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

frc environmental

PO Box 2363, Wellington Point QLD 4160
Telephone: + 61 3286 3850
Facsimile: + 61 3821 7936

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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)				Source of Image
	Northern Section	Southern Section	Eastern Section	Total	
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.

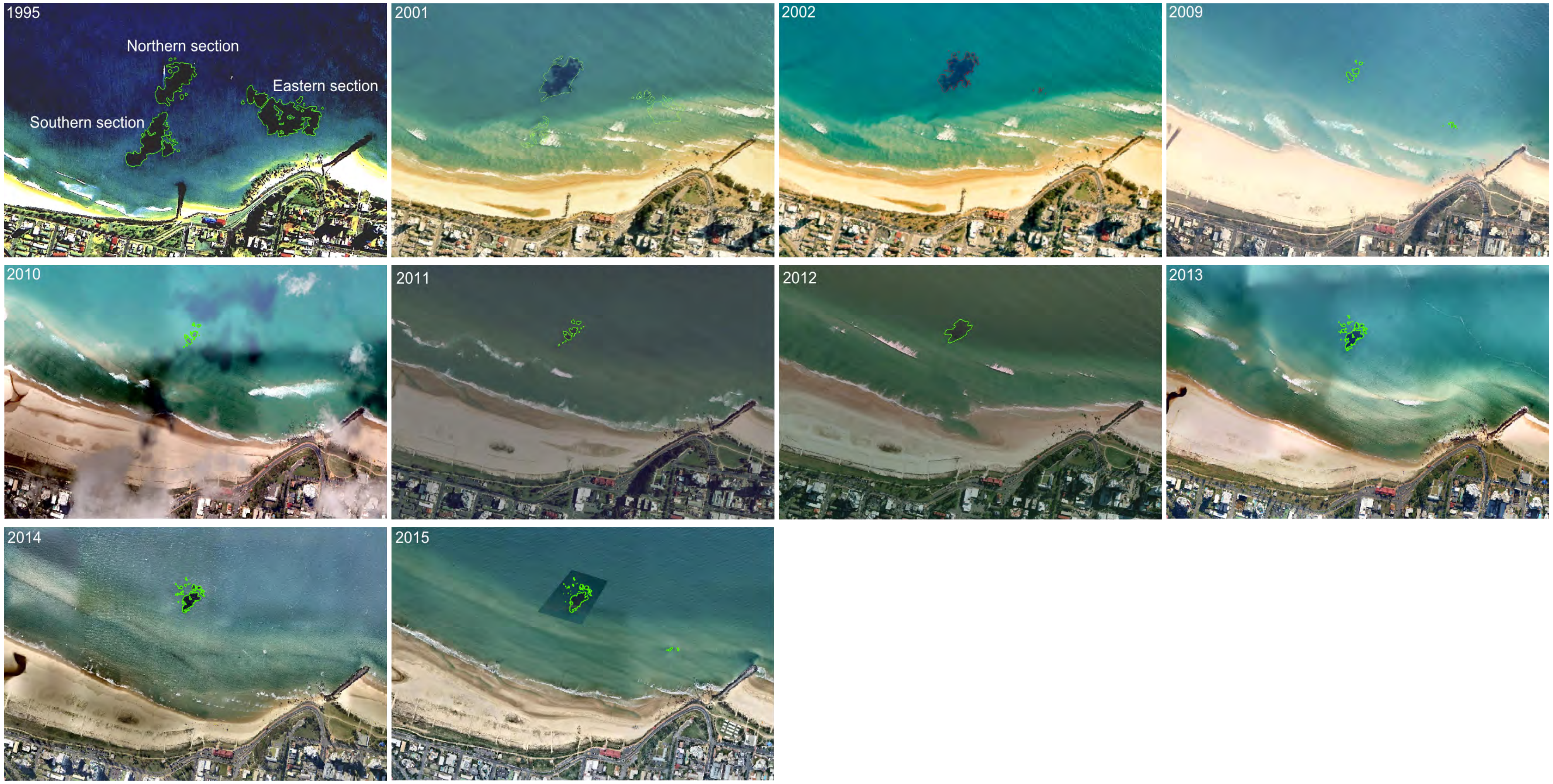


Figure 1.1 Extent of Kirra Reef in 1995, 2001, 2002, 2009, 2010, 2011, 2012, 2013, 2014 and 2015

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.

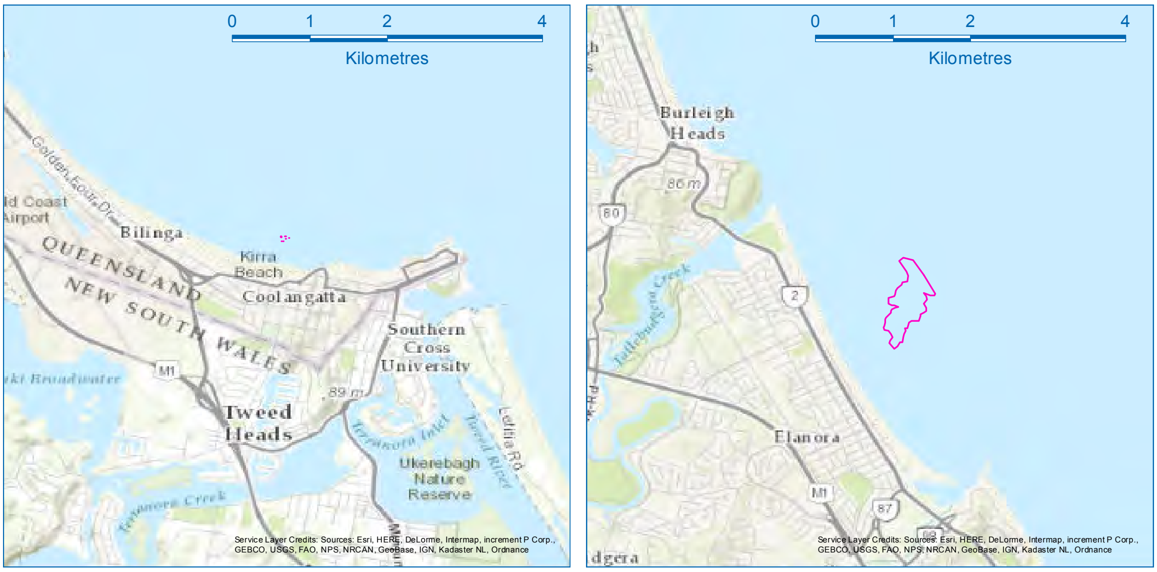
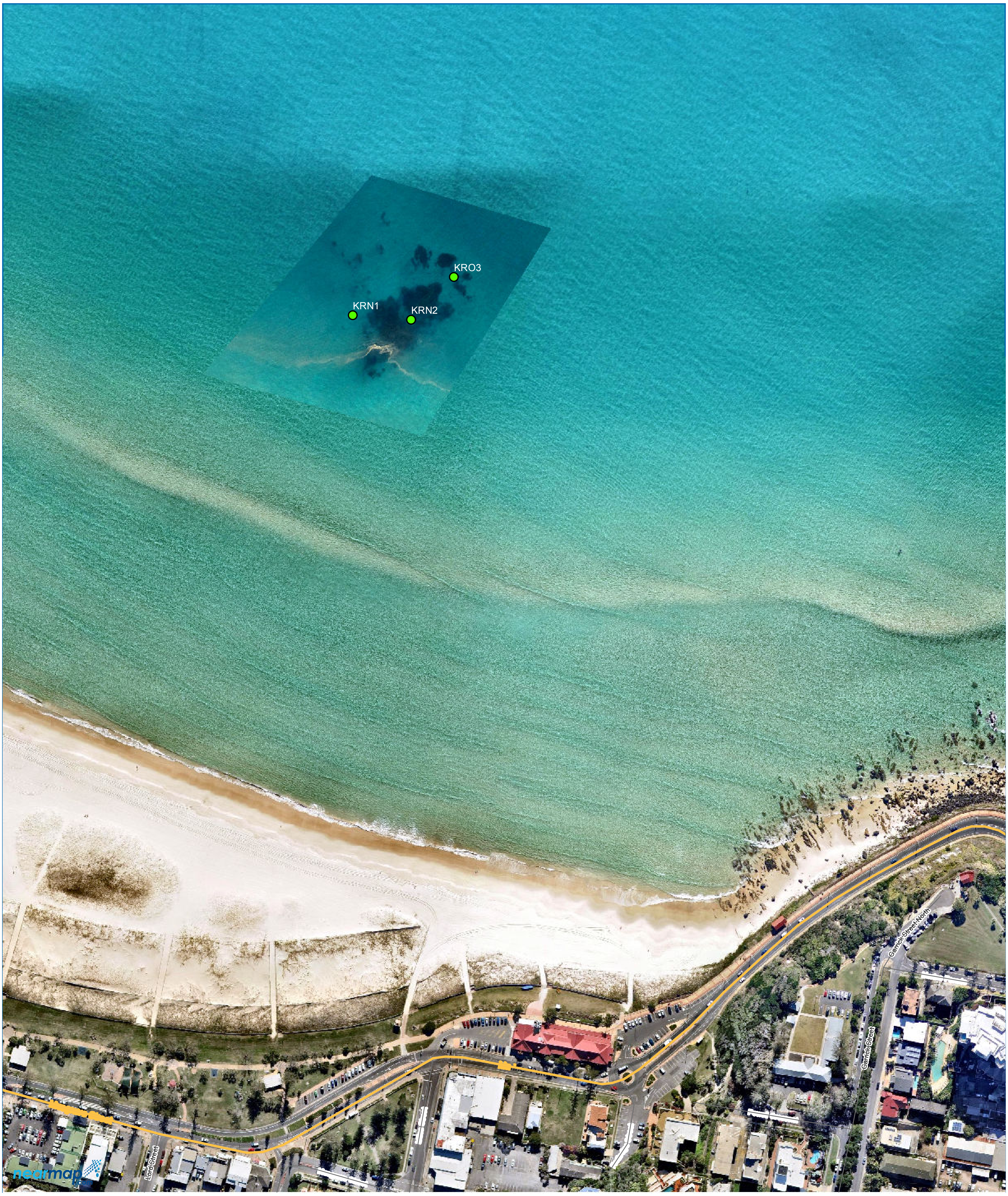


Figure 2.1 Location of (a) Kirra Reef and (b) Palm Beach Reef

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).



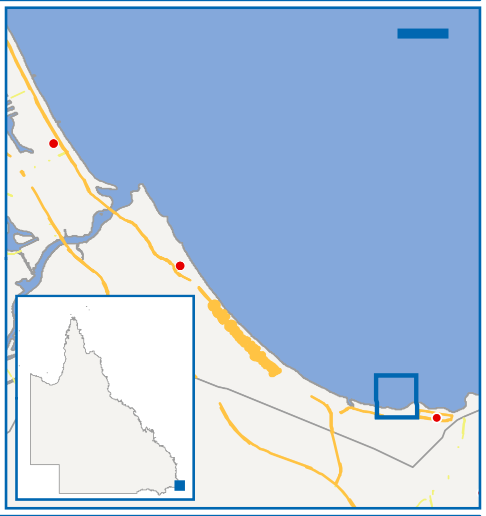
Tweed River Entrance Sand Bypassing Project
Kirra Reef Marine Biota Monitoring 2014

LEGEND

- Survey Site

Road Network

- Highway
- Local Road



Map 1:
Sites surveyed at Kirra Reef in 2015

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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
2015-03-24	CF	01	Coordinate System: GDA 1994 MGA Zone 56 Projection: Transverse Mercator Datum: GDA 1994

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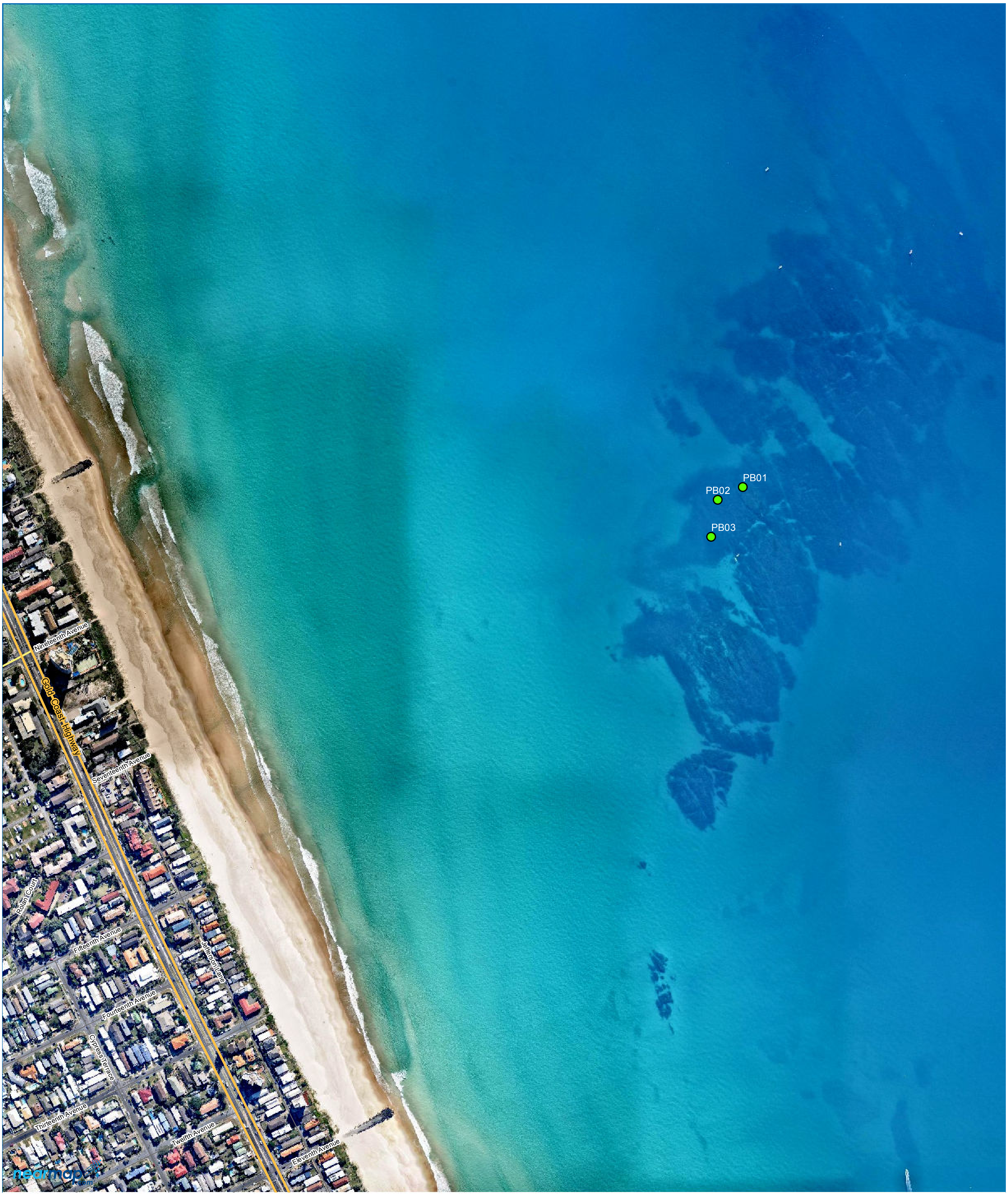

Tweed River Entrance Sand Bypassing Project
Kirra Reef Marine Biota Monitoring 2014

Map 2:
Sites surveyed at Palm Beach in 2015

LEGEND

Survey Site

Road Network
- Highway
- Main Road
- Local Road

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Q 4160 Australia

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

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SCALE

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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

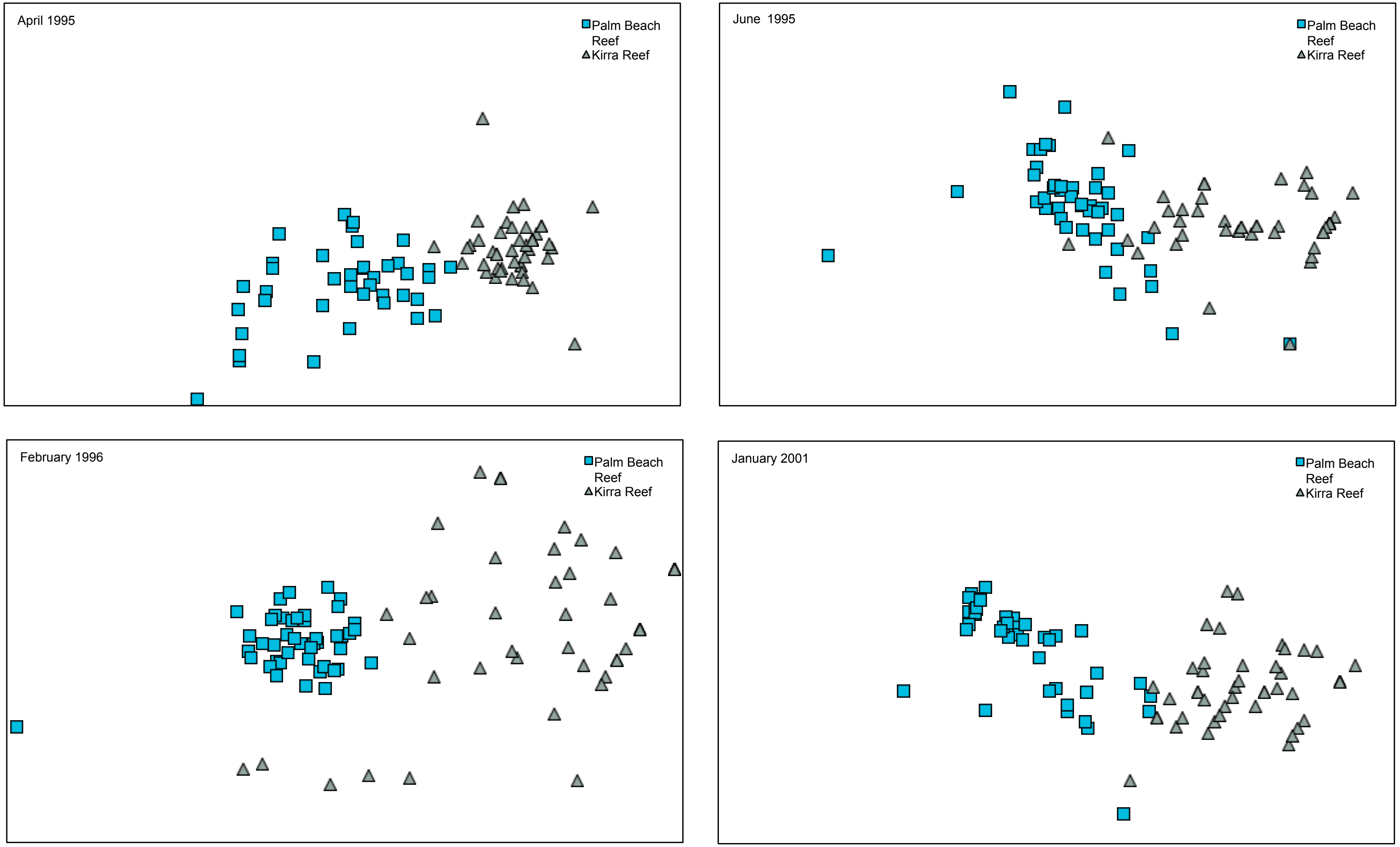


Figure 3.1 Multi-dimensional scaling plot of benthic cover in the April 1995, June 1995, February 1996 and January 2001 surveys.

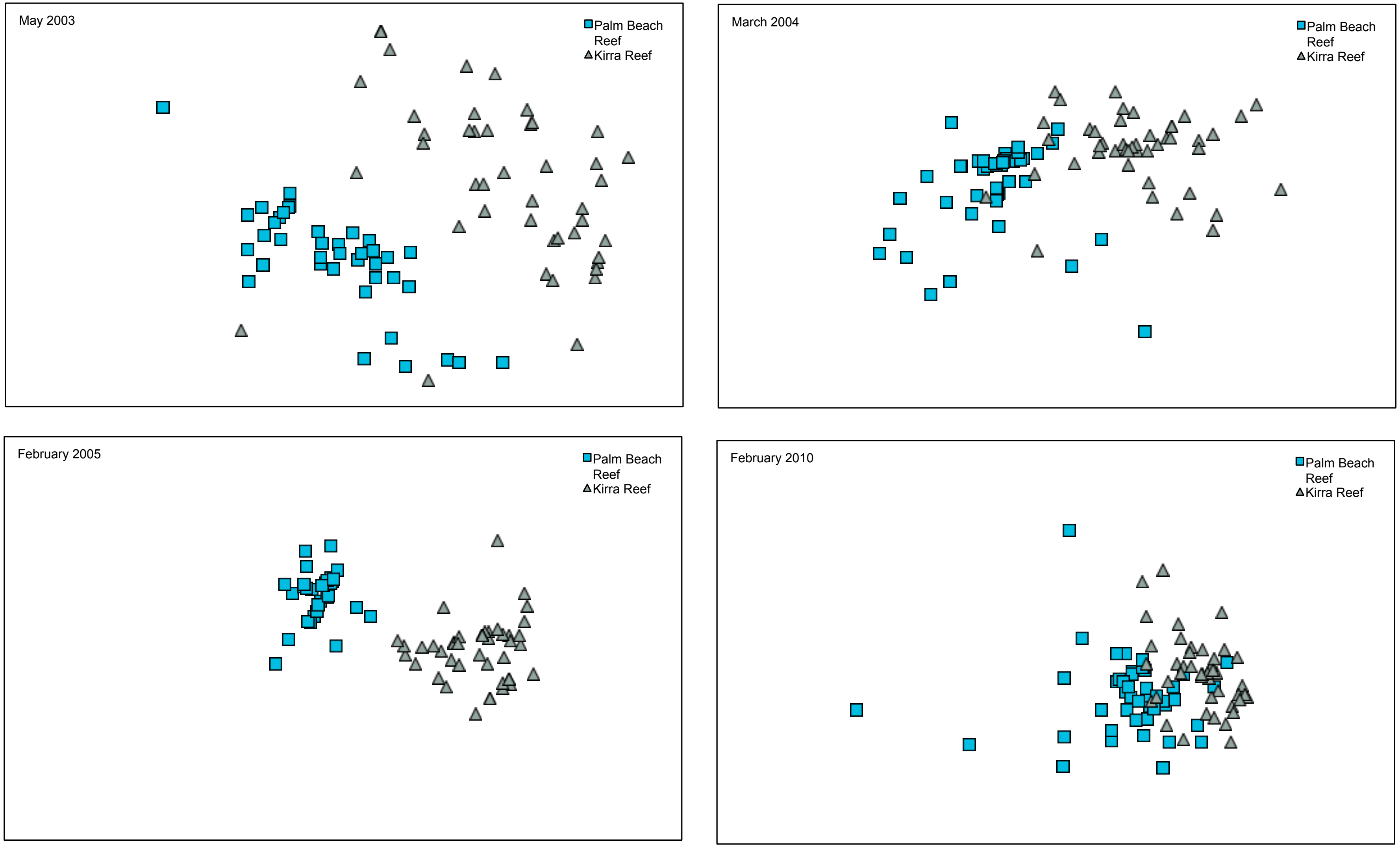


Figure 3.2 Multi-dimensional scale plot of benthic cover in the May 2003, March 2004, February 2005 and February 2010 surveys.

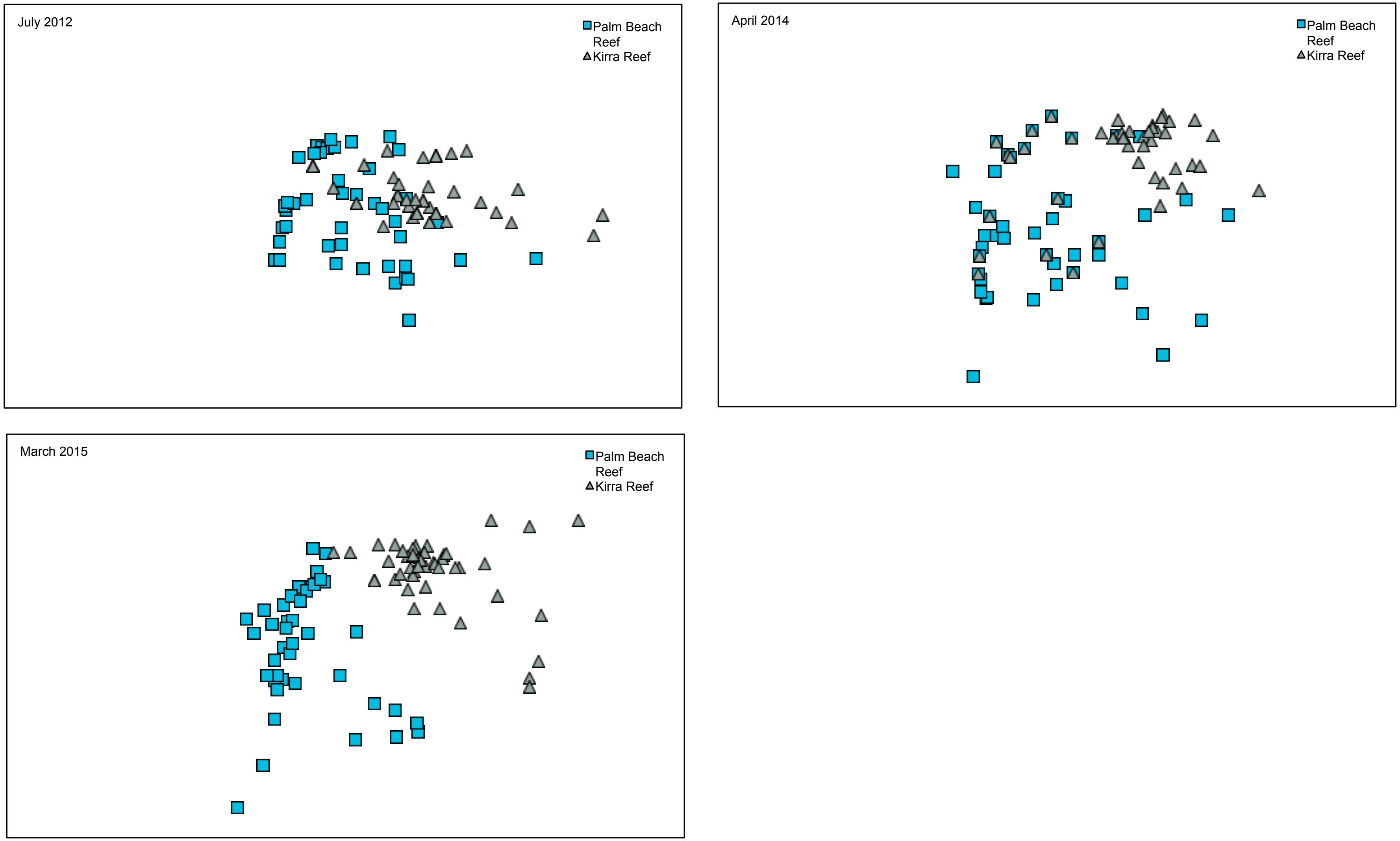


Figure 3.3 Multi-dimensional scale plot of benthic cover in the July 2012, April 2014 and March 2015 surveys.

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.

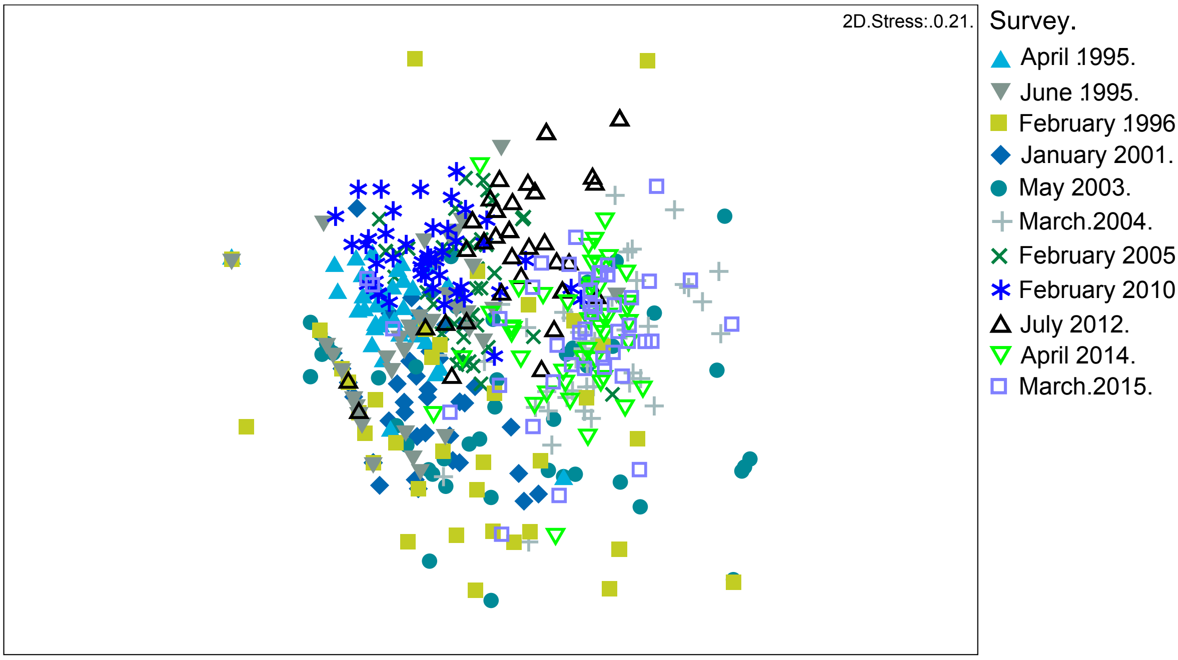


Figure 3.4 Multi-dimensional scale plot of benthic cover at Kirra Reef in all surveys

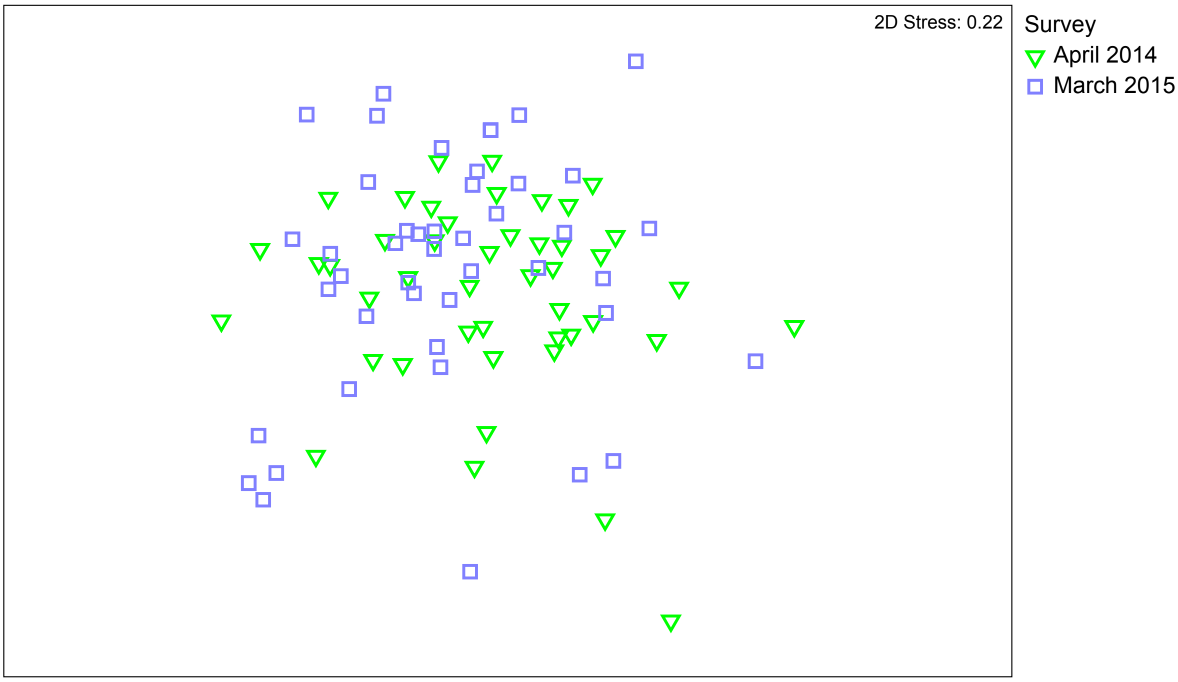


Figure 3.5 Multi-dimensional scale plot of benthic cover at Kirra Reef in April 2014 and March 2015.

