Tweed River Entrance Sand Bypassing Project (TRESBP)

Kirra Reef
Ecological Monitoring 2010

Prepared for:

NSW Land & Property Management Authority
&
QLD Department of Environment & Resource Management

frc **environmental**

PO Box 2363
Wellington Point Qld 4160

Telephone: + 61 7 3820 4900
Facsimile: + 61 7 3207 5640

frc Ref: 100201

Document Control Summary

Project No.:	100201
Status:	Final Report
Project Director:	John Thorogood
Project Manager:	K. McPherson
Title:	Tweed River Entrance Sand Bypassing Project, Kirra Reef Ecological Monitoring 2010
Project Team:	K. McPherson, T. Napier Munn, A. Olds, L. Thorburn, J. Thorogood
Client:	NSW Land & Property Management Authority
Client Contact:	Steve Lawson
Date:	March 2011
Edition:	100201iii
Checked by:	Lauren Thorburn ________________
Issued by:	John Thorogood ________________

Distribution Record

NSW LPM:	1 electronic copy (PDF) and one bound copy

Contents

List of Tables

List of Figures

Summary

frc environmental were commissioned by the NSW Land & Property Management Authority (LPMA) to monitor the condition and bio-diversity of floral and faunal communities at Kirra Reef, and to comment on the impacts of the Tweed River Entrance Sand Bypassing Project (TRESBP). This report presents the results of ecological monitoring (of benthic flora, macro-invertebrates, and fishes) of Kirra Reef, undertaken in February 2010.

The 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 employed in the February 2010 monitoring event (i.e. surveys of benthic cover and fish abundance), were those developed for the Stage I study conducted in 1995, and used in the 1996, 2001, 2003, 2004 and 2005 monitoring events.

Changes to the Ecological Condition of Kirra Reef

The greatest ecological change to the condition of Kirra Reef has been the loss of large areas of hard substrate that support benthic flora and fauna, as a consequence of burial of the reef by sand. However, there have also been subtle changes to the flora and fauna of the remaining reef, which likely result from an interaction between the reduced depth of seabed surrounding the reef, and subsequent enhanced levels of physical disturbance, abrasion and sedimentation with greater wave action. The area of uncovered reef has increased prior to the most recent monitoring event (i.e. February 2010), and the rocky outcrops that are currently exposed support a rich benthic assemblage. The remaining assemblage exhibits signs of ongoing stress and physical disturbance, including a reduction in the cover of macroalgae, sponges and soft coral over time, and enhanced temporal variability (i.e. lower stability) of sponge and fish assemblages, relative to those at Palm Beach Reef. However, Kirra Reef continues to afford habitat to a range of flora and fauna, and is therefore still likely to support many important marine ecological functions and ecosystem services within the region.

Continued reduction in the cover of benthic flora and fauna and decreased abundance and diversity of fish would be expected if there are further decreases in habitat availability. However, given that the areal extent of the reef has been greatly reduced in recent years, it is likely that the assemblages of Kirra Reef are more resilient then anticipated. The overall condition of the floral and faunal assemblages at Kirra Reef is likely to be reflective of the complex interaction between physical disturbance (i.e. burial, sedimentation, wave action, and abrasion), food availability, competition, and local weather and sea conditions.

Impacts of the Sand Bypassing System on Kirra Reef

Predicted impacts focused on accretion of sand around the base of the rock outcrops at Kirra Reef, leading to a reduction in extent of the exposed area of reef. It was anticipated that sand delivery would eventually mimic natural patterns of dispersal, and that the reef would be reduced in size to its natural extent (i.e. pre development of the Tweed River training walls). However, the Project's EIS did not consider the ecological consequences of both the reduced areal extent and increased wave energy (a consequence of decreased depth of the reef habitat available) that would occur. Presumably the benthic flora and fauna assemblages of the reef would be expected to return to a condition consistent with the historical reef extent and natural sand transport patterns and associated coastal fluctuations, wave action, sedimentation and water quality that were observed in the vicinity of the reef prior to the development of the Tweed River training walls.

