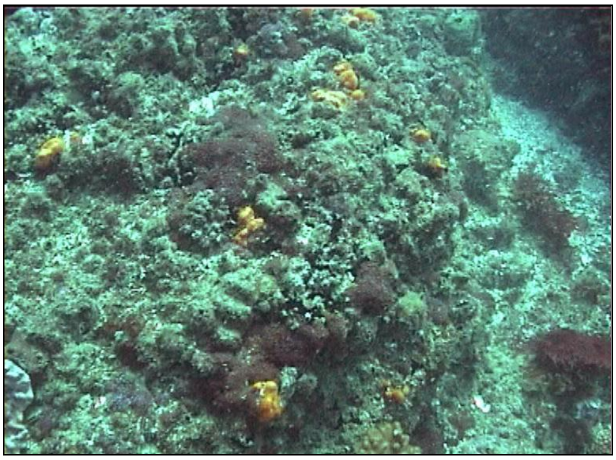
3.3 Benthic Macro-Invertebrates

Sponges

The mean cover of sponges at Kirra Reef declined significantly from more than 20% in March 2004 to less than 1% in February 2010; however it has begun to increase again with the sponges covering 3% in July 2012 (Figure 3.8). The cover of sponges was similar to that recorded during the baseline survey in April 1995 (Figure 3.8). The mean cover of sponges at Palm Beach Reef was often significantly higher than at Kirra Reef, except in February 1996, May 2003 and March 2004 (Figure 3.8 and Table 3.3). In July 2012, the mean cover of sponges on Kirra Reef was less than half that found on Palm Beach Reef (Figure 3.8 and Table 3.3 PERMANOVA pairwise comparisons).

Figure 3.7

Sponges were much more abundant at Palm Beach Reef then at Kirra Reef in February 2010 and July 2012.



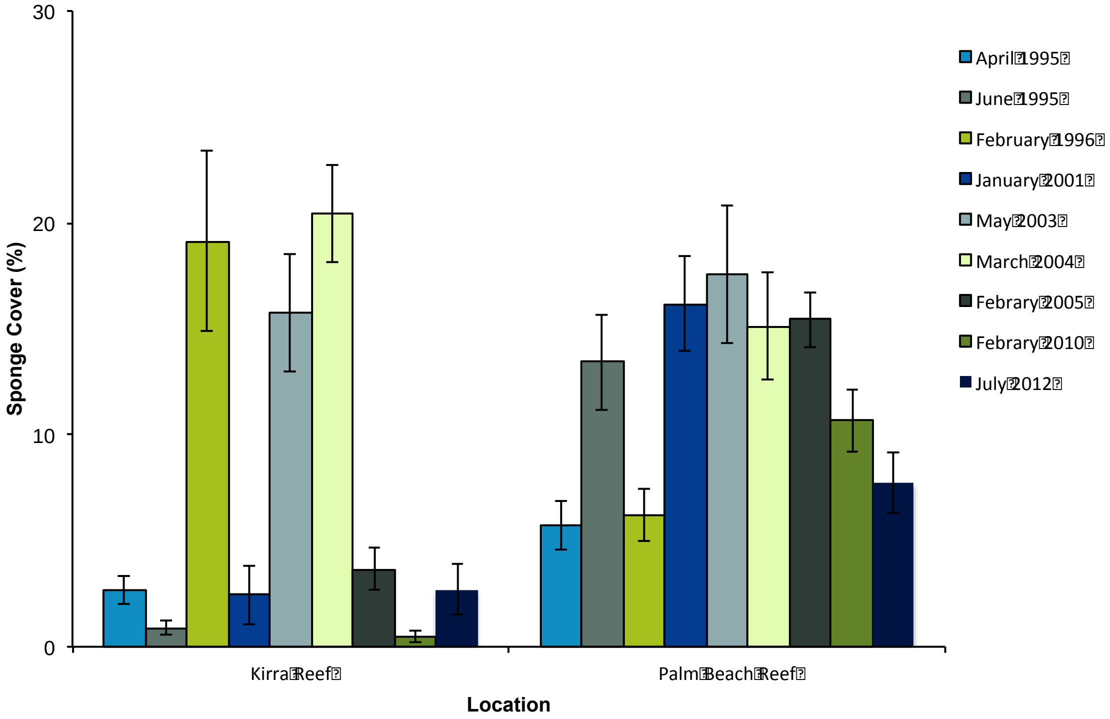


Figure 3.8 Mean cover of sponges (± SE) at Kirra Reef and Palm Beach Reef on all surveys.

Table 3.6 PERMANOVA results for differences in the cover of sponges between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
location	1	3307	3.43	0.2108
survey	7	2446	2.69	0.0312
site (location)	4	958	6.43	0.0002
location x survey	7	1936	2.13	0.0719
site (location) x survey	27	902	6.05	0.0001
error	763	149		

Shading denotes significance at p <0.05

Ascidians

In July 2012, the mean abundance (individual per 0.25 m^2 ± SE) of the ascidian, *Pyura stolonifera* (Figure 3.9), on Kirra Reef was less than one, which is much lower than in April 1995 and January 2001 (Figure 3.10). In July 2012, the mean abundance of *P. stolonifera* on Kirra Reef was approximately half that at Palm Beach Reef (Figure 3.10). Increased mean abundance of *P. stolonifera* in April 1995 and January 2001 could be due to increase recruitment and survival in the years prior to those surveys.

In July 2012, the mean cover of ascidians on Kirra Reef remained less than previously reported in the baseline survey in June 1995 (Figure 3.11 and Table 3.7). The cover of ascidians was also much higher at Palm Beach than Kirra Reef in July 2012 (Table 3.7 and Table 3.3 PERMANOVA pairwise comparisons).

Figure 3.9

Ascidians (*Pyura stolonifera* and *Cnemidocarpa stolonifera*) were not abundant at Kirra Reef in July 2012.

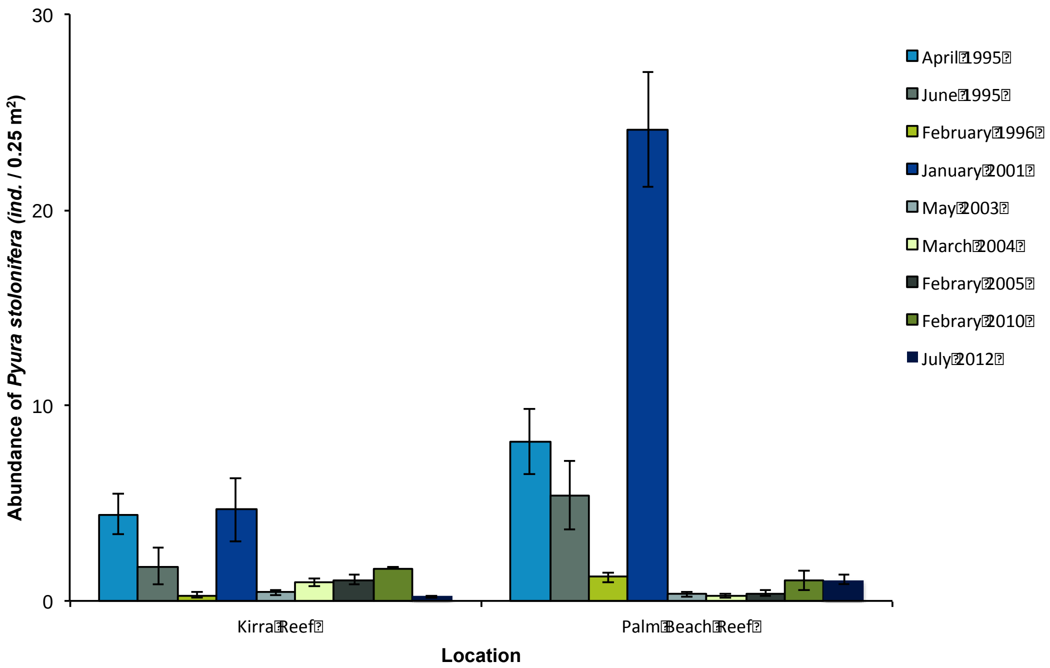


Figure 3.10 Mean abundance of ascidians (*Pyura stolonifera*) (individuals / 0.25 m^2) (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