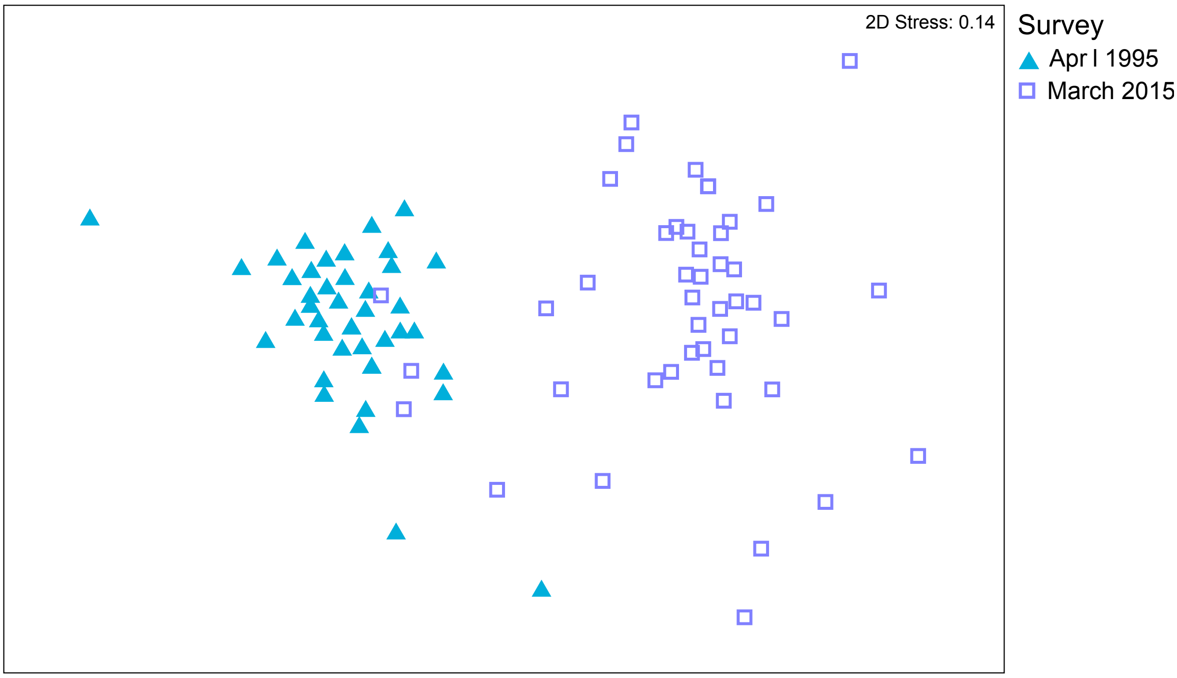


Figure 3.6 Multi-dimensional scale plot of benthic cover at Kirra Reef in April 1995 and March 2015.

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).

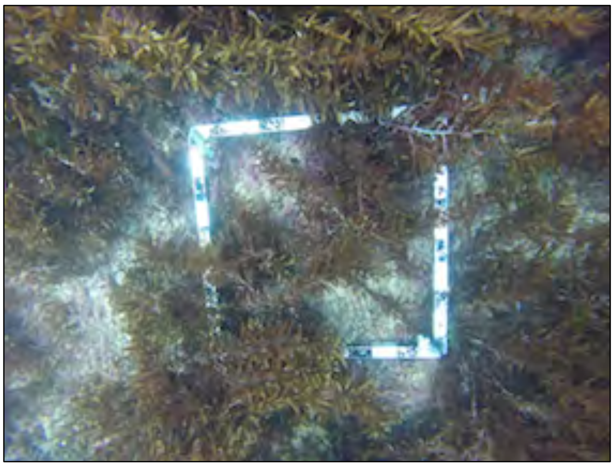
In 2015, no macroalgae was recorded within the quadrats at Palm Beach Reef. The cover of macroalgae on Palm Beach Reef has been consistently lower than Kirra Reef since ecological monitoring began: typically less than 5% of the available surface area (Figure 3.8).

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.



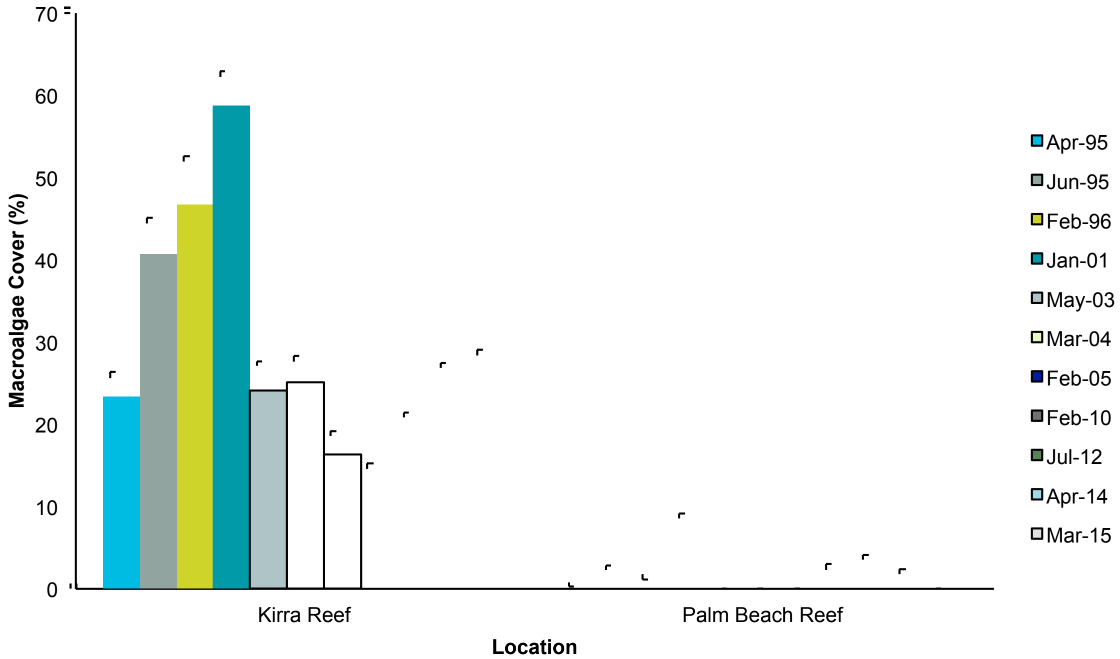


Figure 3.8 Mean cover of macroalgae (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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		

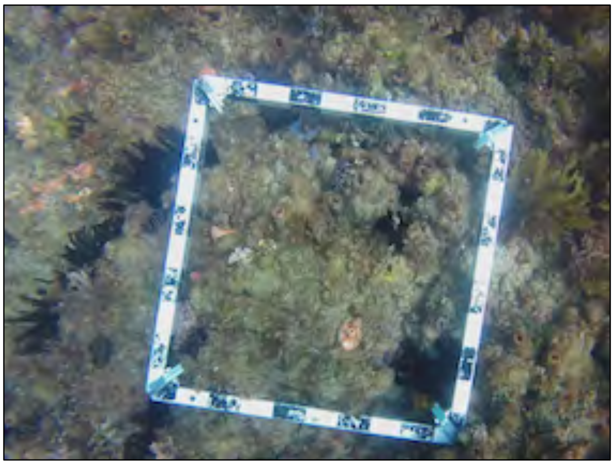
Shading denotes significance at p <0.05

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).



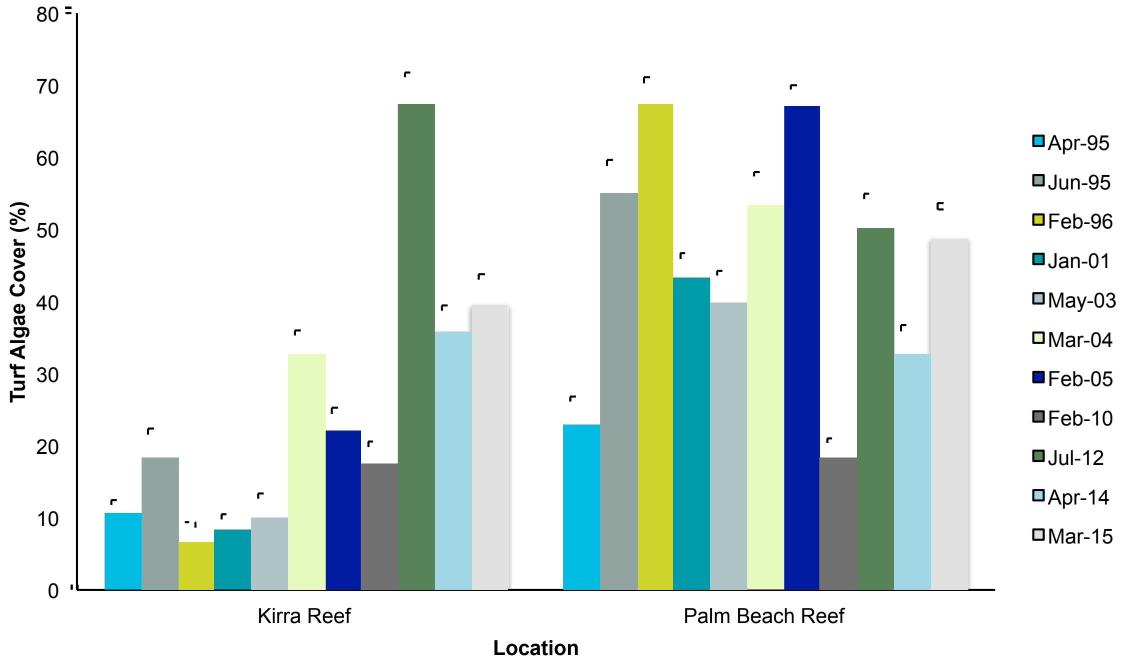


Figure 3.10 Mean cover of turf algae (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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

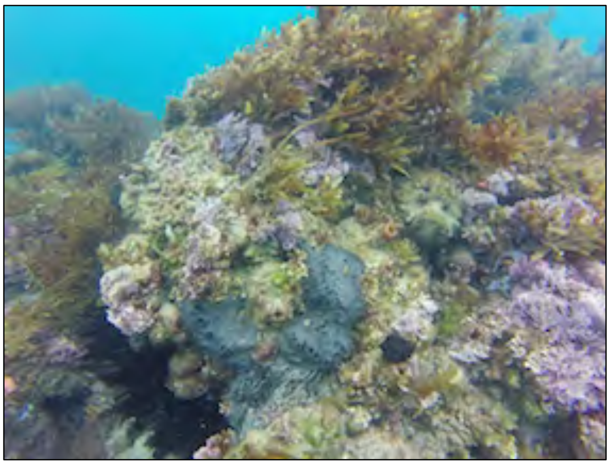
The mean cover of sponges at some sites at both Kirra Reef and Palm Beach Reef has varied significantly during some surveys (note the significant interaction between site (location) x survey in Table 3.4; Figure 3.11). However, the cover of sponges tended to be more temporally variable at Kirra Reef 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.



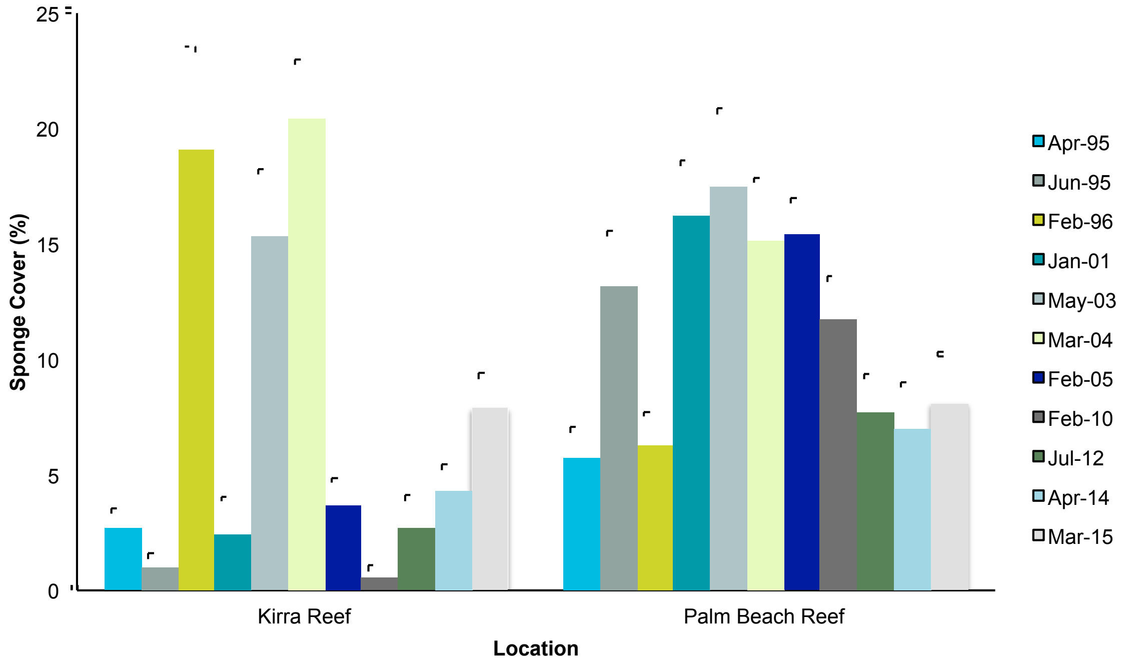


Figure 3.12 Mean cover of sponges (± SE) at Kirra Reef and Palm Beach Reef on all surveys.

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.

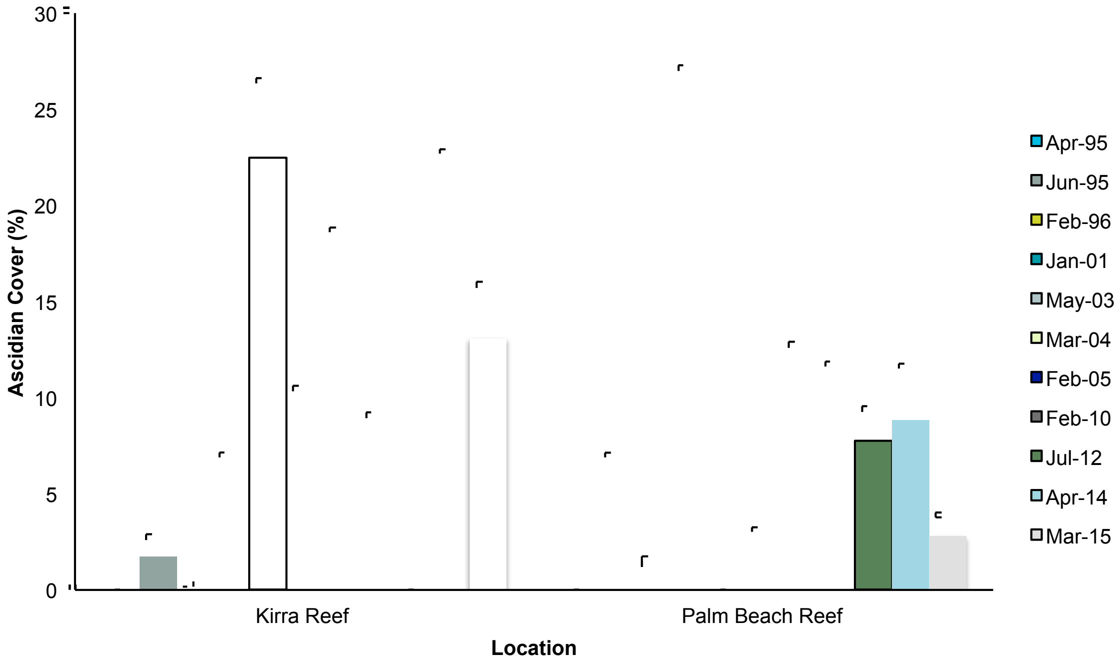


Figure 3.14 Mean cover of ascidians (± SE), other than *Pyura stolonifera*, at Kirra Reef and Palm Beach Reef in all surveys.

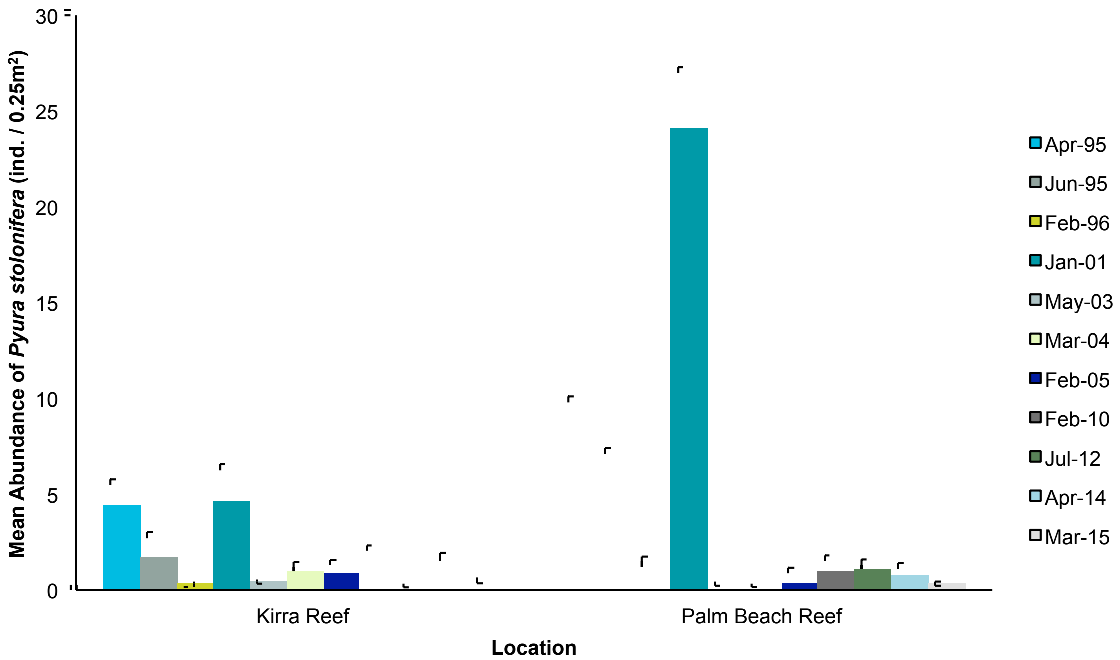


Figure 3.15 Mean abundance of ascidians (*Pyura stolonifera*) (individuals / 0.25 m^2) (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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).

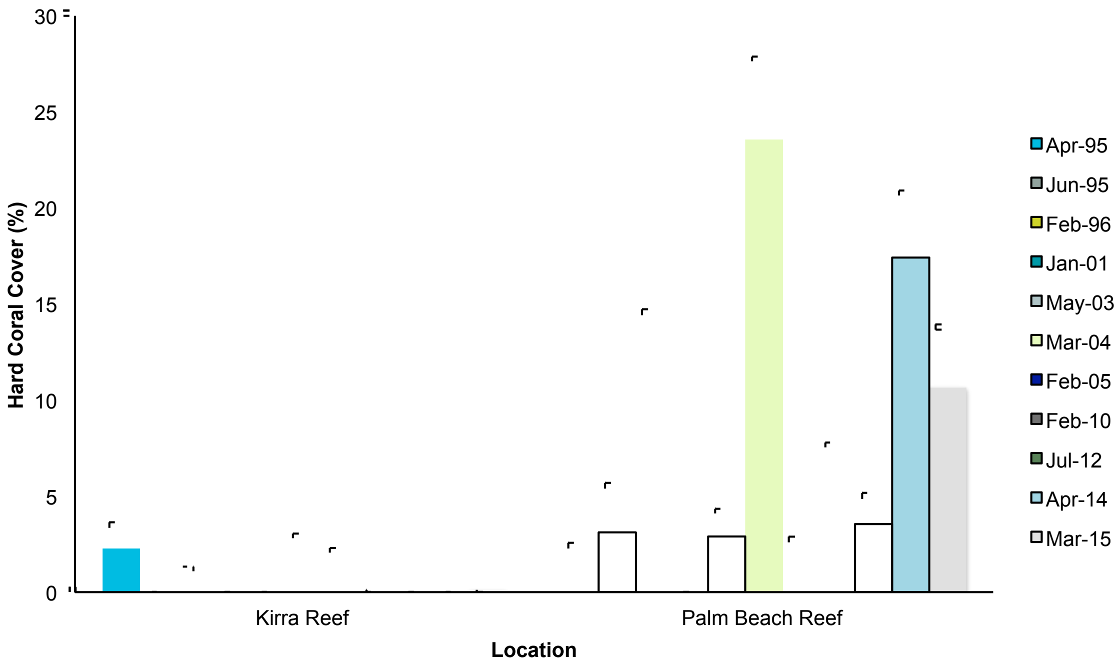


Figure 3.16 Mean cover of hard corals (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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).

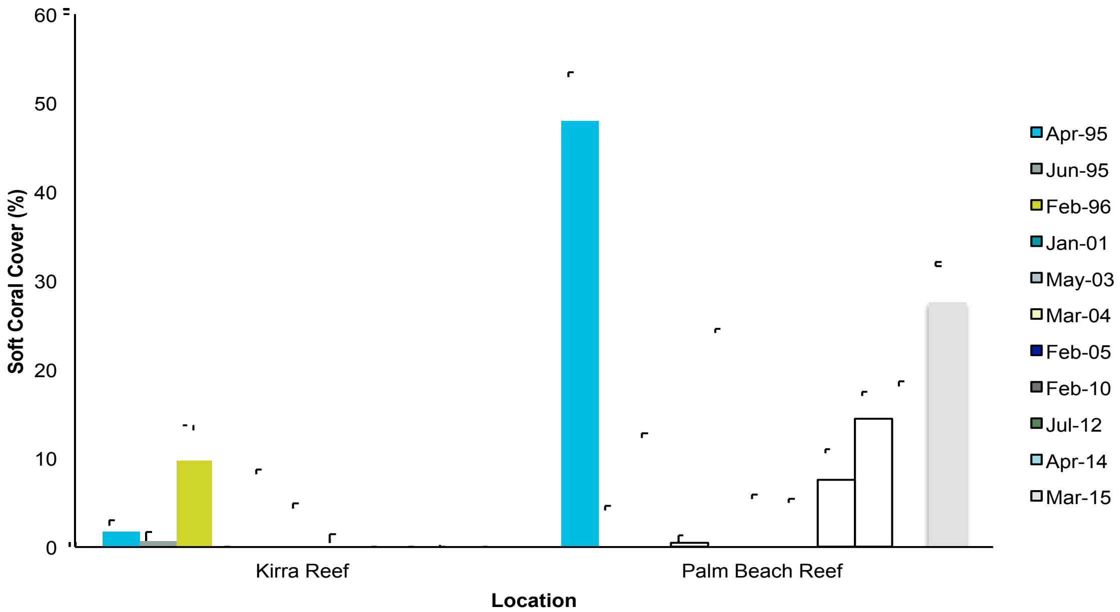


Figure 3.17 Mean cover of soft corals (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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

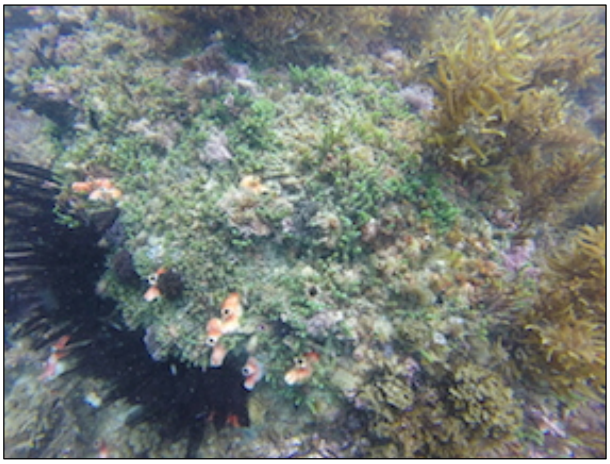
Crinoids

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.



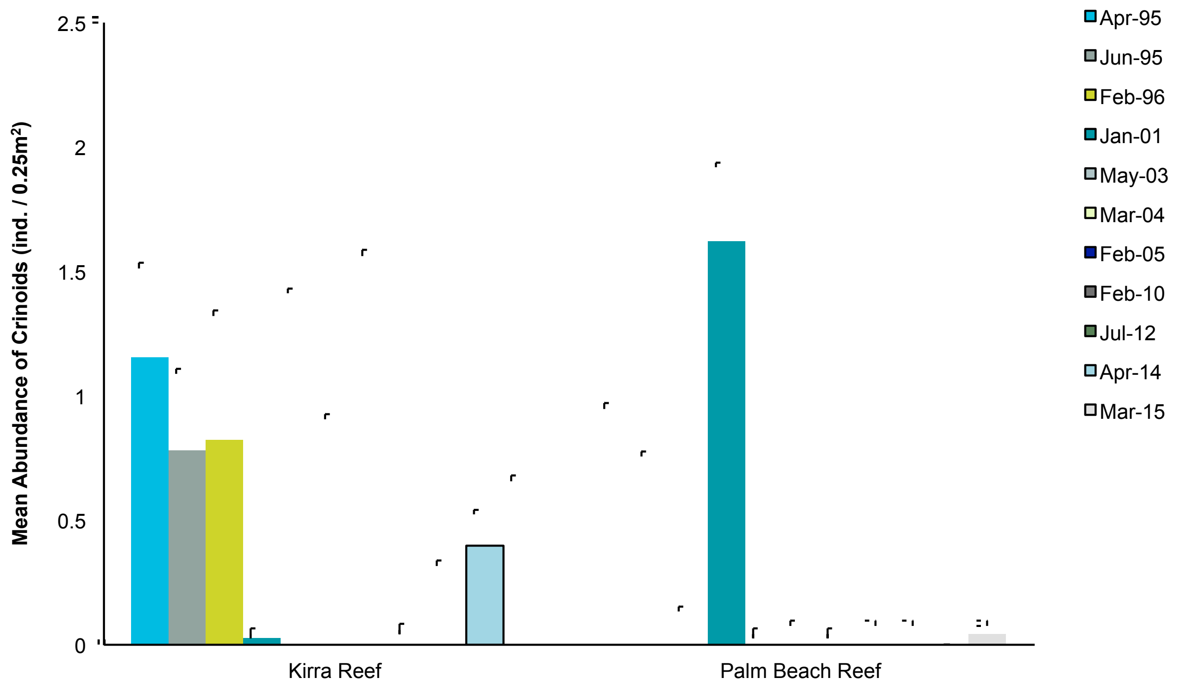


Figure 3.19 Mean abundance of crinoids (individuals / 0.25 m^2) (± SE) at Kirra Reef and Palm Beach Reef in all surveys.

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.