The current extent of Kirra Reef is broadly in accordance with predictions made in the EIS, although dispersion of sand from Kirra Beach and reduction in the sand levels around the reef have been slower than predicted over the past 6 years, due to a period of calmer than usual conditions. The burial and subsequent re-exposure of large sections of Kirra Reef between the February 2005 and 2010 monitoring events, together with recent surveyed trending of reduced sand volumes at Kirra, suggests that the rugosity and extent of the reef may have not reached a physical equilibrium. Ongoing monitoring of the physical and ecological dynamics of Kirra Reef will be required to determine the magnitude of variation in seabed height, benthic cover and biodiversity that will characterise the reef complex in the longer-term.

Impacts of Storms & Seasonality on Kirra Reef

The benthic flora and fauna of Kirra Reef are highly susceptible to the influence of storms, and associated wave action. The impacts of increased wave action and sedimentation on the flora and fauna present at Kirra Reef are likely to be greatest during and immediately following storm conditions, however such 'pulse' impacts would be expected to have lasting influences on the composition and stability of benthic assemblages. This physical disturbance is likely to have contributed to changes to the condition of local floral and faunal assemblages. It is likely that the restored coastal sand supply of the TRESBP interacts with storm-driven disturbances and natural seasonal patterns of coastal zone transport, to result in variation in the extent to which Kirra Reef is covered by sand (and as such, variations in the ecology of the reef). It is noted that shorter-term fluctuations, such as those that are a result of storms or changes in the coastal sand supply, would have been a component of the natural ecology of the reef prior to the development of the training walls (i.e. pre-1960s).

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

The exposed reef currently covers a much smaller area than that exposed in 1995. Logically, this has dramatically reduced the abundance of benthic reefal assemblages, and is also likely to have substantially decreased habitat diversity across Kirra Reef.

Survey monitoring has shown that excess sand volumes have dispersed from the Kirra area over recent years, and this is expected to continue under the current level of sand delivery by the TRESBP. This reduction in sand volumes resulted in an increase in exposed reef area prior to this monitoring event (February 2010) and progressive uncovering of the reef is expected to continue if the excess sand continues to disperse northward from Kirra.

Ongoing reductions in sand levels at Kirra Reef are likely to result in variable diversity and abundance of benthic flora and fauna and fish until a new equilibrium is reached. During times of increased physical disturbance, flora and fauna diversity is likely to decrease, although it is likely that in many respects, observable change in floral and faunal communities lag behind actual physical disturbance. However, sand levels at Kirra Reef are predicted to become similar to levels prior to construction of the Tweed River training walls in the future. Once this occurs, communities are expected to become similar to those recorded prior to construction of the training walls, in the absence of other (new) forms of disturbance. The timeframe for the 'recovery' of communities to this state is currently unknown, and will depend on ambient environmental conditions once sand levels stabilise. Ongoing monitoring will provide insight into the rate of 'recovery' of communities.

1 Introduction

frc environmental were commissioned by the NSW Land & Property Management Authority (LPMA) to monitor the condition, biological abundance and bio-diversity of floral and faunal communities at Kirra Reef. This report responds to the commission, presenting results of surveys of benthic flora and macro-invertebrate fauna, and fishes of Kirra Reef and (for comparative purposes) Palm Beach Reef, in February 2010.

The current condition of Kirra Reef is compared with the condition of nearby Palm Beach Reef, and with the condition of Kirra Reef in 1995, 1996, 2001, 2003, 2004 and 2005 (frc environmental 2005).

1.1 Historical Context of Monitoring

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

frc environmental conducted baseline assessments of Kirra Reef in 1995 (Fisheries Research Consultants 1995a; 1995b), and has undertaken five ecological monitoring surveys of the reef on behalf of TRESBP since 1996 (Fisheries Research Consultants 1996; frc environmental 2001; 2003; 2004; 2005). The ongoing monitoring of Kirra Reef meets the requirements of the Environmental Management System (EMS) Sub-Plan B14 Kirra Reef Management Plan, prepared by the TRESBP in February 2001. It also incorporates additional monitoring activities implemented by the TRESBP in August 2004.

