Tweed River Entrance Sand Bypassing Project

Kirra Reef
Marine Biota Monitoring 2015

Prepared for:

The New South Wales Government, Department of Primary Industries, Lands; and the Queensland Government Department of Science, Information Technology and Innovation

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Summary

The New South Wales Government, Department of Primary Industries, Lands; and the Queensland Government, Department of Science, Information Technology and Innovation commissioned frc environmental on behalf of the Tweed River Entrance Sand Bypassing Project (TRESBP) to monitor the condition and biodiversity of benthic and fish assemblages at Kirra Reef, and to assess potential 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 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 March 2015.

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 March 2015 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, 2010, 2012 and 2014.

Impacts of the Sand Bypassing System on Kirra Reef

The extent of the three major outcrops of Kirra Reef (northern, southern and eastern sections) vary naturally depending on water and sand movements. 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 mechanisms. A large volume of sand was deposited on the southern Gold Coast beaches, and wave action and tidal currents redistributed some of this sand over Kirra Reef. This resulted in a decline in the areal extent of Kirra Reef, with the reef almost completely covered (<100 m^2 exposed) in 2006. The project’s Environmental Impact Statement (EIS) predicted that impacts associated with the gradual accumulation of sand around the base of Kirra Reef were unavoidable.

Since the delivery of large quantities of sand was completed in 2008, the volume of sand delivered by the project has declined, and now closely matches the natural rate of northward sand transport. 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 2009.

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. This was likely to be related to severe storms in late 2009 moving sand further north and / or to the manual removal of 140 000 m^3 of sand from Kirra Beach in 2009.

In December 2013, Kirra Point groyne was extended by 30 m by the City of Gold Coast with the expectation that the beach bar would move seaward as a consequence. At present, the Kirra Point groyne estension in 2013 is unlikely to have had a major impact on the areal extent of Kirra Reef.

The reef has been relatively stable since 2013, with minor (< 5%) changes in the amount of reef exposed. Nonetheless, the areal extent of Kirra Reef remains less than 50% of the extent recorded in 1962 and in 1995 before the TRESBP began. In 2015, the reef comprises the northern section and a part of the eastern section of the reef as recorded pre-TRESBP (all the southern section of the reef remains buried).

Changes to the Ecological Condition of Kirra Reef

The Project's EIS did not consider the ecological consequences of the reduced areal extent of reefal habitat and increased wave energy (a consequence of decreased depth) that would occur as a result of the accretion of sand around Kirra Reef. However, as the TRESBP better mimiced natural patterns of sand transport since 2009, the EIS predicted that the reef's benthic floral and faunal assemblages would return to the conditions exhibited prior to the extension of the Tweed River training walls in the mid 1960s.

Since monitoring commenced, the greatest change to the floral and faunal assemblages of Kirra Reef has been due to the loss of reefal habitat. In addition to a reduction in overall abundance of taxa, the redistribution of sand mediated through complex interactions between physical disturbance (associated with wave action, suspended sediments, sediment deposition and burial), food availability and competition, has resulted in a variety of small-scale changes to the distribution and abundance of the reef's benthic assemblages.

In April 2014 and March 2015, the diversity of assemblages had increased relative to July 2012, as had the cover of macroalgae (though it remained well below the peak of 60% cover recorded in January 2001). This is most likely due to natural succession with more mature communities being established between 2012 and 2015 when the extent of exposed rock was relatively stable. 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 low percentage cover of hard coral and soft coral. This is considered essentially natural, and characteristic of shallow, inshore reefs. Chronic physical disturbance keeps the benthic assemblages of Kirra Reef in a state of early succession. The diversity (and in some cases abundnace) of a reef's benthic assemblage is predicted to increase where the extent of reef remains stable or increases, and where the frequency and severity of storm conditions are less than the long-term average. This was evident in 2014 and 2015 with a relative high cover of sponges and ascidians.

In March 2015, a more diverse assemblage of fish was found on Kirra Reef than on Palm Beach 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 were 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 (with sand covering much of the reef area), overall the composition of the flora and fauna assemblages on Kirra Reef were 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. It is possible that as sand levels have stabilised over the past three years, assemblages are slowly beginning to become more similar to those recorded prior to implementation of the TRESBP, and to those at nearby Palm Beach Reef.

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 near-shore area around the reef. This increase in bed levels was responsible for covering a substatial amount of the reef and subsequently increasing the incidence of wave disturbance and sand scouring around the reef, which negatively impacted the benthic fauna and flora.

As the delivery of sand through the bypassing system now more closely 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 natural processes, than a discrete impact of the sand bypassing activity. Short-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 extension of the training walls.

There appears to be a relationship between the area and / or distribution of rock exposed and storm events at Kirra Reef. Notably, a series of storms in 2009 and stormy conditions between late 2011 and 2012 correspond to large areas of rock becoming exposed. Further, storms in early 2013 corresponds to a clear change in the distribution of rock at Kirra Reef. Since 2013, storm conditions have been calm to moderate and there has been little change in the areal extent and distrubtion of exposed rock at Kirra Reef.

The close proximity of the reef to the coast continues to subject the benthic assemblages to sand abrasion, wave disturbance and sand smothering. 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 March 2015, the areal extent of Kirra Reef was less than 50% of the area exposed in 1995 (i.e. prior to the operation of the TRESBP). This is largely due to the reduction and loss of the southern and eastern sections of the reef, which was predicted in the EIS.

frc environmental 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 and / or increases over time to become more similar with that found prior to the extension of the training walls. In this scenario, it was 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 results from 2014 and 2015 indicate that this process is slowly occurring on Kirra Reef.

The change in areal extent between 2014 and 2015 was approximately 8.5% in the northern section of Kirra Reef. A small area of the eastern section of Kirra Reef also became exposed between 2014 and 2015. Ongoing monitoring will provide insight into the rate of 'recovery' of communities. However, given the small change in areal extent of Kirra Reef and realtively similar flora and fauna communities surveyed in 2014 and 2015, monitoring could be reduced to biannually. If monitoring is reduced, a substantial change (e.g. 15%) in the extent of the exposed reef should be used to triggered annual monitoring.

1 Introduction

frc environmental was commissioned by the New South Wales Government, Department of Primary Industries, Lands; and the Queensland Government, Department of Science, Information Technology and Innovation 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, macro-invertebrate fauna and fish at sites on Kirra Reef and at comparative sites on Palm Beach Reef, in March 2015.

The current condition of Kirra Reef was compared with the current condition of nearby Palm Beach Reef, and with changes to the Kirra Reef community over time, i.e. with previous assessments of Kirra Reef undertaken in 1995, 1996, 2001, 2003, 2004, 2005, 2010, 2012 and 2014 (frc environmental 2014).

1.1 History of the Tweed River Entrance Sand Bypassing Project

The TRESBP was established in 1995 as a joint initiative of the 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 dredging material was delivered out to -10 m mean water depth from Point Danger to North Kirra, with approximately 600 000 m^3 of clean marine 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 7.0 million m^3 of pumped sand and 1.4 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 is also discharged from outlets at Duranbah Beach and occasionally at Snapper Rocks West. There is an outlet at Kirra Beach; however, this has not been used since December 2003. A placement exclusion zone has been established around Kirra Reef extending a minimum of 100 m from the reef edge (1995 extent) to prevent direct 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:

- provide much needed sand nourishment to the severely eroded southern Gold Coast beaches
- reduce the Tweed Entrance Bar, and
- clear a sand trap in the vicinity of the 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 quantity of sand movement along the coast (average natural net longshore sand drfit is estimated to be 500 000 m^3 per year in a northward direction). In 2014, a total of 450 232 m^3 was pumped through the sand bypassing system to the primary placement area at Danger Point. From January to February 2015 an additional 105 119 m^3 of sand was pumped through the system.

Dredging to clear the Tweed River entrance is also undertaken as required, to supplement the sand bypassing system. Dredging campaigns typically remove between 100 000 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. However, since 2008, there has only been one small dredging campaign (200 m^3 of dredged material in 2011).

In 2009, the Queensland government removed approximately 140 000 m^3 of sand from Kirra Beach intertidal zone to the low profile back dunes. In 2013, the City of Gold Coast extended Kirra groyne by 30 m.

1.2 Historical Context for Kirra Reef Monitoring

Kirra Reef is the collective name given to the complex of rocky outcrops located a few hundred metres offshore of Kirra Beach, at between -3 and -10 m and within the influence of wave action. It is subject to naturally shifting sands that intermittently cover and uncover the reef's rocky outcrops (TRESBP 2015a). The exposed extent of Kirra Reef has varied over the past 50 years due to natural storm events, and changes to the coastal environment such as the extension of the Tweed River training walls in the mid-1960s and commencement of the TRESBP (TRESBP 2015a). There are three major outcrops of the reef, the northern, southern and eastern sections, which have been variously exposed in the past (refer to Table 1.1 and Figure 1.1).

Monitoring of Kirra Reef is required under a project-specific Environmental Management System (EMS) prepared by the TRESBP in February 2001[1]. 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 the marine biota of Kirra Reef is required.

frc environmental completed a baseline assessment of Kirra Reef in April and June 1995 (Fisheries Research Consultants 1995a) (Fisheries Research Consultants 1995b) and has undertaken nine subsequent ecological monitoring surveys of the reef on behalf of TRESBP, in February 1996, January 2001, May 2003, March 2004, February 2005, February 2010, July 2012, April 2014 (Fisheries Research Consultants 1996; frc environmental 2001; 2003; 2004; 2005; 2010), and the current survey in March 2015.

1.3 Temporal Changes in the Area of Exposed Reef

A reduction in the exposed extent of Kirra Reef was predicted in the project's EIS (Hyder Consulting 1997). It was also expected that Kirra Reef would return to pre-1960's conditions, before the extension of the Tweed River breakwaters that interrupted the northerly movement of sand were constructed (Lawson et al. 2001).

Prior to 1960, Kirra Reef was partially covered by sand, which varied naturally with the natural supply of sand and wave energy. During the 1960's following the extension of the Tweed River training walls between 1962 and 1965, Kirra Reef became increasingly exposed due to the depleted sand supply (note the increase in area of Kirra Reef from 1962 to 1972 in Table 1.1). Following the Kirra Point groyne contruction in 1972, there was further depletion of sand supply and Kirra Reef was perennially exposed (note the increase in area of Kirra Reef from 1972 to 1995 in Table 1.1; refer to Figure 1.1 for the extent of reef in 1995). Kirra reef groyne was shortened (from 175 m to 145 m) in 1996.

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[1] The ongoing reef monitoring also incorporates additional monitoring activities implemented by the TRESBP in August 2004.

Accumulation of sand on Kirra Reef was observed as a result of indirect sand nourishment by the TRESBP (note the decrease in area of Kirra Reef after 1995 in Table 1.1). Aerial photographs taken in 2003 and 2004 showed the reef to be of significantly less extent than the range of extent observed in 1962 and 1965 (Table 1.1). Loss of reef area continued for some years, and by early 2006, the area of exposed reef had been reduced to <100 m^2. 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 between 2005 and 2009, was slower than predicted (refer to Figure 1.1 for the extent of reef in 2009). 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[2].

In 2009, eight years after the initiation of sand pumping by the TRESBP began, a series of storms shifted approximately 200 000 m^3 of sand from Kirra Beach to the north. This storm was the worst protracted storm for east facing beahes in at least 14 years, with significant wave heights remaining for four days (TRESBP 2014). 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 2015a). Since 2008, sand delivery volumes of the TRESBP have been more consistent with the natural quantity of sand movement along the coast. Ecological surveys recommenced in 2010, as the exposed areas of Kirra Reef increased in extent.

Between November 2011 and August 2012, there was a large increase in the northern section of Kirra Reef, when the area of exposed rock more than doubled (Table 1.1; Figure 1.1). This corresponds to a ‘stormy year’, with one severe storm and two major storms recorded (TRESBP 2015b). Further stormy conditions were recorded in early 2013, with one extreme storm (approximately 1:10 year event) in January and one major storm in February (TRESBP 2015). There was little change in the total area of exposed reef during this time (note the similar area of August 2012 and May 2013 in Table 1.1). However, there was clear distribution changes in the areas of exposed rock (Figure 1.1). The reef area has remained relatively stable since 2013, with minor changes in the area of rock exposed (Table 1.1; Figure 1.1). Wave height data since 2013 indicates calm to moderate conditions, with only minor storms recorded, except in May 2015 when there was a severe storm (TRESBP 2015). In late 2013, Kirra Point groyne was reinstated by 30 m to its orginal constructed length. Given the minor changes in the exposed rock since

[2] Underwater visual inspections were completed by Gilbert Diving and Gold Coast City Council from 2006 to 2010.

2013, this extension of Kirra Point groyne is unlikely to have had a major impact on Kirra Reef.

In 2014, Kirra Reef covered an area of 2 920 m^2; predominantly in the northern section of the reef. In March 2015, this northern section covered an area of approximately 2 672 m^2 (Figure 1.1 and Figure 1.2): an 8.5% decrease in the exposed extent between 2014 and 2015. In March 2015, the rocky outcrops were typically between 1 and 2 m above the clean mobile sand, with several outcrops extending to more than 2 m above the sand. A small section (116 m^2) of the eastern reef was also exposed in March 2015 (Figure 1.1 and Figure 1.2). However, the reef area remains less than 50% of the extent recorded in 1962 and 1995 before the TRESBP began (Table 1.1; reef area between 1962 and 1965 was between 7 000 and 13 300 Department of Land and Water Conservation, photogrammetric analysis).

Table 1.1 Approximate exposed extent of Kirra Reef

Date	Area (m²) Northern Section	Southern Section	Eastern Section	Total	Source of Image
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 Murry 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 Murry 1997 [2]
Nov 1974	6 078	-	-	> 6 078	Rectified image, Boswood and Murry 1997 [2]
Feb 1972	5 480	0	16 631	22 111	Rectified image, Boswood and Murry 1997 [2]
Oct 1962 [1]	-	3 841	742	> 4 583	Rectified image, Boswood and Murry 1997 [2]
Nov 1935	1694	-	1 656	> 3 350	Rectified image, Boswood and Murry 1997 [2]
Sep 1930	5016 [3]	-	1 047	> 6 063	Rectified image, Boswood and Murry 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.

- Images not clear enough to calculate extent.