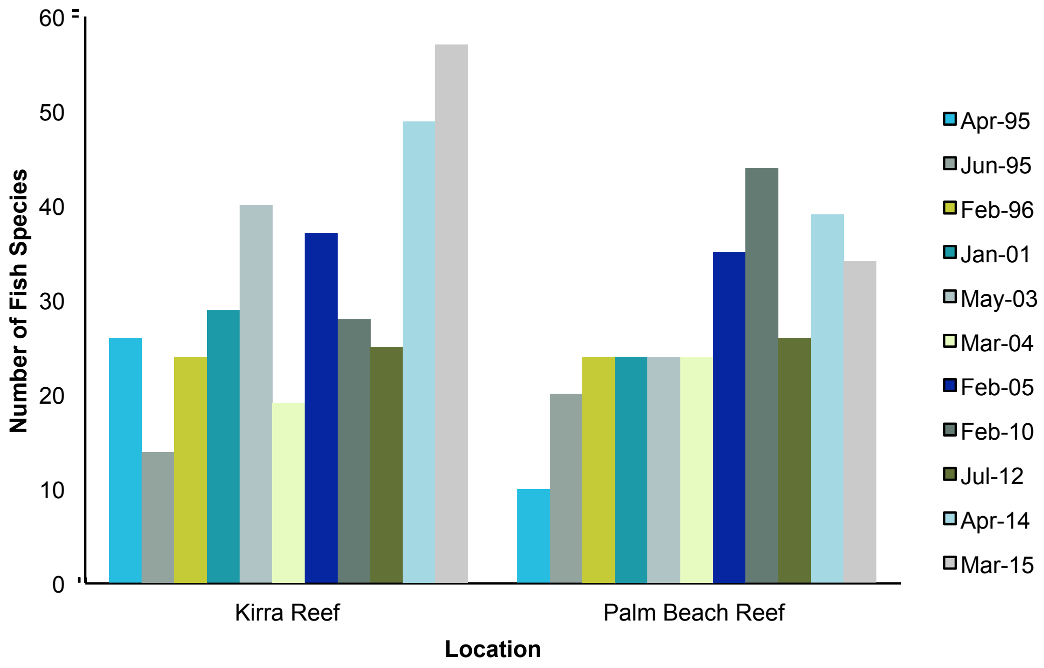


Figure 3.20 Number of fish species recorded at Kirra Reef and Palm Beach Reef on each survey.

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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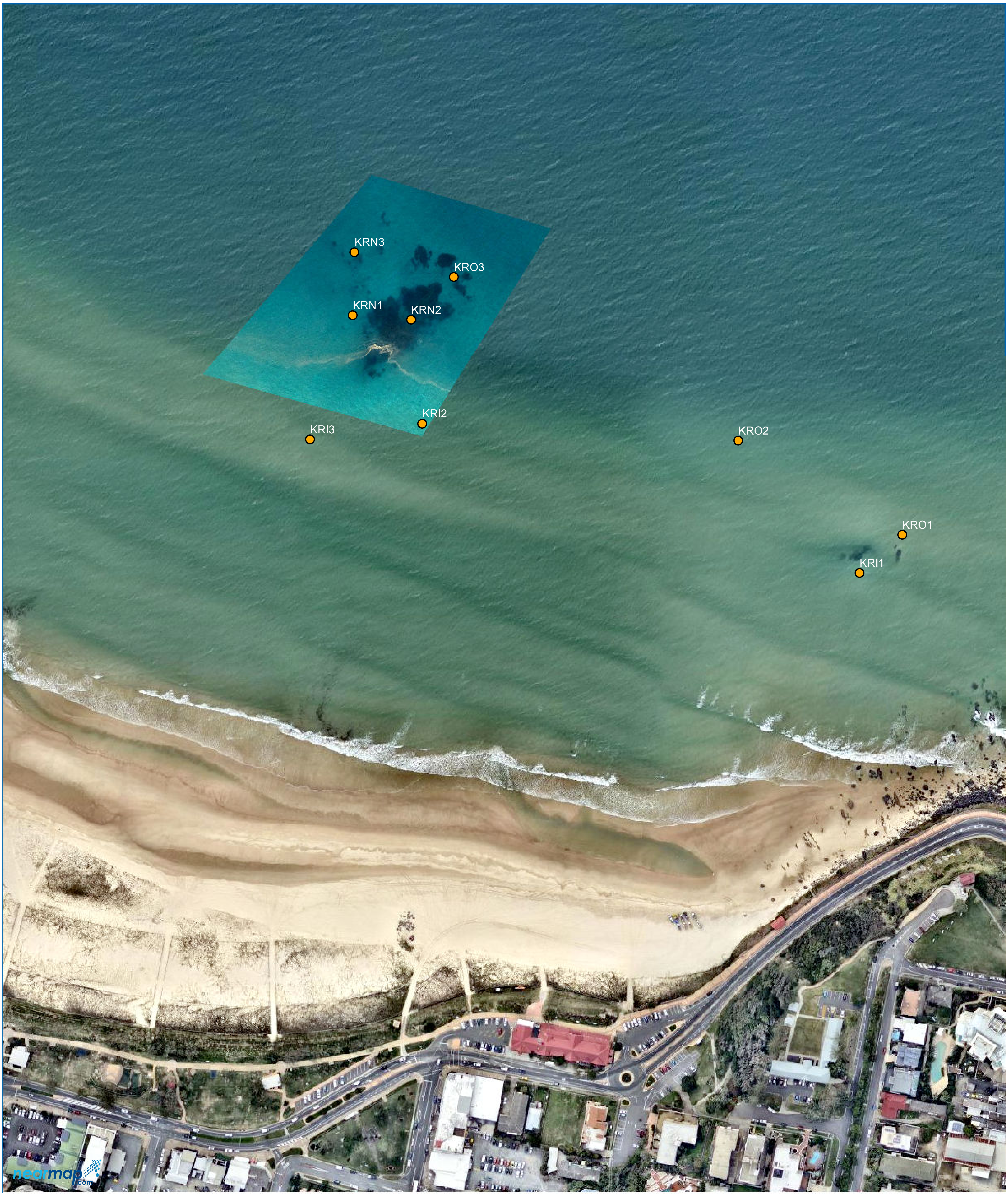
Appendix A History of Sites Surveyed at Kirra Reef

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).

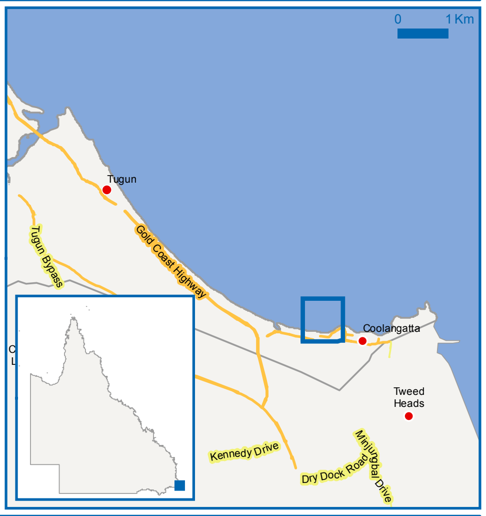


Tweed River Entrance Sand Bypassing Project
Kirra Reef Marine Biota Monitoring 2014

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

LEGEND

- Survey Site



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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.

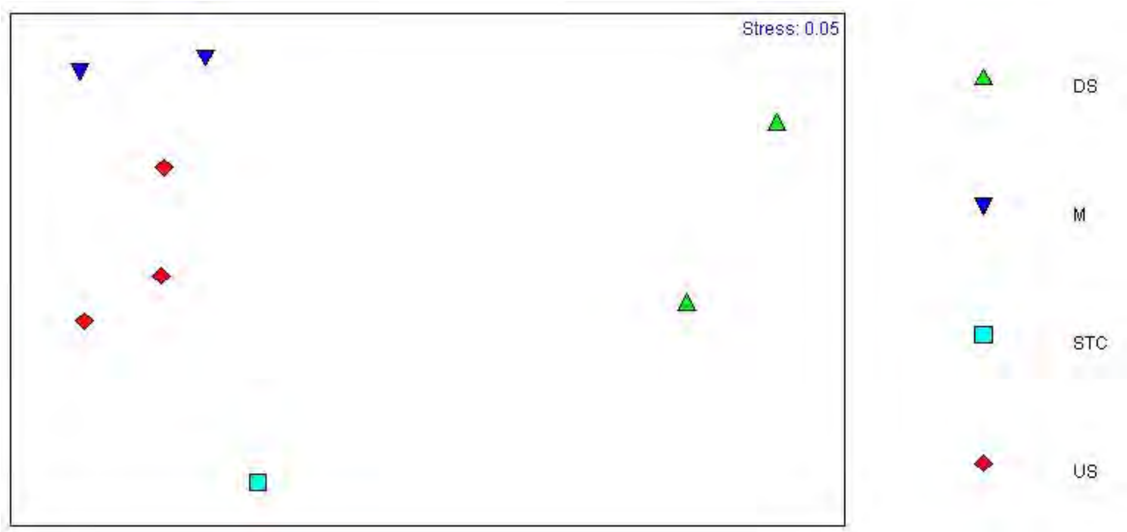

Figure B1 Example of a multi-dimensional scaling ordination for macroinvertebrate communities sampled in riffle habitats of different stream reaches.

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

Table C.1 Benthic assemblage data from Kirra and Palm Beach reefs in March 2015.

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Kirra Reef	KRN1	1	50	40	0	0	0	10	0	0	0	0	1	0
Kirra Reef	KRN1	2	20	20	0	0	10	50	0	0	0	0	0	0
Kirra Reef	KRN1	3	10	50	0	0	10	20	0	10	0	0	1	0
Kirra Reef	KRN1	4	10	20	0	0	5	60	0		0	5	0	4
Kirra Reef	KRN1	5	20	60	0	0	0	8	0	2	0	10	0	2
Kirra Reef	KRN1	6	73	20	0	2	5	0	0	0	0	0	3	0
Kirra Reef	KRN1	7	81	0	0	0	0	10	0	4	0	5	0	0
Kirra Reef	KRN1	8	10	75	0	0	10	5	0	0	0	0	1	2
Kirra Reef	KRN1	9	35	50	0	0	5	5	0	0	0	5	3	1
Kirra Reef	KRN1	10	30	70	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRN1	11	20	30	0	0	30	20	0	0	0	0	0	0
Kirra Reef	KRN1	12	0	75	0	0	0	20	0	5	0	0	0	0
Kirra Reef	KRN1	13	30	45	0	0	0	20	0	0	0	5	2	0
Kirra Reef	KRN1	14	30	50	0	0	10	10	0	0	0	0	0	1
Kirra Reef	KRN1	15	40	30	0	0	10	10	0	0	0	10	0	0
Kirra Reef	KRN2	1	20	65	0	0	10	5	0	0	0	0	1	1

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Kirra Reef	KRN2	2	20	25	0	0	43	2	0	0	0	10	0	1
Kirra Reef	KRN2	3	60	30	0	0	8	2	0	0	0	0	1	0
Kirra Reef	KRN2	4	50	20	0	0	10	0	10	0	0	10	1	0
Kirra Reef	KRN2	5	30	55	0	0	0	5	0	0	0	10	0	1
Kirra Reef	KRN2	6	20	60	0	0	0	10	0	0	0	10	0	1
Kirra Reef	KRN2	7	20	55	0	0	5	0	10	0	0	10	1	0
Kirra Reef	KRN2	8	10	75	0	0	10	5	0	0	0	0	0	1
Kirra Reef	KRN2	9	25	60	0	0	5	5	0	0	0	5	0	1
Kirra Reef	KRN2	10	10	40	0	0	10		0	0	0	40	0	0
Kirra Reef	KRN2	11	0	40	0	0	10	40	0	0	0	10	0	1
Kirra Reef	KRN2	12	15	10	0	0			40	0	0	35	0	0
Kirra Reef	KRN2	13	60	0	0	0	5	30	0	0	0	5	3	3
Kirra Reef	KRN2	14	20	60	0	0		20	0	0	0	0	0	1
Kirra Reef	KRN2	15	15	10	0	0	0	0	60	0	0	15	0	0
Kirra Reef	KRO3	1	20	40	0	0	10	5	0	5	0	20	0	1
Kirra Reef	KRO3	2	30	35	0	0	5	0	0	0	0	30	1	0
Kirra Reef	KRO3	3	20	40	0	0	20	0	0	0	0	20	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Kirra Reef	KRO3	4	10	65	0	0	5	5	10	5	0	0	4	0
Kirra Reef	KRO3	5	20	55	0	0	5	10	0	5	0	5	0	0
Kirra Reef	KRO3	6	0	10	0	0	5	80	0	0	0	5	0	0
Kirra Reef	KRO3	7	20	80	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KRO3	8	30	10	0	0	0	0	45	0	0	15	0	0
Kirra Reef	KRO3	9	40	10	0	0	0	0	10	0	0	40	0	0
Kirra Reef	KRO3	10	20	40	0	0	15	5	0	0	0	20	0	0
Kirra Reef	KRO3	11	20	70	0	0	5	0	0	0	0	5	0	0
Kirra Reef	KRO3	12	40	30	0	0	10	20	0	0	0	0	0	0
Kirra Reef	KRO3	13	20	30	0	0	10	5	30	0	0	5	0	0
Kirra Reef	KRO3	14	10	30	0	0	28	10	0	2	0	20	0	0
Kirra Reef	KRO3	15	25	0	0	0	10	50	0	5	0	10	0	0
Palm Beach	1	1	0	20	25	0	0	0	55	0	0	0	0	0
Palm Beach	1	2	0	85	10	5	0	0	0	0	0	0	0	1
Palm Beach	1	3	0	85	0	0	15	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Palm Beach	1	4	0	10	80	5	5	0	0	0	0	0	0	0
Palm Beach	1	5	0	5	90	5	0	0	0	0	0	0	0	0
Palm Beach	1	6	0	40	30	0	30	0	0	0	0	0	0	0
Palm Beach	1	7	0	60	25	0	5	0	10	0	0	0	0	0
Palm Beach	1	8	0	75	0	0	25	0	0	0	0	0	0	0
Palm Beach	1	9	0	70	0	25	5	0	0	0	0	0	0	0
Palm Beach	1	10	0	10	0	25	5	0	0	60	0	0	0	0
Palm Beach	1	11	0	90	0	0	5	5	0	0	0	0	0	0
Palm Beach	1	12	0	10	0	80	0	0	10	0	0	0	0	0
Palm Beach	1	13	0	50	0	0	50	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Palm Beach	1	14	0	90	0	0	5	5	0	0	0	0	0	0
Palm Beach	1	15	0	50	25	0	0	0	25	0	0	0	0	0
Palm Beach	2	1	0	50	50	0	0	0	0	0	0	0	0	0
Palm Beach	2	2	0	20	70	0	0	0	10	0	0	0	0	0
Palm Beach	2	3	0	40	55	0	5	0	0	0	0	0	0	0
Palm Beach	2	4	0	40	20	0	0	0	40	0	0	0	0	0
Palm Beach	2	5	0	80	0	0	10	0	10	0	0	0	0	0
Palm Beach	2	6	0	50	20	25	0	5	0	0	0	0	0	2
Palm Beach	2	7	0	75	0	5	20	0	0	0	0	0	0	1
Palm Beach	2	8	0	75	20	0	0	5	0	0	0	0	0	1

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Palm Beach	2	9	0	25	0	0	50	0	0	25	0	0	0	0
Palm Beach	2	10	0	45	0	50	5	0	0	0	0	0	0	0
Palm Beach	2	11	0	0	100	0	0	0	0	0	0	0	0	0
Palm Beach	2	12	0	40	10	10	0	40	0	0	0	0	1	0
Palm Beach	2	13	0	60	0	40	0	0	0	0	0	0	0	0
Palm Beach	2	14	0	40	10	0	0	0	0	50	0	0	0	0
Palm Beach	2	15	0	50	30	0	10	10	0	0	0	0	1	0
Palm Beach	3	1	0	20	0	50	25	5	0	0	0	0	0	2
Palm Beach	3	2	0	50	0	0	5	5	0	40	0	0	0	2
Palm Beach	3	3	0	20	20	0	0	5	50	5	0	0	0	1

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Palm Beach	3	4	0	15	70	0	5	5	0	5	0	0	0	1
Palm Beach	3	5	0	40	45	5	0	10	0	0	0	0	0	0
Palm Beach	3	6	0	20	0	60	10	0	0	10	0	0	0	0
Palm Beach	3	7	0	35	20	40	0	5	0	0	0	0	0	0
Palm Beach	3	8	0	90	5	0	5	0	0	0	0	0	0	0
Palm Beach	3	9	0	85	0	0	5	5	0	5	0	0	0	1
Palm Beach	3	10	0	50	50	0	0	0	0	0	0	0	0	0
Palm Beach	3	11	0	45	0	0	50	5	0	0	0	0	0	1
Palm Beach	3	12	0	55	0	0	0	5	0	40	0	0	0	0
Palm Beach	3	13	0	95	0	0	4	1	0	0	0	0	0	1

Location	Site	Replicate	% Macroalgae	% Turf algae	% Soft coral	% Hard coral	% Sponge	% Ascidians	% Bare	% Anemone	% Barnacle	% Crustose coralline algae	# Crinoids	# *Pyura* sp.
Palm Beach	3	14	0	50	0	50	0	0	0	0	0	0	0	0
Palm Beach	3	15	0	90	0	0	5	5	0	0	0	0	0	0

Appendix D Pairwise PERMANOVA Results for the Site (Location) x Survey Interaction

Table D.1 Pairwise comparison of benthic cover assemblages between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	1.3118	0.1774
KRN1, KRO3	1.9722	0.0159
KRN2, KRO3	2.177	0.0086
PB1, PB2	0.93294	0.4048
PB1, PB3	0.66768	0.628
PB2, PB3	1.1288	0.2773
J1995		
KRN1, KRN2	1.7333	0.0664
KRN1, KRO3	4.9532	0.0001
KRN2, KRO3	4.6097	0.0001
PB1, PB2	1.9383	0.0102
PB1, PB3	1.6118	0.0306
PB2, PB3	Negative	
F1996		
KRN1, KRN2	4.3834	0.0001
KRN1, KRO3	2.5365	0.0002
KRN2, KRO3	3.4595	0.0001
PB1, PB2	1.1048	0.3191
PB1, PB3	0.33269	0.9006
PB2, PB3	0.73609	0.6751
2001		
KRN1, KRN2	2.6259	0.0007
KRN1, KRO3	4.4626	0.0001
KRN2, KRO3	3.0904	0.0015
PB1, PB2	2.8134	0.0003
PB1, PB3	3.5628	0.0001
PB2, PB3	3.4353	0.0001

2003		
KRN1, KRN2	2.0417	0.0062
KRN1, KRO3	3.4114	0.0001
KRN2, KRO3	1.2834	0.1963
PB1, PB2	0.85842	0.4905
PB1, PB3	2.5385	0.0007
PB2, PB3	3.7724	0.0001
2004		
KRN1, KRN2	2.4653	0.0005
KRN1, KRO3	1.831	0.0155
KRN2, KRO3	1.0681	0.3629
PB1, PB2	0.71994	0.6214
PB1, PB3	1.2021	0.236
PB2, PB3	0.84609	0.5447
2005		
KRN1, KRN2	2.0028	0.0054
KRN1, KRO3	2.1802	0.0049
KRN2, KRO3	2.3674	0.0021
PB1, PB2	1.5146	0.0798
PB1, PB3	1.1823	0.2569
PB2, PB3	1.649	0.0401
2010		
KRN1, KRN2	1.182	0.2503
KRN1, KRO3	2.7451	0.0001
KRN2, KRO3	2.7733	0.0005
PB1, PB2	1.6247	0.018
PB1, PB3	1.3412	0.0962
PB2, PB3	1.3393	0.139
2012		
KRN1, KRN2	Negative	
KRN1, KRO3	0.18955	0.8705

KRN2, KRO3	1.6049	0.0876
PB1, PB2	2.3693	0.001
PB1, PB3	3.5862	0.0001
PB2, PB3	1.155	0.2749
2014		
KRN1, KRN2	2.2166	0.0015
KRN1, KRO3	4.0369	0.0001
KRN2, KRO3	1.9415	0.0053
PB1, PB2	1.9738	0.0092
PB1, PB3	1.6813	0.0284
PB2, PB3	2.2453	0.0015
2015		
KRN1, KRN2	1.7251	0.0244
KRN1, KRO3	1.7515	0.0182
KRN2, KRO3	0.4322	0.918
PB1, PB2	0.74566	0.6651
PB1, PB3	1.35	0.1414
PB2, PB3	1.3831	0.1251

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.2 Pairwise comparison of benthic cover assemblages at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	3.763	0.0005
A1995, F1996	3.7646	0.0001
A1995, 2001	6.1244	0.0001
A1995, 2003	2.5579	0.0002
A1995, 2004	4.5156	0.0001
A1995, 2005	4.3802	0.0001
A1995, 2010	3.9997	0.0001
A1995, 2012	4.2048	0.0002

Groups	t	P(perm)
A1995, 2014	8.3492	0.0001
A1995, 2015	7.1292	0.0001
J1995, F1996	3.8626	0.0001
J1995, 2001	3.0269	0.0006
J1995, 2003	1.5842	0.0543
J1995, 2004	4.8324	0.0001
J1995, 2005	5.2583	0.0001
J1995, 2010	5.2641	0.0001
J1995, 2012	5.1287	0.0001
J1995, 2014	7.7649	0.0001
J1995, 2015	6.8898	0.0001
F1996, 2001	3.5934	0.0001
F1996, 2003	2.3704	0.0015
F1996, 2004	2.5587	0.0012
F1996, 2005	3.474	0.0001
F1996, 2010	4.2316	0.0001
F1996, 2012	3.0308	0.0001
F1996, 2014	4.4693	0.0001
F1996, 2015	3.8419	0.0001
2001, 2003	2.6578	0.0001
2001, 2004	3.9767	0.0001
2001, 2005	4.6909	0.0001
2001, 2010	6.0339	0.0001
2001, 2012	4.9734	0.0001
2001, 2014	6.1354	0.0001
2001, 2015	4.7606	0.0001
2003, 2004	3.1674	0.0001
2003, 2005	3.6328	0.0001
2003, 2010	3.7599	0.0001
2003, 2012	3.7985	0.0002

Groups	t	P(perm)
2003, 2014	5.5125	0.0001
2003, 2015	4.8899	0.0001
2004, 2005	3.6526	0.0001
2004, 2010	5.0093	0.0001
2004, 2012	1.9234	0.0295
2004, 2014	3.3205	0.0001
2004, 2015	2.4285	0.0014
2005, 2010	2.5575	0.0011
2005, 2012	3.6308	0.0001
2005, 2014	5.5199	0.0001
2005, 2015	4.1662	0.0001
2010, 2012	4.6216	0.0001
2010, 2014	7.1336	0.0001
2010, 2015	6.2806	0.0001
2012, 2014	3.35	0.0001
2012, 2015	3.2027	0.0001
2014, 2015	2.0856	0.0032

Shaded cells indicate significance at the 0.05 level

Table D.3 Pairwise comparison of benthic cover assemblages at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	2.2025	0.0083
A1995, F1996	6.297	0.0001
A1995, 2001	4.4117	0.0001
A1995, 2003	3.4806	0.0001
A1995, 2004	7.9224	0.0001
A1995, 2005	4.0184	0.0001
A1995, 2010	4.0137	0.0001
A1995, 2012	5.3323	0.0001

Groups	t	P(perm)
A1995, 2014	6.0245	0.0001
A1995, 2015	5.5581	0.0001
J1995, F1996	4.7098	0.0001
J1995, 2001	2.5561	0.0065
J1995, 2003	3.2592	0.0001
J1995, 2004	8.8286	0.0001
J1995, 2005	4.3536	0.0001
J1995, 2010	5.7298	0.0001
J1995, 2012	6.1268	0.0001
J1995, 2014	6.3072	0.0001
J1995, 2015	5.9213	0.0001
F1996, 2001	2.1521	0.0129
F1996, 2003	3.6313	0.0001
F1996, 2004	8.6981	0.0001
F1996, 2005	7.3607	0.0001
F1996, 2010	9.1556	0.0001
F1996, 2012	7.7044	0.0001
F1996, 2014	6.8072	0.0001
F1996, 2015	6.5044	0.0001
2001, 2003	3.2213	0.0001
2001, 2004	8.2263	0.0001
2001, 2005	5.3506	0.0001
2001, 2010	7.054	0.0001
2001, 2012	6.0677	0.0001
2001, 2014	5.9559	0.0001
2001, 2015	5.7576	0.0001
2003, 2004	3.0058	0.0001
2003, 2005	2.0468	0.0041
2003, 2010	3.8335	0.0001
2003, 2012	4.0821	0.0001

Groups	t	P(perm)
2003, 2014	2.5686	0.0002
2003, 2015	2.9527	0.0001
2004, 2005	6.0098	0.0001
2004, 2010	7.738	0.0001
2004, 2012	5.9711	0.0001
2004, 2014	3.4066	0.0001
2004, 2015	3.2439	0.0001
2005, 2010	4.2557	0.0001
2005, 2012	5.701	0.0001
2005, 2014	3.7655	0.0001
2005, 2015	4.1628	0.0001
2010, 2012	6.0319	0.0001
2010, 2014	5.7458	0.0001
2010, 2015	5.6661	0.0001
2012, 2014	4.6341	0.0001
2012, 2015	3.7551	0.0001
2014, 2015	1.5671	0.0585

Shaded cells indicate significance at the 0.05 level

Table D.4 Pairwise comparison of benthic cover assemlages at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	4.0875	0.0001
A1995, F1996	3.6251	0.0003
A1995, 2001	3.0617	0.0001
A1995, 2003	4.7849	0.0001
A1995, 2004	5.5214	0.0001
A1995, 2005	4.0084	0.0001
A1995, 2010	5.0064	0.0001
A1995, 2012	8.3322	0.0001

Groups	t	P(perm)
A1995, 2014	6.5129	0.0001
A1995, 2015	5.4083	0.0001
J1995, F1996	4.4362	0.0001
J1995, 2001	3.4542	0.0001
J1995, 2003	4.4752	0.0001
J1995, 2004	4.3089	0.0001
J1995, 2005	2.8387	0.0001
J1995, 2010	2.8916	0.0001
J1995, 2012	3.1656	0.0001
J1995, 2014	4.6919	0.0001
J1995, 2015	4.1852	0.0001
F1996, 2001	3.9298	0.0001
F1996, 2003	2.7861	0.0003
F1996, 2004	3.5195	0.0001
F1996, 2005	4.6587	0.0001
F1996, 2010	4.8043	0.0001
F1996, 2012	5.7756	0.0001
F1996, 2014	4.2939	0.0001
F1996, 2015	3.6794	0.0001
2001, 2003	5.0782	0.0001
2001, 2004	5.8612	0.0001
2001, 2005	3.6262	0.0001
2001, 2010	4.1641	0.0001
2001, 2012	7.3024	0.0001
2001, 2014	6.2404	0.0001
2001, 2015	5.5468	0.0001
2003, 2004	2.1376	0.0027
2003, 2005	3.7544	0.0001
2003, 2010	3.8184	0.0001
2003, 2012	5.5736	0.0001

Groups	t	P(perm)
2003, 2014	1.5919	0.0704
2003, 2015	2.9329	0.0006
2004, 2005	4.7965	0.0001
2004, 2010	4.2237	0.0001
2004, 2012	5.5692	0.0001
2004, 2014	2.3223	0.0009
2004, 2015	2.359	0.0002
2005, 2010	2.6604	0.0002
2005, 2012	6.1413	0.0001
2005, 2014	4.3473	0.0001
2005, 2015	4.7221	0.0001
2010, 2012	5.5077	0.0001
2010, 2014	3.7676	0.0001
2010, 2015	4.1687	0.0001
2012, 2014	7.0079	0.0001
2012, 2015	5.4025	0.0001
2014, 2015	2.7927	0.0001

Shaded cells indicate significance at the 0.05 level

Table D.5 Pairwise comparison of benthic cover assemblages at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	3.6181	0.0001
A1995, F1996	3.3768	0.0001
A1995, 2001	5.6922	0.0001
A1995, 2003	1.5485	0.0888
A1995, 2004	3.4786	0.0001
A1995, 2005	4.7255	0.0001
A1995, 2010	2.934	0.0003
A1995, 2012	2.6315	0.0013

Groups	t	P(perm)
A1995, 2014	2.2488	0.0022
A1995, 2015	2.1734	0.0065
J1995, F1996	2.09	0.0044
J1995, 2001	3.7927	0.0001
J1995, 2003	2.4031	0.0007
J1995, 2004	2.3999	0.0019
J1995, 2005	1.816	0.0101
J1995, 2010	3.574	0.0001
J1995, 2012	3.3074	0.0001
J1995, 2014	3.1027	0.0001
J1995, 2015	1.6587	0.0325
F1996, 2001	4.7551	0.0001
F1996, 2003	2.6978	0.0002
F1996, 2004	1.342	0.1732
F1996, 2005	2.9214	0.0001
F1996, 2010	3.8275	0.0001
F1996, 2012	3.5605	0.0001
F1996, 2014	2.0391	0.0054
F1996, 2015	1.3785	0.1326
2001, 2003	4.3492	0.0001
2001, 2004	4.2856	0.0001
2001, 2005	3.8718	0.0001
2001, 2010	4.5866	0.0001
2001, 2012	4.29	0.0001
2001, 2014	4.6671	0.0001
2001, 2015	3.8439	0.0001
2003, 2004	2.4471	0.0014
2003, 2005	3.209	0.0001
2003, 2010	2.6807	0.0003
2003, 2012	2.5149	0.0002

Groups	t	P(perm)
2003, 2014	1.8428	0.0202
2003, 2015	1.2228	0.2278
2004, 2005	2.8777	0.0006
2004, 2010	3.4276	0.0001
2004, 2012	3.5396	0.0001
2004, 2014	2.1241	0.0047
2004, 2015	1.1785	0.2528
2005, 2010	4.6208	0.0001
2005, 2012	4.2471	0.0001
2005, 2014	3.7299	0.0001
2005, 2015	2.4253	0.0009
2010, 2012	1.801	0.0055
2010, 2014	3.1525	0.0001
2010, 2015	2.6908	0.0003
2012, 2014	2.3517	0.0003
2012, 2015	2.6841	0.0003
2014, 2015	1.5721	0.0589