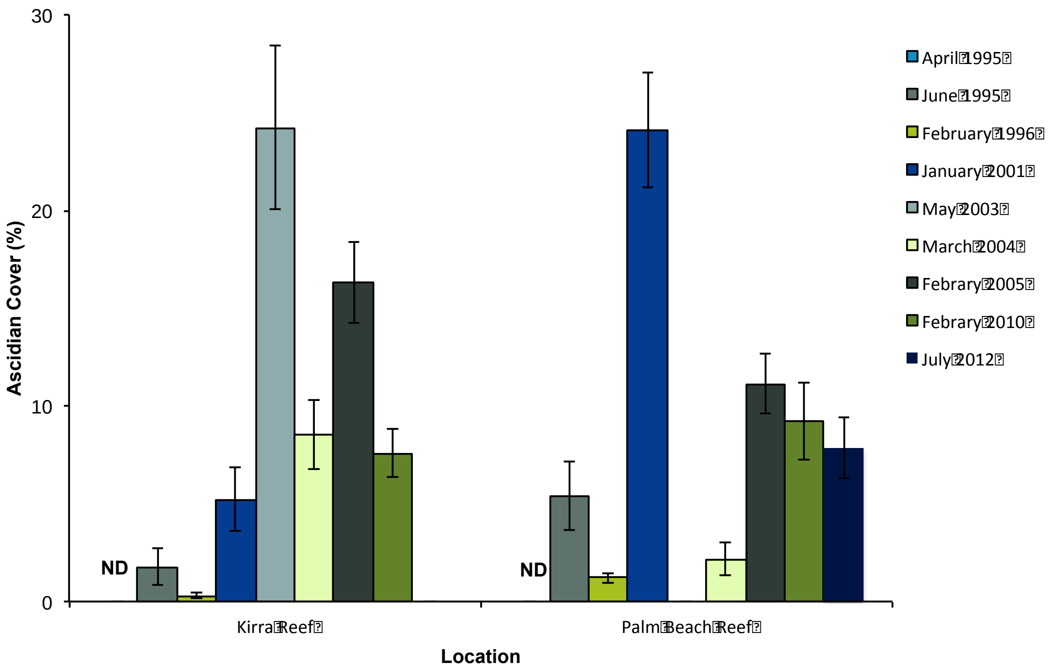


Figure 3.11 Mean cover of ascidians (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.7 PERMANOVA results for the differences in cover of ascidians between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
location	1	72	0.24	0.7052
survey	7	2843	5.11	0.0015
site (location)	4	296	2.71	0.0300
location x survey	7	3334	5.99	0.0008
site (location) x survey	27	553	5.05	0.0001
error	763	109		

Shading denotes significance at $p < 0.05$

Hard Coral

The cover of hard coral is generally low on Kirra Reef, being less than 2% of the available surface area. In July 2012, this trend continued with a mean cover of hard corals of less than 0.5% (Figure 3.12). Hard coral often covered more of the available surface area on Palm Beach Reef than at Kirra Reef over time, except during the baseline survey in April 1995, when the cover of hard coral was low on both reefs (Figure 3.12 and Table 3.8, PERMANOVA location x survey interaction).

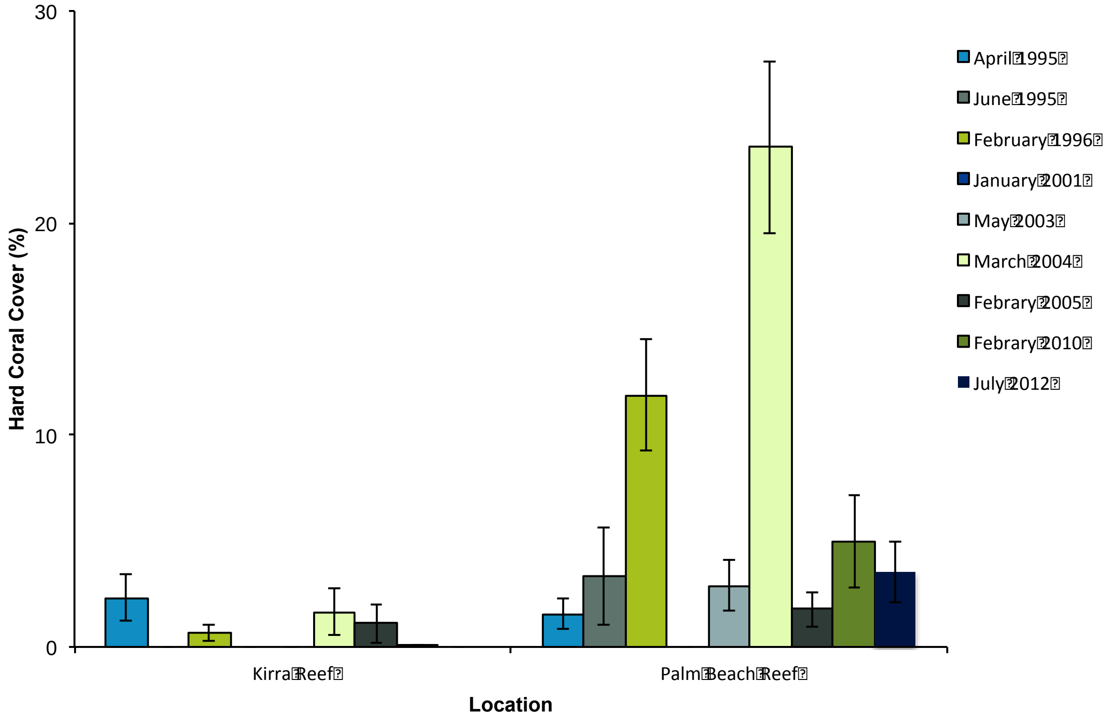


Figure 3.12 Mean cover of hard corals (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.8 PERMANOVA results for the differences in the cover of hard coral between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
location	1	6385	32.92	0.0479
survey	7	1552	18.59	0.0001
site (location)	4	192	1.87	0.1121
location x survey	7	1275	15.27	0.0001
site (location) x survey	27	83	0.81	0.731
error	763	103		

Shading denotes significance at $p < 0.05$

Soft Coral

In July 2012, the mean cover of soft coral was less than 1%, which was similar to the cover of soft coral in June 1995 (Fisheries Research Consultants 1995b; a). Soft coral has not covered a large proportion (<10%) of the area of Kirra Reef, and has not recovered from when the reef was covered by sand in 2010 or 2012 (Figure 3.13). Soft coral generally covers more of the available space on Palm Beach Reef than on Kirra Reef (Figure 3.13). The cover of soft coral at Palm Beach Reef has varied substantially over time, being highest in April 1995 (50%) and declining since that time. In July 2012, soft coral was absent from Kirra Reef and covered only 15% of the available surface area at Palm Beach Reef (Figure 3.13 and Table 3.9).

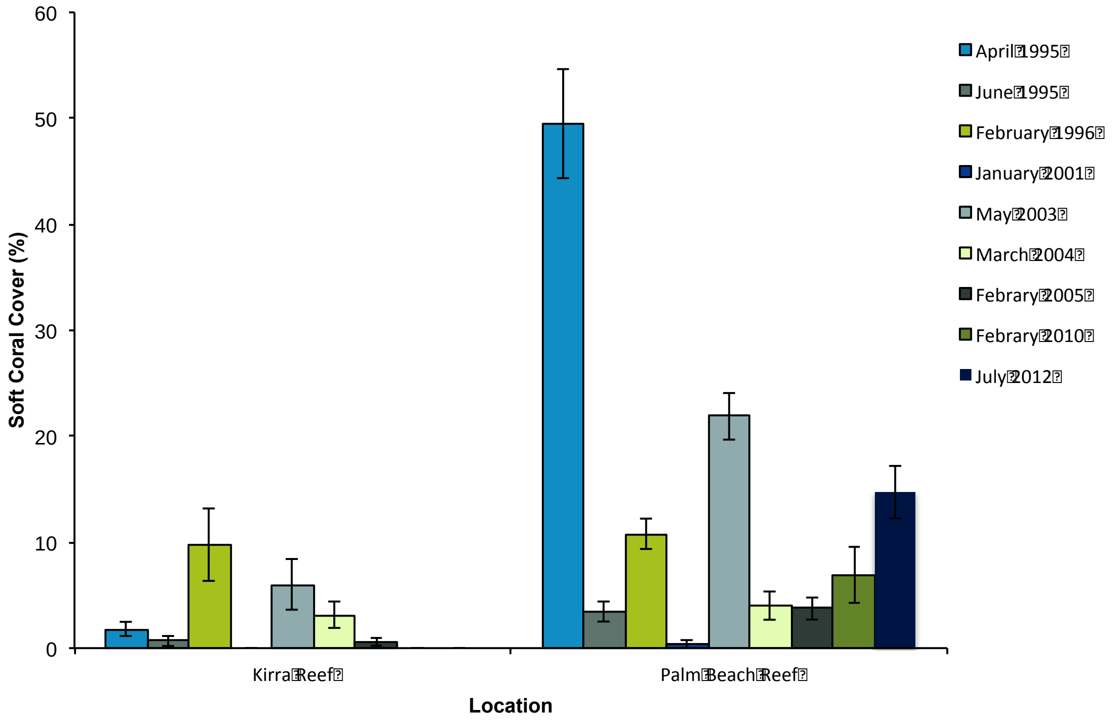


Figure 3.13 Mean cover of soft corals (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.9 PERMANOVA results for the differences in the cover of soft coral between surveys and locations.