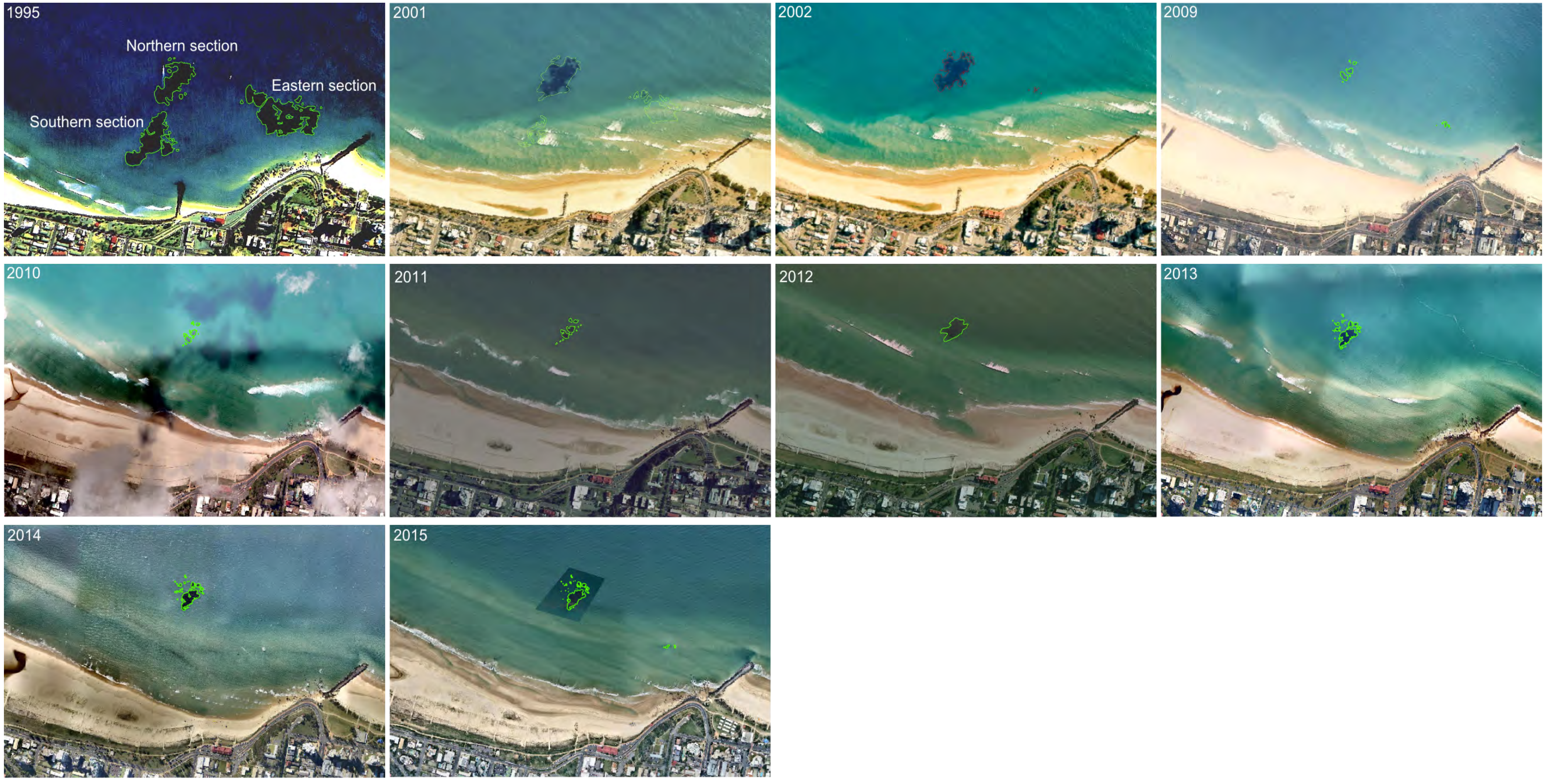


Figure 1.1 Extent of Kirra Reef in 1995, 2001, 2002, 2009, 2010, 2011, 2012, 2013, 2014 and 2015

Figure 1.2 Extent of Kirra Reef in March 2015 (image source: NSW Trade & Investment).

1.4 Faunal and Floral Characteristics of the Survey Region

The south-east Queensland (SEQ) region comprises five sub-regions: the Gold Coast, Inner Moreton Bay, Outer Moreton Bay, Sunshine Coast and Fraser Coast. Coral communities within SEQ are diverse, with an extensive range of coral growth forms (Harrison et al. 1998). The greatest diversity of coral species are typically found at offshore sites like Flinders Reefs where 119 different coral species have been recorded (Harrison et al. 1998).

Subtidal rocky reefs of the Gold Coast region comprise remnants of highly eroded volcanic substratum isolated by wide, variable expanses of soft sediment (Edwards & Smith 2005). They support community assemblages 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).

Gold Coast reef communities 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 (Julian Rocks offshore of Byron Bay), that are dominated by macroalgae and sessile invertbrates (Fisheries Research Consultants 1991; Harriott et al. 1999; Edwards & Smith 2005; Baronio & Butcher 2008; Fellegara 2008; Schlacher-Hoenlinger et al. 2009). Many of the Gold Coast's reefs located close to shore are often affected by human activities (Noriega 2007), and typically have less coral cover. In a 2013 survey of SEQ reefs, Gold Coast reefs had the lowest hard coral cover at 9% (Hutchinson et al. 2013).

Fish of the Gold Coast region are similar in community composition to that recorded offshore of Moreton Bay, at Julian Rocks and the Solitary Islands, offshore of Coffs Harbour, and to a lesser extent at 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, such as Kirra Reef, typically support a lower abundance and diversity of fishes (Edwards & Smith 2005; frc environmental 2005).

Kirra Reef

The benthic assemblages of Kirra Reef are characterised by a high cover of macroalgae and turf algae, and a moderate cover of sessile benthic invertebrates, including a few hard corals (Edwards & Smith 2005; frc environmental 2005). Turf alage covers the majority of the reef substrate. Crinoids (feather stars), ascidians (sea squirts), and sponges are typically the most abundant benthic fauna, whilst anemones, soft corals and urchins are present in low numbers (frc environmental 2014). The composition of benthic assemblages at Kirra Reef is broadly similar to that described from adjacent rocky reefs

(Hollingsworth 1975; Edwards & Smith 2005), and also those of the southern Queensland and northern New South Wales bioregions (refer Harriott et al. 1999; Baronio & Butcher 2008; Fellegara 2008; Schlacher-Hoenlinger et al. 2009).

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 around the base of Kirra Reef appears to be a major factor influencing the abundance (cover) of benthic flora and fauna, periodically resulting in a bare stratum on rocks within 0.8 to 1 m of the seafloor. Outcrops on the eastern section of the reef complex, 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 1995a); (Fisheries Research Consultants 1995b); (Fisheries Research Consultants 1996); (frc environmental 2003); (frc environmental 2004); (frc environmental 2005); (frc environmental 2010).

Strong wave action results in sustained abrasion of the dominant brown macroalgae (*Sargassum flavicans* and *Ecklonia radiata*), causing the fronds to break. The continual re-suspension of algal fragments (commonly referred to as 'cornflakes') can dramatically reduce water clarity and visibility. Algal fragments were largely absent in July 2012 and April 2014 surveys, likely due to long periods of relatively benign sea conditions. In March 2015, a moderate amount of algal fragments was observed, likely due to storm activity in the weeks proceeding the survey (e.g. moderate seas 11 to 14 February and minor storm over 19-22 February).

Palm Beach Reef

Palm Beach Reef is an extensive rocky reef, located between the mouths of Tallebudgera Creek to the north and Currumbin Creek to the south. The Palm Beach comparision sites lie within the inner section of the reef, approximately 400 metres off the beach in 9 to 12 meters of water (compared to 3 to 10 meters at Kirra Reef).

Recent surveys at Palm Beach Reef completed by Reef Check recorded a decline in hard coral cover from 2008 to 2013 (Hutchinson et al. 2013). Sessile invertebrates, including sponges, corals and ascidians, typically dominate the benthic assemblage of Palm Beach Reef (Edwards & Smith 2005; frc environmental 2005; Reef Check 2010). The cover of sessile invertebrates 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. Elevated turbidity together with greater water depth and a high abundance of grazing species, such as urchins, is likely to contribute to a relatively low cover of macroalgae and abundant suspension feeding organisms such as ascidians, sponges, hydrozoans and crinoids at Palm Beach Reef (Smith et al. 2005).

Palm Beach has a lower abundance and diversity of benthic, demersal and pelagic fish compared to Kirra Reef (Smith et al. 2005). The greater density of fish at Kirra Reef may be a consequence of the loss of reef, forcing more fish into a smaller area (Smith et al. 2005). Palm beach recorded a slightly lower diversity of fish than Kirra Reef in 2012 and 2014 surveys (frc environmental 2012; frc environmental 2014).

2 Methods

The methods used in the March 2015 survey were developed for the Stage I survey completed in April and June 1995, and used for subsequent surveys February 1996, January 2001, May 2003, March 2004, February 2005, February 2010, July 2012 and April 2014. Data were collected from Kirra Reef (-28.1625, 153.5309) and Palm Beach Reef (-28.1075, 153.4774), located approximately 9 km north (Figure 2.1).

The main objective of the monitoring was to investigate any change in the marine biota and habitat of Kirra Reef compared to Palm Beach Reef (comparative reef) in order to assess the effect of the sand bypass project (and subsequent increases in sand load) on the ecology of Kirra Reef.

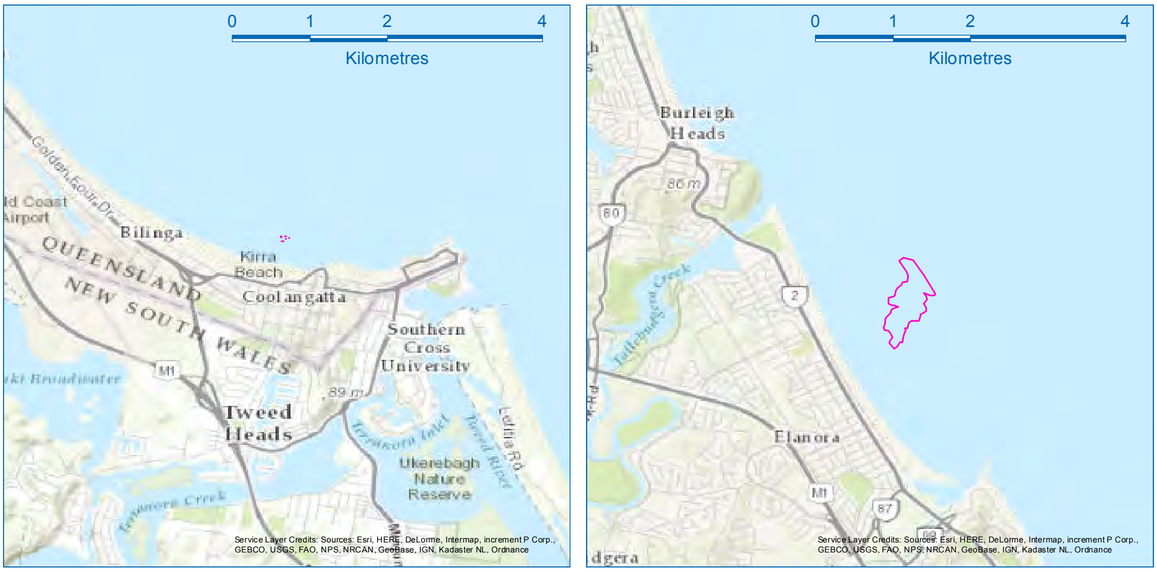
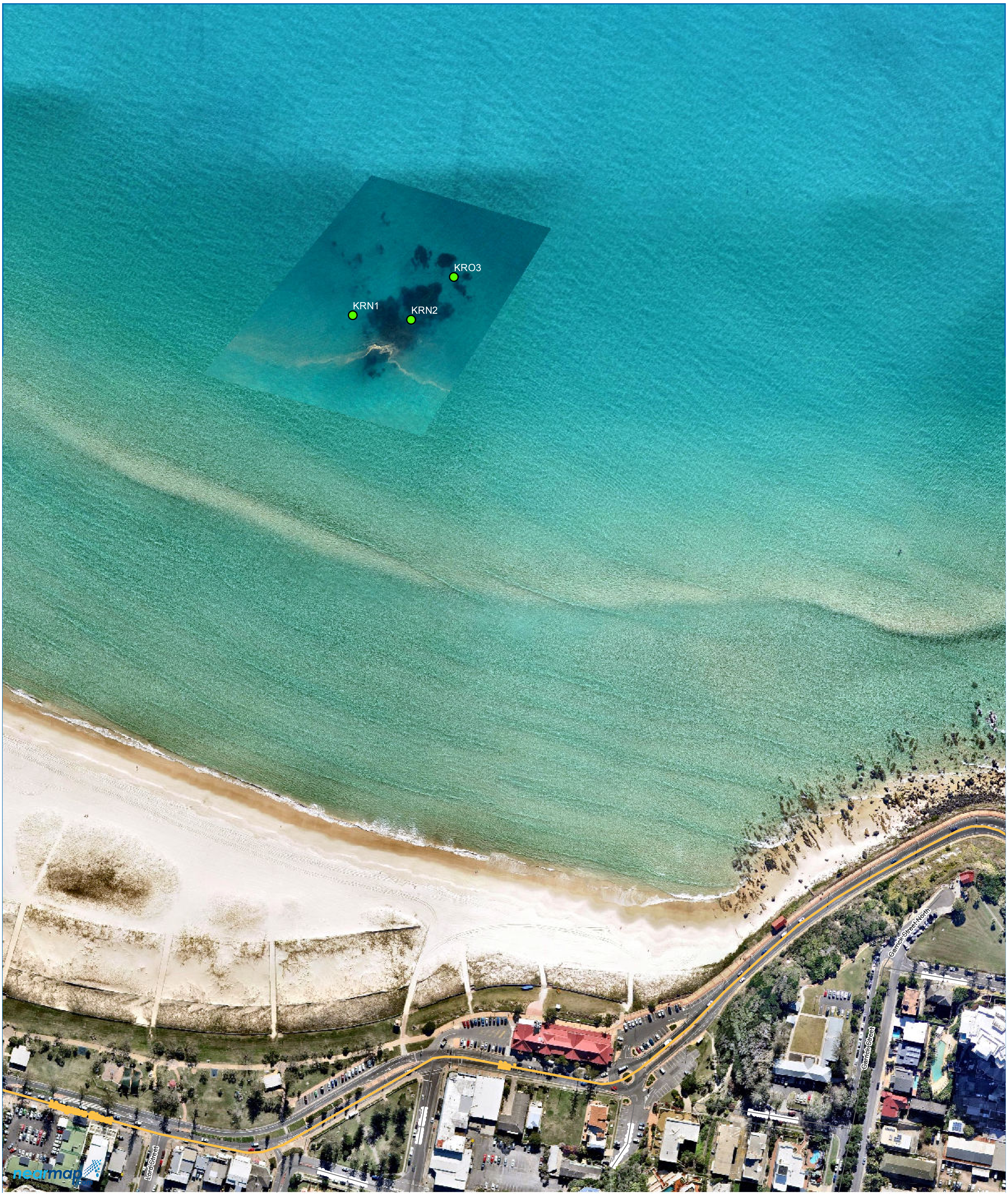


Figure 2.1 Location of (a) Kirra Reef and (b) Palm Beach Reef

2.1 Sites Surveyed

Three sites (KRN1, KRN2, KRO3) at Kirra Reef (water depth 5 to 8 m) were surveyed in March 2015 (Map 1). The remainder of the sites previously surveyed were covered by sand (refer to appendix A for a history of sites previously surveyed). Three comparative sites (PB1, PB2 and PB3) were also surveyed at Palm Beach Reef (water depth 12 to 17 m) (Map 2).