Shaded cells indicate significance at the 0.05 level

Table D.6 Pairwise comparison of benthic cover assemblages at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	4.217	0.0001
A1995, F1996	4.827	0.0001
A1995, 2001	6.9206	0.0001
A1995, 2003	3.0092	0.0001
A1995, 2004	7.1849	0.0001
A1995, 2005	7.8315	0.0001
A1995, 2010	5.938	0.0001
A1995, 2012	4.2985	0.0002

Groups	t	P(perm)
A1995, 2014	3.679	0.0001
A1995, 2015	2.745	0.0002
J1995, F1996	3.2157	0.0001
J1995, 2001	3.129	0.0001
J1995, 2003	2.9355	0.0001
J1995, 2004	3.8981	0.0001
J1995, 2005	3.3026	0.0001
J1995, 2010	2.1894	0.0066
J1995, 2012	2.1692	0.003
J1995, 2014	3.1857	0.0001
J1995, 2015	2.5281	0.0001
F1996, 2001	3.5944	0.0001
F1996, 2003	3.7882	0.0001
F1996, 2004	3.4626	0.0001
F1996, 2005	4.3772	0.0002
F1996, 2010	6.6217	0.0001
F1996, 2012	1.8266	0.0155
F1996, 2014	3.7024	0.0001
F1996, 2015	1.4981	0.0726
2001, 2003	5.4723	0.0001
2001, 2004	4.2716	0.0001
2001, 2005	2.2278	0.0016
2001, 2010	5.7491	0.0001
2001, 2012	2.1945	0.0031
2001, 2014	4.2227	0.0001
2001, 2015	3.1306	0.0001
2003, 2004	6.0845	0.0001
2003, 2005	6.2298	0.0001
2003, 2010	6.3608	0.0001
2003, 2012	3.4258	0.0001

Groups	t	P(perm)
2003, 2014	4.1097	0.0001
2003, 2015	1.9326	0.0142
2004, 2005	4.3811	0.0001
2004, 2010	7.2451	0.0001
2004, 2012	3.2097	0.0001
2004, 2014	3.7027	0.0001
2004, 2015	2.8417	0.0002
2005, 2010	6.0059	0.0001
2005, 2012	2.4449	0.001
2005, 2014	4.0577	0.0001
2005, 2015	3.193	0.0001
2010, 2012	3.8602	0.0001
2010, 2014	3.366	0.0001
2010, 2015	4.2799	0.0001
2012, 2014	2.7801	0.0001
2012, 2015	1.5457	0.0589
2014, 2015	2.8304	0.0001

Shaded cells indicate significance at the 0.05 level

Table D.7 Pairwise comparison of benthic cover assemblages at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	3.0699	0.0003
A1995, F1996	4.3067	0.0001
A1995, 2001	4.6544	0.0001
A1995, 2003	2.1102	0.0082
A1995, 2004	4.4183	0.0001
A1995, 2005	6.1455	0.0001
A1995, 2010	2.9347	0.0001
A1995, 2012	4.1339	0.0001

Groups	t	P(perm)
A1995, 2014	4.1143	0.0001
A1995, 2015	3.8836	0.0001
J1995, F1996	2.7833	0.0001
J1995, 2001	1.8475	0.0048
J1995, 2003	2.5891	0.0003
J1995, 2004	2.1412	0.003
J1995, 2005	2.88	0.0001
J1995, 2010	1.8056	0.0092
J1995, 2012	2.651	0.0001
J1995, 2014	2.2398	0.0005
J1995, 2015	2.4378	0.0003
F1996, 2001	5.3576	0.0001
F1996, 2003	3.6098	0.0001
F1996, 2004	2.3729	0.0014
F1996, 2005	3.9723	0.0001
F1996, 2010	4.7664	0.0001
F1996, 2012	1.9037	0.0113
F1996, 2014	1.9469	0.0034
F1996, 2015	2.187	0.001
2001, 2003	4.4248	0.0001
2001, 2004	4.0323	0.0001
2001, 2005	4.6104	0.0001
2001, 2010	2.4025	0.0012
2001, 2012	4.708	0.0001
2001, 2014	3.3838	0.0001
2001, 2015	3.6409	0.0001
2003, 2004	4.2088	0.0001
2003, 2005	6.1101	0.0001
2003, 2010	2.6588	0.0001
2003, 2012	3.9241	0.0001

Groups	t	P(perm)
2003, 2014	3.6287	0.0001
2003, 2015	3.7075	0.0001
2004, 2005	3.1248	0.0001
2004, 2010	3.9388	0.0001
2004, 2012	2.7132	0.0001
2004, 2014	1.6243	0.0441
2004, 2015	2.161	0.0028
2005, 2010	5.3318	0.0001
2005, 2012	2.2658	0.0042
2005, 2014	2.362	0.0015
2005, 2015	2.2605	0.0009
2010, 2012	4.506	0.0001
2010, 2014	3.5061	0.0001
2010, 2015	3.6109	0.0001
2012, 2014	1.7247	0.0301
2012, 2015	1.605	0.0391
2014, 2015	1.4105	0.0915

Shaded cells indicate significance at the 0.05 level

Table D.8 Pairwise comparison of macroalgae cover between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	2.1003	0.055
KRN1, KRO3	1.1785	0.276
KRN2, KRO3	1.4498	0.167
PB1, PB2	0.1410	1
PB1, PB3	0.3573	1
PB2, PB3	0.4472	1
J1995		
KRN1, KRN2	0.4765	0.649
KRN1, KRO3	3.9456	0.001
KRN2, KRO3	4.7553	0.001
PB1, PB2	0.9227	0.746
PB1, PB3	0.7625	0.75
PB2, PB3	0.3388	1
F1996		
KRN1, KRN2	6.8307	0.001
KRN1, KRO3	0.821	0.424
KRN2, KRO3	5.3781	0.001
PB1, PB2	0	1
PB1, PB3	0.8801	0.449
PB2, PB3	1.0135	0.365
2001		
KRN1, KRN2	1.0868	0.33
KRN1, KRO3	2.5057	0.021
KRN2, KRO3	3.6573	0.003
PB1, PB2	2.5215	0.019
PB1, PB3	1.8229	0.092
PB2, PB3	0.1235	0.904

2003		
KRN1, KRN2	0.0966	0.973
KRN1, KRO3	3.0966	0.005
KRN2, KRO3	2.4204	0.019
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
2004		
KRN1, KRN2	2.0592	0.06
KRN1, KRO3	0.841	0.405
KRN2, KRO3	1.0271	0.339
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
2005		
KRN1, KRN2	4.1055	0.001
KRN1, KRO3	0.4978	0.712
KRN2, KRO3	3.3002	0.007
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
2010		
KRN1, KRN2	1.8225	0.086
KRN1, KRO3	2.4356	0.019
KRN2, KRO3	3.9469	0.001
PB1, PB2	1.7447	0.009
PB1, PB3	1.4646	0.099
PB2, PB3	1.4573	0.487
2012		
KRN1, KRN2	0.3643	0.744
KRN1, KRO3	1.3744	0.177

KRN2, KRO3	2.0182	0.057
PB1, PB2	0.3692	0.786
PB1, PB3	1.478	0.277
PB2, PB3	1.4	0.257
2014		
KRN1, KRN2	0.8977	0.421
KRN1, KRO3	1.402	0.183
KRN2, KRO3	0.3532	0.743
PB1, PB2	0.9581	0.728
PB1, PB3	0.7276	1
PB2, PB3	0.1756	1
2015		
KRN1, KRN2	0.7449	0.489
KRN1, KRO3	1.3682	0.202
KRN2, KRO3	0.6193	0.579
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey
Shaded cells indicate significance at the 0.05 level

Table D.9 Pairwise comparison of macroalgae cover at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	4.2912	0.002
A1995, F1996	1.0061	0.343
A1995, 2001	6.3263	0.001
A1995, 2003	2.1914	0.041
A1995, 2004	2.2612	0.041
A1995, 2005	1.4013	0.202
A1995, 2010	1.3147	0.226
A1995, 2012	0.3954	0.739

Groups	t	P(perm)
A1995, 2014	2.1522	0.039
A1995, 2015	2.7901	0.014
J1995, F1996	1.0171	0.333
J1995, 2001	2.7882	0.012
J1995, 2003	2.6074	0.018
J1995, 2004	5.6555	0.001
J1995, 2005	5.6852	0.001
J1995, 2010	3.4703	0.003
J1995, 2012	3.169	0.01
J1995, 2014	2.4055	0.025
J1995, 2015	1.8532	0.089
F1996, 2001	4.1453	0.001
F1996, 2003	0.5996	0.605
F1996, 2004	0.7074	0.481
F1996, 2005	2.0713	0.043
F1996, 2010	2.0137	0.034
F1996, 2012	0.5592	0.607
F1996, 2014	0.4164	0.713
F1996, 2015	0.5936	0.585
2001, 2003	4.6183	0.001
2001, 2004	4.3385	0.001
2001, 2005	8.404	0.001
2001, 2010	8.5811	0.001
2001, 2012	5.0101	0.001
2001, 2014	5.2743	0.001
2001, 2015	3.8573	0.002
2003, 2004	0.1667	0.926
2003, 2005	4.2053	0.001
2003, 2010	4.3033	0.001
2003, 2012	1.3455	0.207

Groups	t	P(perm)
2003, 2014	0.3307	0.807
2003, 2015	0.0836	0.939
2004, 2005	4.1374	0.001
2004, 2010	4.2075	0.001
2004, 2012	1.4397	0.173
2004, 2014	0.4992	0.668
2004, 2015	0.0541	0.967
2005, 2010	0.2573	0.801
2005, 2012	1.4907	0.168
2005, 2014	4.7088	0.001
2005, 2015	3.2061	0.002
2010, 2012	1.4148	0.17
2010, 2014	4.9699	0.001
2010, 2015	3.1881	0.002
2012, 2014	1.2056	0.259
2012, 2015	1.233	0.235
2014, 2015	0.3415	0.72

Shaded cells indicate significance at the 0.05 level

Table D.10 Pairwise comparison of macroalgae cover at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	2.9369	0.01
A1995, F1996	7.9251	0.001
A1995, 2001	5.6104	0.001
A1995, 2003	0.1378	0.929
A1995, 2004	1.8965	0.081
A1995, 2005	0.5209	0.622
A1995, 2010	4.9233	0.001
A1995, 2012	1.0315	0.337
A1995, 2014	1.0574	0.326

Groups	t	P(perm)
A1995, 2015	5.1955	0.001
J1995, F1996	3.1157	0.009
J1995, 2001	2.7808	0.009
J1995, 2003	5.1157	0.001
J1995, 2004	3.9237	0.001
J1995, 2005	9.4126	0.001
J1995, 2010	3.7584	0.002
J1995, 2012	4.3394	0.001
J1995, 2014	3.7813	0.001
J1995, 2015	0.8136	0.441
F1996, 2001	1.4488	0.16
F1996, 2003	7.2792	0.001
F1996, 2004	10.419	0.001
F1996, 2005	9.6202	0.001
F1996, 2010	16.23	0.001
F1996, 2012	8.3442	0.001
F1996, 2014	9.8029	0.001
F1996, 2015	8.7656	0.001
2001, 2003	5.2849	0.001
2001, 2004	7.6092	0.001
2001, 2005	6.6876	0.001
2001, 2010	11.306	0.001
2001, 2012	6.1968	0.001
2001, 2014	6.9805	0.001
2001, 2015	6.3529	0.001
2003, 2004	1.5483	0.158
2003, 2005	0.3057	0.821
2003, 2010	3.9507	0.001
2003, 2012	0.8166	0.462
2003, 2014	0.7907	0.465

Groups	t	P(perm)
2003, 2015	0.5976	0.595
2004, 2005	1.6397	0.121
2004, 2010	2.8223	0.009
2004, 2012	0.6438	0.593
2004, 2014	0.9636	0.358
2004, 2015	1.0311	0.338
2005, 2010	5.7173	0.001
2005, 2012	0.6798	0.526
2005, 2014	0.6541	0.549
2005, 2015	0.4058	0.737
2010, 2012	2.9367	0.007
2010, 2014	4.35	0.001
2010, 2015	3.8137	0.001
2012, 2014	0.1519	0.919
2012, 2015	0.2816	0.814
2014, 2015	0.1672	0.911

Shaded cells indicate significance at the 0.05 level

Table D.11 Pairwise comparison of macroalgae cover at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	0.57404	0.582
A1995, F1996	1.3568	0.204
A1995, 2001	3.3836	0.003
A1995, 2003	2.2314	0.046
A1995, 2004	0.4529	0.696
A1995, 2005	2.7511	0.018
A1995, 2010	0.9182	0.367
A1995, 2012	3.1559	0.004
A1995, 2014	0.1367	0.893
A1995, 2015	1.5573	0.14

Groups	t	P(perm)
J1995, F1996	3.2941	0.004
J1995, 2001	1.1998	0.24
J1995, 2003	0.8026	0.452
J1995, 2004	1.5042	0.176
J1995, 2005	0.1279	0.915
J1995, 2010	1.8042	0.097
J1995, 2012	0.4277	0.704
J1995, 2014	0.3277	0.795
J1995, 2015	0.3144	0.774
F1996, 2001	0.9611	0.346
F1996, 2003	2.4094	0.022
F1996, 2004	0.9065	0.397
F1996, 2005	2.6153	0.019
F1996, 2010	1.7449	0.106
F1996, 2012	2.8079	0.007
F1996, 2014	1.378	0.202
F1996, 2015	1.4746	0.168
2001, 2003	4.5504	0.002
2001, 2004	2.3406	0.036
2001, 2005	4.9126	0.001
2001, 2010	3.7945	0.003
2001, 2012	5.1671	0.001
2001, 2014	3.2762	0.006
2001, 2015	3.4733	0.005
2003, 2004	1.9374	0.071
2003, 2005	0.2811	0.833
2003, 2010	1.2989	0.2
2003, 2012	0.6181	0.552
2003, 2014	1.8919	0.077
2003, 2015	1.8597	0.084

Groups	t	P(perm)
2004, 2005	2.2291	0.045
2004, 2010	1.0197	0.315
2004, 2012	2.4957	0.025
2004, 2014	0.5141	0.646
2004, 2015	0.6348	0.586
2005, 2010	1.6936	0.122
2005, 2012	0.3584	0.746
2005, 2014	2.3126	0.045
2005, 2015	2.3113	0.038
2010, 2012	2.0616	0.066
2010, 2014	0.681	0.518
2010, 2015	0.5773	0.591
2012, 2014	2.6712	0.013
2012, 2015	2.6918	0.016
2014, 2015	0.1443	0.927

Shaded cells indicate significance at the 0.05 level

Table D.12 Pairwise comparison of macroalgae cover at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	1.0847	0.483
A1995, F1996	1.8013	0.124
A1995, 2001	1.7878	0.118
A1995, 2003	1.1932	0.482
A1995, 2004	1.1932	0.496
A1995, 2005	1.1932	0.452
A1995, 2010	1.5571	0.061
A1995, 2012	1.6534	0.088
A1995, 2014	0.141	1
A1995, 2015	0.4981	0.85
J1995, F1996	0.3646	0.859

Groups	t	P(perm)
J1995, 2001	1.2929	0.5
J1995, 2003	1.2929	0.492
J1995, 2004	1.2929	0.472
J1995, 2005	0.4498	0.587
J1995, 2010	0.4388	0.786
J1995, 2012	1.1168	0.473
J1995, 2014	1.2929	0.49
J1995, 2015	1.1932	0.485
F1996, 2001	0.2823	0.847
F1996, 2003	2.7792	0.016
F1996, 2004	2.7792	0.019
F1996, 2005	2.7792	0.022
F1996, 2010	1.0274	0.42
F1996, 2012	1.0724	0.354
F1996, 2014	1.9041	0.093
F1996, 2015	2.7792	0.014
2001, 2003	2.493	0.038
2001, 2004	2.493	0.046
2001, 2005	2.493	0.044
2001, 2010	0.8986	0.536
2001, 2012	0.9301	0.453
2001, 2014	1.8708	0.129
2001, 2015	2.493	0.041
2003, 2004	Denominator is 0	
2003, 2005	Denominator is 0	
2003, 2010	1.7447	0.005
2003, 2012	1.8613	0.098
2003, 2014	1	1
2003, 2015	Denominator is 0	
2004, 2005	Denominator is 0	

Groups	t	P(perm)
2004, 2010	1.7447	0.004
2004, 2012	1.8613	0.105
2004, 2014	1	1
2004, 2015	Denominator is 0	
2005, 2010	1.7447	0.004
2005, 2012	1.8613	0.118
2005, 2014	1	1
2005, 2015	Denominator is 0	
2010, 2012	0.0312	0.98
2010, 2014	1.5856	0.044
2010, 2015	1.7447	0.008
2012, 2014	1.6845	0.085
2012, 2015	1.8613	0.099
2014, 2015	1	1

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.13 Pairwise comparison of macroalgae cover at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	0.4472	1
A1995, F1996	2.2108	0.043
A1995, 2001	3.0963	0.003
A1995, 2003	1	1
A1995, 2004	1	1
A1995, 2005	1	1
A1995, 2010	1	1
A1995, 2012	1.7056	0.139
A1995, 2014	0.9581	0.737
A1995, 2015	1.1475	0.347
J1995, F1996	2.9309	0.007

Groups	t	P(perm)
J1995, 2001	1	1
J1995, 2003	1	1
J1995, 2004	1	1
J1995, 2005	1	1
J1995, 2010	1.4	0.263
J1995, 2012	0.6638	0.744
J1995, 2014	1	1
J1995, 2015	1	1
F1996, 2001	2.6574	0.006
F1996, 2003	3.4336	0.003
F1996, 2004	3.4336	0.001
F1996, 2005	3.4336	0.001
F1996, 2010	3.4336	0.006
F1996, 2012	0.8766	0.463
F1996, 2014	0.0466	1
F1996, 2015	3.4336	0.003
2001, 2003	3.2278	0.001
2001, 2004	3.2278	0.001
2001, 2005	3.2278	0.001
2001, 2010	3.2278	0.001
2001, 2012	1.974	0.072
2001, 2014	2.4286	0.029
2001, 2015	3.2278	0.002
2003, 2004	Denominator is 0	
2003, 2005	Denominator is 0	
2003, 2010	Denominator is 0	
2003, 2012	1.964	0.091
2003, 2014	1.2336	0.486
2003, 2015	Denominator is 0	
2004, 2005	Denominator is 0	

Groups	t	P(perm)
2004, 2010	Denominator is 0	
2004, 2012	1.964	0.1
2004, 2014	1.2336	0.496
2004, 2015	Denominator is 0	
2005, 2010	Denominator is 0	
2005, 2012	1.964	0.09
2005, 2014	1.2336	0.483
2005, 2015	Denominator is 0	
2010, 2012	1.964	0.086
2010, 2014	1.2336	0.482
2010, 2015	Denominator is 0	
2012, 2014	0.6538	0.626
2012, 2015	1.964	0.089
2014, 2015	1.2336	0.452

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.14 Pairwise comparison of macroalgae cover at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	0.3388	1
A1995, F1996	0.4385	0.832
A1995, 2001	2.1377	0.062
A1995, 2003	1	1
A1995, 2004	1	1
A1995, 2005	1	1
A1995, 2010	0.0851	1
A1995, 2012	2.97×10^{-9}	1
A1995, 2014	0.4472	1
A1995, 2015	6.71×10^{-9}	1
J1995, F1996	2.0468	0.068

Groups	t	P(perm)
J1995, 2001	1.3817	0.47
J1995, 2003	1.3817	0.477
J1995, 2004	1.3817	0.478
J1995, 2005	0.4803	0.742
J1995, 2010	0.3388	1
J1995, 2012	0.2197	1
J1995, 2014	1.3817	0.499
J1995, 2015	1	1
F1996, 2001	2.0735	0.055
F1996, 2003	2.7386	0.006
F1996, 2004	2.7386	0.007
F1996, 2005	2.7386	0.003
F1996, 2010	0.7268	0.572
F1996, 2012	0.4385	0.801
F1996, 2014	0.2411	1
F1996, 2015	2.7386	0.011
2001, 2003	2.3432	0.007
2001, 2004	2.3432	0.009
2001, 2005	2.3432	0.008
2001, 2010	2.1745	0.029
2001, 2012	2.1377	0.049
2001, 2014	1.8857	0.06
2001, 2015	2.3432	0.01
2003, 2004	Denominator is 0	
2003, 2005	Denominator is 0	
2003, 2010	1.4573	0.478
2003, 2012	1	1
2003, 2014	1	1
2003, 2015	Denominator is 0	
2004, 2005	Denominator is 0	

Groups	t	P(perm)
2004, 2010	1.4573	0.493
2004, 2012	1	1
2004, 2014	1	1
2004, 2015	Denominator is 0	
2005, 2010	1.4573	0.487
2005, 2012	1	1
2005, 2014	1	1
2005, 2015	Denominator is 0	
2010, 2012	0.0851	1
2010, 2014	0.5255	1
2010, 2015	1.4573	0.475
2012, 2014	0.4472	1
2012, 2015	1	1
2014, 2015	1	1

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.15 Pairwise comparison of turf algae cover between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	0.6063	0.668
KRN1, KRO3	0.7977	0.576
KRN2, KRO3	1.262	0.301
PB1, PB2	1.5001	0.168
PB1, PB3	1.3893	0.199
PB2, PB3	0.0973	1
J1995		
KRN1, KRN2	4.2178	0.001
KRN1, KRO3	11.317	0.001
KRN2, KRO3	8.2681	0.001
PB1, PB2	2.9875	0.007
PB1, PB3	2.2453	0.046
PB2, PB3	0.4644	0.686
F1996		
KRN1, KRN2	3.1701	0.002
KRN1, KRO3	2.6732	0.01
KRN2, KRO3	1.1966	0.479
PB1, PB2	0.1139	0.915
PB1, PB3	0.1875	0.879
PB2, PB3	0.3419	0.755
2001		
KRN1, KRN2	1.4542	0.215
KRN1, KRO3	3.9413	0.001
KRN2, KRO3	2.637	0.023
PB1, PB2	4.4591	0.001
PB1, PB3	0.6159	0.531
PB2, PB3	4.9587	0.001

2003		
KRN1, KRN2	0.1794	0.921
KRN1, KRO3	1.2798	0.23
KRN2, KRO3	1.4807	0.182
PB1, PB2	0.15	0.912
PB1, PB3	0.0318	1
PB2, PB3	0.1164	0.94
2004		
KRN1, KRN2	0.35	0.77
KRN1, KRO3	0.3796	0.748
KRN2, KRO3	Negative	
PB1, PB2	0.7567	0.474
PB1, PB3	0.3286	0.75
PB2, PB3	1.4627	0.179
2005		
KRN1, KRN2	1.4609	0.194
KRN1, KRO3	0.3496	0.765
KRN2, KRO3	1.9787	0.069
PB1, PB2	1.039	0.38
PB1, PB3	1.01	0.373
PB2, PB3	1.7665	0.087
2010		
KRN1, KRN2	1.3697	0.195
KRN1, KRO3	4.0143	0.001
KRN2, KRO3	2.2338	0.041
PB1, PB2	1.2022	0.258
PB1, PB3	1.8555	0.069
PB2, PB3	1.0357	0.303
2012		
KRN1, KRN2	0.2276	0.839
KRN1, KRO3	2.1006	0.048

KRN2, KRO3	2.4945	0.027
PB1, PB2	4.2019	0.001
PB1, PB3	5.9837	0.001
PB2, PB3	1.1891	0.254
2014		
KRN1, KRN2	2.1646	0.039
KRN1, KRO3	3.0459	0.008
KRN2, KRO3	0.4416	0.638
PB1, PB2	2.9731	0.007
PB1, PB3	3.0055	0.004
PB2, PB3	5.4602	0.001
2015		
KRN1, KRN2	0.2397	0.826
KRN1, KRO3	0.7155	0.488
KRN2, KRO3	0.4672	0.667
PB1, PB2	0.3994	0.724
PB1, PB3	0.0607	0.976
PB2, PB3	0.5156	0.614

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.16 Pairwise comparison of turf algae cover at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	5.9829	0.001
A1995, F1996	1.1384	0.27
A1995, 2001	4.2713	0.001
A1995, 2003	0.6843	0.557
A1995, 2004	4.5085	0.001
A1995, 2005	2.6916	0.009
A1995, 2010	1.479	0.157
A1995, 2012	5.8156	0.001

Groups	t	P(perm)
A1995, 2014	7.7386	0.001
A1995, 2015	5.3036	0.001
J1995, F1996	3.1701	0.001
J1995, 2001	1.5796	0.189
J1995, 2003	1.6821	0.165
J1995, 2004	6.6474	0.001
J1995, 2005	4.9044	0.001
J1995, 2010	7.9218	0.001
J1995, 2012	7.0795	0.001
J1995, 2014	10.354	0.001
J1995, 2015	7.1726	0.001
F1996, 2001	2.7338	0.012
F1996, 2003	1.3836	0.197
F1996, 2004	2.5073	0.023
F1996, 2005	1.0793	0.292
F1996, 2010	0.5246	0.596
F1996, 2012	4.4774	0.001
F1996, 2014	4.5271	0.001
F1996, 2015	3.3755	0.002
2001, 2003	1.1775	0.376
2001, 2004	6.1672	0.001
2001, 2005	4.4149	0.001
2001, 2010	5.9945	0.001
2001, 2012	6.8081	0.001
2001, 2014	9.7297	0.001
2001, 2015	6.7572	0.001
2003, 2004	4.1109	0.001
2003, 2005	2.6133	0.014
2003, 2010	1.4148	0.15
2003, 2012	5.6316	0.001

Groups	t	P(perm)
2003, 2014	6.4851	0.001
2003, 2015	4.8941	0.002
2004, 2005	1.5009	0.152
2004, 2010	3.9001	0.002
2004, 2012	2.6565	0.013
2004, 2014	1.8489	0.081
2004, 2015	1.0459	0.327
2005, 2010	2.0463	0.045
2005, 2012	3.7721	0.002
2005, 2014	3.5193	0.002
2005, 2015	2.4611	0.026
2010, 2012	5.4415	0.001
2010, 2014	7.0535	0.001
2010, 2015	4.7688	0.001
2012, 2014	1.4416	0.148
2012, 2015	1.766	0.112
2014, 2015	0.5975	0.544

Shaded cells indicate significance at the 0.05 level

Table D.17 Pairwise comparison of turf algae cover at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	1.0009	0.386
A1995, F1996	4.9079	0.001
A1995, 2001	2.0766	0.043
A1995, 2003	1.2861	0.289
A1995, 2004	3.9778	0.002
A1995, 2005	1.2312	0.269
A1995, 2010	1.5947	0.132
A1995, 2012	7.9886	0.001
A1995, 2014	3.4861	0.005

Groups	t	P(perm)
A1995, 2015	4.346	0.001
J1995, F1996	4.2178	0.002
J1995, 2001	1.188	0.28
J1995, 2003	0.6288	0.657
J1995, 2004	4.7247	0.001
J1995, 2005	2.317	0.031
J1995, 2010	2.2578	0.025
J1995, 2012	8.6213	0.001
J1995, 2014	4.1112	0.001
J1995, 2015	4.8967	0.001
F1996, 2001	2.5031	0.026
F1996, 2003	1.5675	0.127
F1996, 2004	7.0626	0.001
F1996, 2005	6.5088	0.001
F1996, 2010	4.3539	0.001
F1996, 2012	10.489	0.001
F1996, 2014	6.023	0.001
F1996, 2015	6.5437	0.001
2001, 2003	0.1558	0.953
2001, 2004	5.3825	0.001
2001, 2005	3.3624	0.002
2001, 2010	2.9225	0.002
2001, 2012	9.1223	0.001
2001, 2014	4.6914	0.001
2001, 2015	5.4018	0.001
2003, 2004	4.3806	0.002
2003, 2005	2.186	0.046
2003, 2010	2.3381	0.02
2003, 2012	8.0247	0.001
2003, 2014	3.9649	0.002

Groups	t	P(perm)
2003, 2015	4.7372	0.002
2004, 2005	3.1595	0.003
2004, 2010	1.8635	0.07
2004, 2012	4.1837	0.001
2004, 2014	Negative	
2004, 2015	1.1182	0.292
2005, 2010	0.7951	0.481
2005, 2012	7.3405	0.001
2005, 2014	2.7709	0.01
2005, 2015	3.7188	0.004
2010, 2012	5.7369	0.001
2010, 2014	1.7095	0.114
2010, 2015	2.6664	0.017
2012, 2014	3.9229	0.001
2012, 2015	2.6543	0.01
2014, 2015	1.0506	0.333

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.18 Pairwise comparison of turf algae cover at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	9.1147	0.001
A1995, F1996	3.9886	0.002
A1995, 2001	2.0352	0.071
A1995, 2003	1.3082	0.223
A1995, 2004	6.2828	0.001
A1995, 2005	3.7586	0.001
A1995, 2010	5.0122	0.001
A1995, 2012	23.451	0.001
A1995, 2014	5.3026	0.001

Groups	t	P(perm)
A1995, 2015	4.4114	0.001
J1995, F1996	10.2	0.001
J1995, 2001	5.8023	0.001
J1995, 2003	4.5847	0.002
J1995, 2004	2.5121	0.028
J1995, 2005	3.2053	0.007
J1995, 2010	1.4676	0.175
J1995, 2012	6.9842	0.001
J1995, 2014	2.9901	0.01
J1995, 2015	1.2289	0.252
F1996, 2001	3.751	0.001
F1996, 2003	2.5255	0.021
F1996, 2004	7.594	0.001
F1996, 2005	5.0087	0.001
F1996, 2010	6.075	0.001
F1996, 2012	23.303	0.001
F1996, 2014	6.6455	0.001
F1996, 2015	5.3659	0.001
2001, 2003	1.74E-08	1
2001, 2004	3.3466	0.008
2001, 2005	1.8701	0.068
2001, 2010	3.2139	0.004
2001, 2012	14.582	0.001
2001, 2014	2.7013	0.015
2001, 2015	2.9565	0.011
2003, 2004	2.5923	0.023
2003, 2005	1.5241	0.144
2003, 2010	2.7096	0.016
2003, 2012	10.82	0.001
2003, 2014	2.1106	0.056