Factor	**df**	**MS effect**	**Pseudo-F**	**p (perm)**
location	1	12939	40.21	0.0163
survey	7	2814	7.33	0.0002
site (location)	4	319	1.44	0.2126
location x survey	7	2560	6.67	0.0002
site (location) x survey	27	381	1.73	0.0136
error	763	221		

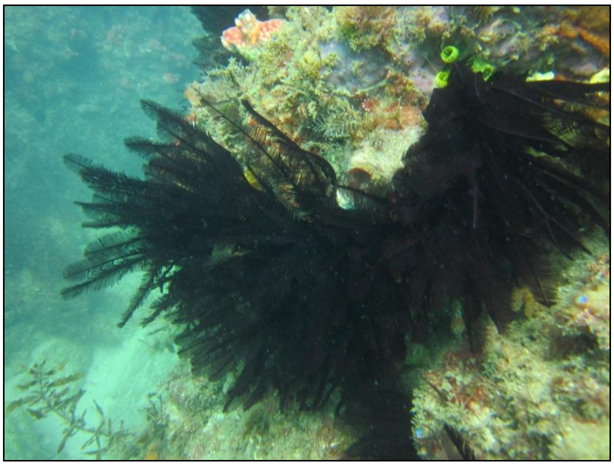
Shading denotes significance at p <0.05

Crinoids

The mean abundance (individuals / 0.25 m^2) of crinoids (Figure 3.14) at Kirra Reef and Palm Beach Reef has declined considerably since the baseline survey of 1995 (Figure 3.15). The mean abundance of crinoids on Kirra Reef declined significantly between February 2005 and February 2010, but has increased slightly between February 2010 and July 2012 (Figure 3.15). In July 2012, the abundance was extremely patchy over Kirra Reef, with most individuals found in crevices. In comparison, the abundance of crinoids at Palm Beach Reef was low but similar to that recorded in each monitoring event since May 2003. Crinoids are often found on new reef structures in the region, where they quickly recruit and cling to bare hard surfaces (Schlacher-Hoenlinger et al. 2006).

Figure 3.14

Crinoids (feather stars) were patchily distributed found at Kirra and Palm Beach reefs in July 2012.



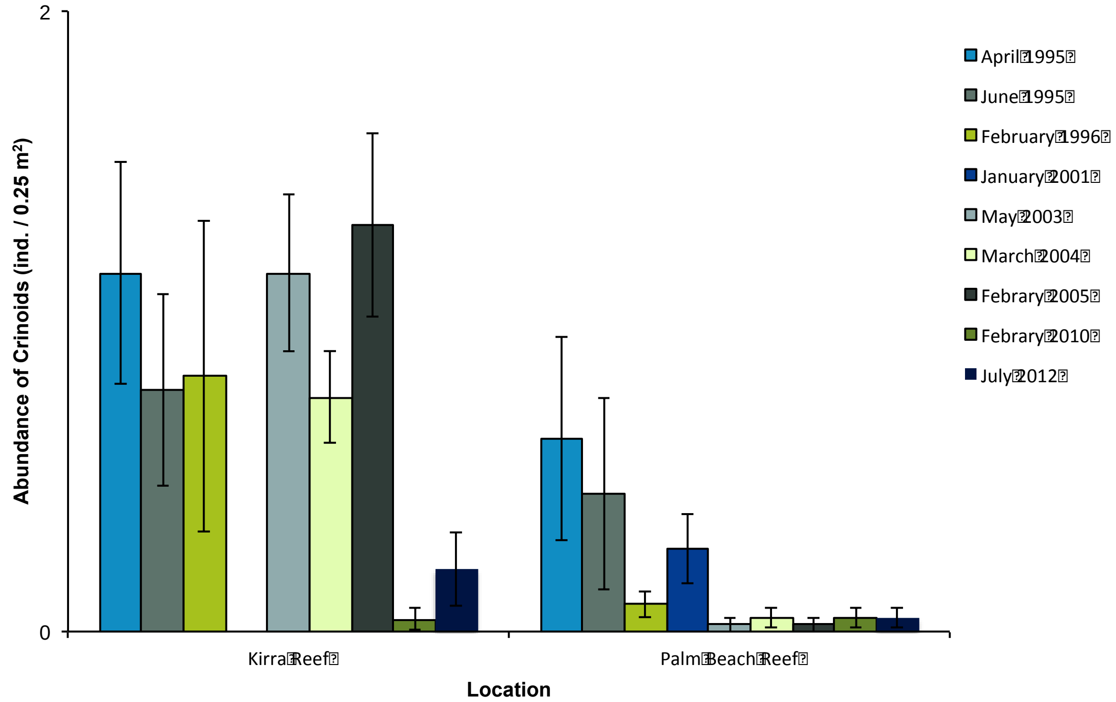


Figure 3.15 Mean abundance of crinoids (individuals / 0.25 m^2) (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.10 PERMANOVA results for the differences in Crinoid density between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
location	1	23.93	5.01	0.2014
survey	7	7.75	1.37	0.2615
site (location)	4	4.74	2.10	0.0809
location x survey	7	16.97	3.00	0.0213
site (location) x survey	27	5.62	2.48	0.0004
error	763	2.26		

Shading denotes significance at $p < 0.05$

3.4 Fish

The species richness of fish recorded from Kirra Reef across all monitoring events has ranged from 12 to 40. In July 2012, 28 species were identified at the reef (Figure 3.16). Species richness at Palm Beach Reef was slightly lower (25 species) and the variation between sampling periods was generally less than on Kirra Reef. However, the fish assemblages as a whole were quite similar between both reefs.

In July 2012, the assemblage of fish at Kirra Reef comprised species from all trophic levels, including detritivores, planktivores, herbivores and carnivores (Appendix B). As in previous surveys, the assemblage was dominated by herbivores and planktivores. Yellowtail, Australian mado, stripeys, sweep and wobbegong sharks were very abundant and remained the dominant species (Figure 3.17, Figure 3.18 and Appendix B). Several species previously recorded in February 2010 (e.g. sawtail surgeons, silver trevally, blue-spotted maskrays, round batfish and leaping bonito), were not observed in July 2012. However, there were also several species recorded at Kirra Reef for the first time in July 2012, including: Yellowfin surgeons, white-spotted eagle rays, fortescue, Gunther's wrasse and Jansen's wrasse (Figure 3.19 & Figure 3.20, Appendix B).

Moon wrasse, neon damsels, clownfish, large-scale palma, Australian mado, rabbitfish and yellowtail continued to be abundant at Palm Beach in July 2012. The complete list of species recorded and the relative abundance is presented in Appendix B.

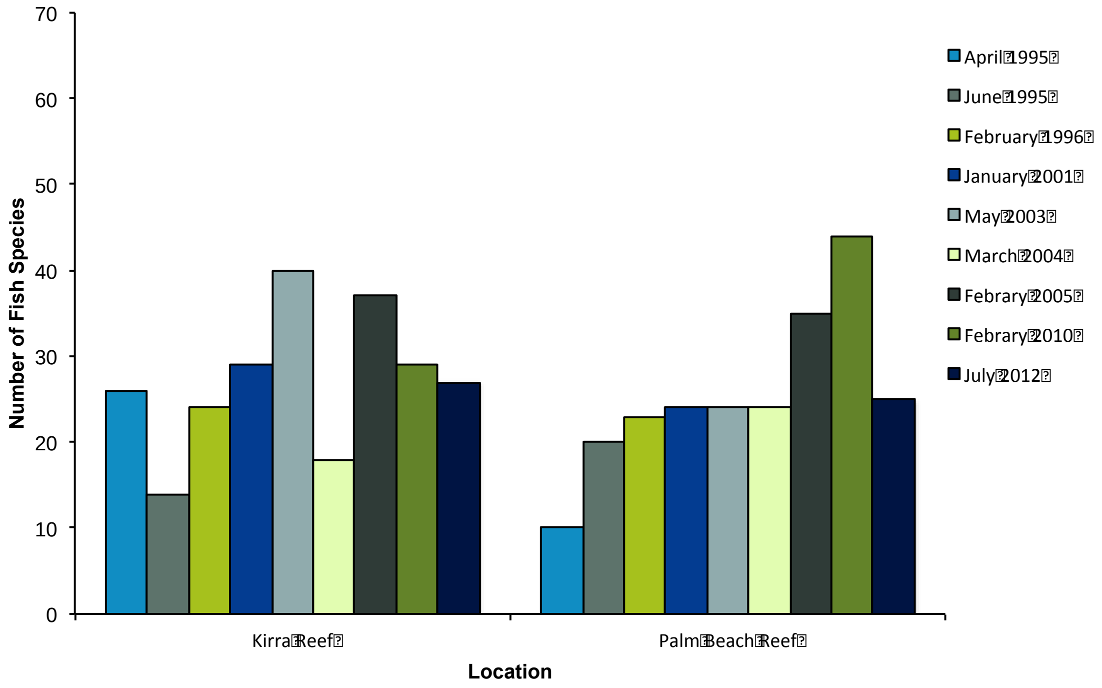


Figure 3.16 Number of fish species recorded at Kirra Reef and Palm Beach Reef on each survey.