Tweed River Entrance Sand Bypassing Project
Kirra Reef Marine Biota Monitoring 2014

Map 1:
Sites surveyed at Kirra Reef in 2015

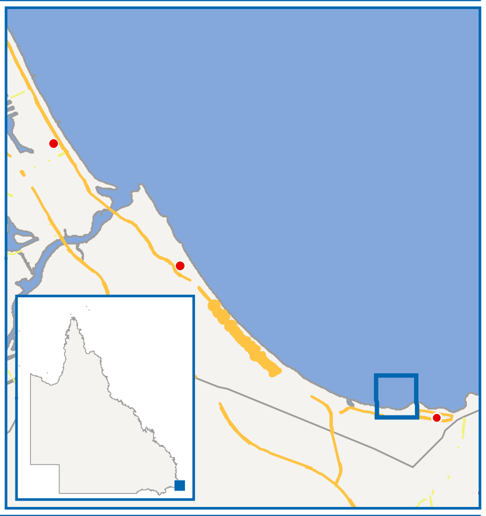
LEGEND

Survey Site

Road Network

Highway

Local Road



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DATE	DRAWN BY	VERSION	PROJECTION
2015-03-24	CF	01	Coordinate System: GDA 1994 MGA Zone 56 Projection: Transverse Mercator Datum: GDA 1994

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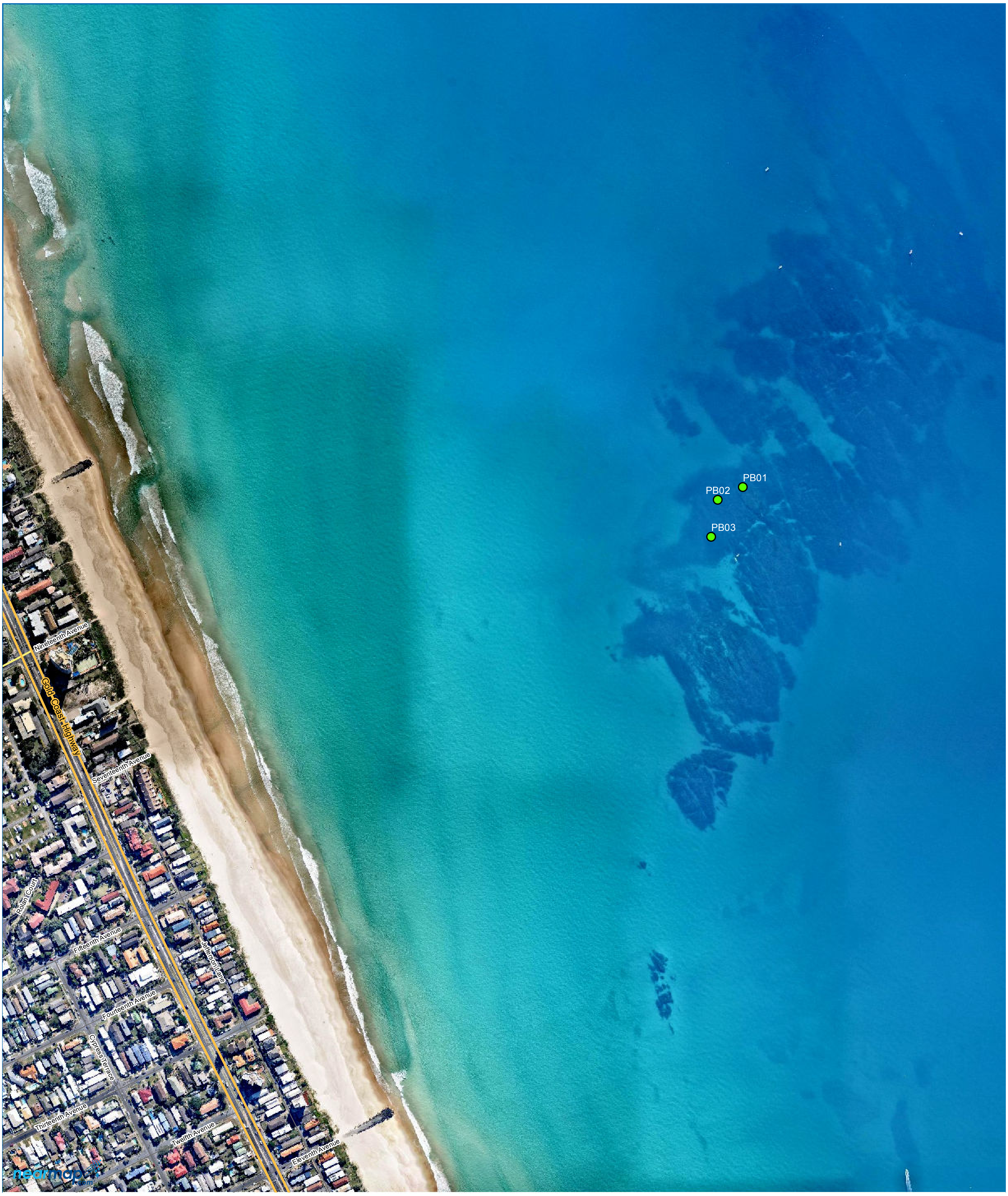

Tweed River Entrance Sand Bypassing Project
Kirra Reef Marine Biota Monitoring 2014

Map 2:
Sites surveyed at Palm Beach in 2015

LEGEND

Survey Site

Road Network

- Highway
- Main Road
- Local Road

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Document Path: Y:\Projects\2015\150211_NSWTI_Kirra_2015\Mapping\Workspaces\150211_sitemaps.mxd

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SCALE

0 50 100 200

Metres

Scale: 1:5,000 @ A3

2.2 Benthic Flora and Macroinvertebrates

At each site, benthic assemblages were surveyed in fifteen 0.25 m^2 quadrats, with the percent cover of benthic macroalgae, turf algae, sponges, ascidians, hard corals and soft corals assessed visually (Figure 2.2). Quadrats were placed haphazardly, which included horizontal and sloping surfaces. The minimum distance between quadrats was approximately 2 m. The number of large ascidians (*Pyura stolonifera*), crinoids (feather stars), barnacles, urchins, tubeworms, polychaetes, hydroids, zoanthids and cowries, and the dominant species of macroalgae were also recorded, and quantitative notes were made on the apparent health of each taxonomic group.

The capture of data for each quadrat took between approximately 2 and 5 minutes.

Figure 2.2

Diver surveying benthic assemblages at Kirra Reef in March 2015.

2.3 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). A baited remote underwater video (BRUV; baited with pilchards), and footage captured by a diver swimming hapazard trasects over the reef were recorded.

Video footage from each BRUV (approximately 20 minutes) and video transects (approximately 35 minutes) was reviewed by an ecologist experienced in marine fish identification.

2.4 Data Analysis

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. PERMANOVA uses permutational methods (*Psuedo-F*) to derive statistical significance, which require fewer assumptions to be met than analogous methods, such as multivariate analysis of variance (MANOVA) (Anderson 2001; Anderson et al. 2008). This analysis enables an examination of changes in the community as a whole.

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 as a random factor) as the factors. Data were square root transformed to down-weight dominating species abundance; converted to a Bray Curtis distance matrix; and, tested for significance using as many permutations as allowed (9800 to 9937 unique permuations achieved for all factors and factor combinations; except location where 10 unique permutations were achieved).). Post hoc pairwise test was used to determine the magnitude of difference.

Non-metric multidimensional scaling (nMDS) ordinations were used to visually represent the variation in the composition of assemblages between reefs, separately for each survey. nMDS ordinations were also used to visually represent the variation in the composition of assemblages surveys at Kirra Reef for all surveys; baseline survey in April 1995 and March 2015; and, April 2014 and March 2015.

Separate univariate PERMANOVAs were used to compare differences in the cover of macroalgae, turf algae and the abundance of crinoids and ascidians. Data were converted to a eucildean distances matrix; and, tested for significance using as many permutations as allowed (998 to 999 unique permuations achieved for all factors and factor combinations; except location where 10 unique permutations were achieved). Factors were survey (fixed factor), locations (Palm Beach Reef and Kirra Reef, fixed factor) and sites (nested in locations and a random factor). Post hoc pairwise test was used to determine the magnitude of difference. Monte Carlo procedures were used to calculate empirical P values for the survey x location test.

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

3 Results

3.1 Cover of Benthic Assemblages

The composition of benthic fauna and flora (% cover and type combined, Appendix C) varied between most sites at both Kirra Reef and Palm Beach Reef and between nearly all surveys at each site (note the significant interaction of site (location) x survey in Table 3.1; Appendix D). Nevertheless, there appeared to be substantial differences in the composition of the benthic assemblages between the two reefs in each survey from 1995 to 2015 (Figure 3.1 to Figure 3.3).

In 2015, there was some overlap in the composition of assemblages on Kirra and Palm Beach Reefs (Figure 3.3). However, there was also some clear patterns of difference, including:

- a greater cover of macroalgae at Kirra Reef; no macroalgae was recorded at Palm Beach Reef (refer to Section 3.2)
- a lower cover of soft corals and hard corals at Kirra Reef (refer to Section 3.3), and
- a slightly lower cover of turf algae at Kirra Reef (refer to Section 3.2).

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)**
survey	10	35195	10.02	0.001
location	1	393860	140.64	0.111
site (location)	4	2800.4	3.76	0.001
location x survey	10	18533	5.28	0.001
site (location) x survey	40	3512.9	4.72	0.001
error	924	744.27	10.02	

Shading denotes significance at p <0.05

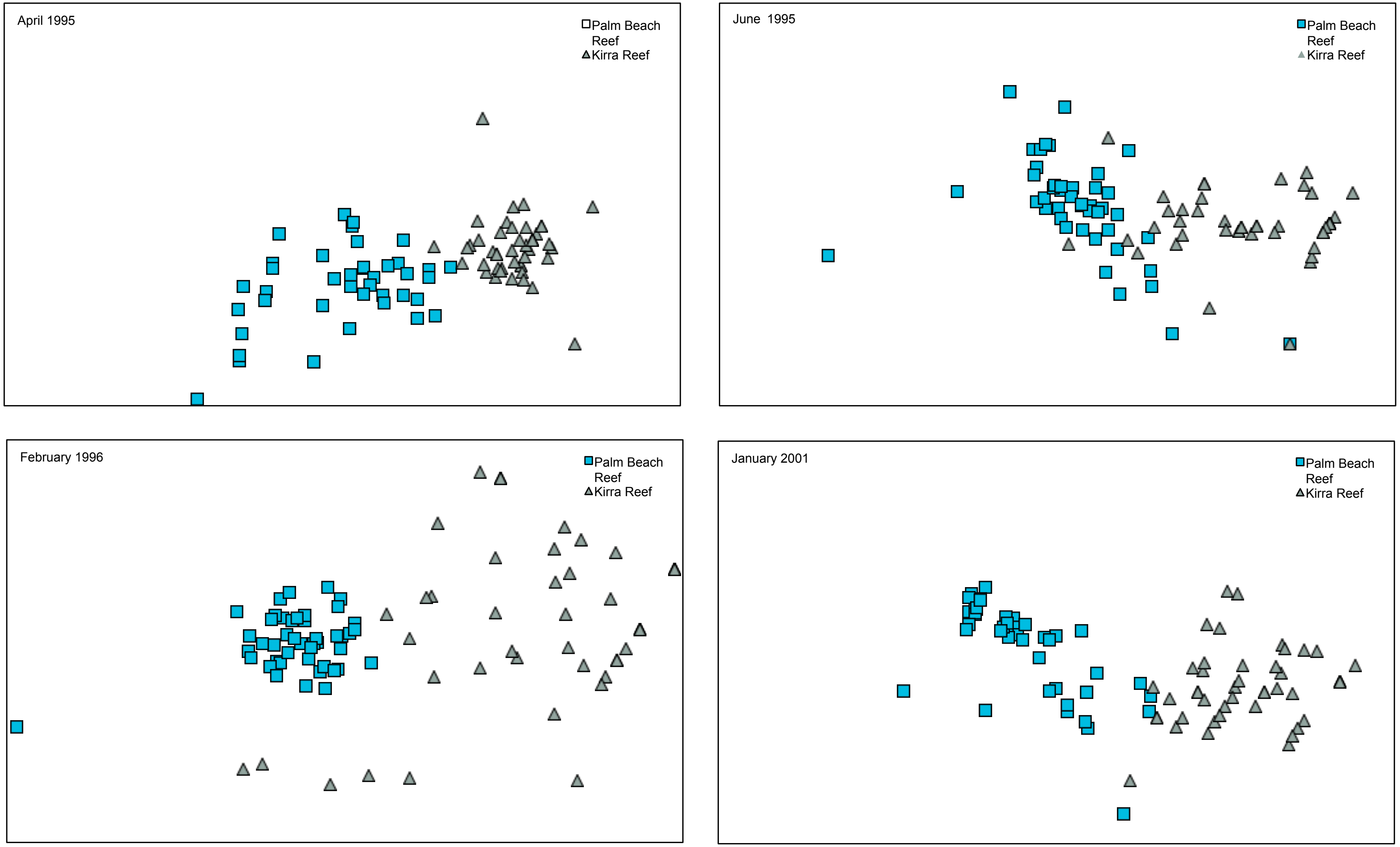


Figure 3.1 Multi-dimensional scaling plot of benthic cover in the April 1995, June 1995, February 1996 and January 2001 surveys.

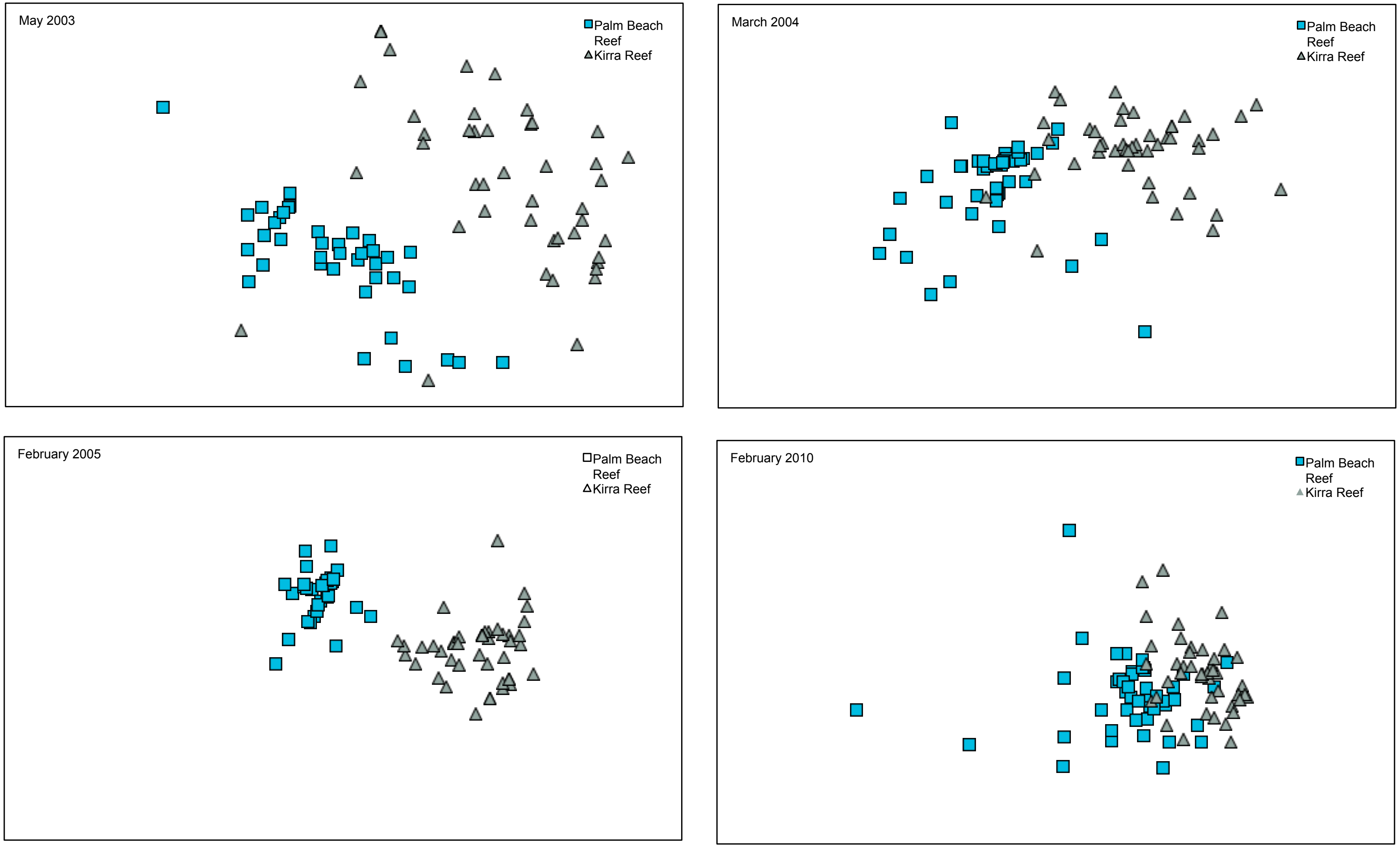


Figure 3.2 Multi-dimensional scale plot of benthic cover in the May 2003, March 2004, February 2005 and February 2010 surveys.