Groups	t	P(perm)
2003, 2015	2.5712	0.023
2004, 2005	1.0069	0.313
2004, 2010	0.58172	0.594
2004, 2012	10.268	0.001
2004, 2014	0.5474	0.613
2004, 2015	0.61537	0.574
2005, 2010	1.371	0.19
2005, 2012	9.9245	0.001
2005, 2014	0.50722	0.63
2005, 2015	1.3349	0.214
2010, 2012	7.2688	0.001
2010, 2014	1.013	0.307
2010, 2015	8.32E-02	0.946
2012, 2014	10.624	0.001
2012, 2015	6.3325	0.001
2014, 2015	1.0027	0.328

Shaded cells indicate significance at the 0.05 level

Table D.19 Pairwise comparison of turf algae cover at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	4.8064	0.001
A1995, F1996	4.167	0.002
A1995, 2001	0.88426	0.401
A1995, 2003	0.96743	0.372
A1995, 2004	1.9095	0.075
A1995, 2005	5.1764	0.001
A1995, 2010	2.3502	0.037
A1995, 2012	0.62381	0.545
A1995, 2014	0.35311	0.76
A1995, 2015	1.8279	0.077

Groups	t	P(perm)
J1995, F1996	0.20985	0.842
J1995, 2001	5.4746	0.001
J1995, 2003	3.2392	0.002
J1995, 2004	1.7092	0.109
J1995, 2005	0.34223	0.764
J1995, 2010	9.9904	0.001
J1995, 2012	6.36	0.001
J1995, 2014	5.9279	0.001
J1995, 2015	2.0078	0.058
F1996, 2001	4.3675	0.003
F1996, 2003	2.8168	0.018
F1996, 2004	1.4538	0.152
F1996, 2005	4.02E-02	0.983
F1996, 2010	8.0138	0.001
F1996, 2012	5.3673	0.001
F1996, 2014	4.8035	0.001
F1996, 2015	1.7116	0.114
2001, 2003	0.37522	0.704
2001, 2004	1.5196	0.135
2001, 2005	6.727	0.001
2001, 2010	5.0928	0.001
2001, 2012	1.9056	0.078
2001, 2014	0.74521	0.476
2001, 2015	1.4156	0.186
2003, 2004	0.98034	0.343
2003, 2005	3.3408	0.004
2003, 2010	3.2518	0.007
2003, 2012	1.6268	0.114
2003, 2014	0.82396	0.444
2003, 2015	0.85772	0.418

Groups	t	P(perm)
2004, 2005	1.6419	0.103
2004, 2010	4.013	0.002
2004, 2012	2.5557	0.019
2004, 2014	1.8955	0.073
2004, 2015	0.15219	0.893
2005, 2010	13.132	0.001
2005, 2012	7.2725	0.001
2005, 2014	7.1666	0.001
2005, 2015	1.9709	0.073
2010, 2012	2.0033	0.052
2010, 2014	4.0213	0.001
2010, 2015	4.0841	0.001
2012, 2014	1.2341	0.231
2012, 2015	2.5132	0.025
2014, 2015	1.8163	0.074

Shaded cells indicate significance at the 0.05 level

Table D.20 Pairwise comparison of turf algae cover at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	3.6591	0.004
A1995, F1996	8.1496	0.001
A1995, 2001	7.7382	0.001
A1995, 2003	3.2684	0.005
A1995, 2004	6.3709	0.001
A1995, 2005	7.3989	0.001
A1995, 2010	0.22482	0.851
A1995, 2012	5.5122	0.001
A1995, 2014	0.78193	0.474
A1995, 2015	3.9537	0.002
J1995, F1996	2.9005	0.01

Groups	t	P(perm)
J1995, 2001	1.8242	0.07
J1995, 2003	0.90477	0.413
J1995, 2004	1.7119	0.108
J1995, 2005	2.121	0.054
J1995, 2010	4.198	0.001
J1995, 2012	1.4059	0.204
J1995, 2014	3.9417	0.001
J1995, 2015	Negative	
F1996, 2001	1.6715	0.113
F1996, 2003	4.4887	0.001
F1996, 2004	1.2841	0.246
F1996, 2005	1.0207	0.33
F1996, 2010	9.7074	0.001
F1996, 2012	1.3975	0.176
F1996, 2014	7.8317	0.001
F1996, 2015	3.1043	0.006
2001, 2003	3.4664	0.002
2001, 2004	0.13202	0.911
2001, 2005	0.57308	0.583
2001, 2010	10.002	0.001
2001, 2012	0.128	0.902
2001, 2014	7.2695	0.001
2001, 2015	1.9823	0.057
2003, 2004	3.0202	0.008
2003, 2005	3.6366	0.001
2003, 2010	4.0124	0.001
2003, 2012	2.5401	0.017
2003, 2014	3.5739	0.002
2003, 2015	0.96851	0.366
2004, 2005	0.35227	0.764

Groups	t	P(perm)
2004, 2010	7.4962	0.001
2004, 2012	0.21548	0.846
2004, 2014	6.3166	0.001
2004, 2015	1.8245	0.094
2005, 2010	8.9929	0.001
2005, 2012	0.54944	0.618
2005, 2014	7.1309	0.001
2005, 2015	2.2791	0.038
2010, 2012	6.309	0.001
2010, 2014	0.71597	0.511
2010, 2015	4.6229	0.001
2012, 2014	5.6077	0.001
2012, 2015	1.4857	0.173
2014, 2015	4.1973	0.002

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.21 Pairwise comparison of turf algae cover at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	3.5199	0.003
A1995, F1996	6.2758	0.001
A1995, 2001	2.2732	0.031
A1995, 2003	2.3189	0.034
A1995, 2004	3.6261	0.003
A1995, 2005	7.8826	0.001
A1995, 2010	0.63451	0.555
A1995, 2012	6.5135	0.001
A1995, 2014	4.4979	0.001
A1995, 2015	3.5038	0.002
J1995, F1996	1.8413	0.058

Groups	t	P(perm)
J1995, 2001	2.0605	0.052
J1995, 2003	1.0279	0.337
J1995, 2004	0.21905	0.884
J1995, 2005	2.7471	0.018
J1995, 2010	3.3947	0.002
J1995, 2012	1.9712	0.068
J1995, 2014	Negative	
J1995, 2015	3.34E-02	1
F1996, 2001	5.1617	0.001
F1996, 2003	2.9718	0.005
F1996, 2004	2.305	0.031
F1996, 2005	0.94581	0.362
F1996, 2010	6.7437	0.001
F1996, 2012	0.12541	0.914
F1996, 2014	2.4304	0.027
F1996, 2015	1.7729	0.089
2001, 2003	0.73021	0.487
2001, 2004	2.0523	0.051
2001, 2005	7.2779	0.001
2001, 2010	2.0261	0.048
2001, 2012	5.4547	0.001
2001, 2014	2.9238	0.007
2001, 2015	2.0621	0.074
2003, 2004	0.8931	0.382
2003, 2005	3.9418	0.003
2003, 2010	2.0502	0.062
2003, 2012	3.1137	0.003
2003, 2014	1.2378	0.23
2003, 2015	1.0483	0.327
2004, 2005	3.4087	0.002

Groups	t	P(perm)
2004, 2010	3.555	0.005
2004, 2012	2.4619	0.018
2004, 2014	0.27737	0.818
2004, 2015	0.25184	0.836
2005, 2010	9.0313	0.001
2005, 2012	0.8295	0.469
2005, 2014	3.9019	0.002
2005, 2015	2.6526	0.018
2010, 2012	7.0674	0.001
2010, 2014	4.7362	0.001
2010, 2015	3.3721	0.007
2012, 2014	2.6313	0.008
2012, 2015	1.8991	0.08
2014, 2015	4.03E-02	0.984

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.22 Pairwise comparison of sponge cover between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	0.9726	0.449
KRN1, KRO3	0.1935	1
KRN2, KRO3	1	0.451
PB1, PB2	0.3649	0.716
PB1, PB3	0.3898	0.735
PB2, PB3	4.9×10^{-9}	1
J1995		
KRN1, KRN2	1.344	0.342
KRN1, KRO3	0.6193	0.749
KRN2, KRO3	1.0583	0.583
PB1, PB2	1.9689	0.043
PB1, PB3	0.5196	0.619
PB2, PB3	1.685	0.085
F1996		
KRN1, KRN2	2.9557	0.005
KRN1, KRO3	2.3079	0.024
KRN2, KRO3	3.8146	0.002
PB1, PB2	0.8651	0.445
PB1, PB3	0.8876	0.386
PB2, PB3	Negative	
2001		
KRN1, KRN2	1.866	0.01
KRN1, KRO3	1.866	0.005
KRN2, KRO3	Denominator is 0	
PB1, PB2	1.6352	0.122
PB1, PB3	2.9548	0.003
PB2, PB3	1.6394	0.122

2003		
KRN1, KRN2	0.2172	0.868
KRN1, KRO3	1.3403	0.209
KRN2, KRO3	1.6953	0.107
PB1, PB2	0.1246	0.926
PB1, PB3	3.927	0.001
PB2, PB3	5.9996	0.001
2004		
KRN1, KRN2	4.4513	0.001
KRN1, KRO3	1.2273	0.25
KRN2, KRO3	2.948	0.014
PB1, PB2	0.0632	1
PB1, PB3	1.2435	0.255
PB2, PB3	1.5283	0.157
2005		
KRN1, KRN2	2.1093	0.059
KRN1, KRO3	1.9505	0.095
KRN2, KRO3	Negative	
PB1, PB2	0.7139	0.541
PB1, PB3	1.4491	0.197
PB2, PB3	1.8644	0.1
2010		
KRN1, KRN2	1.6182	0.228
KRN1, KRO3	1.6182	0.218
KRN2, KRO3	Denominator is 0	
PB1, PB2	0.5367	0.596
PB1, PB3	2.73	0.017
PB2, PB3	2.9381	0.013
2012		
KRN1, KRN2	1.9582	0.079
KRN1, KRO3	2.2191	0.036

KRN2, KRO3	1.7398	0.215
PB1, PB2	0.9876	0.359
PB1, PB3	0.1457	0.898
PB2, PB3	0.8535	0.463
2014		
KRN1, KRN2	2.0279	0.082
KRN1, KRO3	2.7647	0.014
KRN2, KRO3	0.9914	0.411
PB1, PB2	0.9937	0.377
PB1, PB3	0.0805	0.941
PB2, PB3	1.3409	0.202
2015		
KRN1, KRN2	0.4087	0.738
KRN1, KRO3	0.7698	0.498
KRN2, KRO3	0.2351	0.836
PB1, PB2	0.6583	0.572
PB1, PB3	0.4733	0.657
PB2, PB3	0.1916	0.872

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.23 Pairwise comparison of sponge cover at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	0.9726	0.44
A1995, F1996	2.6435	0.022
A1995, 2001	0.9559	0.521
A1995, 2003	1.8532	0.093
A1995, 2004	2.5649	0.02
A1995, 2005	1.4084	0.207
A1995, 2010	0.8929	0.483
A1995, 2012	1.1101	0.329

A1995, 2014	1.1893	0.321
A1995, 2015	1.2027	0.319
J1995, F1996	3.108	0.002
J1995, 2001	1.4028	0.147
J1995, 2003	2.2372	0.045
J1995, 2004	3.2677	0.005
J1995, 2005	2.2563	0.034
J1995, 2010	0.04.69	1
J1995, 2012	1.6501	0.136
J1995, 2014	0.2213	1
J1995, 2015	2.0804	0.05
F1996, 2001	1.3585	0.198
F1996, 2003	0.3938	0.774
F1996, 2004	0.6854	0.515
F1996, 2005	1.7172	0.102
F1996, 2010	3.0705	0.006
F1996, 2012	1.4606	0.162
F1996, 2014	3.1941	0.002
F1996, 2015	1.8799	0.082
2001, 2003	0.8568	0.43
2001, 2004	0.8857	0.417
2001, 2005	0.0742	1
2001, 2010	1.3748	0.163
2001, 2012	6.53×10^{-9}	1
2001, 2014	1.4822	0.089
2001, 2015	0.22586	0.923
2003, 2004	0.17735	0.901
2003, 2005	1.0706	0.317
2003, 2010	2.2112	0.041
2003, 2012	0.9117	0.4
2003, 2014	2.3055	0.034

2003, 2015	1.2086	0.266
2004, 2005	1.2841	0.234
2004, 2010	3.1994	0.002
2004, 2012	0.9835	0.368
2004, 2014	3.4088	0.003
2004, 2015	1.4995	0.176
2005, 2010	2.1753	0.04
2005, 2012	0.0843	1
2005, 2014	2.434	0.014
2005, 2015	0.2238	0.927
2010, 2012	1.612	0.134
2010, 2014	0.2537	0.909
2010, 2015	1.997	0.056
2012, 2014	1.7497	0.123
2012, 2015	0.2575	0.887
2014, 2015	2.2665	0.019

Shaded cells indicate significance at the 0.05 level

Table D.24 Pairwise comparison of sponge cover at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	1.344	0.323
A1995, F1996	0.2017	1
A1995, 2001	1.7838	0.231
A1995, 2003	2.4738	0.021
A1995, 2004	8.2147	0.001
A1995, 2005	0.25	1
A1995, 2010	1.7838	0.222
A1995, 2012	0.8322	0.549
A1995, 2014	1.765	0.122
A1995, 2015	2.0871	0.014
J1995, F1996	1.188	0.485

J1995, 2001	1	1
J1995, 2003	2.888	0.005
J1995, 2004	8.8162	0.001
J1995, 2005	1.6536	0.218
J1995, 2010	1	1
J1995, 2012	0.8217	0.578
J1995, 2014	2.9713	0.011
J1995, 2015	2.669	0.001
F1996, 2001	1.4676	0.231
F1996, 2003	2.315	0.034
F1996, 2004	7.8528	0.001
F1996, 2005	1.04×10^{-8}	1
F1996, 2010	1.4676	0.213
F1996, 2012	0.8344	0.686
F1996, 2014	1.355	0.258
F1996, 2015	1.8667	0.062
2001, 2003	2.9869	0.006
2001, 2004	8.9458	0.001
2001, 2005	2.1026	0.087
2001, 2010	Denominator is 0	
2001, 2012	1.7398	0.215
2001, 2014	3.2868	0.004
2001, 2015	2.8096	0.001
2003, 2004	4.0074	0.002
2003, 2005	2.386	0.039
2003, 2010	2.9869	0.007
2003, 2012	2.7559	0.01
2003, 2014	1.6456	0.128
2003, 2015	0.768	0.471
2004, 2005	8.1161	0.001
2004, 2010	8.9458	0.001

2004, 2012	8.6547	0.001
2004, 2014	7.1247	0.001
2004, 2015	5.4149	0.001
2005, 2010	2.1026	0.098
2005, 2012	1.1358	0.34
2005, 2014	1.5604	0.191
2005, 2015	1.9688	0.03
2010, 2012	1.7398	0.264
2010, 2014	3.2868	0.004
2010, 2015	2.8096	0.001
2012, 2014	2.5909	0.018
2012, 2015	2.4846	0.003
2014, 2015	0.9902	0.434

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.25 Pairwise comparison of sponge cover at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	1.833	0.176
A1995, F1996	3.7321	0.002
A1995, 2001	3.1539	0.007
A1995, 2003	3.7194	0.003
A1995, 2004	3.8682	0.001
A1995, 2005	0.60172	0.7
A1995, 2010	3.1539	0.009
A1995, 2012	3.1539	0.016
A1995, 2014	1.9008	0.089
A1995, 2015	2.4964	0.021
J1995, F1996	3.9463	0.001
J1995, 2001	1.8708	0.216
J1995, 2003	4.1606	0.001

J1995, 2004		4.5108	0.001
J1995, 2005		0.68313	0.615
J1995, 2010		1.8708	0.213
J1995, 2012		1.8708	0.249
J1995, 2014		3.0741	0.004
J1995, 2015		3.6354	0.001
F1996, 2001		4.0534	0.001
F1996, 2003		1.6258	0.126
F1996, 2004		2.1592	0.043
F1996, 2005		3.8146	0.001
F1996, 2010		4.0534	0.001
F1996, 2012		4.0534	0.001
F1996, 2014		3.2852	0.005
F1996, 2015		3.125	0.001
2001, 2003		4.3833	0.001
2001, 2004		4.84	0.001
2001, 2005		1.4676	0.481
2001, 2010	Denominator is 0		
2001, 2012	Denominator is 0		
2001, 2014		3.729	0.003
2001, 2015		4.2623	0.001
2003, 2004		0.75688	0.489
2003, 2005		3.8456	0.002
2003, 2010		4.3833	0.001
2003, 2012		4.3833	0.001
2003, 2014		2.7993	0.016
2003, 2015		2.4922	0.011
2004, 2005		4.0016	0.002
2004, 2010		4.84	0.001
2004, 2012		4.84	0.001
2004, 2014		2.5556	0.013

2004, 2015	2.1448	0.033
2005, 2010	1.4676	0.482
2005, 2012	1.4676	0.487
2005, 2014	2.1555	0.053
2005, 2015	2.6977	0.02
2010, 2012	Denominator is 0	
2010, 2014	3.729	0.003
2010, 2015	4.2623	0.001
2012, 2014	3.729	0.003
2012, 2015	4.2623	0.001
2014, 2015	0.5587	0.641

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.26 Pairwise comparison of sponge cover at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	0.7873	0.449
A1995, F1996	0.62777	0.574
A1995, 2001	3.3721	0.003
A1995, 2003	2.7993	0.006
A1995, 2004	1.0109	0.415
A1995, 2005	3.1191	0.005
A1995, 2010	1.9472	0.066
A1995, 2012	0.64663	0.575
A1995, 2014	0.40168	0.709
A1995, 2015	0.79466	0.486
J1995, F1996	1.6044	0.123
J1995, 2001	3.0674	0.003
J1995, 2003	2.5314	0.015
J1995, 2004	0.59934	0.691
J1995, 2005	2.7532	0.009

J1995, 2010	1.4478	0.162
J1995, 2012	0.15964	0.873
J1995, 2014	0.12246	0.953
J1995, 2015	0.27374	0.834
F1996, 2001	3.869	0.002
F1996, 2003	3.1302	0.004
F1996, 2004	1.4189	0.166
F1996, 2005	4.1918	0.004
F1996, 2010	2.6579	0.015
F1996, 2012	1.4411	0.167
F1996, 2014	0.86844	0.41
F1996, 2015	1.3043	0.233
2001, 2003	0.26554	0.779
2001, 2004	1.8276	0.077
2001, 2005	1.6632	0.11
2001, 2010	1.9436	0.071
2001, 2012	3.1418	0.002
2001, 2014	2.6114	0.013
2001, 2015	2.3998	0.026
2003, 2004	1.7516	0.082
2003, 2005	1.5162	0.159
2003, 2010	1.7587	0.093
2003, 2012	2.5874	0.013
2003, 2014	2.3331	0.033
2003, 2015	2.1531	0.037
2004, 2005	0.76443	0.579
2004, 2010	0.30657	0.817
2004, 2012	0.67737	0.649
2004, 2014	0.58241	0.634
2004, 2015	0.32526	0.807
2005, 2010	0.67289	0.512

2005, 2012	2.8875	0.01
2005, 2014	1.7581	0.105
2005, 2015	1.4471	0.183
2010, 2012	1.5631	0.129
2010, 2014	1.1115	0.26
2010, 2015	0.80003	0.454
2012, 2014	2.69E-02	1
2012, 2015	0.37285	0.75
2014, 2015	0.30715	0.82

Shaded cells indicate significance at the 0.05 level

Table D.27 Pairwise comparison of sponge cover at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	2.5623	0.009
A1995, F1996	0.60015	0.59
A1995, 2001	2.709	0.011
A1995, 2003	4.3366	0.002
A1995, 2004	2.5628	0.017
A1995, 2005	3.9225	0.001
A1995, 2010	2.7248	0.014
A1995, 2012	0.11659	1
A1995, 2014	0.50168	0.736
A1995, 2015	0.33858	0.833
J1995, F1996	2.2031	0.021
J1995, 2001	0.80993	0.456
J1995, 2003	0.76277	0.509
J1995, 2004	1.3647	0.21
J1995, 2005	0.32492	0.812
J1995, 2010	0.64338	0.573
J1995, 2012	2.4763	0.011
J1995, 2014	2.8025	0.004

J1995, 2015	2.0985	0.046
F1996, 2001	2.0901	0.047
F1996, 2003	3.8138	0.004
F1996, 2004	1.7247	0.118
F1996, 2005	3.1534	0.005
F1996, 2010	2.1613	0.052
F1996, 2012	0.46839	0.699
F1996, 2014	1.0627	0.295
F1996, 2015	0.11273	0.957
2001, 2003	1.9821	0.059
2001, 2004	0.78427	0.482
2001, 2005	0.76254	0.464
2001, 2010	0.20077	0.86
2001, 2012	2.5411	0.019
2001, 2014	3.1107	0.006
2001, 2015	1.8443	0.083
2003, 2004	2.8376	0.008
2003, 2005	1.4493	0.163
2003, 2010	1.7311	0.093
2003, 2012	4.1891	0.003
2003, 2014	4.653	0.001
2003, 2015	3.4616	0.003
2004, 2005	1.8026	0.113
2004, 2010	0.95584	0.357
2004, 2012	2.3182	0.039
2004, 2014	3.1146	0.004
2004, 2015	1.4346	0.202
2005, 2010	0.5004	0.642
2005, 2012	3.6884	0.001
2005, 2014	4.3854	0.001
2005, 2015	2.6676	0.013

2010, 2012	2.5752	0.015
2010, 2014	3.091	0.005
2010, 2015	1.9383	0.07
2012, 2014	0.59399	0.635
2012, 2015	0.24756	0.889
2014, 2015	0.68384	0.618

Shaded cells indicate significance at the 0.05 level

Table D.28 Pairwise comparison of sponge cover at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	1.8729	0.102
A1995, F1996	0.6649	0.537
A1995, 2001	1.2624	0.214
A1995, 2003	3.3785	0.002
A1995, 2004	2.8196	0.002
A1995, 2005	2.5698	0.023
A1995, 2010	0.0327	1
A1995, 2012	1.0072	0.386
A1995, 2014	0.9995	0.345
A1995, 2015	0.5974	0.667
J1995, F1996	1.0398	0.336
J1995, 2001	0.4644	0.639
J1995, 2003	4.7998	0.001
J1995, 2004	1.8564	0.065
J1995, 2005	0.5595	0.712
J1995, 2010	2.0207	0.051
J1995, 2012	0.3398	0.796
J1995, 2014	0.432	0.706
J1995, 2015	0.6721	0.567
F1996, 2001	0.5433	0.614
F1996, 2003	3.2435	0.002

F1996, 2004	2.406	0.018
F1996, 2005	1.6155	0.126
F1996, 2010	0.7328	0.494
F1996, 2012	0.4726	0.672
F1996, 2014	0.4289	0.701
F1996, 2015	0.1141	0.946
2001, 2003	3.8364	0.001
2001, 2004	2.0894	0.033
2001, 2005	1.0124	0.305
2001, 2010	1.3613	0.204
2001, 2012	0.0332	0.988
2001, 2014	0.0351	0.991
2001, 2015	0.305	0.767
2003, 2004	3.9419	0.001
2003, 2005	5.829	0.001
2003, 2010	4.0975	0.001
2003, 2012	2.7435	0.003
2003, 2014	2.8982	0.001
2003, 2015	2.2029	0.001
2004, 2005	1.5758	0.125
2004, 2010	2.8709	0.006
2004, 2012	1.918	0.072
2004, 2014	2.0042	0.054
2004, 2015	2.1112	0.041
2005, 2010	2.7744	0.012
2005, 2012	0.7746	0.515
2005, 2014	0.8951	0.429
2005, 2015	1.0952	0.314
2010, 2012	1.0596	0.316
2010, 2014	1.0582	0.359
2010, 2015	0.6338	0.651

2012, 2014	0.0599	1
2012, 2015	0.2941	0.773
2014, 2015	0.2474	0.803

Shaded cells indicate significance at the 0.05 level

Table D.29 Pairwise comparison of ascidian cover between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	Denominator is 0	
KRN2, KRO3	Denominator is 0	
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
J1995		
KRN1, KRN2	0.8018	0.629
KRN1, KRO3	0.4159	0.882
KRN2, KRO3	0.851	0.866
PB1, PB2	0.736	0.619
PB1, PB3	1.0193	0.4
PB2, PB3	0.4818	0.647
F1996		
KRN1, KRN2	2.3227	0.051
KRN1, KRO3	1.7507	0.138
KRN2, KRO3	1	1
PB1, PB2	1.7797	0.087
PB1, PB3	1.7885	0.098
PB2, PB3	0.1503	1
2001		
KRN1, KRN2	2.8372	0.008
KRN1, KRO3	3.3153	0.001
KRN2, KRO3	0.9581	0.729
PB1, PB2	3.4371	0.003
PB1, PB3	1.793	0.083
PB2, PB3	1.2036	0.234

2003		
KRN1, KRN2	3.1929	0.001
KRN1, KRO3	5.0125	0.001
KRN2, KRO3	0.9216	0.367
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
2004		
KRN1, KRN2	2.508	0.029
KRN1, KRO3	2.165	0.028
KRN2, KRO3	0.3547	0.802
PB1, PB2	0.7649	0.639
PB1, PB3	0.0826	1
PB2, PB3	0.6382	0.92
2005		
KRN1, KRN2	1.2673	0.228
KRN1, KRO3	2.5661	0.024
KRN2, KRO3	1.8268	0.109
PB1, PB2	2.9725	0.009
PB1, PB3	0.9625	0.48
PB2, PB3	0.5351	0.686
2010		
KRN1, KRN2	0.7576	0.457
KRN1, KRO3	0.8653	0.411
KRN2, KRO3	0.0161	1
PB1, PB2	2.0976	0.043
PB1, PB3	0.9112	0.466
PB2, PB3	0.4236	0.717
2012		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	Denominator is 0	

KRN2, KRO3	Denominator is 0	
PB1, PB2	0.6423	0.605
PB1, PB3	1.9498	0.067
PB2, PB3	0.8949	0.471
2014		
KRN1, KRN2	2.5172	0.021
KRN1, KRO3	4.6629	0.001
KRN2, KRO3	2.1732	0.038
PB1, PB2	1.7623	0.076
PB1, PB3	1.7243	0.091
PB2, PB3	0.4972	0.64
2015		
KRN1, KRN2	1.5218	0.155
KRN1, KRO3	0.5269	0.629
KRN2, KRO3	0.662	0.557
PB1, PB2	1.2256	0.341
PB1, PB3	3.5104	0.004
PB2, PB3	0.0958	1

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey
Shaded cells indicate significance at the 0.05 level

Table D.30 Pairwise comparison of ascidian cover at site KRN1 between each year.