Figure 3.17

Yellowtail and sweep were abundant at Kirra Reef in July 2012.

Figure 3.18

Striped sea pike were abundant at Kirra Reef in July 2012.

Figure 3.19

Fortescue were recorded at Kirra Reef for the first time in July 2012.

Figure 3.20

Jansen's wrasse were recorded at Kirra Reef for the first time in July 2012.

4 Discussion

4.1 Changes to the Ecological Condition of Kirra Reef

The greatest change to the ecological condition of Kirra Reef has been the loss of large areas of hard substrate that support benthic flora and fauna, due to burial by shifting sand. The delivery of large sand volumes during the Initial TRESBP operations resulted in a significant increase to the beach width at Kirra, with wave action and tidal currents redistributing some of this sand over Kirra Reef.

In the last few years there has been a loss of more than 200,000 m^3 of sand from the upper beach and offshore area between the Kirra Point groyne and the Miles Street groyne (August 2008 to August 2009). About 60,000 m^3 of this sand was lost from the beach above the water line, and about 160,000 m^3 was lost in shallow waters out to about 6 metres depth. By Mid 2009, seabed levels in the nearshore area had reduced by up to about 2 metres and there was an increase in the extent of reef habitat, with a large increase in the area of northern section of rocky reef occuring between February 2010 and July 2012.

In July 2012, the rocky outcrops in the northern section of Kirra Reef supported a moderately diverse benthic assemblage, dominated by macroalgae. This assemblage exhibited signs of ongoing stress from physical disturbance, including a reduced cover of macroalgae, hard coral and soft coral, and greater variation in the cover of sponges, relative to both previous surveys and the cover of similar organisms at Palm Beach Reef. However, Kirra Reef continues to provide habitat to a range of flora and fauna, and provides important marine ecological functions and services in the region.

Benthic Macroalgae

The cover of macroalgae at Kirra Reef increased slightly between the February 2010 and July 2012 surveys; however, it remained well below the peak of 60% cover recorded in January 2001. The cover of macroalgae also declined at Palm Beach Reef over the same period. However, the cover of macroalgae at Palm Beach Reef was generally much lower than at Kirra Reef over time. There are several possible reasons for the lower cover of macroalgae at Palm Beach including:

- Palm Beach Reef is slightly deeper than Kirra Reef and generally has higher turbidity, and therefore greater light attenuation. The quantity and quality of available light affects the distribution and growth of macroalgae (Miller & Etter 2008).

- Differences in the pattern of recruitment of algal species to the reefs due to different water currents and timing of the surveys (Kennelly 1987b).
- Increased competition with turf algae and sessile benthic invertebrates, which compete for space with macroalgae (Kennelly 1987a; Miller & Etter 2008).
- Presence of different species and higher density of herbivores at Palm Beach Reef (particularly sea urchins and herbivorous fish), which would graze on macroalgae (McCook 1997; Jompa & McCook 2002).

Temporal variation in the cover of macroalgae at Kirra Reef is likely to be principally due to the effect of physical disturbance from wave action. The negative effect of physical disturbance on the cover of macroalgae is evident during survey events when algal fragments form a dense covering over the reef. Increased smothering by sand can reduce the diversity (Hatcher et al. 1989), abundance, recruitment, growth, survival and seasonal regeneration of macroalgae (Umar & Price 1998; Cheshire et al. 1999). Biological assemblages exposed to physical stress also typically exhibit greater levels of temporal and spatial variability (Warwick & Clarke 1993; Chapman et al. 1995).

An alternative explanation for the changes in the cover of macroalgae on Kirra Reef over time is that as the extent of the reef changed; the fish associated with the reef became more concentrated, increasing the grazing pressure. Increased grazing pressure from fish and mobile invertebrates can reduce the coverage and diversity of macroalgae on reefs (McCook 1997; Jompa & McCook 2002).

The cover of turf algae at both Kirra and Palm Beach reefs also varied significantly between surveys, typically covering less of the available surface area on Kirra Reef than Palm Beach Reef. The reduced cover of macroalgae at Palm Beach Reef may allow turf algae to cover more of the available surface area on that reef, due to reduced competition. However in 2012, both Kirra and Palm Beach reefs showed major increases in turf algae percent cover from 2010 to 2012. Kirra reef showed the greatest recorded increase in turf algae cover, because turf algae had colonised newly exposed substrate. Turf algae can withstand sediment deposition, and can more rapidly re-colonise available rocky surface, than canopy-forming macroalgae (Airoldi 1998; Irving & Connell 2002). However, the relationship between algal dynamics, physical disturbance, water quality and herbivore grazing activity is complex, and the cover of turf algae can exhibit extreme temporal variability as a consequence of the interaction between top-down and bottom-up processes (Russ 2003; Bellwood et al. 2006; Hughes et al. 2007; Albert et al. 2008; Hoey & Bellwood 2008; Mumby 2009). Further investigation would be required to determine the exact mechanisms of change in both macroalgae and turf algae assemblages on these reefs.

Benthic Macroinvertebrates

The cover of benthic macroinvertebrates was much lower at Kirra Reef than Palm Beach Reef. The continued burial and re-emergence of rocky outcrops (mediated by the sand bypassing project) is likely to have increased temporal variability in the distribution and abundance of benthic macroinvertebrates. Additional perturbations such as wave action and sand abrasion are likely to have resulted in the decline in the cover and diversity of the benthic macroinvertebrates at Kirra Reef between some surveys particularly between March 2004 and February 2005. Benthic macroinvertebrates such as ascidians, sponges, hard coral and soft coral, are highly susceptible to the effects of storm and wave disturbance, physical abrasion and burial by sand (Kay & Keough 1981; Walker et al. 2008), which affects settlement, growth rates and survival of these taxa (Dodge & Vaisnys 1977; Rogers 1990).

Physical disturbance from sand burial, sand abrasion and the action of storm waves appear to keep the benthic assemblages on Kirra Reef in a state of early succession. It is common for early pioneer species, such as macroalgae or barnacles, to recruit rapidly to a hard surface in large numbers, allowing these species to dominate assemblages early in the successional trajectory (Walker et al. 2007). Another indicator of the early state of succession at Kirra Reef, is that the cover of hard and soft coral has remained very low. Reduced cover of hard coral on Kirra Reef was most likely due to increased physical disturbance from sand burial and abrasion. The cover may be affected indirectly through increased competition with macroalgae for space. The presence of large macroalgae can affect the recruitment and survival of sessile benthic invertebrates as fronds moving with wave action, sweep and abrade the surface of rocks, killing new recruits, especially corals (Kennelly 1989; McCook et al. 2001). It can take several years for hard and soft coral to become dominant on reefs in the region (Schlacher-Hoenlinger et al. 2009). Therefore, we would not expect hard coral to become abundant until several years after the reef had been uncovered, and only if the physical disturbance regime and supply of new recruits was sufficient to support survival of these species. It should be noted that the cover of hard and soft corals at Kirra Reef was both very low and very patchy even prior to the start of the sand bypassing operations.

Due to increased wave action and sedimentation mediated by the sand bypassing project, the mean cover of ascidians and sponges was expected to be much lower on Kirra Reef than Palm Beach Reef. This was the case, with ascidians covering less than 1% of Kirra reef, compared with 8% cover on Palm Beach Reef. A similar result was found for sponges, which covered 3% of the area on Kirra Reef and 8% of the area on Palm Beach Reef. Decreased cover of sponges and ascidians on Kirra Reef is an additional indicator of increased stress from physical disturbance, particularly from increased wave action and physical abrasion from sand scour, which can affect the presence of some species over time (Warwick & Clarke 1993; Chapman et al. 1995; Walker et al. 2008). Sponges and ascidians are highly susceptible to smothering and sand abrasion, unless they have a thick tunic (outer covering made of keratin) like the ascidian *P. stolonifera,* or strong internal keratin, silicon or calcareous structures in the case of sponges (Kay & Keough 1981; McGuinness 1987; Walker et al. 2008).

Fish

The reduction in area of hard substrate at Kirra Reef over time has affected the composition of fish assemblages; however, the reef continues to support a high diversity of reef-associated, and pelagic (i.e. non-reef associated) fish species. This indicates that despite its diminished size, Kirra Reef continues to provide valuable habitat for a variety of fish species from different functional groups.