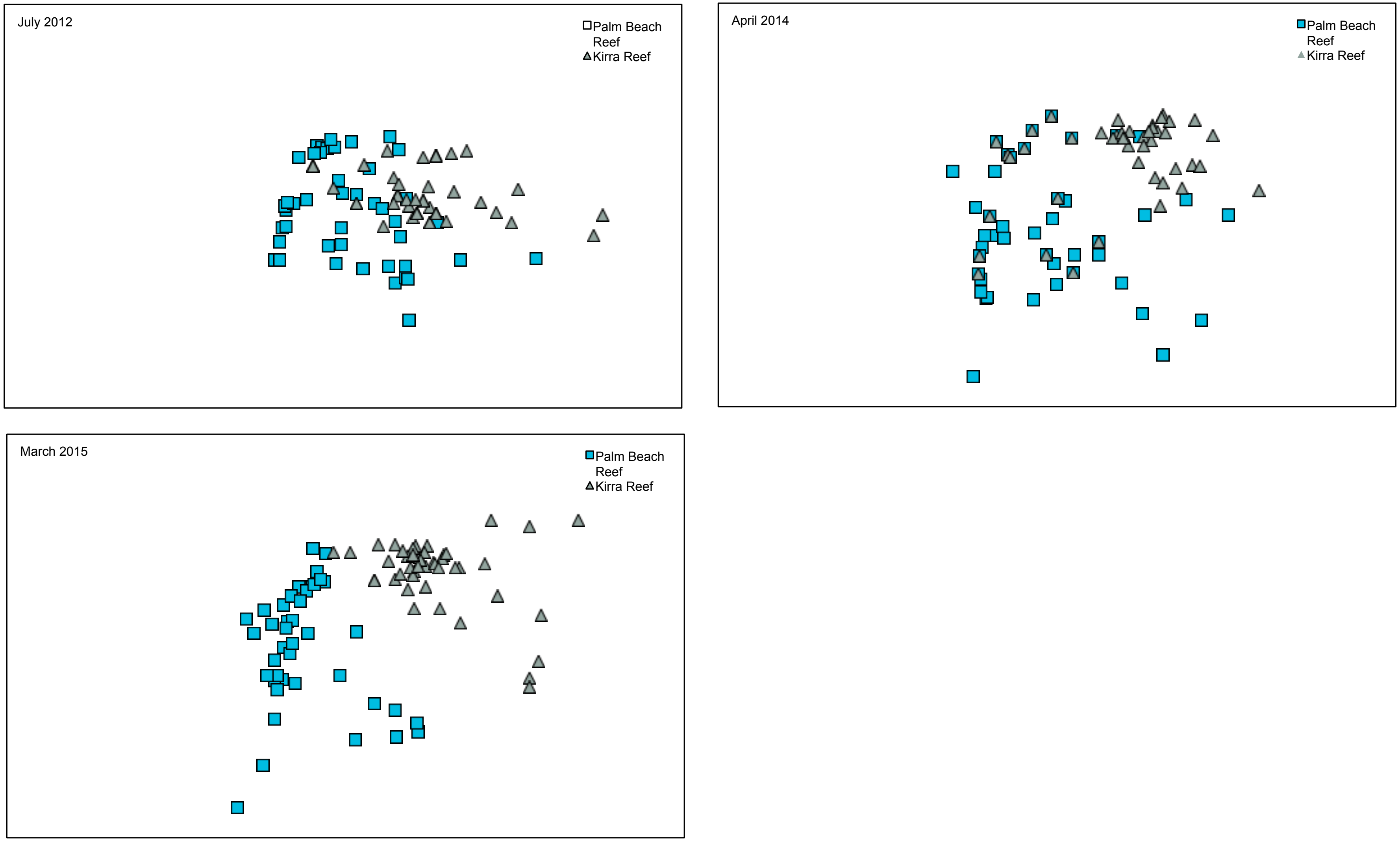


Figure 3.3 Multi-dimensional scale plot of benthic cover in the July 2012, April 2014 and March 2015 surveys.

Benthic assemblages at Kirra Reef appeared to show some overlap between surveys (Figure 3.4;). However, nearly all surveys were different at each site at both Kirra Reef and Palm Beach Reef (Appendix D). Benthic assemblages in March 2015 and April 2014 were very similar compared to benthic assemblages in the baseline survey in April 1995 and March 2015 (note the greater overlap in Figure 3.5 compared to Figure 3.6).

The benthic assemblages recorded in April 2014 and March 2015 were representative of a community in succession or exposed to frequent disturbance. There was no cover of ascidians or crustose coralline algae recorded at Kirra Reef in April 1995, but they were present in March 2015. Hard and soft corals were present in April 1995 (albeit in relatively low density), but soft corals were not recorded in March 2015, and hard corals were very rare.

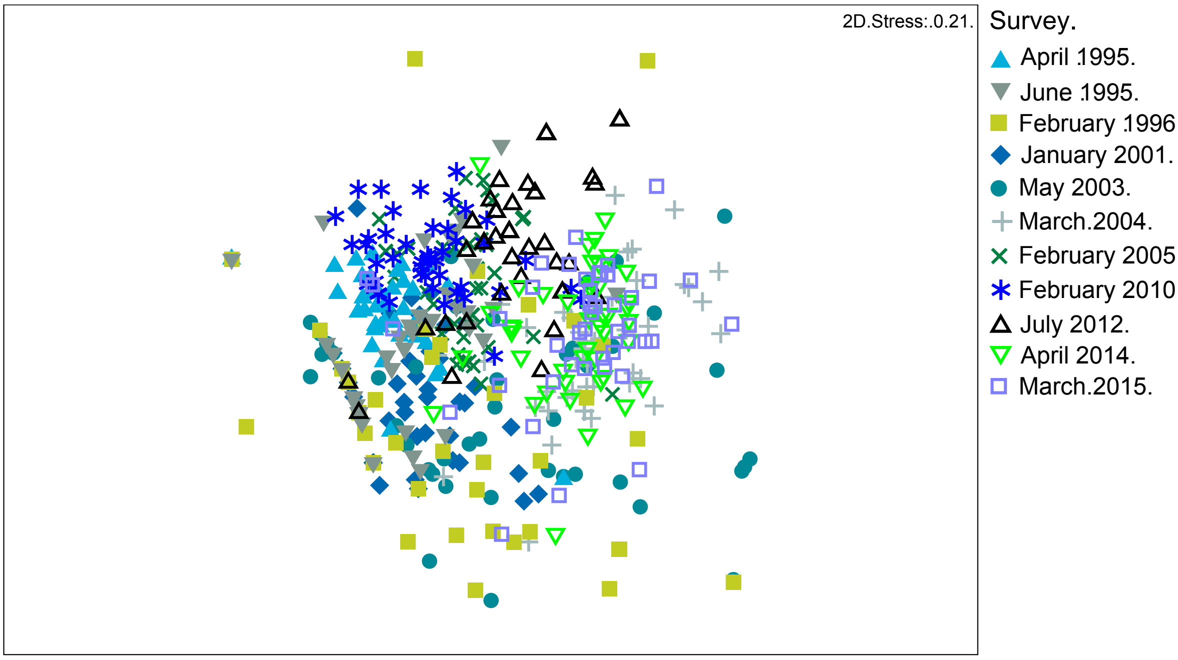


Figure 3.4 Multi-dimensional scale plot of benthic cover at Kirra Reef in all surveys

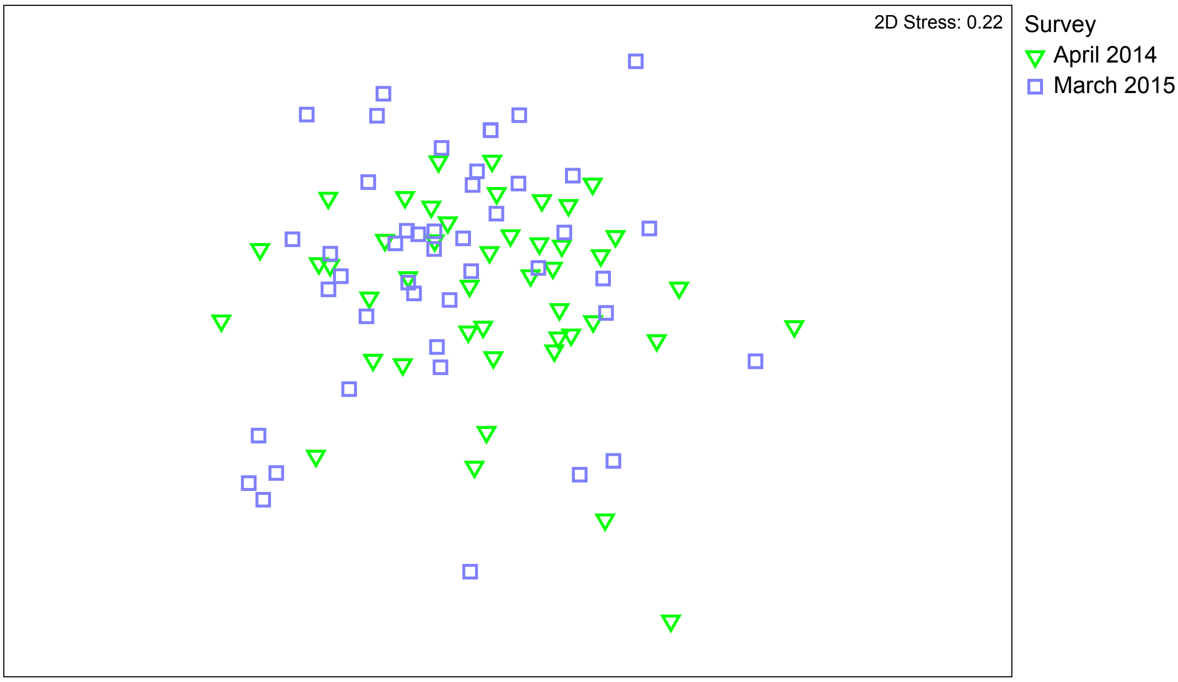


Figure 3.5 Multi-dimensional scale plot of benthic cover at Kirra Reef in April 2014 and March 2015.

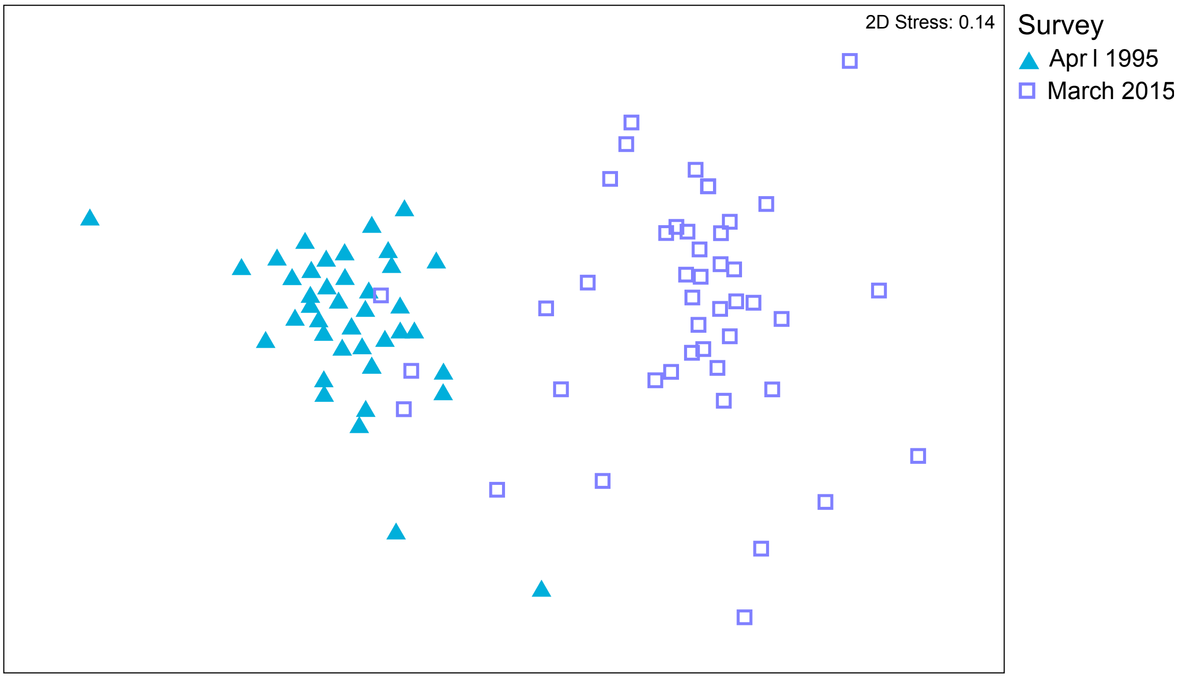


Figure 3.6 Multi-dimensional scale plot of benthic cover at Kirra Reef in April 1995 and March 2015.

3.2 Benthic Algae

Macroalgae

In March 2015, as in previous surveys, the macroalgae *Sargassum* sp. dominated the benthic assemblages at all sites at Kirra Reef (Figure 3.7). Other species present included:

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

Juvenile kelp (from the genus *Macrocystis*) was also emerging on some areas of Kirra Reef.

The cover of macroalage varied between sites and surveys at both Kirra Reef and Palm Beach Reef, with the magnitude of difference varying over time (note the significant interaction between site (location) x survey in Table 3.2). Macroalgae cover varied between surveys, with 2001 being the most different to the other years (Appendix D). There were differences between sites at Kirra Reef in June 1995, February 1996, January 2001, May 2003, February 2005 and February 2010 and between sites at Palm Beach Reef in January 2001 and February 2010. In recent surveys (2012 to 2015), the cover of macroalgae at sites at both Kirra Reef and Palm Beach Reef was similar (Appendix D), indicating a relatively consistent distribution across both reefs.

The mean cover of macroalgae at Kirra Reef has declined since its peak in 2001, with the greatest magnitude of decline recorded between January 2001 and May 2003 (Figure 3.8). In surveys between June 1995 and May 2003, *Sargassum* sp. formed dense carpets over the rocky substrate, covering up to 58% of the available surface area of the reef. In February 2010 macroalgal cover was 12%. Macroalgal cover has increased to 26% in March 2015. This is similar to the cover recorded in April 1995 (23% cover) (Figure 3.8).