Groups	**t**	**P(perm)**
A1995, J1995	1.4349	0.475
A1995, F1996	2.3227	0.052
A1995, 2001	3.4099	0.001
A1995, 2003	1.3817	0.475
A1995, 2004	1.3307	0.211
A1995, 2005	4.889	0.001
A1995, 2010	4.1728	0.001
A1995, 2012	Denominator is 0	

A1995, 2014	3.2074	0.001
A1995, 2015	3.7355	0.001
J1995, F1996	0.7754	0.504
J1995, 2001	2.8757	0.005
J1995, 2003	0.5415	0.716
J1995, 2004	0.4317	0.823
J1995, 2005	4.411	0.001
J1995, 2010	3.4359	0.003
J1995, 2012	1.4349	0.479
J1995, 2014	2.3872	0.008
J1995, 2015	3.2499	0.001
F1996, 2001	3.217	0.001
F1996, 2003	1.0331	0.478
F1996, 2004	0.953	0.546
F1996, 2005	4.725	0.001
F1996, 2010	3.9255	0.001
F1996, 2012	2.3227	0.033
F1996, 2014	2.9185	0.001
F1996, 2015	3.5608	0.001
2001, 2003	2.3401	0.034
2001, 2004	2.4548	0.02
2001, 2005	1.5511	0.152
2001, 2010	0.0519	0.958
2001, 2012	3.4099	0.001
2001, 2014	1.0182	0.316
2001, 2015	0.4801	0.653
2003, 2004	0.1128	1
2003, 2005	3.878	0.002
2003, 2010	2.6829	0.009
2003, 2012	1.3817	0.473
2003, 2014	1.6463	0.115

2003, 2015	2.7452	0.006
2004, 2005	3.9926	0.001
2004, 2010	2.8356	0.009
2004, 2012	1.3307	0.21
2004, 2014	1.7944	0.086
2004, 2015	2.8541	0.002
2005, 2010	1.7268	0.103
2005, 2012	4.889	0.001
2005, 2014	2.6571	0.011
2005, 2015	1.0447	0.303
2010, 2012	4.1728	0.001
2010, 2014	1.1084	0.283
2010, 2015	0.573	0.588
2012, 2014	3.2074	0.001
2012, 2015	3.7355	0.001
2014, 2015	1.501	0.15

Denominator is 0 indicates all quadrats had zero percent cover in each year
Shaded cells indicate significance at the 0.05 level

Table D.31 Pairwise comparison of ascidian cover at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	1.4676	0.47
A1995, F1996	Denominator is 0	
A1995, 2001	1.2336	0.499
A1995, 2003	3.7316	0.001
A1995, 2004	4.2982	0.002
A1995, 2005	5.8746	0.001
A1995, 2010	2.9175	0.003
A1995, 2012	Denominator is 0	
A1995, 2014	5.6301	0.001
A1995, 2015	2.6248	0.001

J1995, F1996		1.4676	0.481
J1995, 2001		0.7016	0.864
J1995, 2003		3.6349	0.001
J1995, 2004		3.9637	0.002
J1995, 2005		5.5611	0.001
J1995, 2010		2.6962	0.002
J1995, 2012		1.4676	0.51
J1995, 2014		5.3985	0.001
J1995, 2015		2.3884	0.008
F1996, 2001		1.2336	0.473
F1996, 2003		3.7316	0.001
F1996, 2004		4.2982	0.001
F1996, 2005		5.8746	0.001
F1996, 2010		2.9175	0.002
F1996, 2012	Denominator is 0		
F1996, 2014		5.6301	0.001
F1996, 2015		2.6248	0.002
2001, 2003		3.45	0.001
2001, 2004		3.1851	0.007
2001, 2005		4.7446	0.001
2001, 2010		2.2517	0.037
2001, 2012		1.2336	0.458
2001, 2014		4.8238	0.001
2001, 2015		1.9259	0.073
2003, 2004		2.1744	0.041
2003, 2005		1.4313	0.179
2003, 2010		2.1843	0.041
2003, 2012		3.7316	0.001
2003, 2014		0.9326	0.388
2003, 2015		2.4084	0.035
2004, 2005		1.5205	0.166

2004, 2010	0.1907	0.852
2004, 2012	4.2982	0.001
2004, 2014	2.1538	0.05
2004, 2015	0.5986	0.563
2005, 2010	1.4771	0.149
2005, 2012	5.8746	0.001
2005, 2014	0.8128	0.445
2005, 2015	1.9202	0.065
2010, 2012	2.9175	0.002
2010, 2014	2.0661	0.049
2010, 2015	0.3462	0.733
2012, 2014	5.6301	0.001
2012, 2015	2.6248	0.002
2014, 2015	2.4715	0.014

Denominator is 0 indicates all quadrats had zero percent cover in each year

Table D.32 Pairwise comparison of ascidian cover at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	1.1357	0.475
A1995, F1996	1	1
A1995, 2001	1	1
A1995, 2003	5.769	0.001
A1995, 2004	3.091	0.001
A1995, 2005	4.0896	0.001
A1995, 2010	4.1469	0.001
A1995, 2012	Denominator is 0	
A1995, 2014	7.684	0.001
A1995, 2015	2.1642	0.002
J1995, F1996	1.0801	0.466
J1995, 2001	0.9915	0.751
J1995, 2003	4.9678	0.001

J1995, 2004	2.0326	0.044
J1995, 2005	2.0105	0.048
J1995, 2010	2.0752	0.045
J1995, 2012	1.1357	0.459
J1995, 2014	6.0247	0.001
J1995, 2015	1.5536	0.153
F1996, 2001	0.5571	1
F1996, 2003	5.7467	0.001
F1996, 2004	3.0559	0.001
F1996, 2005	4.0267	0.001
F1996, 2010	4.0849	0.001
F1996, 2012	1	1
F1996, 2014	7.6479	0.001
F1996, 2015	2.1409	0.001
2001, 2003	5.7087	0.001
2001, 2004	2.997	0.004
2001, 2005	3.9098	0.001
2001, 2010	3.9695	0.001
2001, 2012	1	1
2001, 2014	7.5792	0.001
2001, 2015	2.1039	0.003
2003, 2004	3.2425	0.003
2003, 2005	3.9816	0.001
2003, 2010	3.9359	0.002
2003, 2012	5.769	0.001
2003, 2014	0.6325	0.546
2003, 2015	2.7778	0.008
2004, 2005	0.575	0.671
2004, 2010	0.5157	0.661
2004, 2012	3.091	0.003
2004, 2014	3.3942	0.002

2004, 2015	0.0471	1
2005, 2010	0.0792	0.96
2005, 2012	4.0896	0.001
2005, 2014	4.6507	0.001
2005, 2015	0.4753	0.693
2010, 2012	4.1469	0.001
2010, 2014	4.5797	0.002
2010, 2015	0.4322	0.727
2012, 2014	7.684	0.001
2012, 2015	2.1642	0.003
2014, 2015	2.6767	0.021

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.33 Pairwise comparison of ascidian cover at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	1.8459	0.009
A1995, F1996	3.1406	0.001
A1995, 2001	7.8694	0.001
A1995, 2003	Denominator is 0	
A1995, 2004	1.8153	0.035
A1995, 2005	6.4869	0.001
A1995, 2010	2.5891	0.004
A1995, 2012	4.284	0.001
A1995, 2014	2.8243	0.018
A1995, 2015	1.4676	0.47
J1995, F1996	1.3493	0.146
J1995, 2001	4.3892	0.001
J1995, 2003	1.8459	0.004
J1995, 2004	1.2128	0.29
J1995, 2005	0.0598	0.991

J1995, 2010	0.5608	0.716
J1995, 2012	0.5443	0.621
J1995, 2014	1.2796	0.187
J1995, 2015	1.6814	0.021
F1996, 2001	7.3274	0.001
F1996, 2003	3.1406	0.002
F1996, 2004	0.2649	0.867
F1996, 2005	4.1398	0.001
F1996, 2010	1.4968	0.149
F1996, 2012	3.3363	0.002
F1996, 2014	0.2525	0.854
F1996, 2015	1.7509	0.1
2001, 2003	7.8694	0.001
2001, 2004	6.9999	0.001
2001, 2005	5.9473	0.001
2001, 2010	6.0877	0.001
2001, 2012	4.7958	0.001
2001, 2014	7.2241	0.001
2001, 2015	7.6804	0.001
2003, 2004	1.8153	0.046
2003, 2005	6.4869	0.001
2003, 2010	2.5891	0.005
2003, 2012	4.284	0.001
2003, 2014	2.8243	0.024
2003, 2015	1.4676	0.446
2004, 2005	2.8875	0.006
2004, 2010	1.1446	0.303
2004, 2012	2.8863	0.009
2004, 2014	0.0838	1
2004, 2015	1.2563	0.315
2005, 2010	1.0202	0.36

2005, 2012	1.0796	0.346
2005, 2014	3.6986	0.003
2005, 2015	5.5285	0.001
2010, 2012	1.6726	0.099
2010, 2014	1.3361	0.223
2010, 2015	2.207	0.017
2012, 2014	3.173	0.004
2012, 2015	3.9498	0.001
2014, 2015	1.7678	0.165

Denominator is 0 indicates all quadrats had zero percent cover in each year

Table D.34 Pairwise comparison of ascidian cover at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	2.318	0.016
A1995, F1996	2.0477	0.033
A1995, 2001	3.6346	0.001
A1995, 2003	Denominator is 0	
A1995, 2004	2.2563	0.1
A1995, 2005	7.8971	0.001
A1995, 2010	4.2915	0.001
A1995, 2012	2.4495	0.001
A1995, 2014	2.1314	0.002
A1995, 2015	1.4917	0.081
J1995, F1996	1.9048	0.052
J1995, 2001	2.2679	0.033
J1995, 2003	2.318	0.013
J1995, 2004	1.5546	0.15
J1995, 2005	3.6409	0.005
J1995, 2010	2.3569	0.021
J1995, 2012	0.9318	0.455
J1995, 2014	1.3927	0.231

J1995, 2015		0.1413	0.923
F1996, 2001		3.4374	0.002
F1996, 2003		2.0477	0.047
F1996, 2004		0.8683	0.424
F1996, 2005		7.3352	0.001
F1996, 2010		4.0183	0.001
F1996, 2012		2.2117	0.002
F1996, 2014		2.0168	0.005
F1996, 2015		1.2075	0.226
2001, 2003		3.6346	0.001
2001, 2004		3.2656	0.004
2001, 2005		0.12193	0.916
2001, 2010		0.3335	0.756
2001, 2012		1.2654	0.22
2001, 2014		0.0694	0.965
2001, 2015		2.1878	0.05
2003, 2004		2.2563	0.104
2003, 2005		7.8971	0.001
2003, 2010		4.2915	0.001
2003, 2012		2.4495	0.002
2003, 2014		2.1314	0.001
2003, 2015		1.4917	0.098
2004, 2005		6.7783	0.001
2004, 2010		3.7741	0.001
2004, 2012		2.0086	0.012
2004, 2014		1.9207	0.022
2004, 2015		0.9712	0.589
2005, 2010		0.3254	0.777
2005, 2012		1.6146	0.136
2005, 2014	Negative		
2005, 2015		3.1109	0.004

2010, 2012	1.0977	0.309
2010, 2014	0.157	0.866
2010, 2015	2.2043	0.036
2012, 2014	0.8179	0.455
2012, 2015	0.9466	0.425
2014, 2015	1.4095	0.232

Denominator is 0 indicates all quadrats had zero percent cover in each year

Table D.35 Pairwise comparison of ascidian cover at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	2.0701	0.045
A1995, F1996	3.0551	0.003
A1995, 2001	4.2017	0.001
A1995, 2003	Denominator is 0	
A1995, 2004	1.3307	0.252
A1995, 2005	2.9283	0.001
A1995, 2010	1.9969	0.007
A1995, 2012	2.6062	0.005
A1995, 2014	2.2836	0.002
A1995, 2015	5.0031	0.001
J1995, F1996	1.542	0.21
J1995, 2001	3.449	0.005
J1995, 2003	2.0701	0.042
J1995, 2004	0.2352	0.893
J1995, 2005	1.9602	0.045
J1995, 2010	1.3062	0.209
J1995, 2012	0.5866	0.614
J1995, 2014	1.4523	0.171
J1995, 2015	0.2673	0.8
F1996, 2001	4.0482	0.001
F1996, 2003	3.0551	0.007

F1996, 2004	0.9236	0.637
F1996, 2005	2.7216	0.002
F1996, 2010	1.8399	0.026
F1996, 2012	2.1367	0.024
F1996, 2014	2.0984	0.006
F1996, 2015	3.7092	0.002
2001, 2003	4.2017	0.001
2001, 2004	3.4727	0.001
2001, 2005	1.6334	0.113
2001, 2010	1.6435	0.119
2001, 2012	3.1634	0.004
2001, 2014	1.8022	0.087
2001, 2015	3.4743	0.005
2003, 2004	1.3307	0.222
2003, 2005	2.9283	0.001
2003, 2010	1.9969	0.009
2003, 2012	2.6062	0.007
2003, 2014	2.2836	0.001
2003, 2015	5.0031	0.001
2004, 2005	2.0181	0.049
2004, 2010	1.3816	0.188
2004, 2012	0.7442	0.555
2004, 2014	1.5282	0.137
2004, 2015	0.4988	0.777
2005, 2010	0.2042	0.887
2005, 2012	1.6026	0.104
2005, 2014	0.2693	0.829
2005, 2015	1.9572	0.026
2010, 2012	1.0349	0.427
2010, 2014	0.0392	1
2010, 2015	1.2624	0.255

2012, 2014	1.1349	0.283
2012, 2015	0.4811	0.712
2014, 2015	1.4165	0.188

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.36 Pairwise comparison of *Pyura* abundance between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	0.2740	0.909
KRN1, KRO3	0.8473	0.547
KRN2, KRO3	0.8881	0.459
PB1, PB2	1.7035	0.1
PB1, PB3	1.3881	0.211
PB2, PB3	2.3244	0.029
J1995		
KRN1, KRN2	0.8018	0.594
KRN1, KRO3	0.4588	0.885
KRN2, KRO3	0.8635	0.873
PB1, PB2	0.7975	0.603
PB1, PB3	1.0629	0.386
PB2, PB3	0.4818	0.712
F1996		
KRN1, KRN2	2.3227	0.051
KRN1, KRO3	1.7507	0.148
KRN2, KRO3	1	1
PB1, PB2	1.7797	0.095
PB1, PB3	1.7885	0.114
PB2, PB3	0.15027	1
2001		
KRN1, KRN2	1	1
KRN1, KRO3	3.4099	0.001
KRN2, KRO3	3.3153	0.001
PB1, PB2	3.4371	0.004
PB1, PB3	1.793	0.093
PB2, PB3	1.2036	0.235

2003		
KRN1, KRN2	0.6258	0.659
KRN1, KRO3	2.4773	0.039
KRN2, KRO3	2.1754	0.037
PB1, PB2	1.4676	0.499
PB1, PB3	2.5698	0.023
PB2, PB3	3.2922	0.008
2004		
KRN1, KRN2	0.6563	0.604
KRN1, KRO3	2.0925	0.045
KRN2, KRO3	1.5097	0.189
PB1, PB2	1.57	0.238
PB1, PB3	1.4265	0.278
PB2, PB3	1.02 x 10-8	1
2005		
KRN1, KRN2	2.1322	0.084
KRN1, KRO3	3.1059	0.001
KRN2, KRO3	0.38618	0.774
PB1, PB2	1.188	0.475
PB1, PB3	1.765	0.157
PB2, PB3	0.6193	0.662
2010		
KRN1, KRN2	0.348	0.781
KRN1, KRO3	0.2704	0.845
KRN2, KRO3	0.525	0.635
PB1, PB2	1.2963	0.473
PB1, PB3	1.4716	0.366
PB2, PB3	0.7497	0.405
2012		
KRN1, KRN2	1.7118	0.167
KRN1, KRO3	2.4773	0.05

KRN2, KRO3	1.4676	0.489
PB1, PB2	0.1122	1
PB1, PB3	0.5017	0.702
PB2, PB3	0.331	0.835
2014		
KRN1, KRN2	1.0984	0.329
KRN1, KRO3	0.3919	0.804
KRN2, KRO3	0.9733	0.442
PB1, PB2	1.6823	0.152
PB1, PB3	1.1966	0.498
PB2, PB3	1.8935	0.087
2015		
KRN1, KRN2	0.1817	1
KRN1, KRO3	1.9314	0.089
KRN2, KRO3	3.0756	0.01
PB1, PB2	1.1966	0.474
PB1, PB3	2.6458	0.025
PB2, PB3	1.3644	0.316

Shaded cells indicate significance at the 0.05 level

Table D.37 Pairwise comparison of *Pyura* abundance at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	1.4506	0.207
A1995, F1996	2.8243	0.006
A1995, 2001	3.5949	0.004
A1995, 2003	3.0588	0.008
A1995, 2004	3.1062	0.007
A1995, 2005	3.5286	0.003
A1995, 2010	1.0779	0.331
A1995, 2012	3.0588	0.004

Groups	t	P(perm)
A1995, 2014	1.8935	0.078
A1995, 2015	2.8902	0.013
J1995, F1996	0.7754	0.522
J1995, 2001	1.4349	0.468
J1995, 2003	0.9594	0.458
J1995, 2004	1.0124	0.483
J1995, 2005	1.3752	0.484
J1995, 2010	0.7806	0.481
J1995, 2012	0.9594	0.511
J1995, 2014	0.0537	1
J1995, 2015	0.8329	0.489
F1996, 2001	2.3227	0.044
F1996, 2003	0.5234	0.739
F1996, 2004	0.6761	0.603
F1996, 2005	2.066	0.07
F1996, 2010	3.0889	0.012
F1996, 2012	0.5234	0.749
F1996, 2014	1.8424	0.1
F1996, 2015	0.1523	1
2001, 2003	2.4773	0.05
2001, 2004	1.9743	0.117
2001, 2005	1	1
2001, 2010	4.9344	0.001
2001, 2012	2.4773	0.037
2001, 2014	3.926	0.002
2001, 2015	2.1972	0.047
2003, 2004	0.20851	1
2003, 2005	2.0706	0.104
2003, 2010	3.6672	0.001
2003, 2012	2.23×10^{-9}	1

Groups	t	P(perm)
2003, 2014	2.443	0.029
2003, 2015	0.3584	0.854
2004, 2005	1.6287	0.228
2004, 2010	3.7297	0.003
2004, 2012	0.2085	1
2004, 2014	2.5293	0.027
2004, 2015	0.5199	0.741
2005, 2010	4.7748	0.001
2005, 2012	2.0706	0.085
2005, 2014	3.7327	0.001
2005, 2015	1.9314	0.081
2010, 2012	3.6672	0.003
2010, 2014	1.3375	0.236
2010, 2015	3.227	0.004
2012, 2014	2.443	0.033
2012, 2015	0.3584	0.873
2014, 2015	1.9911	0.08

Shaded cells indicate significance at the 0.05 level

Table D.38 Pairwise comparison of *Pyura* abundance at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	1.206	0.429
A1995, F1996	1.5404	0.21
A1995, 2001	1.3702	0.35
A1995, 2003	1.1542	0.405
A1995, 2004	1.1878	0.371
A1995, 2005	0.9578	0.476
A1995, 2010	0.4341	0.753
A1995, 2012	1.4775	0.232
A1995, 2014	1.0056	0.444

Groups	t	P(perm)
A1995, 2015	1.1961	0.396
J1995, F1996	1.4676	0.511
J1995, 2001	0.5916	1
J1995, 2003	0.2281	0.896
J1995, 2004	0.1187	1
J1995, 2005	0.7663	0.465
J1995, 2010	1.8275	0.089
J1995, 2012	1.1513	0.497
J1995, 2014	0.8384	0.517
J1995, 2015	0.1336	1
F1996, 2001	1	1
F1996, 2003	2.1754	0.046
F1996, 2004	2.2191	0.045
F1996, 2005	2.2755	0.044
F1996, 2010	2.9505	0.001
F1996, 2012	1.4676	0.492
F1996, 2014	3.5229	0.001
F1996, 2015	3.5555	0.001
2001, 2003	0.9402	0.452
2001, 2004	0.8522	0.496
2001, 2005	1.3892	0.197
2001, 2010	2.3305	0.027
2001, 2012	0.5789	1
2001, 2014	1.7269	0.137
2001, 2015	1.0205	0.458
2003, 2004	0.1348	1
2003, 2005	0.6222	0.595
2003, 2010	1.7581	0.111
2003, 2012	1.7599	0.16
2003, 2014	0.6822	0.588

Groups	t	P(perm)
2003, 2015	0.1581	1
2004, 2005	0.7499	0.532
2004, 2010	1.8668	0.091
2004, 2012	1.7507	0.142
2004, 2014	0.8673	0.487
2004, 2015	Negative	
2005, 2010	1.1923	0.301
2005, 2012	1.9933	0.091
2005, 2014	0.1079	1
2005, 2015	0.8241	0.476
2010, 2012	2.7637	0.005
2010, 2014	1.4056	0.199
2010, 2015	1.9577	0.063
2012, 2014	2.9915	0.008
2012, 2015	2.6622	0.017
2014, 2015	1.0467	0.382

Shaded cells indicate significance at the 0.05 level

Table D.39 Pairwise comparison of *Pyura* abundance at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	0.88741	0.463
A1995, F1996	2.8125	0.003
A1995, 2001	1.6976	0.118
A1995, 2003	2.8823	0.004
A1995, 2004	2.019	0.03
A1995, 2005	2.1295	0.025
A1995, 2010	1.3695	0.212
A1995, 2012	2.8823	0.003
A1995, 2014	2.1297	0.018
A1995, 2015	2.8488	0.001

Groups	t	P(perm)
J1995, F1996	1.0749	0.479
J1995, 2001	2.2165	0.039
J1995, 2003	1.1263	0.474
J1995, 2004	0.4912	0.98
J1995, 2005	0.5678	0.984
J1995, 2010	0.0239	1
J1995, 2012	1.1263	0.463
J1995, 2014	0.5481	0.999
J1995, 2015	1.1009	0.496
F1996, 2001	3.3748	0.001
F1996, 2003	1	1
F1996, 2004	2.8434	0.006
F1996, 2005	2.8655	0.009
F1996, 2010	3.3504	0.001
F1996, 2012	1	1
F1996, 2014	4.8544	0.003
F1996, 2015	0.4472	1
2001, 2003	3.4099	0.001
2001, 2004	2.9689	0.002
2001, 2005	3.0253	0.001
2001, 2010	2.623	0.007
2001, 2012	3.4099	0.001
2001, 2014	3.0212	0.001
2001, 2015	3.3928	0.001
2003, 2004	3.1897	0.001
2003, 2005	3.29	0.002
2003, 2010	3.5555	0.001
2003, 2012	Denominator is 0	-
2003, 2014	5.996	0.001
2003, 2015	1	1

Groups	t	P(perm)
2004, 2005	0.2912	0.851
2004, 2010	1.2971	0.221
2004, 2012	3.1897	0.003
2004, 2014	0.2292	0.902
2004, 2015	3.0375	0.004
2005, 2010	1.564	0.175
2005, 2012	3.29	0.001
2005, 2014	0.1297	1
2005, 2015	3.1059	0.001
2010, 2012	3.5555	0.001
2010, 2014	1.6209	0.169
2010, 2015	3.4634	0.001
2012, 2014	5.996	0.001
2012, 2015	1	1
2014, 2015	5.5498	0.001

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.40 Pairwise comparison of *Pyura* abundance at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	0.2401	0.905
A1995, F1996	2.6127	0.02
A1995, 2001	5.7533	0.001
A1995, 2003	3.7932	0.001
A1995, 2004	3.6014	0.001
A1995, 2005	3.8307	0.001
A1995, 2010	3.8307	0.001
A1995, 2012	3.1696	0.002
A1995, 2014	3.7143	0.001
A1995, 2015	3.8307	0.001

Groups	t	P(perm)
J1995, F1996	1.3682	0.128
J1995, 2001	4.1455	0.001
J1995, 2003	1.7991	0.01
J1995, 2004	1.726	0.013
J1995, 2005	1.8137	0.012
J1995, 2010	1.8137	0.004
J1995, 2012	1.5642	0.042
J1995, 2014	1.7697	0.01
J1995, 2015	1.8137	0.012
F1996, 2001	7.3274	0.001
F1996, 2003	2.9104	0.005
F1996, 2004	2.3342	0.042
F1996, 2005	3.0239	0.001
F1996, 2010	3.0239	0.004
F1996, 2012	1.1497	0.31
F1996, 2014	2.6641	0.012
F1996, 2015	3.0239	0.001
2001, 2003	7.8379	0.001
2001, 2004	7.7577	0.001
2001, 2005	7.8536	0.001
2001, 2010	7.8536	0.001
2001, 2012	7.575	0.001
2001, 2014	7.8051	0.001
2001, 2015	7.8536	0.001
2003, 2004	1.57	0.24
2003, 2005	0.5916	1
2003, 2010	0.5916	1
2003, 2012	2.8159	0.019
2003, 2014	0.7483	0.726
2003, 2015	0.5916	1

Groups	t	P(perm)
2004, 2005	1.969	0.134
2004, 2010	1.969	0.122
2004, 2012	1.7679	0.111
2004, 2014	0.8144	0.575
2004, 2015	1.969	0.111
2005, 2010	Negative	
2005, 2012	3.0324	0.003
2005, 2014	1.1966	0.458
2005, 2015	Negative	
2010, 2012	3.0324	0.005
2010, 2014	1.1966	0.488
2010, 2015	9.02×10^{-10}	1
2012, 2014	2.3426	0.047
2012, 2015	3.0324	0.01
2014, 2015	1.1966	0.48

Shaded cells indicate significance at the 0.05 level

Table D.41 Pairwise comparison of *Pyura* abundance at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	0.4179	0.723
A1995, F1996	2.3638	0.044
A1995, 2001	2.6474	0.012
A1995, 2003	3.1293	0.001
A1995, 2004	3.0015	0.01
A1995, 2005	2.6975	0.012
A1995, 2010	1.9839	0.05
A1995, 2012	1.9644	0.058
A1995, 2014	1.0082	0.347
A1995, 2015	2.8668	0.009
J1995, F1996	1.9048	0.061

Groups	t	P(perm)
J1995, 2001	2.2679	0.027
J1995, 2003	2.318	0.018
J1995, 2004	2.2463	0.023
J1995, 2005	2.0897	0.041
J1995, 2010	1.7333	0.085
J1995, 2012	1.6813	0.111
J1995, 2014	1.1317	0.288
J1995, 2015	2.1728	0.028
F1996, 2001	3.4374	0.002
F1996, 2003	2.0477	0.041
F1996, 2004	1.6239	0.153
F1996, 2005	0.7407	0.557
F1996, 2010	0.2647	0.875
F1996, 2012	0.6799	0.578
F1996, 2014	1.1729	0.286
F1996, 2015	1.198	0.32
2001, 2003	3.6346	0.001
2001, 2004	3.6003	0.001
2001, 2005	3.5263	0.001
2001, 2010	3.355	0.004
2001, 2012	3.3285	0.004
2001, 2014	3.0373	0.003
2001, 2015	3.5653	0.001
2003, 2004	1.4676	0.475
2003, 2005	1.4676	0.228
2003, 2010	1.403	0.467
2003, 2012	2.4286	0.003
2003, 2014	1.963	0.101
2003, 2015	1.7398	0.219
2004, 2005	0.92819	0.69

Groups	t	P(perm)
2004, 2010	1.1915	0.488
2004, 2012	2.1034	0.024
2004, 2014	1.8249	0.116
2004, 2015	0.7483	0.733
2005, 2010	0.7419	0.682
2005, 2012	1.3569	0.277
2005, 2014	1.517	0.181
2005, 2015	0.4264	0.865
2010, 2012	0.2461	0.888
2010, 2014	0.8766	0.462
2010, 2015	0.9766	0.506
2012, 2014	0.7734	0.486
2012, 2015	1.7644	0.083
2014, 2015	1.6823	0.173

Shaded cells indicate significance at the 0.05 level

Table D.42 Pairwise comparison of *Pyura* abundance at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	2.3128	0.034
A1995, F1996	3.0498	0.002
A1995, 2001	1.3078	0.199
A1995, 2003	3.0506	0.002
A1995, 2004	3.2124	0.001
A1995, 2005	3.0777	0.001
A1995, 2010	2.622	0.022
A1995, 2012	3.0115	0.003
A1995, 2014	3.2294	0.001
A1995, 2015	3.1	0.001
J1995, F1996	1.542	0.204
J1995, 2001	3.449	0.003

Groups	t	P(perm)
J1995, 2003	1.5449	0.198
J1995, 2004	1.9786	0.109
J1995, 2005	1.6121	0.199
J1995, 2010	0.5765	0.511
J1995, 2012	1.4368	0.213
J1995, 2014	2.026	0.044
J1995, 2015	1.6777	0.192
F1996, 2001	4.0482	0.001
F1996, 2003	8.93×10^{-9}	1
F1996, 2004	2.2687	0.047
F1996, 2005	0.3146	0.874
F1996, 2010	0.9163	0.471
F1996, 2012	0.2869	0.884
F1996, 2014	2.7139	0.024
F1996, 2015	0.6179	0.697
2001, 2003	4.0488	0.001
2001, 2004	4.1756	0.001
2001, 2005	4.0699	0.001
2001, 2010	3.7014	0.001
2001, 2012	4.0179	0.001
2001, 2014	4.189	0.001
2001, 2015	4.0876	0.001
2003, 2004	2.4052	0.043
2003, 2005	0.3232	0.885
2003, 2010	0.9186	0.458
2003, 2012	0.2935	0.885
2003, 2014	2.9103	0.018
2003, 2015	0.6481	0.65
2004, 2005	1.4856	0.224
2004, 2010	1.4175	0.347

Groups	t	P(perm)
2004, 2012	1.969	0.101
2004, 2014	0.4472	1
2004, 2015	2.0088	0.088
2005, 2010	1.0016	0.449
2005, 2012	0.5246	0.679
2005, 2014	1.765	0.139
2005, 2015	0.1737	1
2010, 2012	0.8034	0.47
2010, 2014	1.4716	0.361
2010, 2015	1.07	0.488
2012, 2014	2.2248	0.05
2012, 2015	0.7782	0.553
2014, 2015	2.6458	0.028

Shaded cells indicate significance at the 0.05 level

Table D.43 Pairwise comparison of soft coral cover between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	1	1
KRN1, KRO3	2.6062	0.005
KRN2, KRO3	2.842	0.002
PB1, PB2	1.3402	0.177
PB1, PB3	0.0301	0.984
PB2, PB3	1.5185	0.138
J1995		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	1.4676	0.243
KRN2, KRO3	1.4676	0.242
PB1, PB2	0.7505	0.535
PB1, PB3	0.4755	0.635
PB2, PB3	0.2475	0.83
F1996		
KRN1, KRN2	3.059	0.002
KRN1, KRO3	3.2514	0.001
KRN2, KRO3	1	1
PB1, PB2	1.3742	0.225
PB1, PB3	1.0385	0.39
PB2, PB3	0.4228	0.707
2001		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	Denominator is 0	
KRN2, KRO3	Denominator is 0	
PB1, PB2	1	1
PB1, PB3	Denominator is 0	
PB2, PB3	1	1

2003		
KRN1, KRN2	7.7×10^{-9}	1
KRN1, KRO3	1.1704	0.341
KRN2, KRO3	1.4542	0.226
PB1, PB2	1.8755	0.076
PB1, PB3	0.2961	0.828
PB2, PB3	2.4652	0.027
2004		
KRN1, KRN2	1.1832	0.363
KRN1, KRO3	1.2601	0.252
KRN2, KRO3	0.6319	0.707
PB1, PB2	1.4547	0.194
PB1, PB3	0.673	0.55
PB2, PB3	0.5672	0.813
2005		
KRN1, KRN2	1.7838	0.21
KRN1, KRO3	Denominator is 0	
KRN2, KRO3	1.7838	0.217
PB1, PB2	1.7328	0.153
PB1, PB3	1.0902	0.367
PB2, PB3	0.4311	0.838
2010		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	Denominator is 0	
KRN2, KRO3	Denominator is 0	
PB1, PB2	0.3164	0.665
PB1, PB3	0.1657	0.678
PB2, PB3	0.1441	0.825
2012		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	Denominator is 0	

KRN2, KRO3	Denominator is 0	
PB1, PB2	0.3234	0.807
PB1, PB3	0.064	0.959
PB2, PB3	0.3622	0.755
2014		
KRN1, KRN2	1	1
KRN1, KRO3	Denominator is 0	
KRN2, KRO3	1	1
PB1, PB2	0.6492	0.565
PB1, PB3	2.9588	0.009
PB2, PB3	1.3374	0.208
2015		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	Denominator is 0	
KRN2, KRO3	Denominator is 0	
PB1, PB2	0.6134	0.566
PB1, PB3	0.5219	0.633
PB2, PB3	1.1909	0.267