There is a high degree of inter-annual variability in the species and abundance of the fish present at Kirra Reef compared with the assemblage at Palm Beach Reef, which is likely to reflect temporal variability in the available habitat as a consequence of reef burial and re-emergence. The diversity, quality and areal extent of reef habitat are the most important factors influencing the distribution, abundance, biomass and diversity of reef fish (Bellwood & Hughes 2001; Friedlander et al. 2003). Diversity and abundance of fish can increase with greater structural complexity and increased heterogeneity of available habitats (Bellwood & Hughes 2001). Logically, this suggests that periods of chronic reef burial may reduce the overall diversity of reef-associated fish species. Therefore, maintaining or increasing the total availability of habitat, should have a positive effect on the diversity of fish assemblages. This is particularly important for several species that depend on the presence of reef habitat (i.e. oldwife, moray eels, damselfish and Australian mado) that had previously been common at Kirra Reef, but were not found in July 2012.

The abundance and diversity of fish are likely to be lowest following periods of severe weather, which create unfavourable conditions for many species, and may further exacerbate the affects of sedimentation. The biomass of fish is known to decrease with increasing exposure to physical disturbance from wave action and strong currents (Friedlander et al. 2003). As the surveys were completed at different times of the year, variation in the prevailing conditions at the time of sampling could also influence the types of fish observed and the amount of reef habitat that is available at any time. Many of the species may also be affected by seasonal changes in the water temperature, such as damselfish, which are less abundant in cool waters. However, the overall diversity of the fish assemblage at Kirra Reef is likely to reflect the complex interactions between physical disturbance (i.e. sedimentation mediated by the sand bypassing project and wave action), food availability and competition, and local weather and sea conditions.

4.2 Impacts of the Sand Bypassing System on Kirra Reef

In addition to assessing changes to the ecological condition of Kirra Reef over time, frc environmental was commissioned to assess any noticeable impacts of the TRESBP on the extent of the reef, taking into account the impacts predicted in the:

- Tweed River Entrance Sand Bypassing Project Permanent Bypassing System Environmental Impact Statement / Impact Assessment Study, prepared by Hyder Consulting, Paterson Britton & Partners Pty Ltd and WBM Oceanics Australia Joint Venture in June 1997
- Impact Assessment Review Report for Tweed River Entrance Sand Bypassing Project Permanent Bypassing System, prepared by the Queensland Department of Environment in March 1998, and
- Report on Historic Changes at Kirra Beach, prepared by P.K. Boswood and R. J. Murray of the then Queensland Department of Environment in March 1997.

The EIS / IAS is a document of broad scope. Our comparison of predicted and actual impacts on Kirra Reef has focused on three principle sections of the EIS / IAS relevant to the consideration of the ecology of Kirra Reef: 'The Existing Environment', 'The Environmental Impacts' and, 'Environmental Management'. A more comprehensive review of these sections can be found in our previous monitoring reports (frc environmental 2003; 2004; 2005). In summary, the predicted impacts included accretion of sand around the base of the rock outcrops at Kirra Reef, causing a reduction in extent of the uncovered area of reef. It was predicted that sand delivery as part of the project would eventually mimic 'natural' patterns of sand dispersal, and that the reef would reduce in size to its natural extent (pre development of the Tweed River training walls). However, the EIS did not go on to predict the ecological consequences of both the reduced areal extent or increased wave energy (a consequence of decreased depth) that occurred. Presumably the benthic flora and fauna assemblages of the reef would be expected to return to a condition consistent with the historical reef extent and natural sand transport patterns (and associated coastal fluctuations, wave action, sedimentation and water quality) that were observed in the vicinity of the reef prior to the development of the Tweed River training walls.

The current extent of Kirra Reef, and that present throughout much of the last decade, is quite different to that of the late 1980s / early 1990s. In July 2012, the areal extent of Kirra Reef was similar to that found in the 2003 survey. When compared with the historical extent of the reef, the current extent of the northern section of the reef most closely approximates that recorded in 1930. However, there has been a consistent decline in the extent of the eastern and inner western sections of the reef, due to increased sand deposited as part of the TRESBP project. Therefore, the extent of Kirra Reef in July 2012 is broadly in accordance with predictions made in the EIS.

While the extent of the reef continues to change over time, the delivery of sand as part of the project now closely matches the natural rate of longshore sand transport, so short-term and seasonal changes in the extent of the reef are now more likely to be the result of wave and current action than a discrete impact of the sand bypassing activity. Ongoing monitoring to assess the physical and ecological dynamics of Kirra Reef will be valuable to determine the magnitude and frequency of changes in the diversity of the benthic assemblages found on Kirra Reef under a mature sand-bypassing regime.

4.3 Impacts of Storms & Seasonality on Kirra Reef

Sessile benthic assemblages on Kirra Reef are highly susceptible to the influence of storms, and associated wave action (Kay & Keough 1981; Walker et al. 2008). The shallow reef is surrounded by mobile sand, which can shift naturally in response to wave action during storms causing burial of large sections of Kirra Reef. This effect has reduced the extent of rocky substrate available for colonisation, and also the availability of refuge habitats, such as crevices and overhangs, which are sheltered from wave action and sand abrasion. The total volume of sand on Kirra Beach has not changed significantly since August 2009 (TRESBP 2012). However, there has been an increase in the extent of the reef in July 2012, which may be a result of relatively benign conditions experienced through 2010 and 2011 and a redistribution of sand through wave action and tidal currents (TRESBP 2012).

During storm events the height of waves are much larger, so given the shallow depth of Kirra Reef, waves are more likely to shoal and break across the reef during these periods, increasing physical disturbance, abrasion and sedimentation of benthic assemblages. Storm disturbance can cause local reductions in the species richness and abundance of coral (Woodley et al. 1981; Massel & Done 1993; Hughes 1994; Connell et al. 1997) and alter fish assemblages indirectly through habitat modifications (Kaufman 1983; Jones & Syms 1998) or directly by increasing mortality (Lassig 1983). However, there is relatively little known about how increases in the frequency and intensity of storms may impact on the broader assemblage of sessile macroinvertebrates on coral reefs (Moran & Reaka Kudla 1991; Lugo et al. 2000) except that increased physical disturbance has a negative effect on the diversity of intertidal sessile macroinvertebrates (Walker et al. 2008). The hydrodynamic forces produced by wave action are an important source of disturbance in intertidal habitats, inflicting damage through direct physical impact and abrasion (Paine & Levin 1981; Denny 1983; Shanks & Wright 1986; Bell & Denny 1994; Walker et al. 2008). Increased storm severity and the resulting wave action can impose significant forces on marine habitats (Denny 1983), which affects the frequency and magnitude of disturbance to a range of benthic species (Ebeling et al. 1985; Walker et al. 2008).

Storm and wave action (and associated sedimentation and abrasion) continue to be important forces shaping the distribution and abundance of benthic species at Kirra Reef. Increased magnitude and frequency of physical disturbance, resulting from increased exposure or susceptibility to storms and associated wave action (as on Kirra Reef), can lead to a decrease in the diversity of sessile invertebrate assemblages (Walker et al. 2008). Disturbance-driven reductions in biodiversity have the potential to impact negatively on the health and productivity of reef ecosystems (Walker et al. 2008), especially given that many of these species (e.g. sponges, bryozoans and ascidians) contribute a range of vital ecosystem services to reefs, including: nutrient cycling (Scheffers et al. 2004), trophic interactions and food webs (Lesser 2006; Pawlik et al. 2007), bio-erosion (Rutzler 2002; Lopez-Victoria et al. 2006), and stabilizing substrata (Diaz & Rutzler 2001; Wulff 2001).

The impacts of increased wave action and sedimentation on the benthic assemblages at Kirra Reef are likely to be greatest during and immediately following storm conditions. Partitioning the influence of storm and wave driven disturbance, from that of the operation of the TRESBP, would require a much more statistically powerful, and temporarily replicated experimental monitoring design.

4.4 Long-term Impacts of the Sand Bypassing System on Kirra Reef

In July 2012, Kirra Reef covered an area of approximately 45 to 50% (3700 m^2) of the reef area present in 1995 (i.e. prior to the operation of the TRESBP). This is largley due to the reduction in the inner western and eastern sections of the reef (Figure 1.2). Logically, the loss of reef habitat has dramatically reduced the availability of hard substratum available for colonisation and consequently the diversity of benthic sessile assemblages.

While there is sufficient structure available, we expect that the assemblage of fish will continue to resemble the historical assemblage at Kirra Reef and also that of Palm Beach Reef, perhaps with the inclusion of a greater proportion of cryptic benthic species as they recruit to Kirra Reef. Given that fish are mobile, the greatest effect on these assemblages is likely to be short-term (reversible) changes due to the prevailing conditions and changes to the extent of available habitat to provide shelter and food.

5 Conclusions

Initial ‘catch-up’ bypassing of sand resulted in the substantial burrial of Kirra Reef. ‘Maintenance’ bypassing more closely reflects natural patterns of long-shore sand transport and is gradually allowing the reef to re-emerge. The current extent of Kirra Reef is broadly in accordance with predictions made in the EIS.