Under Sub-Plan B14, if the area of exposed reef on aerial photographs is smaller than the range of areas shown on aerial photographs from 1962 / 1965, then monitoring of the marine biota of Kirra Reef is required. Interpretation of aerial photographs taken in August 2002 indicated there had been substantial changes to the reef since 1962 / 65. Loss of reef area continued for some years, with aerial photographs from November 2003 showing the inner Western Reef and entire Eastern Reef covered by sand, and the area of the outer Western Reef greatly reduced (Figure 1.1). Interpretation of aerial photography from April 2004 indicated that the extent of the outer western reef was further reduced, although a small outcrop of eastern reef had been uncovered (Figure 1.1). By early 2006, the area of exposed reef had been reduced to 100 m^2. Ecological surveys were postponed at this time and, as a consequence of extensive reef burial, were not conducted between 2006 and 2010. Over this period, visual inspections of the reef were conducted in place of full surveys, on behalf of TRESBP by dive teams from Gilbert Diving and Gold Coast City Council. By February 2010, the area of Kirra Reef had increased and this ecological survey was commissioned.

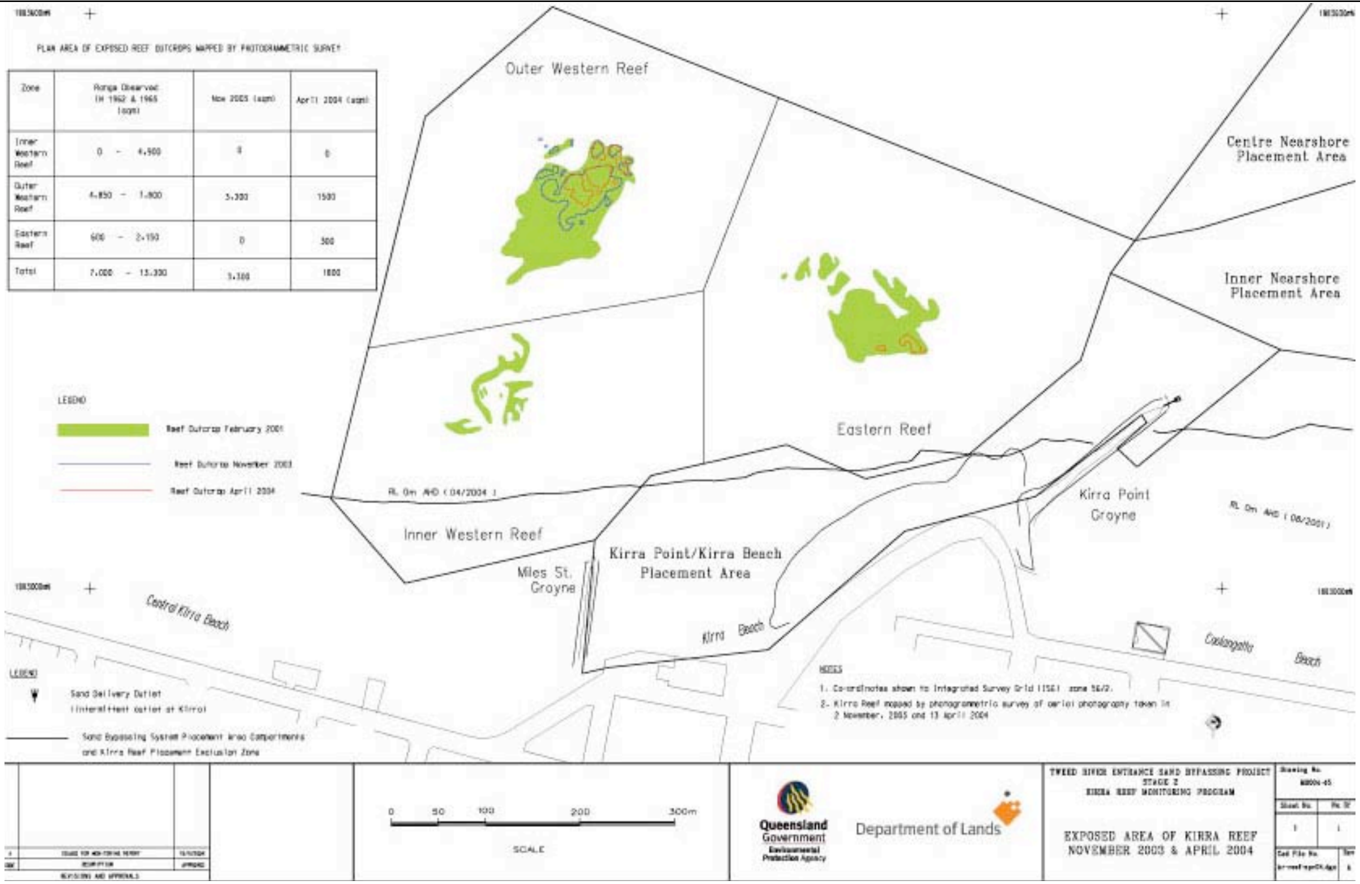
1.2 Sand Nourishment History

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

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

Commissioning commenced in March 2001 and operation of the TRESBP commenced in May 2001, since then approximately 5.0 million m^3 of pumped sand and 1.5 million m^3 of dredged sand (derived from dredging of the Tweed River mouth) has been deposited along the southern Gold Coast beaches. Most of the sand delivered both by pumping and dredge has been placed in the primary placement area, south east of Snapper Rocks. This sand has then been transported around Snapper Rocks headland and to the southern Gold Coast beaches by wave and current action. The majority of sand is currently delivered to Point Danger, with some also delivered to Duranbah Beach. At Kirra Point, sand was historically discharged into the surf zone to feed onto the beaches to the north up until December 2003. A sand placement exclusion zone of approximately 100 metres around Kirra Reef ensured that no sand was directly placed on the reef. Accumulation of sand on Kirra Reef thus occurs only by sand transport by waves and currents along the seabed, rather than by direct depositional smothering (Hyder et al. 1997).