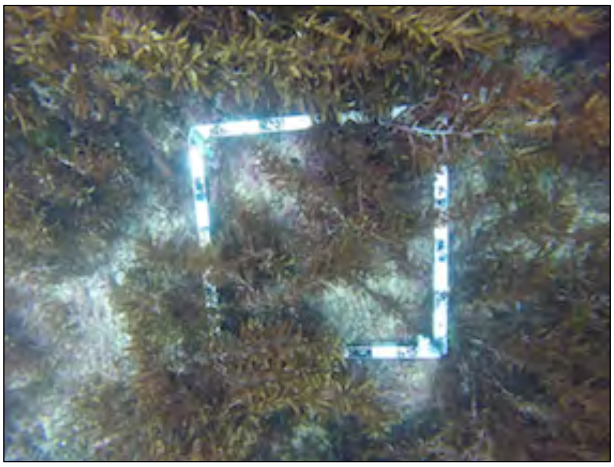
In 2015, no macroalgae was recorded within the quadrats at Palm Beach Reef. The cover of macroalgae on Palm Beach Reef has been consistently lower than Kirra Reef since ecological monitoring began: typically less than 5% of the available surface area (Figure 3.8).

Macroalgae species recorded previously at Palm Beach Reef, included:

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

Figure 3.7

Sargassum sp. dominated the macroalgal communities of Kirra Reef in March 2015.



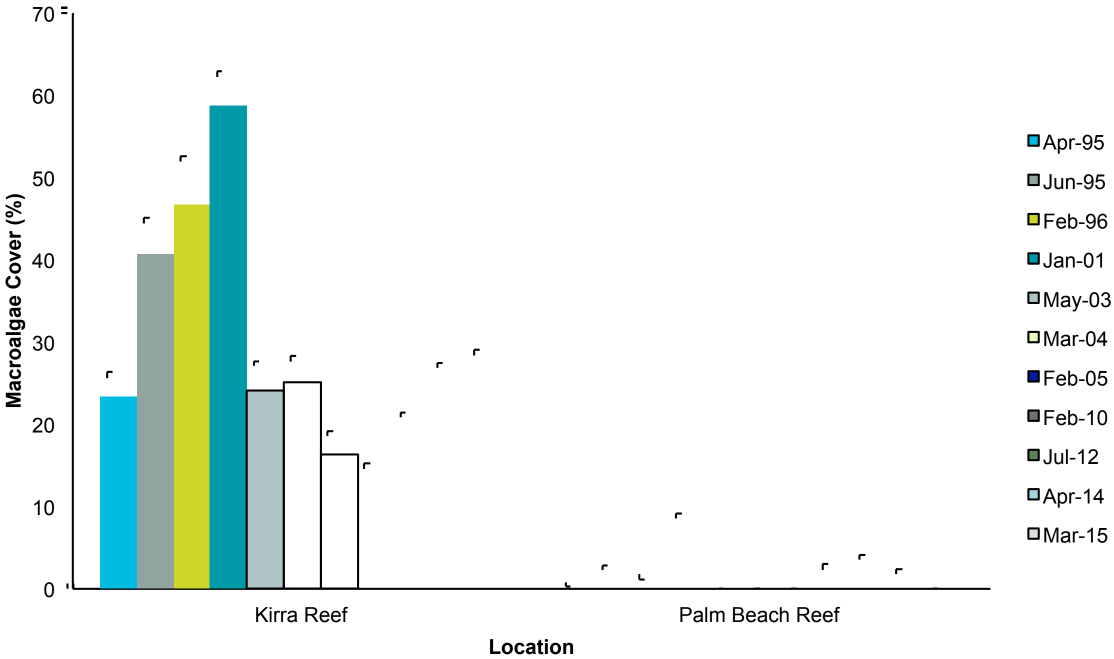


Figure 3.8 Mean cover of macroalgae (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.2 Univariate PERMANOVA results for differences in the cover of macroalgae between surveys and location.

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	5404.1	5.1714	0.002
location	1	184730	53.381	0.096
site (location)	4	3460.6	20.612	0.001
location x survey	10	3723	3.5627	0.003
site (location) x survey	40	1045	6.2242	0.001
error	924	167.89		

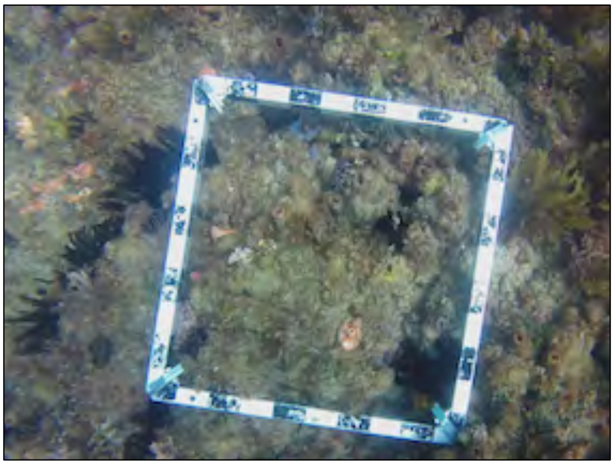
Shading denotes significance at p <0.05

Turf Algae

The mean cover of turf algae varied between sites and surveys at both Kirra Reef and Palm Beach Reef (note the significant interaction between site (location) x survey in Table 3.3). Specifically, there were significant differences between sites at both Kirra Reef and Palm Beach Reef in June 1995, January 2001, February 2010, July 2012 and April 2014 (as well as between sites in February 1996 at Kirra Reef). The cover of turf algae varied between most surveys at all sites at each reef (Appendix D). Both Kirra and Palm Beach reefs showed major increases in the percent cover of turf algae from 2010 to 2012, followed by a decrease in cover between 2012 and 2014 (Figure 3.10). The cover of turf algae is typically lower at Kirra Reef than at Palm Beach Reef (July 2012 being an exception), and was again slightly lower at Kirra Reef in March 2015 (Table 3.10). In March 2015, turf algae was more prevalent at Kirra Reef than during the baseline survey of April 1995.

Figure 3.9

Areas of Palm Beach Reef support little macroalgae but have a high cover of turf algae (March 2015).



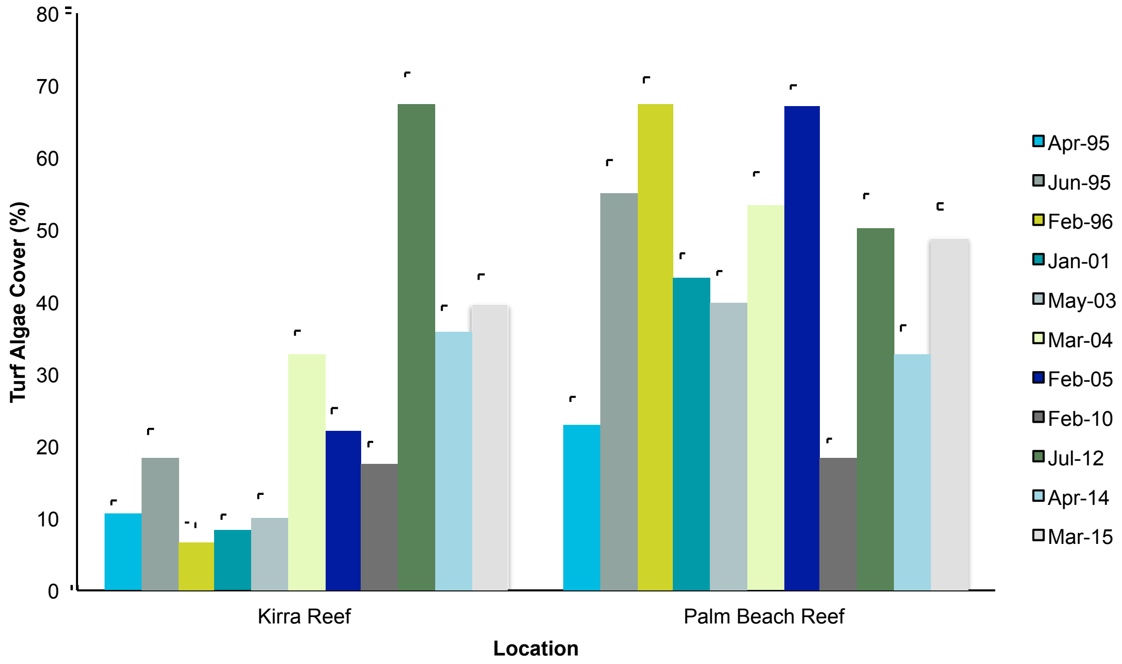


Figure 3.10 Mean cover of turf algae (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.3 Univariate PERMANOVA results for differences in the cover of turf algae between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	13782	8.7319	0.001
location	1	102450	59.896	0.115
site (location)	4	1710.5	4.9753	0.001
location x survey	10	12610	7.9896	0.001
site (location) x survey	40	1578.4	4.591	0.001
error	924	343.79		

Shading denotes significance at $p < 0.05$

3.3 Benthic Macroinvertebrates

Sponges

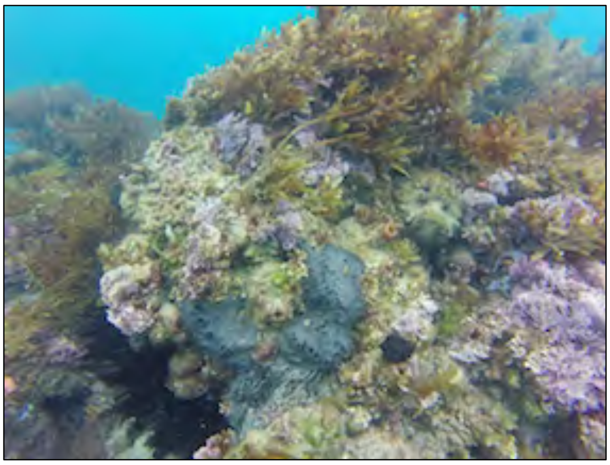
The mean cover of sponges at some sites at both Kirra Reef and Palm Beach Reef has varied significantly during some surveys (note the significant interaction between site (location) x survey in Table 3.4; Figure 3.11). However, the cover of sponges tended to be more temporally variable at Kirra Reef than at Palm Beach Reef (Figure 3.12). The cover of sponges at Kirra Reef varied between sites in February 1996, January 2001, March 2004, July 2012 and April 2014. However, the cover of sponges at Palm Beach Reef only varied between sites in January 2001 and February 2010 (Appendix D). The cover of sponges varied between survey at each site, with 1995, 1996 and 2001 most different to other years (Appendix D).

The mean cover of sponges at Kirra Reef declined between March 2004 (20% cover) and February 2010 (less than 1% cover). Since 2010, the cover of sponges has increased slightly, with sponges covering 8% of the reef in March 2015 (Figure 3.12). In March 2015, the cover of sponges was higher than recorded during the baseline survey in April 1995 (3% cover) (Figure 3.12).

The mean cover of sponges at Palm Beach Reef has declined since May 2003, but has consistently ranged between 7% and 8% since 2012 (Figure 3.12). The mean cover of sponges at Palm Beach Reef was similar to the cover of sponges at Kirra Reef in March 2015 (Figure 3.12).

Figure 3.11

Sponges at Kirra Reef in 2015.



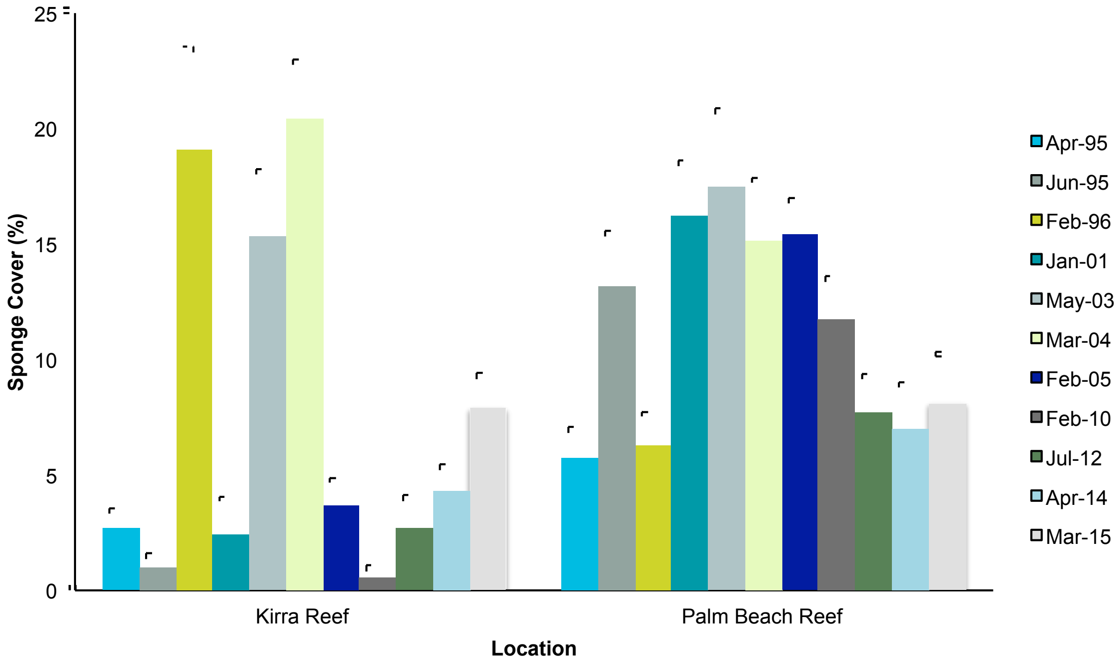


Figure 3.12 Mean cover of sponges (± SE) at Kirra Reef and Palm Beach Reef on all surveys.

Table 3.4 Univariate PERMANOVA results for differences in the cover of sponges between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	1857.6	2.76	0.018
location	1	3967.1	5.89	0.210
site (location)	4	673.54	4.77	0.001
location x survey	10	1490	2.21	0.032
site (location) x survey	40	673.31	4.77	0.001
error	924	141.08		

Shading denotes significance at $p < 0.05$

Ascidians

The mean abundance of all ascidians other than *Pyura stolonifera* has varied signifcantly between sites at Kirra Reef and Palm Beach Reef and between surveys at each site (Figure 3.14 and note the significant interaction between site (location) x survey in Table 3.5). The abundance of ascidians was different between sites at Kirra Reef in January 2001, May 2003, March 2004, February 2005 and April 2014; and different at Palm Beach Reef in January 2001, February 2005, February 2010 and March 2015. The abundance of ascidians varied between surveys at each site, with 1995 being most different when the abundance of ascidians was low (Appendix D). In March 2015, the abundance of all other ascidians on Kirra Reef and Palm Beach Reef was higher than previously reported in the baseline survey in April 1995 (when no ascidians were recorded). The mean abundance was higher at Kirra Reef than at Palm Beach Reef (Figure 3.14).

The mean abundance of *Pyura stolonifera* has varied considerably between sites at Kirra Reef and Palm Beach Reef over time (note the significant interaction between site (location) x survey in Table 3.6). In March 2015, the mean abundance (individual per 0.25 m^2 ± SE) of the ascidian, *P. stolonifera* (Figure 3.13), was similar at Kirra Reef and Palm Beach Reef (Figure 3.15). The mean abundance of *P. stolonifera* has ranged from 0.2 to 1.7 individuals per 0.25 m^2 at both reefs since May 2003.

Figure 3.13

Ascidians (*Cnemidocarpa stolonifera*) at Kirra Reef in March 2015.