The re-emergence of the reef has increased the extent of hard substrate available for colonisation by plants and animals characteristic of the region. However, both diversity of assemblages and the absolute abundance of taxa are less than prior to the commencement of sand bypassing.

Now that the delivery of sand more closely matches the natural rate, it is expected that the reef may undergo short term changes in extent due to seasonal shifts in sand delivery; however, the diversity of benthic assemblages on Kirra Reef should increase gradually over time, especially if a larger extent of the rocky reef remains uncovered. This creates more space for a greater suite of species to recruit and reduces the likelihood of sand abrasion and wave damage. In this scenario, it is expected that that newly exposed areas of Kirra Reef in 2012 that were dominated by turf algae, would be colonised by other organisms including macroalgae, sponges, ascidians and potentially hard and soft coral over time.

The diversity of fishes associated with Kirra Reef is broadly similar to that recorded prior to the commencement of sand bypassing. Given that fish are mobile, the greatest effect on these assemblages is like to be short term changes due to the prevailing conditions and changes to the extend of available habitat that provides shelter and food for a variety of different species. These changes are likely to be more frequent due to increased wave expose. If Kirra Reef continues to increase in size, fishes associated with reef are likely to include a greater proportion of cryptic benthic species more typical of assemblages in a later stage of succession.

The timeframe for the ‘recovery’ of communities to this state is currently unknown, and will depend on ambient environmental conditions. Ongoing monitoring will provide insight into the rate of ‘recovery’ of communities. It is recommended that monitoring is repeated in in early 2013 (February or March, when previous surveys have been undertaken) to confirm the results of the July 2012 survey and account for seasonal differences. Based on the results of this survey, recommendations could be made regarding the frequency of future monitoring.

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Appendix A Introduction to Data Analysis Used

Multivariate Analyses

Multivariate statistical techniques are widely used in ecology to assess the similarities / relationships between communities. Whereas univariate analyses can only compare one variable at a time (e.g. an index of community structure such as a diversity index, or a single indicator species), multivariate analyses can compare samples based on the extent that communities share particular taxa and abundances (Clarke & Warwick 2001).

The first step of multivariate analysis usually involves the creation of a matrix of similarity coefficients, computed between every pair of samples. The coefficient is usually a measure of how close the abundance is for each species (defined so that 100% = total similarity and 0% = complete dissimilarity). The Bray Curtis similarity measure is commonly the most appropriate for biological data (Clarke & Warwick 2001).

Multi-dimensional Scaling

Non-metric multi-dimensional scaling ordinations (nMDS) attempt to place samples in two dimensional space, so that the rank order of the distances between samples matches the rank order of the matching similarities from the similarity matrix (Clarke & Warwick 2001). This provides a visual representation of the similarities between communities within each sample. Each of the axes is not related to any particular value; in fact axes can be rotated to provide the best visual representation of the data. Ordinations are particularly useful tools for analysing, and visually presenting, differences between communities. Ordinations are essentially maps of samples, in which the placement of samples on the map reflects the similarly of the community to the communities in other samples (Clarke & Warwick 2001). Distances between samples on an ordination attempt to match the similarities in community structure: nearby points represent communities with very few attributes (species or abundance of species); points far apart have very few attributes in common (Clarke & Warwick 2001).

A stress coefficient is calculated to reflect the extent to which the multi-dimensional scaling ordination and the similarity matrix agree (Clarke & Warwick 2001) (i.e. how well the multi-dimensional scaling ordination accurately reflects the relationship between samples). Stress values of <0.15 are generally acceptable.

In Figure A2, each sample is represented on the multi-dimensional scaling ordination. By looking at the distances between each sample, we can infer that samples (communities) from the same stream reach (e.g. sites DS, M, STC and US) group together. That is, they are more similar to each other than they are to samples taken from other stream reaches.

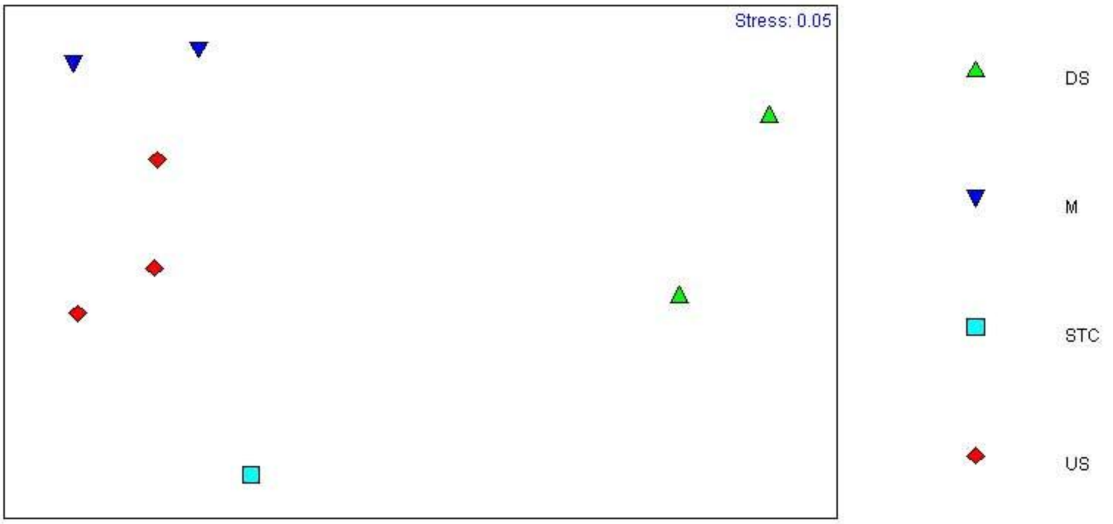

Figure A2 Example of a multi-dimensional scaling ordination for macro-invertebrate communities sampled in riffle habitats of different stream reaches.

Analysis of Similarity

ANOSIM is analogous to ANOVA in univariate statistics (Smith 2003). A global R statistic is calculated to determine whether there is a significant difference between all samples. If there are differences, then pairwise comparisons are conducted to test for differences between pairs of samples (analogous to post-hoc tests in ANOVA).

The R value lies between -1 and +1 (all similarities within groups are less than any similarity between groups), with a value of zero representing the null hypothesis (no difference among a set of samples) (Clarke & Warwick 2001). Comparison of pairwise R values can give an indication of how different communities are: R values close to 0 indicate little difference, values around 0.5 indicate some overlap and values close to 1 to indicate many or substantial differences. In many instances however, researches are primarily interested in whether the R value is statistically different from zero (usually at a confidence level of 0.05) (Clarke & Warwick 2001) (i.e. whether they can reject the null hypothesis).

ANOSIM can provide information on whether the (visual) differences between communities in the multi-dimensional scaling ordination are significant; it is an independent test from the multi-dimensional scaling ordination. It is based on testing the differences between the rank similarities in the similarity matrix, not on the distances between samples in the multi-dimensional scaling ordination (Clarke & Warwick 2001).

Permutational Multivariate Analysis of Variance

PERMANOVA is used to test simultaneous responses of one or more variables to one or more factors in an *a priori* structured design, using random permutation of the data to assess significance (Anderson 2004). PERMANOVA generates an pseudo F-statistic similar to traditional ANOVA, but p-values are calculated with permutations, which does not assume normal data distribution. PERMANOVA can provide information on whether the (visual) differences between communities in a multi-dimensional scaling ordination are significant; however, it is an independent test from the multi-dimensional scaling ordination.

Were significant differences among factors are found, post-hoc pairwise comparison can then be used to test for differences between pairs of samples (analogous to post-hoc tests in ANOVA).

The level of multivariate dispersion among samples within each of the test groups can be examined using the permutational analysis of multivariate dispersions (PERMDISP) routine (Anderson 2004). In traditional impact assessment, a change in the dispersion of data can also indicate an impact.

Similarity Percentage – Species Contributions

SIMPER analysis provides information on how dissimilar communities from various groups are (e.g. how similar all of the macro-invertebrate samples taken for a particular habitat within a stream reach are), and how similar each group (e.g. reach) is to any other group. SIMPER analysis also identifies the species / taxa that are contributing to the dissimilarity between two communities, in rank order (i.e. it identifies which species is contributing the most to the differences). SIMPER analysis may help to identify potential ‘indicator’ species. For example, if a particular species consistently contributes greatly to the differences between impacted and unimpacted communities, it may be a useful indicator. The abundance of this indicator species can then be compared between sites using univariate techniques such as ANOVA.

Appendix B Cover and Abundance of Benthic Fauna and Flora on Kirra and Palm Beach Reefs in July 2012

Table B. 1 R statistic of pairwise ANOSIM results for differences in the composition of benthic assemblages between surveys for each reef.