In order to restore the depleted southern Gold Coast beaches, reduce the Tweed entrance bar, and improve the efficiency of the sand bypass system by clearing the sand trap and pulling back Letitia Spit against the southern Tweed breakwater, relatively high quantities of sand were delivered to the southern Gold Coast beaches during the early operational years of the TRESBP. These objectives have now been achieved, and the quantity of sand delivered since 2005 is more consistent with the natural movement of sand along the coast.



frc environmental deep thinking. science.	Kirra Reef Ecological Monitoring 2010
	Figure 1.1 Extent of Kirra Reef in 2001, 2003, 2004 & 2010.
	NSW Department of Lands — February 2010

1.3 Faunal and Floral Character of the Study Region

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

The fish fauna of the Gold Coast region is similar to that recorded at Flat and Shag Rocks offshore of Moreton Bay, and Julian Rocks and the Solitary Islands, in northern NSW (Robinson & Pollard 1982; Parker 1995; 1999; Edwards & Smith 2005; Malcolm 2009; CSIRO 2009). Though logically, the smaller inshore reefs of the Gold Coast typically support a lower abundance, richness and diversity of reef fish (refer Edwards & Smith 2005; frc environmental 2005).

Kirra Reef

Kirra Reef is the collective name given to the complex of rocky outcrops located offshore of Kirra Beach, in water depths of between 3 and 7 metres. The reef's outcrops rarely rise more than 1 metre above the clean mobile sands that surround them, however several outcrops extend to more than 2 metres above the seafloor.

The biota of the reef complex is characterised by prolific macroalgae and sessile benthic invertebrates (Edwards & Smith 2005; frc environmental 2005). Macroalgae 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 (Fisheries Research Consultants 1995a; 1995b; 1996; frc environmental 2003; 2004; 2005; Edwards & Smith 2005). The composition of benthic assemblages at Kirra Reef is broadly similar to that described from adjacent rocky reefs (including Palm Beach Reef) (Hollingsworth 1975; Edwards & Smith 2005), and those of the southern QLD and northern NSW bioregions (refer Harriott et al 1999; Baronio & Butcher 2008; Fellegara 2008).