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.44 Pairwise comparison of soft coral cover at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	1	1
A1995, F1996	3.2101	0.001
A1995, 2001	1	1
A1995, 2003	1.3819	0.229
A1995, 2004	0.83666	0.739
A1995, 2005	1	1

Groups	t	P(perm)
A1995, 2010	1	1
A1995, 2012	1	1
A1995, 2014	1	1
A1995, 2015	1	1
J1995, F1996	3.2514	0.001
J1995, 2001	Denominator is 0	
J1995, 2003	1.4446	0.238
J1995, 2004	1.3817	0.503
J1995, 2005	Denominator is 0	
J1995, 2010	Denominator is 0	
J1995, 2012	Denominator is 0	
J1995, 2014	Denominator is 0	
J1995, 2015	Denominator is 0	
F1996, 2001	3.2514	0.001
F1996, 2003	1.9469	0.067
F1996, 2004	3.1236	0.002
F1996, 2005	3.2514	0.001
F1996, 2010	3.2514	0.001
F1996, 2012	3.2514	0.001
F1996, 2014	3.2514	0.001
F1996, 2015	3.2514	0.001
2001, 2003	1.4446	0.214
2001, 2004	1.3817	0.489
2001, 2005	Denominator is 0	
2001, 2010	Denominator is 0	
2001, 2012	Denominator is 0	
2001, 2014	Denominator is 0	
2001, 2015	Denominator is 0	
2003, 2004	1.2534	0.345
2003, 2005	1.4446	0.214

Groups	t	P(perm)
2003, 2010	1.4446	0.215
2003, 2012	1.4446	0.21
2003, 2014	1.4446	0.22
2003, 2015	1.4446	0.207
2004, 2005	1.3817	0.473
2004, 2010	1.3817	0.486
2004, 2012	1.3817	0.482
2004, 2014	1.3817	0.501
2004, 2015	1.3817	0.474
2005, 2010	Denominator is 0	
2005, 2012	Denominator is 0	
2005, 2014	Denominator is 0	
2005, 2015	Denominator is 0	
2010, 2012	Denominator is 0	
2010, 2014	Denominator is 0	
2010, 2015	Denominator is 0	
2012, 2014	Denominator is 0	
2012, 2015	Denominator is 0	
2014, 2015	Denominator is 0	

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.45 Pairwise comparison of soft coral cover at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	Denominator is 0	
A1995, F1996	1	1
A1995, 2001	Denominator is 0	
A1995, 2003	1.8239	0.104
A1995, 2004	1.964	0.117
A1995, 2005	1.7838	0.207

Groups	t	P(perm)
A1995, 2010	Denominator is 0	
A1995, 2012	Denominator is 0	
A1995, 2014	1	1
A1995, 2015	Denominator is 0	
J1995, F1996	1	1
J1995, 2001	Denominator is 0	
J1995, 2003	1.8239	0.095
J1995, 2004	1.964	0.09
J1995, 2005	1.7838	0.223
J1995, 2010	Denominator is 0	
J1995, 2012	Denominator is 0	
J1995, 2014	1	1
J1995, 2015	Denominator is 0	
F1996, 2001	1	1
F1996, 2003	1.4542	0.197
F1996, 2004	0.82199	0.569
F1996, 2005	0.20473	1
F1996, 2010	1	1
F1996, 2012	1	1
F1996, 2014	0.72761	1
F1996, 2015	1	1
2001, 2003	1.8239	0.102
2001, 2004	1.964	0.104
2001, 2005	1.7838	0.201
2001, 2010	Denominator is 0	
2001, 2012	Denominator is 0	
2001, 2014	1	1
2001, 2015	Denominator is 0	
2003, 2004	1.0765	0.399
2003, 2005	1.4123	0.203

Groups	t	P(perm)
2003, 2010	1.8239	0.105
2003, 2012	1.8239	0.089
2003, 2014	1.7429	0.108
2003, 2015	1.8239	0.105
2004, 2005	0.74462	0.597
2004, 2010	1.964	0.11
2004, 2012	1.964	0.093
2004, 2014	1.7056	0.165
2004, 2015	1.964	0.098
2005, 2010	1.7838	0.218
2005, 2012	1.7838	0.219
2005, 2014	1.344	0.364
2005, 2015	1.7838	0.238
2010, 2012	Denominator is 0	
2010, 2014	1	1
2010, 2015	Denominator is 0	
2012, 2014	1	1
2012, 2015	Denominator is 0	
2014, 2015	1	1

Denominator is 0 indicates all quadrats had zero percent cover in each year

Table D.46 Pairwise comparison of soft coral cover at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	1.3481	0.261
A1995, F1996	2.842	0.003
A1995, 2001	2.842	0.002
A1995, 2003	1.661	0.17
A1995, 2004	0.0879	1
A1995, 2005	2.842	0.004
A1995, 2010	2.842	0.004

Groups	t	P(perm)
A1995, 2012	2.842	0.002
A1995, 2014	2.842	0.004
A1995, 2015	2.842	0.005
J1995, F1996	1.4676	0.222
J1995, 2001	1.4676	0.238
J1995, 2003	0.34967	0.745
J1995, 2004	0.91891	0.536
J1995, 2005	1.4676	0.218
J1995, 2010	1.4676	0.243
J1995, 2012	1.4676	0.23
J1995, 2014	1.4676	0.223
J1995, 2015	1.4676	0.228
F1996, 2001	Denominator is 0	
F1996, 2003	1	1
F1996, 2004	1.5865	0.096
F1996, 2005	Denominator is 0	
F1996, 2010	Denominator is 0	
F1996, 2012	Denominator is 0	
F1996, 2014	Denominator is 0	
F1996, 2015	Denominator is 0	
2001, 2003	1	1
2001, 2004	1.5865	0.092
2001, 2005	Denominator is 0	
2001, 2010	Denominator is 0	
2001, 2012	Denominator is 0	
2001, 2014	Denominator is 0	
2001, 2015	Denominator is 0	
2003, 2004	1.106	0.461
2003, 2005	1	1
2003, 2010	1	1

Groups	t	P(perm)
2003, 2012	1	1
2003, 2014	1	1
2003, 2015	1	1
2004, 2005	1.5865	0.099
2004, 2010	1.5865	0.101
2004, 2012	1.5865	0.109
2004, 2014	1.5865	0.092
2004, 2015	1.5865	0.104
2005, 2010	Denominator is 0	
2005, 2012	Denominator is 0	
2005, 2014	Denominator is 0	
2005, 2015	Denominator is 0	
2010, 2012	Denominator is 0	
2010, 2014	Denominator is 0	
2010, 2015	Denominator is 0	
2012, 2014	Denominator is 0	
2012, 2015	Denominator is 0	
2014, 2015	Denominator is 0	

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.47 Pairwise comparison of soft coral cover at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	4.0095	0.001
A1995, F1996	3.4061	0.002
A1995, 2001	4.2699	0.001
A1995, 2003	2.1819	0.041
A1995, 2004	3.5032	0.002
A1995, 2005	3.5501	0.001
A1995, 2010	2.9756	0.009

Groups	t	P(perm)
A1995, 2012	2.5802	0.013
A1995, 2014	1.9028	0.087
A1995, 2015	1.9003	0.064
J1995, F1996	2.486	0.017
J1995, 2001	2.3155	0.016
J1995, 2003	3.7183	0.001
J1995, 2004	1.308	0.219
J1995, 2005	1.5815	0.134
J1995, 2010	1.1219	0.307
J1995, 2012	3.0001	0.005
J1995, 2014	4.3236	0.001
J1995, 2015	2.1792	0.023
F1996, 2001	4	0.001
F1996, 2003	2.3008	0.02
F1996, 2004	0.48176	0.713
F1996, 2005	0.55216	0.657
F1996, 2010	0.12432	0.978
F1996, 2012	1.5362	0.146
F1996, 2014	2.8894	0.008
F1996, 2015	1.409	0.21
2001, 2003	4.3754	0.001
2001, 2004	2.2436	0.008
2001, 2005	2.8014	0.01
2001, 2010	1.5738	0.011
2001, 2012	3.6897	0.001
2001, 2014	4.9851	0.001
2001, 2015	2.5177	0.007
2003, 2004	2.4456	0.023
2003, 2005	2.5873	0.015
2003, 2010	1.457	0.176

Groups	t	P(perm)
2003, 2012	0.68447	0.497
2003, 2014	0.48454	0.666
2003, 2015	Negative	
2004, 2005	9.98E-09	1
2004, 2010	0.38548	0.829
2004, 2012	1.7433	0.093
2004, 2014	2.9905	0.007
2004, 2015	1.5721	0.16
2005, 2010	0.40052	0.881
2005, 2012	1.8555	0.092
2005, 2014	3.1595	0.004
2005, 2015	1.6078	0.152
2010, 2012	0.90308	0.424
2010, 2014	1.8711	0.082
2010, 2015	1.096	0.273
2012, 2014	1.1795	0.262
2012, 2015	0.47449	0.622
2014, 2015	0.34316	0.781

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey

Shaded cells indicate significance at the 0.05 level

Table D.48 Pairwise comparison of soft coral cover at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	8.5162	0.001
A1995, F1996	6.6299	0.001
A1995, 2001	9.1553	0.001
A1995, 2003	4.292	0.002
A1995, 2004	9.061	0.001
A1995, 2005	9.0336	0.001
A1995, 2010	6.811	0.001

Groups	t	P(perm)
A1995, 2012	6.0128	0.001
A1995, 2014	4.5231	0.001
A1995, 2015	3.3105	0.006
J1995, F1996	2.5812	0.021
J1995, 2001	1.3373	0.28
J1995, 2003	7.0419	0.001
J1995, 2004	0.96613	0.423
J1995, 2005	0.93863	0.422
J1995, 2010	0.52113	0.755
J1995, 2012	1.9082	0.076
J1995, 2014	1.781	0.092
J1995, 2015	2.7112	0.008
F1996, 2001	3.6582	0.001
F1996, 2003	3.6892	0.003
F1996, 2004	3.4539	0.002
F1996, 2005	3.4141	0.004
F1996, 2010	1.1974	0.267
F1996, 2012	Negative	
F1996, 2014	0.48458	0.684
F1996, 2015	1.5097	0.162
2001, 2003	8.4577	0.001
2001, 2004	0.58575	0.71
2001, 2005	0.55628	0.617
2001, 2010	1.1418	0.32
2001, 2012	2.6044	0.014
2001, 2014	2.2123	0.016
2001, 2015	3.1047	0.001
2003, 2004	8.3418	0.001
2003, 2005	8.2486	0.001
2003, 2010	4.1069	0.002

Groups	t	P(perm)
2003, 2012	2.9687	0.012
2003, 2014	1.6252	0.121
2003, 2015	0.39635	0.732
2004, 2005	Negative	
2004, 2010	0.96472	0.54
2004, 2012	2.4366	0.019
2004, 2014	2.0969	0.043
2004, 2015	3.0041	0.003
2005, 2010	0.95941	0.527
2005, 2012	2.4225	0.023
2005, 2014	2.0919	0.039
2005, 2015	2.9984	0.002
2010, 2012	1.0329	0.325
2010, 2014	1.232	0.218
2010, 2015	2.1243	0.051
2012, 2014	0.44632	0.711
2012, 2015	1.4106	0.182
2014, 2015	0.86135	0.428

Shaded cells indicate significance at the 0.05 level

Table D.49 Pairwise comparison of soft coral cover at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	4.4201	0.001
A1995, F1996	3.44	0.002
A1995, 2001	4.8839	0.001
A1995, 2003	2.6726	0.013
A1995, 2004	4.2502	0.001
A1995, 2005	4.4168	0.001
A1995, 2010	3.4442	0.003
A1995, 2012	2.7462	0.011

Groups	t	P(perm)
A1995, 2014	3.928	0.001
A1995, 2015	2.7091	0.015
J1995, F1996	2.655	0.014
J1995, 2001	2	0.11
J1995, 2003	3.5442	0.002
J1995, 2004	0.10283	1
J1995, 2005	0.12585	1
J1995, 2010	0.74924	0.71
J1995, 2012	2.41	0.019
J1995, 2014	1.0792	0.306
J1995, 2015	1.7398	0.105
F1996, 2001	4.5147	0.002
F1996, 2003	1.3719	0.22
F1996, 2004	2.0467	0.067
F1996, 2005	2.5669	0.023
F1996, 2010	0.66354	0.653
F1996, 2012	0.75168	0.51
F1996, 2014	1.2543	0.268
F1996, 2015	0.4159	0.725
2001, 2003	4.84	0.001
2001, 2004	1.3188	0.488
2001, 2005	1.4573	0.472
2001, 2010	1.4198	0.015
2001, 2012	3.2679	0.001
2001, 2014	2.5186	0.042
2001, 2015	2.3729	0.014
2003, 2004	3.0144	0.006
2003, 2005	3.4699	0.002
2003, 2010	1.5508	0.136
2003, 2012	0.33883	0.785

Groups	t	P(perm)
2003, 2014	2.3719	0.03
2003, 2015	0.48297	0.675
2004, 2005	0.19271	1
2004, 2010	0.6388	0.615
2004, 2012	2.1391	0.041
2004, 2014	0.79506	0.487
2004, 2015	1.5843	0.121
2005, 2010	0.79091	0.659
2005, 2012	2.407	0.023
2005, 2014	1.1064	0.311
2005, 2015	1.7603	0.114
2010, 2012	1.1162	0.34
2010, 2014	0.12431	0.949
2010, 2015	0.82664	0.456
2012, 2014	1.5925	0.138
2012, 2015	0.17688	0.897
2014, 2015	1.1218	0.265

Shaded cells indicate significance at the 0.05 level

Table D50 Pairwise comparison of crinoid abundance between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	0.2633	1
KRN1, KRO3	2.1653	0.06
KRN2, KRO3	1.8049	0.108
PB1, PB2	1	1
PB1, PB3	9.02×10^{-10}	1
PB2, PB3	1	1
J1995		
KRN1, KRN2	1.3791	0.339
KRN1, KRO3	0.5837	0.618
KRN2, KRO3	1.872	0.039
PB1, PB2	Denominator is 0	
PB1, PB3	1.4676	0.51
PB2, PB3	1.4676	0.48
F1996		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	1.7164	0.075
KRN2, KRO3	1.7164	0.106
PB1, PB2	Negative	
PB1, PB3	0.5916	1
PB2, PB3	0.5916	1
2001		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	1	1
KRN2, KRO3	1	1
PB1, PB2	0.0924	1
PB1, PB3	0.8461	0.479
PB2, PB3	0.7063	0.544

2003		
KRN1, KRN2	0.6808	0.556
KRN1, KRO3	3.6191	0.001
KRN2, KRO3	3.0356	0.006
PB1, PB2	Denominator is 0	
PB1, PB3	1	1
PB2, PB3	1	1
2004		
KRN1, KRN2	0.2633	1
KRN1, KRO3	2.1653	0.06
KRN2, KRO3	1.8049	0.108
PB1, PB2	1	1
PB1, PB3	9.02×10^{-10}	1
PB2, PB3	1	1
2005		
KRN1, KRN2	2.9398	0.007
KRN1, KRO3	0.8815	0.414
KRN2, KRO3	1.9556	0.079
PB1, PB2	Denominator is 0	
PB1, PB3	1	1
PB2, PB3	1	1
2010		
KRN1, KRN2	7.27×10^{-9}	1
KRN1, KRO3	7.21×10^{-9}	1
KRN2, KRO3	Negative	
PB1, PB2	Negative	
PB1, PB3	1	1
PB2, PB3	1	1
2012		
KRN1, KRN2	0.9572	0.682
KRN1, KRO3	1.4676	0.499

KRN2, KRO3	1.3882	0.227
PB1, PB2	1.4676	0.489
PB1, PB3	1.4676	0.489
PB2, PB3	Denominator is 0	
2014		
KRN1, KRN2	1.8564	0.109
KRN1, KRO3	0.2646	1
KRN2, KRO3	1.4462	0.256
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
2015		
KRN1, KRN2	0.7483	0.618
KRN1, KRO3	1.0205	0.423
KRN2, KRO3	0.3859	0.83
PB1, PB2	1.4676	0.479
PB1, PB3	Denominator is 0	
PB2, PB3	1.4676	0.487

Denominator is 0 indicates all quadrats at both sites had zero percent cover in that survey
Shaded cells indicate significance at the 0.05 level

Table D.51 Pairwise comparison of crinoid abundance at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	0.5287	0.752
A1995, F1996	2.0855	0.1
A1995, 2001	2.0855	0.084
A1995, 2003	2.4483	0.016
A1995, 2004	0.2312	1
A1995, 2005	2.3983	0.033
A1995, 2010	1.7658	0.166
A1995, 2012	1.4739	0.231

Groups	t	P(perm)
A1995, 2014	1.1344	0.386
A1995, 2015	0.52337	0.741
J1995, F1996	1.54	0.225
J1995, 2001	1.504	0.223
J1995, 2003	1.3844	0.21
J1995, 2004	0.6763	0.649
J1995, 2005	1.5014	0.192
J1995, 2010	1.3791	0.316
J1995, 2012	1.2571	0.449
J1995, 2014	1.122	0.408
J1995, 2015	0.2076	0.938
F1996, 2001	Denominator is 0	
F1996, 2003	3.7801	0.001
F1996, 2004	3.5	0.006
F1996, 2005	3.4622	0.001
F1996, 2010	1	1
F1996, 2012	1.4676	0.492
F1996, 2014	1.3817	0.483
F1996, 2015	2.5825	0.016
2001, 2003	3.7801	0.002
2001, 2004	3.5	0.007
2001, 2005	3.4622	0.001
2001, 2010	1	1
2001, 2012	1.4676	0.47
2001, 2014	1.3817	0.478
2001, 2015	2.5825	0.016
2003, 2004	2.7749	0.013
2003, 2005	0.2498	0.898
2003, 2010	3.6191	0.002
2003, 2012	3.4651	0.002

Groups	t	P(perm)
2003, 2014	3.2609	0.006
2003, 2015	2.0513	0.061
2004, 2005	2.6436	0.016
2004, 2010	2.6833	0.026
2004, 2012	2.066	0.115
2004, 2014	1.355	0.335
2004, 2015	0.8501	0.55
2005, 2010	3.3345	0.001
2005, 2012	3.2111	0.003
2005, 2014	3.0544	0.002
2005, 2015	2.0635	0.045
2010, 2012	0.5916	1
2010, 2014	0.8367	0.729
2010, 2015	2.2856	0.055
2012, 2014	0.3902	1
2012, 2015	2.0125	0.121
2014, 2015	1.6733	0.157

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.52 Pairwise comparison of crinoid abundance at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	1.2827	0.235
A1995, F1996	1.3882	0.218
A1995, 2001	1.3882	0.217
A1995, 2003	0.65633	0.573
A1995, 2004	0.56659	0.841
A1995, 2005	0.96674	0.562
A1995, 2010	1.2827	0.245
A1995, 2012	0.6208	0.649

Groups	t	P(perm)
A1995, 2014	0.27906	0.948
A1995, 2015	0.66102	0.812
J1995, F1996	1	1
J1995, 2001	1	1
J1995, 2003	3.0356	0.005
J1995, 2004	2.0706	0.067
J1995, 2005	1.1966	0.46
J1995, 2010	Negative	
J1995, 2012	1.1671	0.488
J1995, 2014	2.5944	0.015
J1995, 2015	1.7748	0.154
F1996, 2001	Denominator is 0	
F1996, 2003	3.2139	0.002
F1996, 2004	2.4773	0.02
F1996, 2005	1.7398	0.238
F1996, 2010	1	1
F1996, 2012	1.3882	0.238
F1996, 2014	2.955	0.009
F1996, 2015	2.1676	0.052
2001, 2003	3.2139	0.005
2001, 2004	2.4773	0.021
2001, 2005	1.7398	0.229
2001, 2010	1	1
2001, 2012	1.3882	0.208
2001, 2014	2.955	0.004
2001, 2015	2.1676	0.039
2003, 2004	1.8497	0.099
2003, 2005	2.4927	0.018
2003, 2010	3.0356	0.005
2003, 2012	1.7643	0.114

Groups	t	P(perm)
2003, 2014	1.4117	0.221
2003, 2015	1.9818	0.067
2004, 2005	1.009	0.482
2004, 2010	2.0706	0.097
2004, 2012	0.167	1
2004, 2014	0.60876	0.698
2004, 2015	0.21896	1
2005, 2010	1.1966	0.473
2005, 2012	0.54132	0.845
2005, 2014	1.5999	0.218
2005, 2015	0.75679	0.641
2010, 2012	1.1671	0.478
2010, 2014	2.5944	0.022
2010, 2015	1.7748	0.15
2012, 2014	0.63818	0.695
2012, 2015	Negative	
2014, 2015	0.81168	0.502

Denominator is 0 indicates all quadrats had zero percent cover in each year

Table D.53 Pairwise comparison of soft coral cover at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	1.3481	0.261
A1995, F1996	2.842	0.003
A1995, 2001	2.842	0.002
A1995, 2003	1.661	0.17
A1995, 2004	0.0879	1
A1995, 2005	2.842	0.004
A1995, 2010	2.842	0.004
A1995, 2012	2.842	0.002
A1995, 2014	2.842	0.004

Groups	t	P(perm)
A1995, 2015	2.842	0.005
J1995, F1996	1.4676	0.222
J1995, 2001	1.4676	0.238
J1995, 2003	0.34967	0.745
J1995, 2004	0.91891	0.536
J1995, 2005	1.4676	0.218
J1995, 2010	1.4676	0.243
J1995, 2012	1.4676	0.23
J1995, 2014	1.4676	0.223
J1995, 2015	1.4676	0.228
F1996, 2001	Denominator is 0	
F1996, 2003	1	1
F1996, 2004	1.5865	0.096
F1996, 2005	Denominator is 0	
F1996, 2010	Denominator is 0	
F1996, 2012	Denominator is 0	
F1996, 2014	Denominator is 0	
F1996, 2015	Denominator is 0	
2001, 2003	1	1
2001, 2004	1.5865	0.092
2001, 2005	Denominator is 0	
2001, 2010	Denominator is 0	
2001, 2012	Denominator is 0	
2001, 2014	Denominator is 0	
2001, 2015	Denominator is 0	
2003, 2004	1.106	0.461
2003, 2005	1	1
2003, 2010	1	1
2003, 2012	1	1
2003, 2014	1	1

Groups	t	P(perm)
2003, 2015	1	1
2004, 2005	1.5865	0.099
2004, 2010	1.5865	0.101
2004, 2012	1.5865	0.109
2004, 2014	1.5865	0.092
2004, 2015	1.5865	0.104
2005, 2010	Denominator is 0	
2005, 2012	Denominator is 0	
2005, 2014	Denominator is 0	
2005, 2015	Denominator is 0	
2010, 2012	Denominator is 0	
2010, 2014	Denominator is 0	
2010, 2015	Denominator is 0	
2012, 2014	Denominator is 0	
2012, 2015	Denominator is 0	
2014, 2015	Denominator is 0	

Denominator is 0 indicates all quadrats had zero percent cover in each year

Shaded cells indicate significance at the 0.05 level

Table D.54 Pairwise comparison of soft coral cover at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	4.0095	0.001
A1995, F1996	3.4061	0.002
A1995, 2001	4.2699	0.001
A1995, 2003	2.1819	0.041
A1995, 2004	3.5032	0.002
A1995, 2005	3.5501	0.001
A1995, 2010	2.9756	0.009
A1995, 2012	2.5802	0.013
A1995, 2014	1.9028	0.087

Groups	t	P(perm)
A1995, 2015	1.9003	0.064
J1995, F1996	2.486	0.017
J1995, 2001	2.3155	0.016
J1995, 2003	3.7183	0.001
J1995, 2004	1.308	0.219
J1995, 2005	1.5815	0.134
J1995, 2010	1.1219	0.307
J1995, 2012	3.0001	0.005
J1995, 2014	4.3236	0.001
J1995, 2015	2.1792	0.023
F1996, 2001	4	0.001
F1996, 2003	2.3008	0.02
F1996, 2004	0.48176	0.713
F1996, 2005	0.55216	0.657
F1996, 2010	0.12432	0.978
F1996, 2012	1.5362	0.146
F1996, 2014	2.8894	0.008
F1996, 2015	1.409	0.21
2001, 2003	4.3754	0.001
2001, 2004	2.2436	0.008
2001, 2005	2.8014	0.01
2001, 2010	1.5738	0.011
2001, 2012	3.6897	0.001
2001, 2014	4.9851	0.001
2001, 2015	2.5177	0.007
2003, 2004	2.4456	0.023
2003, 2005	2.5873	0.015
2003, 2010	1.457	0.176
2003, 2012	0.68447	0.497
2003, 2014	0.48454	0.666

Groups	t	P(perm)
2003, 2015	Negative	
2004, 2005	9.98E-09	1
2004, 2010	0.38548	0.829
2004, 2012	1.7433	0.093
2004, 2014	2.9905	0.007
2004, 2015	1.5721	0.16
2005, 2010	0.40052	0.881
2005, 2012	1.8555	0.092
2005, 2014	3.1595	0.004
2005, 2015	1.6078	0.152
2010, 2012	0.90308	0.424
2010, 2014	1.8711	0.082
2010, 2015	1.096	0.273
2012, 2014	1.1795	0.262
2012, 2015	0.47449	0.622
2014, 2015	0.34316	0.781

Shaded cells indicate significance at the 0.05 level

Table D.55 Pairwise comparison of soft coral cover at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	8.5162	0.001
A1995, F1996	6.6299	0.001
A1995, 2001	9.1553	0.001
A1995, 2003	4.292	0.002
A1995, 2004	9.061	0.001
A1995, 2005	9.0336	0.001
A1995, 2010	6.811	0.001
A1995, 2012	6.0128	0.001
A1995, 2014	4.5231	0.001
A1995, 2015	3.3105	0.006

Groups	t	P(perm)
J1995, F1996	2.5812	0.021
J1995, 2001	1.3373	0.28
J1995, 2003	7.0419	0.001
J1995, 2004	0.96613	0.423
J1995, 2005	0.93863	0.422
J1995, 2010	0.52113	0.755
J1995, 2012	1.9082	0.076
J1995, 2014	1.781	0.092
J1995, 2015	2.7112	0.008
F1996, 2001	3.6582	0.001
F1996, 2003	3.6892	0.003
F1996, 2004	3.4539	0.002
F1996, 2005	3.4141	0.004
F1996, 2010	1.1974	0.267
F1996, 2012	Negative	
F1996, 2014	0.48458	0.684
F1996, 2015	1.5097	0.162
2001, 2003	8.4577	0.001
2001, 2004	0.58575	0.71
2001, 2005	0.55628	0.617
2001, 2010	1.1418	0.32
2001, 2012	2.6044	0.014
2001, 2014	2.2123	0.016
2001, 2015	3.1047	0.001
2003, 2004	8.3418	0.001
2003, 2005	8.2486	0.001
2003, 2010	4.1069	0.002
2003, 2012	2.9687	0.012
2003, 2014	1.6252	0.121
2003, 2015	0.39635	0.732

Groups	t	P(perm)
2004, 2005	Negative	
2004, 2010	0.96472	0.54
2004, 2012	2.4366	0.019
2004, 2014	2.0969	0.043
2004, 2015	3.0041	0.003
2005, 2010	0.95941	0.527
2005, 2012	2.4225	0.023
2005, 2014	2.0919	0.039
2005, 2015	2.9984	0.002
2010, 2012	1.0329	0.325
2010, 2014	1.232	0.218
2010, 2015	2.1243	0.051
2012, 2014	0.44632	0.711
2012, 2015	1.4106	0.182
2014, 2015	0.86135	0.428

Shaded cells indicate significance at the 0.05 level

Table D.56 Pairwise comparison of soft coral cover at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	4.4201	0.001
A1995, F1996	3.44	0.002
A1995, 2001	4.8839	0.001
A1995, 2003	2.6726	0.013
A1995, 2004	4.2502	0.001
A1995, 2005	4.4168	0.001
A1995, 2010	3.4442	0.003
A1995, 2012	2.7462	0.011
A1995, 2014	3.928	0.001
A1995, 2015	2.7091	0.015
J1995, F1996	2.655	0.014

Groups	t	P(perm)
J1995, 2001	2	0.11
J1995, 2003	3.5442	0.002
J1995, 2004	0.10283	1
J1995, 2005	0.12585	1
J1995, 2010	0.74924	0.71
J1995, 2012	2.41	0.019
J1995, 2014	1.0792	0.306
J1995, 2015	1.7398	0.105
F1996, 2001	4.5147	0.002
F1996, 2003	1.3719	0.22
F1996, 2004	2.0467	0.067
F1996, 2005	2.5669	0.023
F1996, 2010	0.66354	0.653
F1996, 2012	0.75168	0.51
F1996, 2014	1.2543	0.268
F1996, 2015	0.4159	0.725
2001, 2003	4.84	0.001
2001, 2004	1.3188	0.488
2001, 2005	1.4573	0.472
2001, 2010	1.4198	0.015
2001, 2012	3.2679	0.001
2001, 2014	2.5186	0.042
2001, 2015	2.3729	0.014
2003, 2004	3.0144	0.006
2003, 2005	3.4699	0.002
2003, 2010	1.5508	0.136
2003, 2012	0.33883	0.785
2003, 2014	2.3719	0.03
2003, 2015	0.48297	0.675
2004, 2005	0.19271	1

Groups	t	P(perm)
2004, 2010	0.6388	0.615
2004, 2012	2.1391	0.041
2004, 2014	0.79506	0.487
2004, 2015	1.5843	0.121
2005, 2010	0.79091	0.659
2005, 2012	2.407	0.023
2005, 2014	1.1064	0.311
2005, 2015	1.7603	0.114
2010, 2012	1.1162	0.34
2010, 2014	0.12431	0.949
2010, 2015	0.82664	0.456
2012, 2014	1.5925	0.138
2012, 2015	0.17688	0.897
2014, 2015	1.1218	0.265

Shaded cells indicate significance at the 0.05 level

Table D.57 Pairwise comparison of crinoid abundance between sites in each year.