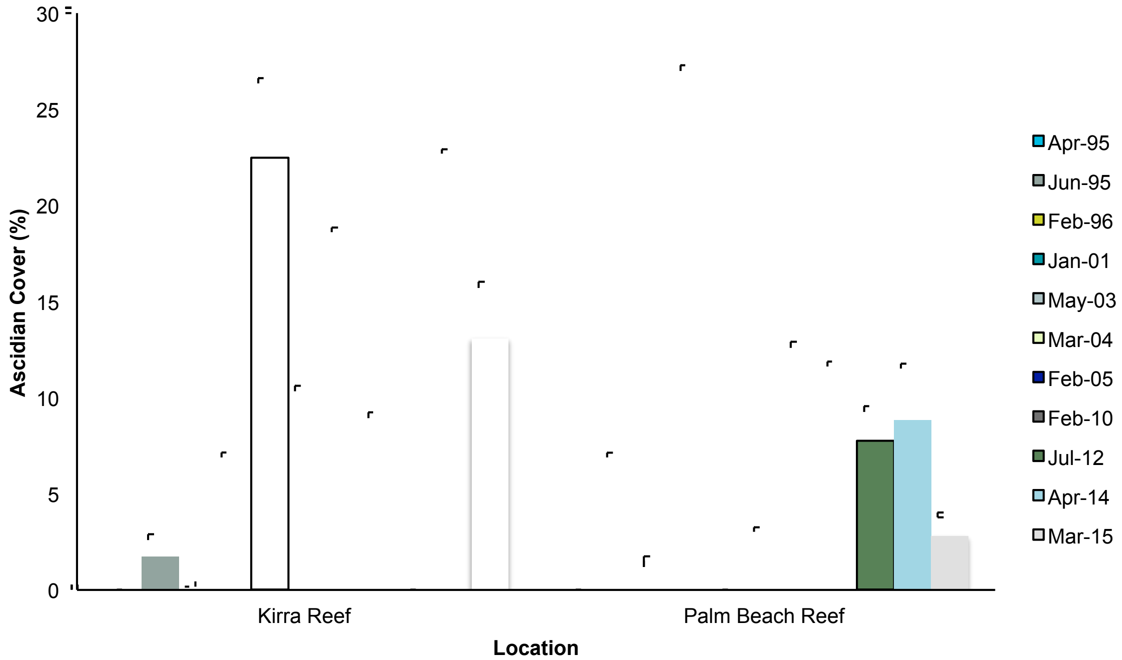


Figure 3.14 Mean cover of ascidians (± SE), other than *Pyura stolonifera*, at Kirra Reef and Palm Beach Reef in all surveys.

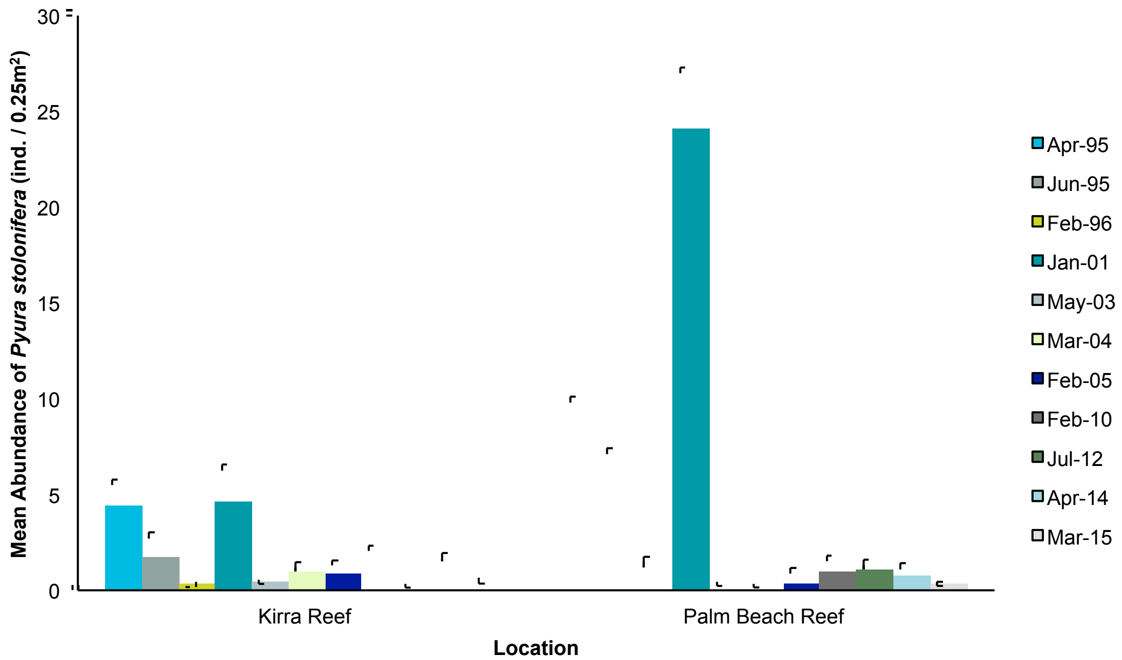


Figure 3.15 Mean abundance of ascidians (*Pyura stolonifera*) (individuals / 0.25 m^2) (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.5 Univariate PERMANOVA results for the differences in cover of all ascidians other than *Pyura stolonifera* between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	2665.8	4.74	0.001
location	1	1360.3	7.10	0.104
site (location)	4	191.54	1.49	0.212
location x survey	10	2629	4.68	0.001
site (location) x survey	40	562.1	4.38	0.001
error	924	128.28		

Shading denotes significance at p <0.05

Table 3.6 Univariate PERMANOVA results for the differences in *Pyura stolonifera* density between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	1625.4	11.842	0.001
location	1	1244.5	6.0881	0.206
site (location)	4	204.42	5.6799	0.001
location x survey	10	797.24	5.8082	0.001
site (location) x survey	40	137.26	3.8138	0.001
error	924	35.991		

Shading denotes significance at p <0.05

Hard Coral

There was a significant difference between the cover of hard corals at Kirra Reef and Palm Beach Reef during some surveys (note the significant interaction between location x survey in Table 3.7). Specifically, there was significantly more hard coral at Palm Beach Reef than Kirra Reef in Febraury 1996, March 2004, April 2014 and March 2015 (Table 3.8).

The cover of hard coral is typically low on Kirra Reef, accounting for less than 2% of the available substrate. In March 2015, hard coral covered less than 1% of the area of Kirra Reef, which was less than the cover recorded during the baseline survey in April 1995 (Figure 3.16). In contrast, hard coral covered 11% of the surface area at Palm Beach Reef, which was greater than the cover recorded in April 1995 (Figure 3.16).

The cover of hard corals at Palm Beach Reef has been more variable over time, compared to the cover of hard coral at Kirra Reef (Figure 3.16). With the exception of the surveys in April 1995 and January 2001, when the cover of hard coral was low on both reefs, hard corals are typically more prevalent at Palm Beach Reef (Figure 3.16).

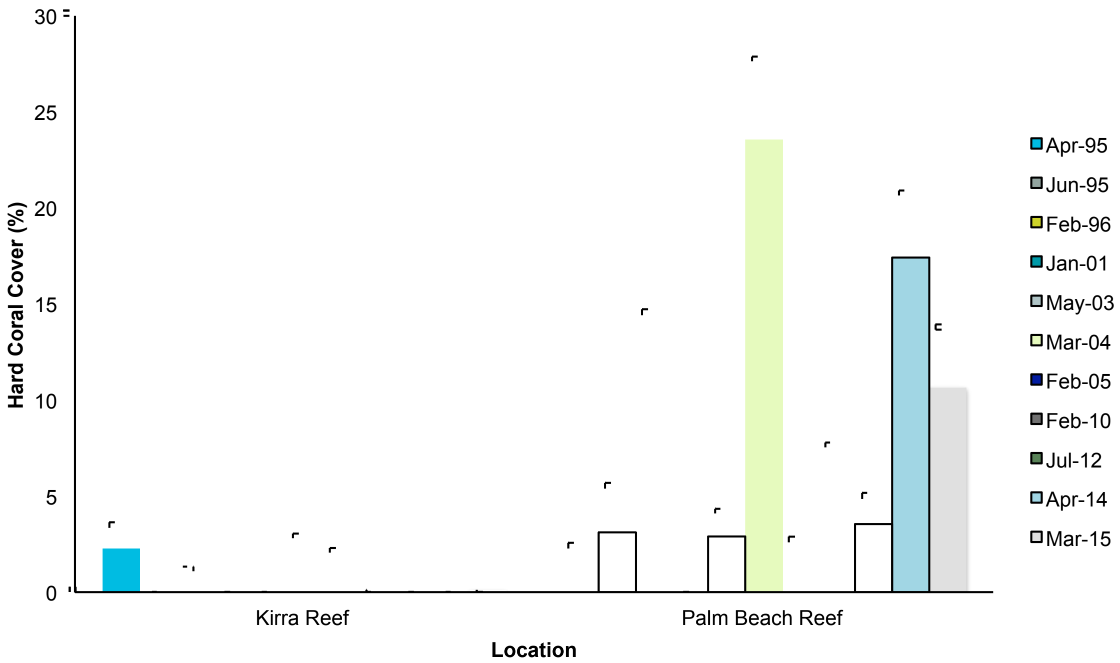


Figure 3.16 Mean cover of hard corals (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

Table 3.7 Univariate PERMANOVA results for the differences in the cover of hard coral between surveys and locations.

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	1340.9	14.52	0.001
location	1	11697	77.75	0.097
site (location)	4	150.44	1.19	0.341
location x survey	10	1250.2	13.54	0.001
site (location) x survey	40	92.341	0.73	0.917
error	924	126.12		

Shading denotes significance at p <0.05

Table 3.8 PERMANOVA post hoc pairwise results for the differences in the cover of hard coral between locations in each survey event.

Survey	Hard Corals	
	t	p (MC) [a]
Apr 1995	0.54	0.606
Jun 1995	1.82	0.140
Feb 1996	5.41	0.006
Jan 2001	-	-
May 2003	1.66	0.168
Mar 2004	7.65	0.001
Feb 2005	0.49	0.646
Feb 2010	1.56	0.197
Jul 2012	2.83	0.053
Apr 2014	5.25	0.011
Mar 2015	6.95	0.003

Shading denotes significance at p <0.05

[a] p values based on Monte Carlo tests

Soft Coral

The cover of soft coral was significantly different between sites at both Kirra Reef and Palm Beach Reef and during some surveys (note the significant interaction between site (location) x survey). There was no soft coral recorded at Kirra Reef in March 2015. The cover of soft coral has declined at Kirra Reef since 2003, and has covered less than 2% of the available substrate since 2005, which is similar to the cover of soft coral described for the baseline surveys in 1995 (Figure 3.17). The cover of soft coral was consistent between sites in each survey, except between sites in:

- April 1995 at Kirra Reef
- 1996 at Kirra Reef
- 2003 at Palm Beach Reef, and
- 2014 at Palm Beach Reef (Appendix D).

Soft corals have historically covered more of the available space on Palm Beach Reef than on Kirra Reef. However, there was more temporal variability within sites at Palm Beach Reef than at Kirra Reef (Appendix D). The cover of soft coral at Palm Beach Reef has varied over time, and was highest in April 1995 (48% cover). Despite increasing since February 2005, it is still lower than the cover recorded during the baseline survey in April 1995 (Figure 3.17).

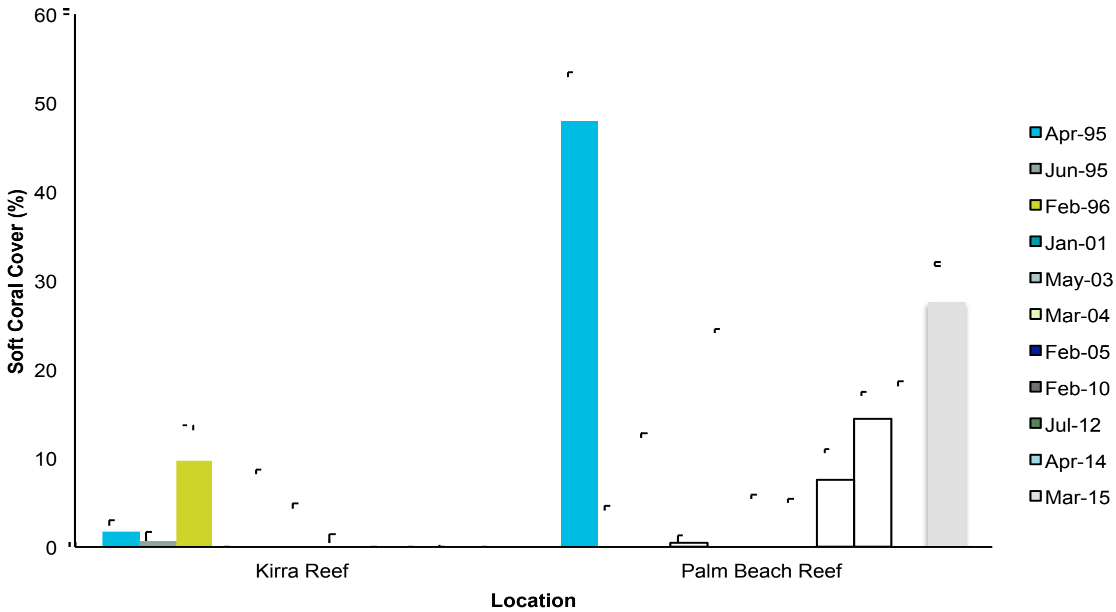


Figure 3.17 Mean cover of soft corals (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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

Factor	df	MS effect	Pseudo-F	p (perm)
survey	10	4465.7	13.23	0.001
location	1	32922	66.20	0.117
site (location)	4	497.32	2.66	0.036
location x survey	10	4098.2	12.14	0.001
site (location) x survey	40	337.6	1.81	0.002
error	924	186.88		

Shading denotes significance at $p < 0.05$

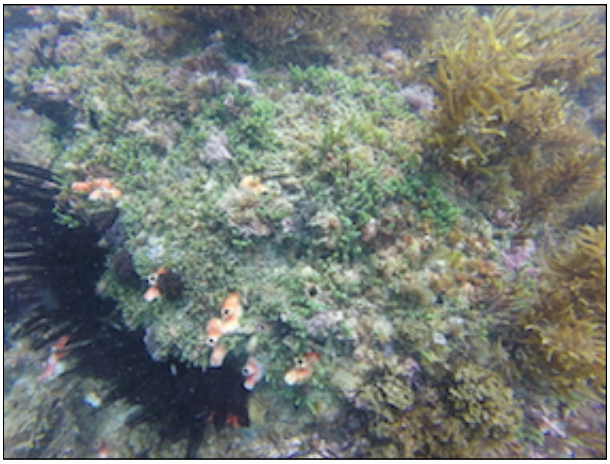
Crinoids

There is a significant difference between some sites at both Kirra Reef and Parm Beach Reef that varies through time (note the significant interaction between site (location) x survey in Table 3.10). The abundance of crinoids has been similar between sites in all years at Palm Beach Reef; and was different beween sites at Kirra Reef in June 1995, February 1996, May 2003 and February 2005 (Appendix D). Within each site, there has been some natural temporal variability, particualrly at Palm Beach Reef sites in 2001 (Appendix D). The mean abundance (individuals / 0.25 m^2) of crinoids (Figure 3.18) at Kirra Reef and Palm Beach Reef has generally been less than 2 individuals per 0.25 m^2, and has declined at both locations since the baseline survey in April 1995 (Figure 3.19). However, the mean abundance of crinoids on Kirra Reef has shown a slight increase since February 2010 (Figure 3.19).