Fluctuations in the height of sand around the bases of rocky outcrops is a major factor influencing the cover of benthic flora and fauna, and periodically results in a zone of low coverage on rocks nearer to the seafloor. Exposure to wave-driven sand abrasion is also an important factor in determining the distribution of flora and fauna over the reef. Outcrops on the eastern side of the reef complex, where wave action and sand suspension are naturally the strongest, have historically supported a lower abundance of benthic fauna than outcrops on the northwest (Fisheries Research Consultants 1995a; 1995b; 1996; frc environmental 2003, 2004, 2005). Strong wave action results in sustained abrasion of the dominant brown macroalgae (*Sargassum flavicans* & *Ecklonia radiata*), and the continual re-suspension of damaged algal fragments (commonly referred to as 'cornflakes') can dramatically reduce water clarity and visibility.

Palm Beach Reef

Palm Beach Reef is an extensive rocky reef, lying between the mouths of Tallebudgera Creek to the north and Currumbin Creek to the south. The inner section of the reef is approximately 400 metres off the beach, and lies in 9 to 10 metres of water. Palm Beach Reef lies in slightly deeper water, and is characterised by much greater topographical relief than Kirra Reef.

Sessile invertebrates, including sponges, corals and ascidians, dominate the benthic assemblage of Palm Beach Reef (Edwards & Smith 2005; frc environmental 2005; Reef Check 2010). The cover of ascidians, sponges and other invertebrates at Palm Beach Reef has historically been comparable to the outer outcrops of Kirra Reef. However, the cover of macroalgae has consistently been lower at Palm Beach Reef than at Kirra Reef. The proximity of Palm Beach Reef to the two creek mouths, and the absence of strong currents in the area, typically results in a high level of turbidity. A factor that together with greater depth, likely contributes to the low cover of macroalgae.

2 Methods

The methods adopted in the February 2010 monitoring event were those developed for the Stage I study conducted in 1995, and used in the 1996, 2001, 2003, 2004 and 2005 monitoring events (following the requirements of the ToR). Data was collected from Kirra Reef, and from Palm Beach Reef to the north, which is adopted as a control location in the experimental design (Figure 2.1).

The data obtained from this monitoring event has been analysed to assess the nature and magnitude of change in floral community structure, and the abundance of selected faunal taxa, that may be attributable to the impacts of the sand bypass project.