Reef	1995-1996	1996-2001	2001-2003	2003-2004	2004-2005	2005-2010	2010-2012
Kirra Reef	0.412	0.101	0.280	0.226	0.468	0.130	0.665
Palm Beach Reef	0.080	0.516	0.413	0.296	0.182	0.832	0.507

Table B.2 Benthic assemblage data from Kirra and Palm Beach reefs in July 2012

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Palm Beach	1	1	10	40	20	0	5	10	20	45	1	0	0	0	0	0	0	0
Palm Beach	1	2	0	30	10	0	0	20	10	30	0	2	0	0	0	0	0	0
Palm Beach	1	3	0	20	40	0	20	5	10	5	0	0	1	0	0	10	5	0
Palm Beach	1	4	10	10	30	0	20	10	20	0	0	2	0	0	0	0	0	0
Palm Beach	1	5	0	10	40	0	5	5	10	30	0	3	0	0	0	0	0	0
Palm Beach	1	6	10	5	10	5	5	10	10	45	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Palm Beach	1	7	0	30	0	0	10	30	10	20	0	2	1	0	0	0	0	0
Palm Beach	1	8	30	0	20	0	0	10	0	40	0	0	0	0	0	0	0	0
Palm Beach	1	9	0	80	0	3	7	5	0	5	0	0	0	0	0	0	0	0
Palm Beach	1	10	0	30	0	40	15	10	0	5	0	2	0	0	0	0	0	0
Palm Beach	1	11	0	40	0	0	20	0	0	40	0	0	1	0	0	0	0	0
Palm Beach	1	12	0	30	5	0	5	0	15	45	0	0	0	0	0	0	0	0
Palm Beach	1	13	0	20	0	0	5	30	0	45	0	4	0	1	0	0	0	0
Palm Beach	1	14	0	10	10	40	0	0	0	40	0	0	0	0	0	0	0	0
Palm Beach	1	15	0	30	40	0	10	15	0	5	1	3	1	1	0	0	0	0
Palm Beach	2	1	5	30	30	5	0	0	0	30	0	0	0	0	0	0	0	1

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Palm Beach	2	2	0	40	20	0	0	5	0	35	0	2	0	0	0	0	0	0
Palm Beach	2	3	0	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	4	0	80	0	0	0	5	0	15	0	0	0	0	0	0	0	0
Palm Beach	2	5	0	20	40	0	20	0	0	20	0	1	0	0	0	0	0	0
Palm Beach	2	6	0	60	30	0	0	5	0	5	0	1	0	0	0	0	0	0
Palm Beach	2	7	0	75	15	5	0	5	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	8	10	70	0	0	0	20	0	0	0	2	0	0	0	5	0	0
Palm Beach	2	9	10	40	10	5	10	5	5	15	0	2	0	0	0	0	0	0
Palm Beach	2	10	0	80	0	0	20	0	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	11	0	85	0	0	5	5	5	0	0	1	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Palm Beach	2	12	0	85	0	0	0	5	10	0	0	1	0	0	0	0	0	0
Palm Beach	2	13	0	30	0	0	20	50	0	0	0	7	0	0	0	0	0	0
Palm Beach	2	14	20	45	0	30	0	5	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	15	0	80	0	0	10	10	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	1	0	75	15	5	0	5	0	0	0	1	0	0	0	0	0	0
Palm Beach	3	2	10	85	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	3	0	45	20	0	30	5	0	0	0	1	0	0	0	0	0	0
Palm Beach	3	4	0	80	20	0	0	0	0	0	0	1	0	0	0	0	0	0
Palm Beach	3	5	0	55	30	0	0	5	10	0	0	0	0	0	0	0	0	0
Palm Beach	3	6	0	60	25	5	0	0	0	10	0	0	0	0	0	1	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Palm Beach	3	7	0	45	35	0	20	0	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	8	0	90	5	5	0	0	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	9	0	30	65	0	5	0	0	0	0	0	0	0	0	0	1	0
Palm Beach	3	10	0	55	0	0	40	5	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	11	0	75	0	5	10	10	0	0	0	4	0	0	0	0	0	0
Palm Beach	3	12	0	60	0	0	20	20	0	0	0	4	0	0	0	0	0	0
Palm Beach	3	13	0	95	5	0	0	0	10	-10	0	0	0	0	0	0	0	2
Palm Beach	3	14	0	75	0	0	5	20	0	0	0	3	0	0	0	0	0	0
Palm Beach	3	15	0	85	10	0	5	0	0	0	0	0	1	0	0	0	0	0
Kirra Reef	KRO3	1	5	70	0	0	0	0	0	25	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Kirra Reef	KRO3	2	5	85	0	0	0	0	0	10	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	3	5	90	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	4	5	90	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	5	5	90	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	6	3	80	0	0	0	0	0	17	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	7	5	70	0	0	0	0	0	25	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	8	5	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	9	10	70	0	0	0	0	0	20	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	10	10	75	0	0	0	0	0	15	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	11	10	80	0	0	0	0	0	10	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Kirra Reef	KRO3	12	5	80	0	0	0	0	0	15	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	13	3	90	0	0	0	0	0	7	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	14	40	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	15	40	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRN1	1	40	30	0	0	0	0	0	30	0	0	0	0	0	0	0	0
Kirra Reef	KRN1	2	10	60	0	0	25	0	0	5	0	0	0	0	0	0	0	0
Kirra Reef	KRN1	3	10	80	0	0	0	0	0	10	0	2	0	0	0	0	0	0
Kirra Reef	KRN1	4	5	80	0	0	0	0	0	15	1	0	0	0	0	0	0	0
Kirra Reef	KRN1	5	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRN1	6	30	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Kirra Reef	KRN1	7	60	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRN1	8	0	100	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Kirra Reef	KRN1	9	0	100	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Kirra Reef	KRN1	10	5	40	0	0	40	0	0	15	0	1	0	0	0	0	0	0
Kirra Reef	KRN1	11	20	65	0	0	15	0	0	0	0	2	0	0	0	0	0	0
Kirra Reef	KRN1	12	0	70	0	0	25	0	0	5	0	0	0	0	0	1	0	0
Kirra Reef	KRN1	13	0	70	0	0	5	0	0	25	0	0	0	0	0	1	0	0
Kirra Reef	KRN1	14	50	0	0	0	0	0	0	50	1	0	0	0	0	0	0	0
Kirra Reef	KRN1	15	70	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	1	40	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Kirra Reef	KRN2	2	5	80	0	0	0	0	0	15	1	0	0	0	0	0	0	0
Kirra Reef	KRN2	3	10	70	0	0	0	0	0	20	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	4	10	60	0	0	0	0	0	30	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	5	40	20	0	0	0	0	0	40	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	6	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	7	10	70	0	0	5	0	0	15	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	8	10	70	0	0	0	0	0	20	5	0	0	0	0	0	0	0
Kirra Reef	KRN2	9	70	20	0	0	0	0	0	10	0	1	0	0	0	0	0	0
Kirra Reef	KRN2	10	10	80	0	0	5	0	0	5	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	11	20	70	0	0	2	0	0	8	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Barnacles	% Bare	# Crinoids	# Pyura sp.	# Echinoidea	# Tube worms	# Polychaetes	# Hydroids	# Zoanthids	# Cowrie
Kirra Reef	KRN2	12	40	40	0	0	0	0	0	20	0	1	0	0	0	0	0	0
Kirra Reef	KRN2	13	30	60	0	0	0	0	0	10	1	0	0	0	0	0	0	0
Kirra Reef	KRN2	14	0	95	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Kirra Reef	KRN2	15	0	95	0	0	0	0	0	5	0	0	0	1	0	0	0	0

Appendix C Relative Abundance of Fish found at Kirra and Palm Beach Reefs in Each Survey

Table C1 Fish species and their relative abundance in July 2012 and in previous surveys.