Groups	t	P(perm)
A1995		
KRN1, KRN2	0.2633	1
KRN1, KRO3	2.1653	0.06
KRN2, KRO3	1.8049	0.108
PB1, PB2	1	1
PB1, PB3	9.02×10^{-10}	1
PB2, PB3	1	1
J1995		
KRN1, KRN2	1.3791	0.339
KRN1, KRO3	0.5837	0.618
KRN2, KRO3	1.872	0.039
PB1, PB2	Denominator is 0	
PB1, PB3	1.4676	0.51
PB2, PB3	1.4676	0.48
F1996		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	1.7164	0.075
KRN2, KRO3	1.7164	0.106
PB1, PB2	Negative	
PB1, PB3	0.5916	1
PB2, PB3	0.5916	1
2001		
KRN1, KRN2	Denominator is 0	
KRN1, KRO3	1	1
KRN2, KRO3	1	1
PB1, PB2	0.0924	1
PB1, PB3	0.8461	0.479
PB2, PB3	0.7063	0.544

2003		
KRN1, KRN2	0.6808	0.556
KRN1, KRO3	3.6191	0.001
KRN2, KRO3	3.0356	0.006
PB1, PB2	Denominator is 0	
PB1, PB3	1	1
PB2, PB3	1	1
2004		
KRN1, KRN2	0.2633	1
KRN1, KRO3	2.1653	0.06
KRN2, KRO3	1.8049	0.108
PB1, PB2	1	1
PB1, PB3	9.02×10^{-10}	1
PB2, PB3	1	1
2005		
KRN1, KRN2	2.9398	0.007
KRN1, KRO3	0.8815	0.414
KRN2, KRO3	1.9556	0.079
PB1, PB2	Denominator is 0	
PB1, PB3	1	1
PB2, PB3	1	1
2010		
KRN1, KRN2	7.27×10^{-9}	1
KRN1, KRO3	7.21×10^{-9}	1
KRN2, KRO3	Negative	
PB1, PB2	Negative	
PB1, PB3	1	1
PB2, PB3	1	1
2012		
KRN1, KRN2	0.9572	0.682
KRN1, KRO3	1.4676	0.499

KRN2, KRO3	1.3882	0.227
PB1, PB2	1.4676	0.489
PB1, PB3	1.4676	0.489
PB2, PB3	Denominator is 0	
2014		
KRN1, KRN2	1.8564	0.109
KRN1, KRO3	0.2646	1
KRN2, KRO3	1.4462	0.256
PB1, PB2	Denominator is 0	
PB1, PB3	Denominator is 0	
PB2, PB3	Denominator is 0	
2015		
KRN1, KRN2	0.7483	0.618
KRN1, KRO3	1.0205	0.423
KRN2, KRO3	0.3859	0.83
PB1, PB2	1.4676	0.479
PB1, PB3	Denominator is 0	
PB2, PB3	1.4676	0.487

Denominator is 0 indicates all quadrats at both sites had zero individuals in that survey

Shaded cells indicate significance at the 0.05 level

Table D.58 Pairwise comparison of crinoid abundance at site KRN1 between each year.

Groups	t	P(perm)
A1995, J1995	0.5287	0.752
A1995, F1996	2.0855	0.1
A1995, 2001	2.0855	0.084
A1995, 2003	2.4483	0.016
A1995, 2004	0.2312	1
A1995, 2005	2.3983	0.033
A1995, 2010	1.7658	0.166
A1995, 2012	1.4739	0.231

Groups	t	P(perm)
A1995, 2014	1.1344	0.386
A1995, 2015	0.52337	0.741
J1995, F1996	1.54	0.225
J1995, 2001	1.504	0.223
J1995, 2003	1.3844	0.21
J1995, 2004	0.6763	0.649
J1995, 2005	1.5014	0.192
J1995, 2010	1.3791	0.316
J1995, 2012	1.2571	0.449
J1995, 2014	1.122	0.408
J1995, 2015	0.2076	0.938
F1996, 2001	Denominator is 0	
F1996, 2003	3.7801	0.001
F1996, 2004	3.5	0.006
F1996, 2005	3.4622	0.001
F1996, 2010	1	1
F1996, 2012	1.4676	0.492
F1996, 2014	1.3817	0.483
F1996, 2015	2.5825	0.016
2001, 2003	3.7801	0.002
2001, 2004	3.5	0.007
2001, 2005	3.4622	0.001
2001, 2010	1	1
2001, 2012	1.4676	0.47
2001, 2014	1.3817	0.478
2001, 2015	2.5825	0.016
2003, 2004	2.7749	0.013
2003, 2005	0.2498	0.898
2003, 2010	3.6191	0.002
2003, 2012	3.4651	0.002

Groups	t	P(perm)
2003, 2014	3.2609	0.006
2003, 2015	2.0513	0.061
2004, 2005	2.6436	0.016
2004, 2010	2.6833	0.026
2004, 2012	2.066	0.115
2004, 2014	1.355	0.335
2004, 2015	0.8501	0.55
2005, 2010	3.3345	0.001
2005, 2012	3.2111	0.003
2005, 2014	3.0544	0.002
2005, 2015	2.0635	0.045
2010, 2012	0.5916	1
2010, 2014	0.8367	0.729
2010, 2015	2.2856	0.055
2012, 2014	0.3902	1
2012, 2015	2.0125	0.121
2014, 2015	1.6733	0.157

Denominator is 0 indicates all quadrats had zero individuals in each year

Shaded cells indicate significance at the 0.05 level

Table D.59 Pairwise comparison of crinoid abundance at site KRN2 between each year.

Groups	t	P(perm)
A1995, J1995	1.2827	0.235
A1995, F1996	1.3882	0.218
A1995, 2001	1.3882	0.217
A1995, 2003	0.6563	0.573
A1995, 2004	0.5666	0.841
A1995, 2005	0.9667	0.562
A1995, 2010	1.2827	0.245
A1995, 2012	0.6208	0.649

Groups	t	P(perm)
A1995, 2014	0.2791	0.948
A1995, 2015	0.661	0.812
J1995, F1996	1	1
J1995, 2001	1	1
J1995, 2003	3.0356	0.005
J1995, 2004	2.0706	0.067
J1995, 2005	1.1966	0.46
J1995, 2010	Negative	
J1995, 2012	1.1671	0.488
J1995, 2014	2.5944	0.015
J1995, 2015	1.7748	0.154
F1996, 2001	Denominator is 0	
F1996, 2003	3.2139	0.002
F1996, 2004	2.4773	0.02
F1996, 2005	1.7398	0.238
F1996, 2010	1	1
F1996, 2012	1.3882	0.238
F1996, 2014	2.955	0.009
F1996, 2015	2.1676	0.052
2001, 2003	3.2139	0.005
2001, 2004	2.4773	0.021
2001, 2005	1.7398	0.229
2001, 2010	1	1
2001, 2012	1.3882	0.208
2001, 2014	2.955	0.004
2001, 2015	2.1676	0.039
2003, 2004	1.8497	0.099
2003, 2005	2.4927	0.018
2003, 2010	3.0356	0.005
2003, 2012	1.7643	0.114

Groups	t	P(perm)
2003, 2014	1.4117	0.221
2003, 2015	1.9818	0.067
2004, 2005	1.009	0.482
2004, 2010	2.0706	0.097
2004, 2012	0.167	1
2004, 2014	0.60876	0.698
2004, 2015	0.21896	1
2005, 2010	1.1966	0.473
2005, 2012	0.54132	0.845
2005, 2014	1.5999	0.218
2005, 2015	0.75679	0.641
2010, 2012	1.1671	0.478
2010, 2014	2.5944	0.022
2010, 2015	1.7748	0.15
2012, 2014	0.63818	0.695
2012, 2015	Negative	
2014, 2015	0.81168	0.502

Denominator is 0 indicates all quadrats had zero individuals in each year

Shaded cells indicate significance at the 0.05 level

Table D.60 Pairwise comparison of crinoid abundance at site KRO3 between each year.

Groups	t	P(perm)
A1995, J1995	0.5689	0.601
A1995, F1996	0.2853	0.832
A1995, 2001	2.4674	0.008
A1995, 2003	2.4674	0.007
A1995, 2004	0.8593	0.481
A1995, 2005	0.6249	0.613
A1995, 2010	2.4674	0.007
A1995, 2012	2.5617	0.004

Groups	t	P(perm)
A1995, 2014	2.1465	0.03
A1995, 2015	2.0174	0.053
J1995, F1996	0.6656	0.608
J1995, 2001	1.872	0.036
J1995, 2003	1.872	0.041
J1995, 2004	0.1691	0.945
J1995, 2005	1.19×10^{-8}	1
J1995, 2010	1.872	0.032
J1995, 2012	1.9743	0.013
J1995, 2014	1.5346	0.154
J1995, 2015	1.4056	0.197
F1996, 2001	1.6682	0.101
F1996, 2003	1.6682	0.115
F1996, 2004	0.81197	0.552
F1996, 2005	0.69174	0.634
F1996, 2010	1.6682	0.103
F1996, 2012	1.7164	0.103
F1996, 2014	1.5153	0.191
F1996, 2015	1.4589	0.231
2001, 2003	9.02×10^{-10}	1
2001, 2004	3.4192	0.002
2001, 2005	2.3688	0.023
2001, 2010	Negative	
2001, 2012	1	1
2001, 2014	0.92269	0.753
2001, 2015	0.95814	0.748
2003, 2004	3.4192	0.001
2003, 2005	2.3688	0.032
2003, 2010	Negative	
2003, 2012	1	1

Groups	t	P(perm)
2003, 2014	0.92269	0.754
2003, 2015	0.95814	0.726
2004, 2005	0.20307	0.915
2004, 2010	3.4192	0.001
2004, 2012	3.6761	0.001
2004, 2014	2.4901	0.02
2004, 2015	2.1314	0.054
2005, 2010	2.3688	0.028
2005, 2012	2.5049	0.016
2005, 2014	1.9024	0.081
2005, 2015	1.7182	0.124
2010, 2012	1	1
2010, 2014	0.92269	0.754
2010, 2015	0.95814	0.739
2012, 2014	1.2929	0.488
2012, 2015	1.2336	0.476
2014, 2015	0.19612	1

Denominator is 0 indicates all quadrats had zero individuals in each year

Shaded cells indicate significance at the 0.05 level

Table D.61 Pairwise comparison of crinoid abundance at site PB1 between each year.

Groups	t	P(perm)
A1995, J1995	Denominator is 0	
A1995, F1996	1	1
A1995, 2001	2.9406	0.003
A1995, 2003	Denominator is 0	
A1995, 2004	1	1
A1995, 2005	Denominator is 0	
A1995, 2010	1	1
A1995, 2012	1.4676	0.475

Groups	t	P(perm)
A1995, 2014	Denominator is 0	
A1995, 2015	Denominator is 0	
J1995, F1996	1	1
J1995, 2001	2.9406	0.002
J1995, 2003	Denominator is 0	
J1995, 2004	1	1
J1995, 2005	Denominator is 0	
J1995, 2010	1	1
J1995, 2012	1.4676	0.475
J1995, 2014	Denominator is 0	
J1995, 2015	Denominator is 0	
F1996, 2001	2.7735	0.005
F1996, 2003	1	1
F1996, 2004	8.88×10^{-9}	1
F1996, 2005	1	1
F1996, 2010	4.86×10^{-9}	1
F1996, 2012	0.59161	1
F1996, 2014	1	1
F1996, 2015	1	1
2001, 2003	2.9406	0.001
2001, 2004	2.7735	0.001
2001, 2005	2.9406	0.003
2001, 2010	2.7735	0.004
2001, 2012	2.6134	0.01
2001, 2014	2.9406	0.001
2001, 2015	2.9406	0.001
2003, 2004	1	1
2003, 2005	Denominator is 0	
2003, 2010	1	1
2003, 2012	1.4676	0.477

Groups	t	P(perm)
2003, 2014	Denominator is 0	
2003, 2015	Denominator is 0	
2004, 2005	1	1
2004, 2010	5.18×10^{-9}	1
2004, 2012	0.59161	1
2004, 2014	1	1
2004, 2015	1	1
2005, 2010	1	1
2005, 2012	1.4676	0.487
2005, 2014	Denominator is 0	
2005, 2015	Denominator is 0	
2010, 2012	0.5916	1
2010, 2014	1	1
2010, 2015	1	1
2012, 2014	1.4676	0.455
2012, 2015	1.4676	0.484
2014, 2015	Denominator is 0	

Denominator is 0 indicates all quadrats at both sites had zero individuals in that survey

Shaded cells indicate significance at the 0.05 level

Table D.62 Pairwise comparison of crinoid abundance at site PB2 between each year.

Groups	t	P(perm)
A1995, J1995	1.5236	0.218
A1995, F1996	1.3096	0.342
A1995, 2001	1.4462	0.189
A1995, 2003	1.5236	0.251
A1995, 2004	1.5236	0.228
A1995, 2005	1.5236	0.234
A1995, 2010	1.3096	0.344
A1995, 2012	1.5236	0.223

Groups	t	P(perm)
A1995, 2014	1.5236	0.218
A1995, 2015	1.106	0.481
J1995, F1996	1	1
J1995, 2001	2.7051	0.004
J1995, 2003	Denominator is 0	
J1995, 2004	Denominator is 0	
J1995, 2005	Denominator is 0	
J1995, 2010	1	1
J1995, 2012	Denominator is 0	
J1995, 2014	Denominator is 0	
J1995, 2015	1.4676	0.494
F1996, 2001	2.5628	0.01
F1996, 2003	1	1
F1996, 2004	1	1
F1996, 2005	1	1
F1996, 2010	9.02×10^{-10}	1
F1996, 2012	1	1
F1996, 2014	1	1
F1996, 2015	0.5916	1
2001, 2003	2.7051	0.003
2001, 2004	2.7051	0.001
2001, 2005	2.7051	0.001
2001, 2010	2.5628	0.011
2001, 2012	2.7051	0.005
2001, 2014	2.7051	0.005
2001, 2015	2.4254	0.02
2003, 2004	Denominator is 0	
2003, 2005	Denominator is 0	
2003, 2010	1	1
2003, 2012	Denominator is 0	

Groups	t	P(perm)
2003, 2014	Denominator is 0	
2003, 2015	1.4676	0.507
2004, 2005	Denominator is 0	
2004, 2010	1	1
2004, 2012	Denominator is 0	
2004, 2014	Denominator is 0	
2004, 2015	1.4676	0.512
2005, 2010	1	1
2005, 2012	Denominator is 0	
2005, 2014	Denominator is 0	
2005, 2015	1.4676	0.465
2010, 2012	1	1
2010, 2014	1	1
2010, 2015	0.5916	1
2012, 2014	Denominator is 0	
2012, 2015	1.4676	0.489
2014, 2015	1.4676	0.469

Denominator is 0 indicates all quadrats at both sites had zero individuals in that survey

Shaded cells indicate significance at the 0.05 level

Table D.63 Pairwise comparison of crinoid abundance at site PB3 between each year.

Groups	t	P(perm)
A1995, J1995	Negative	
A1995, F1996	1.3143	0.515
A1995, 2001	0.6352	0.578
A1995, 2003	1.3905	0.485
A1995, 2004	1.3905	0.479
A1995, 2005	1.3905	0.469
A1995, 2010	1.4676	0.471
A1995, 2012	1.4676	0.48

Groups	t	P(perm)
A1995, 2014	1.4676	0.481
A1995, 2015	1.4676	0.471
J1995, F1996	1.3143	0.478
J1995, 2001	0.6352	0.595
J1995, 2003	1.3905	0.499
J1995, 2004	1.3905	0.503
J1995, 2005	1.3905	0.484
J1995, 2010	1.4676	0.487
J1995, 2012	1.4676	0.458
J1995, 2014	1.4676	0.494
J1995, 2015	1.4676	0.485
F1996, 2001	3.5	0.004
F1996, 2003	0.5916	1
F1996, 2004	0.5916	1
F1996, 2005	0.5916	1
F1996, 2010	1.4676	0.477
F1996, 2012	1.4676	0.482
F1996, 2014	1.4676	0.472
F1996, 2015	1.4676	0.476
2001, 2003	3.6495	0.002
2001, 2004	3.6495	0.002
2001, 2005	3.6495	0.003
2001, 2010	3.8056	0.001
2001, 2012	3.8056	0.001
2001, 2014	3.8056	0.001
2001, 2015	3.8056	0.002
2003, 2004	Negative	
2003, 2005	Negative	
2003, 2010	1	1
2003, 2012	1	1

Groups	t	P(perm)
2003, 2014	1	1
2003, 2015	1	1
2004, 2005	9.02×10^{-10}	1
2004, 2010	1	1
2004, 2012	1	1
2004, 2014	1	1
2004, 2015	1	1
2005, 2010	1	1
2005, 2012	1	1
2005, 2014	1	1
2005, 2015	1	1
2010, 2012	Denominator is 0	
2010, 2014	Denominator is 0	
2010, 2015	Denominator is 0	
2012, 2014	Denominator is 0	
2012, 2015	Denominator is 0	
2014, 2015	Denominator is 0	

Denominator is 0 indicates all quadrats at both sites had zero individuals in that survey

Shaded cells indicate significance at the 0.05 level

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

Table E.1 Fish species and their relative abundance in March 2015 and in previous surveys.

Scientific Name	Common Name	Kirra Reef											Palm Beach Reef										
		Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '14	Mar '15	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '14	Mar '15
Acanthuridae																							
Acanthurus blochii	ring-tailed surgeon	**	**	**	**	**		**	**		***	***	**	**	***	**	**		**	**	**	**	**
Acanthurus xanthopterus	yellowfin surgeon									**	**												
Prionurus microlepidotus	sawtail surgeon								***										**	**	**		
Acanthurus olivaceus	orange-band surgeon											*											
Naso sp.	unicornfish											*											
Apogonidae																							
Apogon cookii	cook's cardinal fish											*						**	**	*			
Apogon doederleini	four lined cardinal fish							**	*		*	*				**		***	**	**			*
Aracanidae																							
Strophiurichthys robustus	freckled boxfish					**					*												
Balastidae																							
Sufflamen chrysopterus	half-moon triggerfish							**			**	**							**	**	*	**	*
Sufflamen fraenatus	bridled triggerfish														*								
Blennidae																							
Plagiotremus tapeinosoma	hit and run blenny						**	*	*	*	*	*							*	**		**	*
Brachaeluridae																							
Brachaelurus waddi	blindshark							*		*								*			*	*	
Carangidae																							
Caranax sp.	trevally										*			**	***	***							
Gnathanodon speciosus	golden trevally																	**					
Pseudocaranx georgianus	silver trevally								***			***					***						
Tracinotus blochii	dart	**									*												
Trachurus novaezelandie	yellowtail	****	****	****		*****	****	****	****	****	****	****	****	****	**	****	****			****	****		

Scientific Name	Common Name	Kirra Reef											Palm Beach Reef										
		Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '14	Mar '15	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Jul '12	Apr '14	Mar '15
Chaetodontidae																							
Chaetodon auriga	threadfin butterfly fish	**	**			**			**		*	*	*	*	**			**				**	
Chaetodon citrinellus	citron butterfly fish					**													**	**	**		
Chaetodon flavirostris	dusky butterfly fish				*						*	*							**	**		**	*
Chaetodon lineolatus	lined butterfly fish				*	*					*				**				*			**	
Heinochus sp.	banner fish	**				*			**			*											
Chaetodon guentheri	gunther's butterflyfish																						*
Chaetodon kleinii	brown butterflyfish																						*
Cheilodactylidae																							
Cheilodactylus fuscus	red morwong			**	**	**	**	*	**		**	**		**		**	**		**	**			
Cheilodactylus vestitus	crested morwong			*				*	*	*	**					*			**	**		*	
Chironemidae																							
Chironemus marmoratus	kelp fish				**	**		**			**	**											
Cirrhitidae																							
Cirrhitichthys sp.	hawkfish					**									*			**	**			*	
Dasyatidae																							
Dasyatis kuhlii	blue-spotted maskray								**														
Pastinachus atrus	cowtail stingray										*	*											
Diodontidae																							
Dicotylichthys punctulatus	three-bar porcupine fish					**	*	***	**	**	**	**				*						**	
Diodon holacanthus	freckled porcupine fish	*		**																	**		
Diodon hystrix	black-spotted porcupine fish					*						*											

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Ephippidae																							
Platax orbicularis	round batfish								*														
Enoplosidae																							
Enoplosus armatus	old wife	***		**	***			**			*	*				**							
Fistularidae																							
Fistularia commersonii	smooth flutemouth	*			**				**			*								**			*
Fistularia petimba	rough flutemouth																			**			
Gerridae																							
Gerres subfasciatus	silver biddy	***	**	**	**	***	*	**	*		**	*											
Haemulidae																							
Plectorhyncus flavomaculatus	gold-spotted sweetlip				*	**		*			*								*	*		*	*
Labridae																							
Achoerodus gouldi	blue groper																*						
Anampses meleagrides	spotted wrasse																				*		
Diproctacanthus xanthurus	yellowtail tubelip									*		*											
Halichoeres sp.	striped wrasse			**	***	*			***	***	***	*				**		*	**	**		***	**
Labroides dimidiatus	cleaner wrasse			**	**	***	**	**	**	**	**	**		*	*	*	**	**	*	**	**	***	**
Notolabrus gymnogensis	crimson-banded wrasse					***	**					**									*		*
Notolabrus sp.	wrasse	**										*	**	**	**								
pseudolabrus guentheri	Gunthers Wrasse									**	***	***									**	**	**
Thalasoma jansenii	Jansen's wrasse									**		**									*	*	*
Thalassoma lunare	moon wrasse					**	**	**		**	**	**			***	***	***	**	****	***	**	***	***
Thalassoma lutascens	yellow moon wrasse	**		**	**	***	*	**		**	*	**		**	***	***	***	**	**	***		***	***
Lutjanidae																							
Lutjanus fluviflamma	black-spot snapper									**	*	**											*

Scientific Name	Common Name	Kirra Reef Apr '95	Kirra Reef Jun '95	Kirra Reef Feb '96	Kirra Reef Jan '01	Kirra Reef May '03	Kirra Reef Mar '04	Kirra Reef Feb '05	Kirra Reef Feb '10	Kirra Reef Jul '12	Kirra Reef Apr '14	Kirra Reef Mar '15	Palm Beach Reef Apr '95	Palm Beach Reef Jun '95	Palm Beach Reef Feb '96	Palm Beach Reef Jan '01	Palm Beach Reef May '03	Palm Beach Reef Mar '04	Palm Beach Reef Feb '05	Palm Beach Reef Feb '10	Palm Beach Reef Jul '12	Palm Beach Reef Apr '14	Palm Beach Reef Mar '15
Microcanthidae																							
Atpichthys strigatus	mado			**	***	***	*	***	***		***	***						***	***	***	**		**
Microcanthus strigatus	stripey	***	***	**	***	***	**	***	***	**	*	**	***	**	**	***		*		***	**	***	**
Monocanthidae																							
Meuschenia trachylepis	yellow-tailed leatherjacket					*													**				
Monocanthus chinensis	fan-bellied leatherjacket	*		*	*				*			*		*	*				**				
Oxymonacanthus longirostris	orange spotted filefish																				*	*	
Monodactylidae																							
Monodactylus argenteus	silver batfish					***								***		**	***						
Schuettea scalaripinnis	eastern pomfred								***		*	***	****	***	***					**			
Mullidae																							
Parupeneus barberinoides	half-and-half goatfish				**			*											**				
Parupeneus ciliatus	diamond-scaled goat fish										*				*								
Parupeneus signatus	black spot goat fish	***	**	***	***							*				***					**	*	*
Muraenidae																							
Gymnothorax favagineus	tessellate moray										*											*	
Gynothorax prasineus	green moray					**	**	***												*		*	
Gynothorax sp.	moray eel					*	*								*						*		
Siderea thyrsoidea	white-eyed moray						**	**															
Myliobatididae																							
Aetobatus narinari	white-spotted eagle ray									**	*												
Orectolobidae																							
Orectolobus ornatus	ornate wobbegong					**	**	**	**	**	*	*		**	**		**		**				**
Ostraciidae																							
Ostracion cubicus																			**				

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Pempheridae																							
Pempheris multiradiata	bullseye									**				***	***	**				**		*	
Pempheris oualensis	black-finned bullseye					*																	
Pinguipedidae																							
Parapercis queenslandiae	queensland grubfish																					*	*
Platycephalidae																							
Platycephalus fuscus	dusky flathead				*			*															
Plesiopidae																							
Trachinops taeniatus	eastern hulafish																						**
Plotosidae																							
Cnidoglanis macrocephala	estuary catfish	*																					
Polynemidae																							
Polydactylus ngipinnis	black-finned threadfin																*						
Pomacanthidae																							
Centropyge tibicen	keyhole angelfish					*		*				*						*	**	**			
Pomacanthus semicirculatus	blue angelfish											*								*			
Centropyge vrolikii	pearly-scaled angelfish																						*
Pomacentridae																							
Abudefduf bengalensis	Bengal sergeant major					**		*				*					**	**	**	*	**	*	
Abudefduf vaigiensis	sergeant major								*		*						***	*	**	***		**	
Abudefduf saxatilis	five-banded sergeant major								**								***			*			
Amphiprion sp.	clown fish	**	**	**		**					*	**			**		**			***	**	*	*
Chromis chrysura	robust puller			**							**	*						*				***	
Chromis nitida	barrier reef chromis			**							**				**							***	
Chrysiptera sp.	Demoiselle					**						*					**	*		**			

Scientific Name	Common Name	Kirra Reef Apr '95	Kirra Reef Jun '95	Kirra Reef Feb '96	Kirra Reef Jan '01	Kirra Reef May '03	Kirra Reef Mar '04	Kirra Reef Feb '05	Kirra Reef Feb '10	Kirra Reef Jul '12	Kirra Reef Apr '14	Kirra Reef Mar '15	Palm Beach Reef Apr '95	Palm Beach Reef Jun '95	Palm Beach Reef Feb '96	Palm Beach Reef Jan '01	Palm Beach Reef May '03	Palm Beach Reef Mar '04	Palm Beach Reef Feb '05	Palm Beach Reef Feb '10	Palm Beach Reef Jul '12	Palm Beach Reef Apr '14	Palm Beach Reef Mar '15
Dascyllus trimaculatus	domino puller							*				**				*						**	
Parma microlepis	white ear puller		**	**	**								**	**	**	**		*	*	*			
Parma oligolepis	large-scaled parma					**	**	**		**	***	**							*	***		*	***
Parma pollepis	banded parma							**											**	**			
Plectroglyphidodon leucozonus	whiteband damsel																				*		*
Pomacentrus australis	Australian damsel	**	**	**									**	**			**	**					
Pomacentrus coelestis	neon damsel					***		**			***	**					***		***	****	**	**	**
Stegastes gascoynei	coral sea gregory					**	*											**		**			
Stegastes sp.	damsel									*											***		
Pomatomidae																							
Pomatomus saltatrix	tailor	****																					
Rhinobatidae																							
Aptychotrema sp.	shovelnose ray	*									*												
Glaucostegus typus	giant shovelnose ray																			*			
Scorpaendiae																							
Centropogon australis	fortescue									**						*							
Pterois volotans	red firefish					*											*						
Scorpaena cardinalis	red scorpionfish					*											*			**			*
Synancia horrida	estuarine stonefish							**				*											
Dendrochirus zebra	zebra lionfish																						*
Scombridae																							
Cybiosarda elegans	leaping bonito								****														
Scomberomorus commerson	spanish mackerel																			**			
Scorpididae																							
Scorpis lineolatus	sweep	***	***	**	**	**	*	**	**	****	*	***	***	***	**	****	**	**	**	***	****	*	***

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Serranidae																							
Anthias sp.	anthias										*											*	
Epinephelus fasciatus	black-tipped cod													**				*	***	**		*	
Diploprion bifasciatum	barred soapfish																					*	*
Plectropomus maculatus	coral trout													*									
Siganidae																							
Siganus fuscescens	rabbit fish				***					*		*				***		***	***	***		*	
Sillaginidae																							
Sillago analis	gold-lined whiting							**			*												
Sparidae																							
Acanthopagrus australis	yellow fin bream	***	***	**	***	***				**	***	**	***	**	**	**				***	**	**	*
Rhabdosargus sarba	tarwhine	***			**						*	**								*			
Sphyraenidae																							
Sphyraena argentea	barracuda										**	*											
Sphyraena obtusata	striped sea pike	****	**	**	**	*		****		**	**	****					*			**	**		
Syngnathidae																							
Sp. 1	pipefish	*																					
Stegestomatidae																							
Stegostoma fasciatum	leopard shark															*							
Tetraodontidae																							
Arothron hispidus	stars and stripes pufferfish				*		**	**	*			*				*	*					*	
Arthron immaculatus	immaculate pufferfish			*																			
Arothron manillensis	narrow lined toadfish				*																		
Arothron stellatus	starry toadfish							*	*			*						**	**				
Canthigaster valentini	black-saddled toby							*									**		**				*
Lagocephalus sp.	toadfish				***							*											

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Torquigener pleurogramma	toadfish	*	*		***										*								
Urolophidae																							
Urolophus sp.	stingaree	*	***	**	**	*		**			*	**											
Zanclidae																							
Zanclus cornutus	moorish idol										*	*											

shading indicates surveys where each species was observed

* < 5 individuals

** 6-20 individuals

*** 21-100 individuals

**** >100 individuals