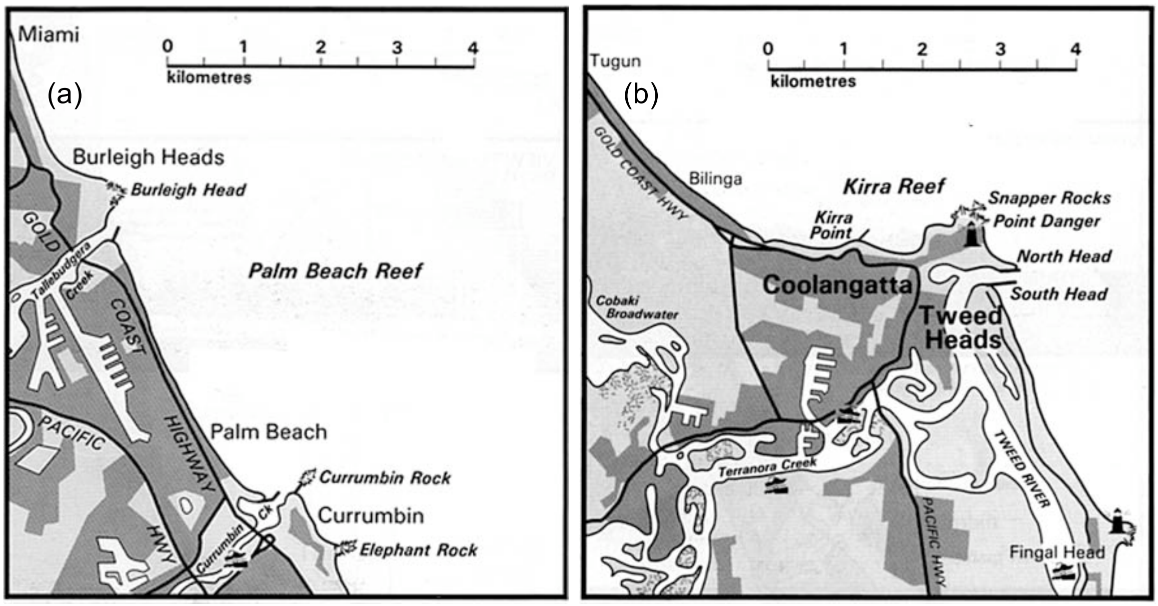


Figure 2.1 Location maps of (a) Palm Beach Reef and (b) Kirra Reef.

2.1 Benthic Flora and Macro-invertebrates

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)(Figure 2.3). 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 (Figure 2.3). 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 (note that this site was not surveyed in February 2010). Consequently, four sites (KRO3, KRN1, KRN2 and KRN3) were surveyed in February 2005. In addition to the sites at Kirra Reef, three control sites have also been surveyed in the shallow section of Palm Beach Reef on each monitoring event. Palm Beach Reef is located approximately 9 km to the north of Kirra Reef (Figure 2.1).

In February 2010 (this monitoring event), 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. Three control sites were also surveyed at Palm Beach Reef.

Figure 2.2

Diver surveying benthic assemblages at Kirra Reef in February 2010.

At each site, benthic communities were surveyed with fifteen 0.25 m^2 replicate quadrats, and the relative cover of benthic macroalgae, turf algae, sponges, ascidians, hard corals and soft corals were recorded. The number of large ascidians (*Pyura* sp.), crinoids (feather stars) and hard coral colonies was also noted. These are the same taxonomic groups recorded in the 1995, 1996, 2001, 2003, 2004 and 2005 monitoring events. The dominant species of macroalgae were also recorded, and notes were made on the apparent condition of each taxonomic group.

Legend

Reef Survey Sites

0 100 200

Metres

N

frc environmental deep thinking. science.	Kirra Reef Ecological Monitoring 2010
	Figure 2.3 Location of Kirra Reef monitoring sites in February 2010.
	NSW Department of Lands — March 2010

2.2 Fishes

The richness and relative abundance of fish species 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 fish assemblage data and assessing fish-habitat linkages (Murphy & Jenkins 2010). These approaches were employed in the 1995, 1996, 2001, 2003, 2004 and 2005 monitoring events. Continuity in the make up of the dive team over the years of monitoring has ensured a high degree of accuracy and precision in fish identification, and in estimates of relative abundance.

2.3 Data Analysis

Due to the small area of the existing emergent outcrops at Kirra Reef, it is no longer appropriate to examine 'outer' and 'inner' reef locations separately, as all remaining reef is likely to be subject to a similar level of impact from wave action and sediment deposition. Furthermore, there is no longer sufficient reef remaining at Kirra Reef east to enable the eastern and western sites to be analysed separately. Therefore, the four sites sampled in February 2010 (i.e. KRO3, KRO1, KRN1 and KRN2) were considered to be random, nested sites within the greater 'Kirra Reef' location. Consequently, all analyses of temporal change at Kirra Reef, and spatial differences between Kirra Reef and Palm Beach Reef, will be restricted to data collected from outer (Kirra) reef sites. The rocks protruding from mobile sands in the vicinity of site KRI2 supported no benthic flora or fauna: therefore this location was omitted from analysis.