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12
Acanthuridae																			
Acanthurus grammoptilus	ring-tailed surgeon	**	**	**	**	**		**	**		**	**	***	**	**		**	**	**
Acanthurus xanthopterus	yellowfin surgeonfish									**									**
Prionurus microlepidotus	sawtail surgeon								***								**	**	**
Apogonidae																			
Apogon cookii	cook's cardinal fish															**	**	*	
Apogon doederleini	four lined cardinal fish							**	*					**		***	**	**	
Aracanidae																			
Strophiurichthys robustus	freckled boxfish					**													
Balastidae																			
Sufflamen chrysopterus	half-moon triggerfish							**									**	**	*
Sufflamen fraenatus	bridled triggerfish												*						
Blenniidae																			
Plagiotremus tapeinosoma	hit and run blenny						**	*	*	*							*	**	
Brachaeluridae																			
Brachaelurus waddi	blindshark							*		*						*			*
Carangidae																			
Caranx sp.	trevally											**	***	***					
Gnathanodon speciosus	golden trevally															**			
Pseudocaranx dentex	silver trevally								***						***				
Trachinotus blochii	dart	**																	
Trachurus novaezelandiae	yellowtail	****	****	****		*****	****	****	****	****	****	****	**	****	****			****	****
Chaetodontidae																			
Chaetodon auriga	threadfin butterfly fish	**	**			**			**		*	*	**			**			
Chaetodon citrinellus	citron butterfly fish					**											**	**	**

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12
Chaetodon flavirostris	dusky butterfly fish				*												**	**	
Chaetodon lineolatus	lined butterfly fish				*	*							**				*		
Henochus sp.	banner fish	**				*			**										
Cheilodactylidae																			
Cheilodactylus fuscus	red morwong			**	**	**	**	*	**	*		**		**	**		**	**	
Cheilodactylus vestitus	crested morwong			*				*	*	*				*			**	**	
Chironemidae																			
Chironemus marmoratus	kelp fish				**	**		**											
Cirrhitidae																			
Cirrhitichthys sp.	hawkfish					**							*			**	**		
Dasyatidae																			
Dasyatis kuhlii	blue-spotted maskray								**										
Diodontidae																			
Dicotylichthys punctulatus	three-bar porcupine fish					**	*	***	**	**				*					
Diodon holocanthus	freckled porcupine fish	*		**															**
Diodon hystrix	black-spotted porcupine fish					*													
Ephippidae																			
Platax orbicularis	round batfish								*										
Enoplosidae																			
Enoplosus armatus	old wife	***		**	***			**						**					
Fistularidae																			
Fistularia commersonii	smooth flutemouth	*			**				**									**	
Fistularia petimba	rough flutemouth																	**	
Gerreidae																			
Gerres subfasciatus	silver biddy	***	**	**	**	***	*	**	*										
Haemulidae																			

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12
Plectorhinchus flavomaculatus	gold-spotted sweetlip				*	**		*									*	*	
Labridae																			
Achoerodus viridis	blue groper														*				
Anampses meleagrides	spotted wrasse																		*
Diproctacanthus xanthurus	yellowtail tubelip									*									
Halichoeres sp.	striped wrasse			**	***	*			***	***				**		*	**	**	
Labroides dimidiatus	cleaner wrasse			**	**	***	**	**	**	**		*	*	*	**	**	*	**	**
Notolabrus gymnogenis	crimson-banded wrasse					***	**												*
Notolabrus sp.	wrasse	**									**	**	**						
Pseudolabrus guentheri	Gunther's wrasse									**									**
Thalassoma jansenii	Jansen's wrasse									**									*
Thalassoma lunare	moon wrasse					**	**	**		**			***	***	***	**	****	***	**
Thalassoma lutescens	yellow moon wrasse	**		**	**	***	*	**		**		**	***	***	***	**	**	***	
Lutjanidae																			
Lutjanus fulviflamma	black-spot snapper									**									
Microcanthidae																			
Atypichthys strigatus	Australian mado			**	***	***	*	***	***							***	***	***	**
Microcanthus strigatus	stripey	***	***	**	***	***	**	***	***	**	***	**	**	***		*		***	**
Monocanthidae																			
Meuschenia trachylepis	yellow-tailed leatherjacket					*											**		
Monacanthus chinensis	fan-bellied leatherjacket	*		*	*				*			*	*				**		
Monodactylidae																			
Monodactylus argenteus	silver batfish					***						***		**	***				
Schuettea scalaripinnis	eastern pomfred								***		****	***	***					**	

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12
Mullidae																			
Parupeneus barberinoides	half-and-half goatfish				**			*									**		
Parupeneus ciliatus	diamond-scaled goat fish												*						
Parupeneus signatus	black spot goat fish	***	**	***	***									***					**
Muraenidae																			
Gymnothorax prasinus	green moray					**	**	***										*	
Gymnothorax sp.	moray eel					*	*						*						*
Siderea thyrsoidea	white-eyed moray						**	**											
Myliobatididae																			
Aetobatus narinari	white-spotted eagle ray									**									
Orectolobidae																			
Orectolobus ornatus	ornate wobbegong					**	**	**	**	**		**	**		**		**		**
Ostraciidae																			
Ostracion cubicus																	**		
Pempheridae																			
Pempheris multiradiata	bullseye									**		***	***	**				**	
Pempheris oualensis	black-finned bullseye					*													
Platycephalidae																			
Platycephalus fuscus	dusky flathead				*			*											
Plotosidae																			
Cnidoglanis macrocephala	estuary catfish	*																	
Polynemidae																			
Polydactylus nigripinnis	black-finned threadfin														*				
Pomacanthidae																			
Centropyge tibicen	keyhole angelfish					*		*								*	**	**	
Pomacanthus semicirculatus	blue angelfish																	*	

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr ‘95	Jun ‘95	Feb ‘96	Jan ‘01	May ‘03	Mar ‘04	Feb ‘05	Feb ‘10	Jul ‘12	Apr ‘95	Jun ‘95	Feb ‘96	Jan ‘01	May ‘03	Mar ‘04	Feb ‘05	Feb ‘10	Jul ‘12
Pomacentridae																			
Abudefduf bengalensis	Bengal sergeant major					**		*							**	**	**	*	**
Abudefduf vaigiensis	sergeant major								*						***	*	**	***	
Abudefduf saxatilis	five-banded sergeant major								**						***			*	
Amphiprion sp.	clown fish	**	**	**		**							**		**			***	**
Chromis chrysura	robust puller			**												*			
Chromis nitida	barrier reef chromis			**									**						
Chrysiptera sp.	demoiselle					**									**	*		**	
Dascyllus trimaculatus	domino puller							*						*					
Parma microlepis	white ear puller		**	**	**						**	**	**	**		*	*	*	
Parma oligolepis	large-scaled parma					**	**	**		**							*	***	
Parma polylepis	banded parma							**									**	**	
Plectroglyphidodon leucozonus	whiteband damsel																		*
Pomacentrus australis	Australian damsel	**	**	**							**	**			**	**			
Pomacentrus coelestis	neon damsel					***		**							***		***	****	**
Stegastes gascoynei	coral sea gregory					**	*									**		**	
Stegastes sp.	damsel									*									***
Pomatomidae																			
Pomatomus saltatrix	tailor	****																	
Rhinobatidae																			
Aptychotrema sp.	shovelnose ray	*																	
Glaucostegus typus	giant shovelnose ray																	*	
Scorpaenidiae																			
Centropogon australis	fortescue									**				*					
Pterois volitans	red firefish					*									*				
Scorpaena cardinalis	red scorpionfish					*									*			**	
Synanceia horrida	estuarine stonefish							**											

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr ‘95	Jun ‘95	Feb ‘96	Jan ‘01	May ‘03	Mar ‘04	Feb ‘05	Feb ‘10	Jul ‘12	Apr ‘95	Jun ‘95	Feb ‘96	Jan ‘01	May ‘03	Mar ‘04	Feb ‘05	Feb ‘10	Jul ‘12
Scombridae																			
Cybiosarda elegans	leaping bonito								****										
Scomberomorus commerson	spanish mackerel																	**	
Scorpididae																			
Scorpis lineolatus	sweep	***	***	**	**	**	*	**	**	****	***	***	**	****	**	**	**	***	****
Serranidae																			
Epinephelus fasciatus	black-tipped cod											**				*	***	**	
Plectropomus maculatus	coral trout											*							
Siganidae																			
Siganus fuscescens	rabbit fish				***					*				***		***	***	***	
Sillaginidae																			
Sillago analis	gold-lined whiting							**											
Sparidae																			
Acanthopagrus australis	yellow fin bream	***	***	**	***	***				**	***	**	**	**				***	**
Rhabdosargus sarba	tarwhine	***			**													*	
Sphyraenidae																			
Sphyraena obtusata	striped sea pike	****	**	**	**	*		****		**					*			**	**
Syngnathidae																			
Signathid sp. 1	pipefish	*																	
Stegostomatidae																			
Stegostoma fasciatum	leopard shark													*					
Tetraodontidae																			
Arothron hispidus	stars and stripes pufferfish				*		**	**	*					*	*				
Arothron immaculatus	immaculate pufferfish			*															
Arothron manilensis	narrow lined toadfish				*														
Arothron stellatus	starry toadfish							*	*							**	**		
Canthigaster valentini	black-saddled toby							*							**		**		
Lagocephalus sp.	toadfish				***														

Scientific Name	Common Name	Kirra Reef									Palm Beach Reef								
		Apr ‘95	Jun ‘95	Feb ‘96	Jan ‘01	May ‘03	Mar ‘04	Feb ‘05	Feb ‘10	Jul ‘12	Apr ‘95	Jun ‘95	Feb ‘96	Jan ‘01	May ‘03	Mar ‘04	Feb ‘05	Feb ‘10	Jul ‘12
Torquigener pleurogramma	toadfish	*	*		***								*						
Urolophidae																			
Urolophus sp.	stingaree	*	***	**	**	*		**											

* < 5 individuals

** 6-20 individuals

*** 21-100 individuals

**** >100 individuals