In March 2015, fewer crinoids were recorded at Palm Beach Reef than at Kirra Reef; crinoids have been rare at Palm Beach Reef since 2003.

Figure 3.18

The distribution of crinoids (feather stars – lower left in this photo) was patchy at Kirra and Palm Beach reefs in March 2015.



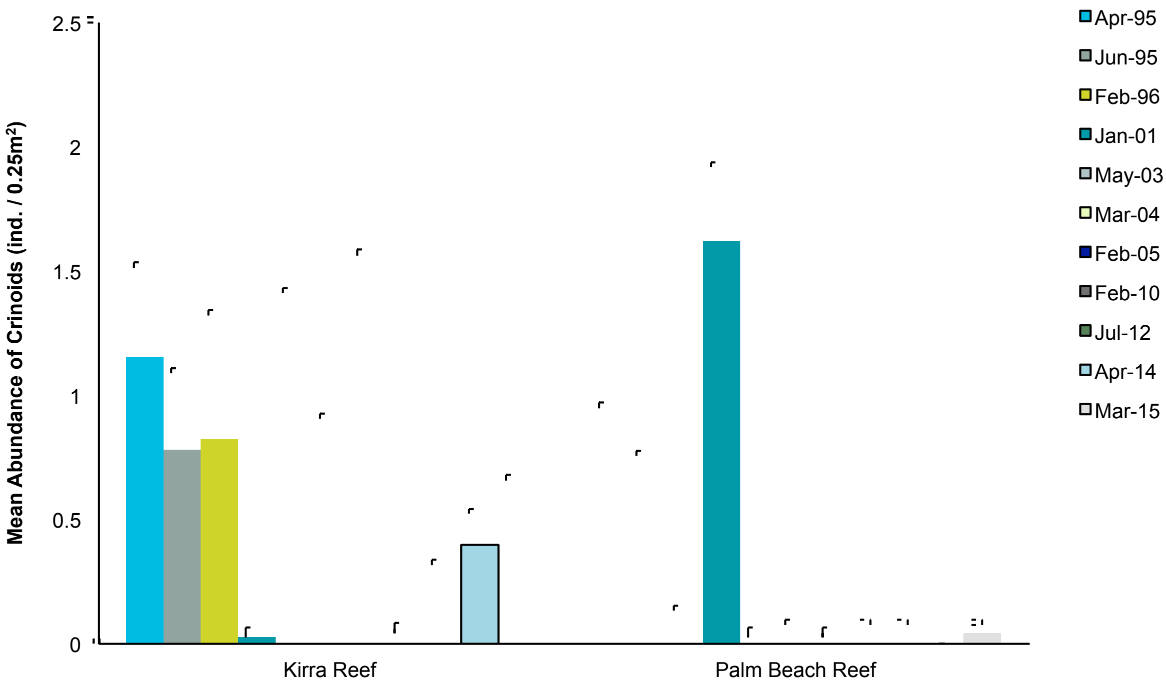


Figure 3.19 Mean abundance of crinoids (individuals / 0.25 m^2) (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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

Factor	**df**	**MS effect**	**Pseudo-F**	**p (perm)**
survey	10	6.9364	1.6147	0.147
location	1	34.945	6.5973	0.194
site (location)	4	5.297	2.7423	0.03
location x survey	10	12.783	2.9757	0.01
site (location) x survey	40	4.2959	2.224	0.001
error	924	1.9316		

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 14 to 57. In March 2015, 57 species were identified at the reef, which was similar to April 2014 (53) and higher than previous surveys (Figure 3.20). Species richness at Palm Beach Reef was lower (34 species) and generally varied less between surveys compared to Kirra Reef.

In March 2015, the assemblage of fish at Kirra Reef comprised species from all trophic levels, including detritivores, planktivores, herbivores and carnivores (Appendix E). As in previous surveys, the assemblage was dominated by herbivores and planktivores. Yellowtail (*Trachurus novaezelandiae*) and striped sea pike (*Sphyraena obtusata*) were the dominant species, present in large schools (Figure 3.21). Australian mado (*Atypichthys strigatus*), ring-tailed surgeon (*Acanthurus blochii*), silver trevally (*Pseudocaranx georgianus*), eastern pomfred (*Schuettea scalaripinnis*), sweep (*Scorpis lineolatus*) and various wrasses were also very abundant releative to other species (Appendix E).

Two new species were observed at Kirra Reef, the orange-band surgeon (*Acanthurus olivaceus*) and the unicornfish (*Naso* sp.). Five new species were recorded at Palm Beach Reef:

- Gunther's butterflyfish (*Chaetodon guentheri*)
- brown butterflyfish (*Chaetodon kleinii*)
- eastern hulafish (*Trachinops taeniatus*)
- pearly-scaled angelfish (*Centropyge vrolikii*), and
- zebra lionfish (*Dendrochirus zebra*).

No threatened or protected fish species listed under the Queensland's *Nature Conservation Act 1992* or nationally under the *Environmental Protection and Biodiversity Conservation Act 1999* were observed. The complete list of species recorded and the relative abundance is presented in Appendix E.

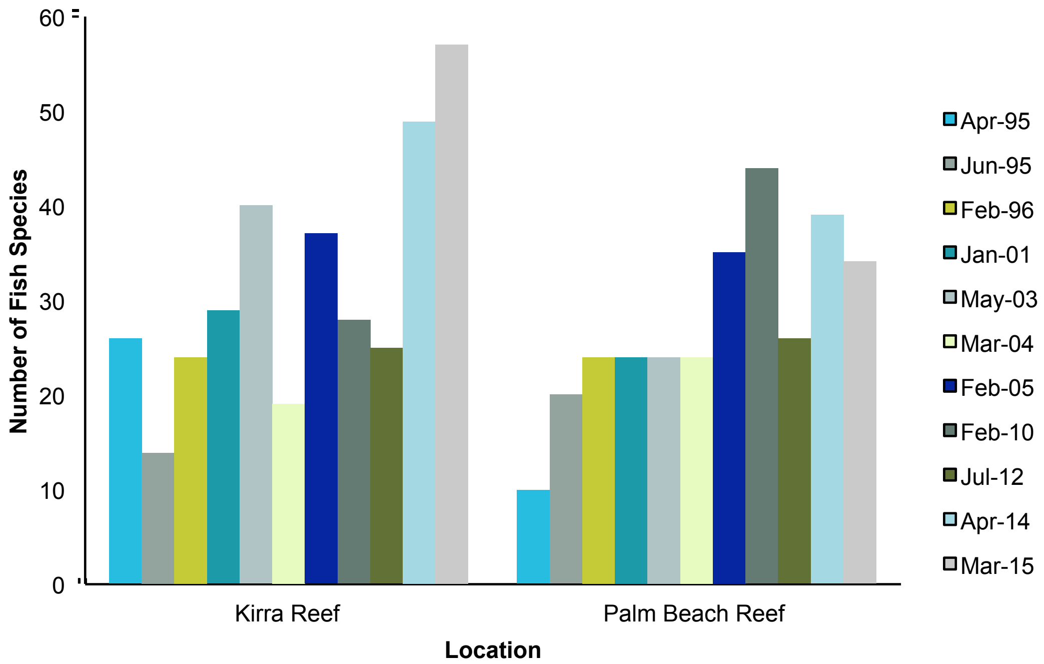


Figure 3.20 Number of fish species recorded at Kirra Reef and Palm Beach Reef on each survey.

Figure 3.21

Yellowtail continued to be abundant at Kirra Reef in March 2015.

Figure 3.22

Reef-associated fish communities at Kirra Reef in March 2015.

4 Discussion

4.1 Changes to the Ecological Condition of Kirra Reef

The greatest change to the ecological condition of Kirra Reef since the baseline survey in 1995 has been the loss of large areas of hard substrate that support benthic flora and fauna. The delivery of large sand volumes during the stage 1 dredging operations (1995 to 1998) and the initial operation of the sand bypass system (2001 to 2008) resulted in an increase in wave action and tidal currents redistributing this sand over Kirra Reef.

The three major outcrops of Kirra Reef (northern, southern and eastern sections) are naturally exposed and covered depending on water and sand movements. In March 2015, the rocky outcrops in the northern section of Kirra Reef were exposed and supported a moderately diverse benthic assemblage, dominated by turf algae. There was a relatively high fish diversity at Kirra Reef. The ecological assemblage exhibited signs of ongoing stress from physical disturbance, including the absence of soft corals and rarity of hard coral (Mumby & Steneck 2008). However, Kirra Reef has a relatively high cover of sponges and ascidians. Sponges, ascidians and crinoids were more abundant at Kirra Reef than at Palm Beach Reef in March 2015.

Kirra Reef continues to provide habitat and support important ecological functions in the region, providing hard substrate for the colonisation of algae and benthic invertebrates, and food and refuge for fish. As sand levels have stabilised since 2008, assemblages have become more similar to those recorded prior to implementation of the TRESBP in April 1995. For example, macroalgal cover in April 1995 and March 2015 was relatively similar. However, assemblage composition is still significantly different to that recorded in the baseline surveys, most noticeably due to a lower cover of bare substrate and higher cover of turf algae and ascidians since surveys have been performed.

Benthic Macroalgae

The cover of macroalgae at Kirra Reef was relatively similar during the 2014 and 2015 surveys, and remained well below the peak of nearly 60% cover recorded in January 2001. There was a steep decline in the cover of macroalgae between January 2001 and May 2003 which appeared to be strongly associated with the decline in reef area during that time as well as a decline in the cover of *Sargassum* sp. (an important indicator species on Kirra Reef). Similar declines were evident at Palm Beach Reef between the January 2001 and May 2003 surveys.

The cover of macroalgae at Palm Beach Reef was much lower than at Kirra Reef over time. There are several possible reasons for the lower cover of macroalgae at Palm Beach:

- Palm Beach Reef is 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 graze on macroalgae (McCook 1997; Jompa & McCook 2002).

Biological assemblages exposed to physical stress typically exhibit greater levels of temporal and spatial variability (Warwick & Clarke 1993; Chapman et al. 1995). 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 as well as the associated associated abrasion and smothering by sand. The effects of these physical disturbances would increase with the reduction of Kirra Reef as edge effects are pronounced and water depth is reduced. Increased smothering by sand can also reduce diversity (Hatcher et al. 1989), abundance, recruitment, growth, survival and seasonal regeneration of macroalgae (Umar & Price 1998; Cheshire et al. 1999).

Changes in the cover of macroalgae on Kirra Reef over time are also likely due to the extent of the reef changing; the fish and mobile invertbrates associated with the reef may have concentrated, which would in turn increase 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 Reef and Palm Beach Reef has varied significantly between surveys. Prior to 2005, turf algae typically covered less of the available surface area on Kirra Reef than Palm Beach Reef. In March 2015, the mean cover of turf algae has increased since baseline surveys in 1995 and was relatively similar between reefs (40 ± 4% at Kirra Reef compared to 48 ± 4% at Palm Beach Reef). The cover of turf algae at Kirra Reef was similar in 2014 and 2015, which was generally higher than previous surveys, except during July 2012 when cover of turf algae peaked at 67 ± 4%.

Turf algae are becoming a dominant component of communities around the world, likely the result of rapid colonisation of openspace after a disturbance (e.g. storms), nutrient enrichment and / or changes in grazing pressures. Turf algae can also reflect a more physically robust growth form suited to high wave energy environments (than foliose macro-algae). Turf algae peaked in the July 2012 survey, likely related to the increase in bare reef exposure following a stormy conditions in early 2009 and between December 2011 and June 2012. Turf algae have been the dominant form of algae on Kirra Reef since this time, albeit the cover lower than the 2012 survey.

Increased cover of turf algae is typically related to good light conditions, high concentrations of nutrients and low numbers of grazers such as fish (or constant grazing pressure preventing macroalgae colonisation). 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 reliably determine the mechanisms of change in both macroalgae and turf algae assemblages on these reefs.

Benthic Macroinvertebrates

At Kirra Reef, the burial and re-emergence of rocky outcrops (influenced by the TRESBP) is likely to have increased temporal variability in the distribution and abundance of benthic macroinvertebrates. Additional perturbations such as wave action and sand abrasion (each influenced through changes in bathymetry, seabed topography and water depth) are likely to have resulted in the decline in cover and diversity of the benthic macroinvertebrates at Kirra Reef between surveys, particularly between March 2004 and February 2005, and during the severe storms of 2009. 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 can affect settlement, growth rate and survival (Dodge & Vaisnys 1977; Rogers 1990).

Physical disturbance from sand burial, sand abrasion and the action of storm waves appear to keep the benthic assemblages of Kirra Reef in a state of early succession. It is common for early pioneer species, such as some macroalgae, 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).

A further indicator of the early state of succession at Kirra Reef is that the cover of hard and soft coral has remained very low (generally < 5%). In March 2015, less than 1%

cover of hard coral, and no soft coral, was recorded. This was likely related to increased physical disturbance from sand burial and abrasion; the loss of reef area since 1995; and, competition and recruitment processes..

Benthic macroinvertebrate cover may also 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 SEQ region (Schlacher-Hoenlinger et al. 2009). Therefore, hard coral is not expected to become abundant until several years after the reef has been uncovered, and only if the physical disturbance regime and supply of new recruits is sufficient to support survival and generational succession of these species. The cover of hard and soft corals at Kirra Reef were both very low and patchy prior to the start of the TRESBP.

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 some species of sponges (Kay & Keough 1981; McGuinness 1987; Walker et al. 2008). Due to increased wave action and sedimentation (which can be influenced by the TRESBP), the mean cover of ascidians and sponges was expected to be much lower on Kirra Reef than Palm Beach Reef. However, in March 2015, the cover of sponges was similar between the reefs, and the cover of ascidians (other than *P. stolonifera*) was greater at Kirra Reef than at Palm Beach Reef. This suggests that Kirra Reef is slowly recovering from the increased stress of physical disturbance such as increased wave action and sand scour and / or that wave and storm conditions have been less severe in the past few years.

Fish

Kirra Reef continues to support a high diversity of reef-associated, and pelagic (i.e. non-reef associated) fish species. Despite its diminished size compared to 1995, Kirra Reef continues to provide valuable habitat for a number 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. This likely reflects the 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 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). This suggests that periods of reef burial reduce the overall diversity of reef-associated fish species at Kirra Reef. Despite the reduction in overall reef space, there was a larger variety of habitats (such as marcoalgae and turf algae) in 2015, which was likely to be related to the high diversity of fish assemblages. This is particularly important for several species that depend on the presence of 'structure' such as provided by reef habitat (i.e. oldwife, moray eels, damselfish and Australian mado that were recorded in March 2015, but were not recorded in July 2012).

The abundance and diversity of fish are likely to be negatively affected following periods of severe weather, which create unfavourable conditions for many species, and may further exacerbate the affects of abrasion and 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 our surveys have been undertaken 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 size of the outcrops exposed, with a greater physical disturbance (from sea conditions and sand movement) and competition; and, lesser food available when the reef is covered.

The data does not support a formal consideration of seasonality.

4.2 Impacts of the Sand Bypassing System on Kirra Reef

The predicted impacts of the TRESBP on the extent of Kirra Reef were outlined in:

- 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 predicted impacts to Kirra Reef as a result of the TRESBP included accretion of sand around the base of the rock outcrops, causing a reduction in extent 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 return to its natural extent (i.e. the extent prior to extension of the Tweed River training walls in 1962). The benthic flora and fauna assemblages of the reef, the historical reef extent and natural sand transport patterns were expected to return to conditions observed before the extension of the training walls between 1962 and 1965. However, the Environmental Impact Study did not predict the ecological consequences of both the reduced areal extent and increased wave energy (a consequence of decreased depth) that have been recorded.

The current extent of Kirra Reef remains less than 50% of that recorded in 1962 and in 1995 before the sand delivery by the TRESBP commenced. However, the extent of reef in 1995 was strongly influenced by a depletion in sand following the construction of the Tweed River training walls and the Kirra Point groyne. Accumulation of sand on Kirra Reef was observed to increase as a result of indirect sand nourishment by the TRESBP, and the reef has been extensively covered (particuarly between 2005 and 2010) as a result.

While the extent of the reef continues to change over time, the delivery of sand as part of the project now more closely matches the natural rate of longshore sand transport. Short-term and seasonal changes in the extent of the reef are now likely to be the result of wave and current action (particularly during servere weather events) than a direct impact of the TRESBP. Therefore, the extent of Kirra Reef in March 2015 is broadly in accordance with predictions made in the EIS, which predicted that the reef would return to a condition similar to that exhibited in the pre-1960's, i.e. before the extension of the Tweed River breakwaters that interrupted littoral sand supply to these beaches.

In December 2013, Kirra Point groyne was extended by 30 m with the expectation that the beach bar would move seaward as a consequence. At present Kirra Point groyne is unlikely to have had a major impact on the areal extent of Kirra Reef. However, ongoing monitoring based on aerial photographs may provide further insight.

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 availability of rocky substrate for colonisation, and the availability of refuge habitats, such as crevices and overhangs, which are sheltered from wave action and sand abrasion.

From an examination of the extent of Kirra Reef from areal maps and wave height data, there appears to be a relationship between the area of rock exposed and storm events. Notably, in a series of storm events in May 2009 corresponds with large areas of rock becoming exposed (with the reef approximately 100 m^2 in 2006 and approximately in 1 009 m^2 2009). Further, a stormy conditions between December 2011 and July 2012 corresponds to the area of exposed rock more than doubling in size. While there was no change to the total area of exposed rock following stormy conditions in early 2013, there was a clear change in the distibution of exposed rock during this time. Since 2013, storm conditions have been calm to moderate and there has been little change in the areal extent and distrubtion of exposed rock at Kirra Reef.

Wave height typically increases during storm events, and given the shallow depth of Kirra Reef, waves are more likely to shoal and break across the reef during storms. This increases the physical disturbance, abrasion and sedimentation of benthic assemblages on Kirra Reef. 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 can alter fish assemblages indirectly through habitat modifications (Kaufman 1983; Jones & Syms 1998) or directly by increasing fish mortality (Lassig 1983). The hydrodynamic forces produced by wave action are an important source of disturbance in subtidal habitats, inflicting damage through direct physical impact and abrasion (Underwood & Kennelly 1990). Direct impacts from physical disturbance at Kirra Reef are evident during survey events when large fragments of macroalgae are present in the water column over the reef.

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. Disturbance-driven reductions in biodiversity have the potential to impact negatively on the health and productivity of reef ecosystems (Walker et al. 2008). Biodiversity is important to reef health 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 temporily replicated experimental design. Given there is a large collection of wave and storm data by TRESBP, this would involve greater temporal sampling of Kirra Reef, including event sampling following severe wave and storm activity.

The data generated by this Kirra Reef biota monitoring program doesn't support statistically rigorous consideration of seasonality (monitoring has been at its most frequent, annual).

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

In April 2014 and March 2015, Kirra Reef covered less than 50% of the reef's extent prior to the operation of the TRESBP. The loss of reef habitat has reduced the availability of hard substratum available for colonisation and consequently the abundance of benthic sessile assemblages.

The reduced depth of water resulting from the accumulation of sand exacerbates the effects of storms and wave action. It is likley that as a consequnece the biological communities of Kirra Reef will reflect early-stage succession, more frequently and for longer periods.

While there is sufficient structure available, frc environmental expect that Kirra Reef will continue to provide important habitat for a diverse assemblage of fishes.

5 Conclusions

Although there is still a substantial portion of the reef covered compared to before the extension of the Tweed River entrance breakwaters, 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 onwards) more closely reflects natural patterns of long-shore sand transport and is the reef has slowly re-emerged.

The extent of the reef has been relatively stable since 2013. This has allowed for some succession in the benthic assemblages, including a relatively high cover of sponges, ascidians and crinoids. With the delivery of sand more closely matching the natural rate, it is expected the reef will undergo short-term changes in extent due to seasonal shifts in sand delivery; however, the diversity of benthic assemblages on Kirra Reef is likely to increase over time. This would create more space for species to recruit, and reduces the influence of sand abrasion and wave damage. It was predicted that the areas of Kirra Reef newly exposed in 2012 would undergo a shift from turf-dominated communities to more diverse communities that could include macroalgae, sponges, ascidians and potentially hard and soft coral. With the exception of hard and soft corals, this prediction was confirmed by the results of the April 2014 and March 2015 surveys.

The diversity of fishes associated with Kirra Reef is broadly similar to that recorded prior to the commencement of sand bypassing in 1995. Given that fish are mobile, the greatest impacts on fish assemblages are likely to be short-term changes due to both the prevailing conditions and changes the extent of available habitat that provides shelter and food for a variety of different species. If Kirra Reef increases in size there is likely to be a greater proportion of cryptic benthic species as these species are more typical of assemblages in a later stage of succession (e.g. (Willis & Anderson 2003)).

Assuming a broadly stable delivery rate of sand, and consequent stable extent of Kirra Reef, 'recovery' is likley to be substantively complete. Floral and faunal communities will undergo succession between severe storm events, but are likley to remain relatively dynamic.

Monitoring in 2017 and 2020 is likley to be adequate to confirm this prediction, whilst any substantive change in the extent of Kirra Reef (>15%) may be used to trigger a 'reactive' monitoring event.

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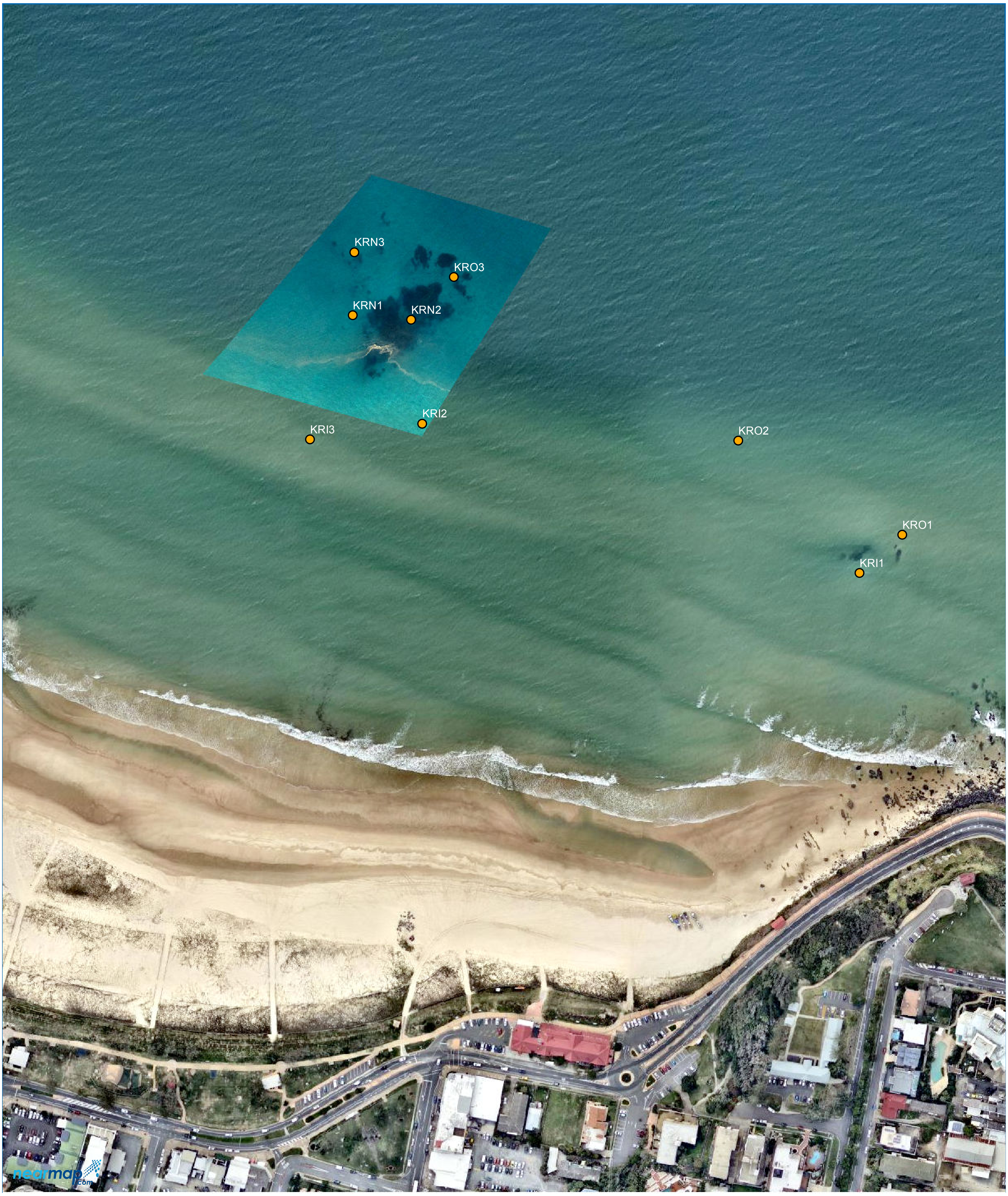
Appendix A History of Sites Surveyed at Kirra Reef

The number of sites surveyed has varied over time as a result of the fluctuating level of sand covering Kirra Reef.

Prior to May 2003, three sites were assessed along the eastern and northern edge of Kirra Reef (Kirra Reef Outer sites 1 to 3) and three sites were examined along the inshore margin of the reef (Kirra Reef Inner sites 1 to 3)(Map A1). Reef-edge (i.e. Kirra Outer) sites were chosen to provide early warning of impacts from offshore placement of dredged sand, whilst inshore sites (i.e. Kirra Inner) were chosen to indicate whether impacts from inshore beach profile development were affecting the reef platform. In May 2003, the three eastern sites at Kirra Reef (i.e. KRO1, KRO2 and KRI1) were completely covered with bare mobile sand. Consequently, only the three western sites at Kirra Reef (i.e. KRO3, KRI2 and KRI3) supported benthic flora and fauna. In March 2004, the extent of the remaining western outcrop of Kirra Reef had been further reduced, so that all inner reef sites were completely covered with mobile sand. Consequently, only a single original reef site (i.e. KRO3) could be surveyed (Figure 2.3). Therefore, to provide an indication of the condition of the remaining reef, two new sites were established (i.e. KRN1 and KRN2)(Figure 2.3), and surveyed in March 2004. The extent of the western reef had been further reduced by February 2005, and a third new site (i.e. KRN3) was established (Figure 2.3). Consequently, four sites (KRO3, KRN1, KRN2 and KRN3) were surveyed in February 2005.

In February 2010, four Kirra Reef sites (i.e. KRO3, KRO1, KRN1 and KRN2) were clear of the surrounding sand and supported benthic flora and fauna. In addition, several rocks protruded from the sand in the vicinity of site KRI2; these were assessed to provide a quantitative indication of broad-scale temporal changes to the inshore reef communities.

In July 2012, April 2014 and March 2015, several sites at Kirra Reef were covered with sand: three sites were emergent and surveyed (i.e. KRO1, KRN1 and KRN2) (Map A1).



Tweed River Entrance Sand Bypassing Project
Kirra Reef Marine Biota Monitoring 2014

Map A1:
Location of Kirra Reef monitoring sites from all surveys

LEGEND

Survey Site

frc environmental
AQUATIC ECOLOGISTS
deep thinking. science.

PO Box 2363
Wellington Point
Q 4160 Australia

P 07 3286 3850
E info@frcenv.com.au
www.frcenv.com.au

SOURCES

DATE	DRAWN BY	VERSION	PROJECTION
2015-09-09	CF	02	Coordinate System: GDA 1994 MGA Zone 56 Projection: Transverse Mercator Datum: GDA 1994

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Appendix B Introduction to Data Analysis Used

Multivariate Analyses

Multivariate statistical techniques are widely used in ecology to assess the similarities / relationships between assemblages. 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 assemblages 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 assemblages 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 assemblages. 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 assemblage structure: nearby points represent assemblages 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 A1, each freshwater macroinvertebrate sample is represented on the multi-dimensional scaling ordination. By looking at the distances between each sample, we can infer that samples (assemblages) 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.

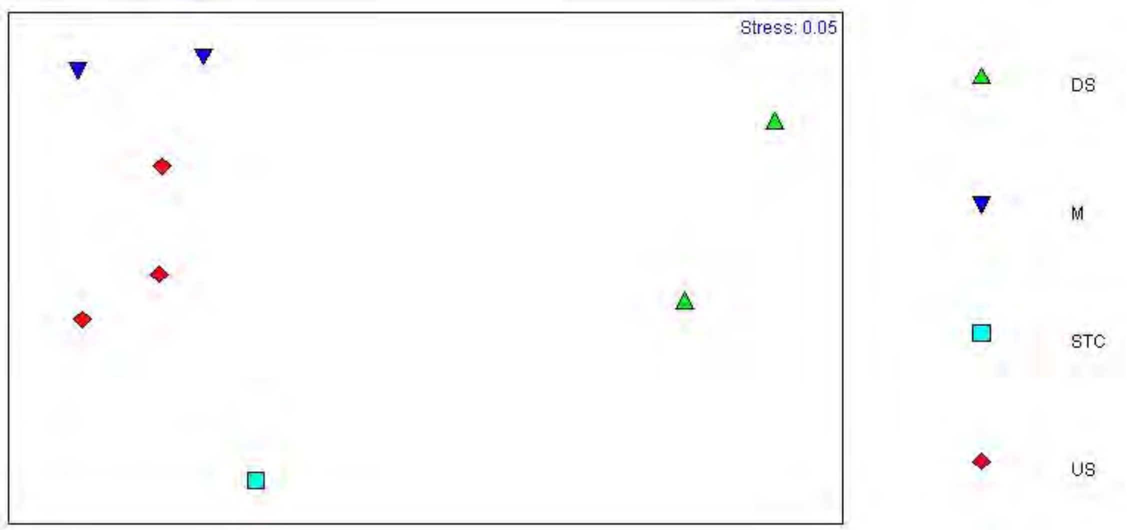

Figure B1 Example of a multi-dimensional scaling ordination for macroinvertebrate communities sampled in riffle habitats of different stream reaches.

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 assemblages 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 assemblages 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 a 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 assemblages 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 assemblages from various groups are (e.g. how similar all of the macroinvertebrate 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 assemblages, 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 assemblages, 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 C Cover and Abundance of Benthic Fauna and Flora on Kirra and Palm Beach Reefs

Data is available on request from:
tresbp.projectoffice@crownland.nsw.gov.

Appendix D Pairwise PERMANOVA Results

Data is available on request from:

tresbp.projectoffice@crownland.nsw.gov.

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

Data is available on request from: tresbp.projectoffice@crownland.nsw.gov.au