Two-factor nested analyses of variance (ANOVA) tests were used to test for differences in broad community structure between locations (i.e. Palm Beach Reef and Kirra Reef) and monitoring events. Location (i.e. reef) and time (i.e. monitoring event) were set as fixed factors in analyses; site was set as random factor and nested within both location and time. Separate analyses were performed on the cover of each benthic taxa (i.e macroalgae, turf algae, corals, sponges and ascidians), and the number of crinoids and *Pyura* colonies. Percent cover data was converted to proportion data, and square-root transformed to achieve homogeneity of variance; the abundance of crinoids and *Pyura* colonies was log-transformed ($\ln(x + 1)$). Where an ANOVA indicated there were significant differences among means, Tukey's post-hoc tests were used to separate and group means from the analysis of variance tests (Zar 1996).

3 Results

A greater area of Kirra Reef was uncovered in February 2010, than on the immediate previous surveys (i.e. 2004 and 2005). The rocky outcrops at site KRO1 (at the eastern end of Kirra Reef) appeared to have been partially covered with sand in recent times. They supported a pronounced line of demarcation (approx. 60 to 80 cm above the seafloor) between a macroalgae dominated assemblage above, and a relatively bare rock surface below (Figure 3.1). In contrast, rocky outcrops at sites KRO3, KRN1 & KRN2 supported a high biotic coverage and showed no signs of recent burial. All control sites at Palm Beach Reef remained exposed.

On the day of sampling the surf zone at high tide was located approximately 150 m inshore of the Outer Western Reef.

Figure 3.1

Rocks at Kirra Reef east (site KRO1) exhibited signs of recent burial. Note the demarcation between macroalgae above, and bare rock below (February 2010).

The following results describe the benthic assemblage of Kirra Reef using data from four sites surveyed on outer Kirra Reef outcrops. Previous reports have described the differences between inner and outer sites at Kirra Reef (e.g. frc environmental 2001, 2003).

Benthic assemblage data from the February 2010 monitoring event is provided in Appendix A. Fish relative abundance data from all monitoring events is provided in Appendix B.

3.1 Benthic Flora

Macroalgae

At Kirra Reef, *Sargassum* sp. has generally been the dominant alga, and in sampling events prior to May 2003 it formed dense carpets over the rocky substrate (Figure 3.2). In May 2003 and March 2004 there was less *Sargassum* and a higher abundance of the kelp *Ecklonia radiata*. In 2005 and 2010, *Sargassum* was again considered to be the dominant macroalgal species at Kirra Reef. Other species present include, *Dictyopteris arostichoides, Dilophus intermedius, Zonaria* sp., *Laurencia brongniartic, Amphiroa anceps, Caulerpa lentillifera* and *Halimeda discoidea*. Palm Beach Reef typically supports a much lower cover of macroalgae then Kirra Reef. This reflects that Palm Beach Reef is deeper and generally experiences higher turbidity, and therefore greater light attenuation, then Kirra Reef. *Amphiroa anceps, Laurencia brongniartic, Chlorodesmis major* and *Zonaria* sp. have been recorded at Palm Beach Reef.

Figure 3.2

Sargassum dominated the macroalgal communities of Kirra Reef in February 2010.

Overall, the cover of macroalgae at Kirra Reef has continued to decline from a peak in January 2001 (Figure 3.3), and in February 2010 was the lowest recorded since monitoring began in April 1995 (Figure 3.3, Table 3.3, Tukey's HSD, α = 0.05). Whilst macroalgal cover at Palm Beach Reef has been consistently less than at Kirra Reef, a similar trend of decline in cover has been recorded at Palm Beach Reef since January 2001 (Table 3.3, Table 3.1). However, the cover of macroalgae at Kirra Reef has varied considerably over time, whereas cover at Palm Beach Reef has not differed between years (with the exception of January 2001)(Figure 3.3, Table 3.1, Tukey's HSD tests, α = 0.05). The variable cover of macroalgae at Kirra Reef is likely to be an indicator of ecological stress associated with a less stable immediate environment; stressed assemblages typically experience lower biological stability and exhibit higher levels of temporal and spatial variability (Warwick & Clarke 1993; Chapman et al 1995). In February 2010, there was no difference in macroalgae cover between monitoring sites at Kirra Reef, or between sites at Palm Beach Reef (Tukey's HSD tests, α = 0.05).

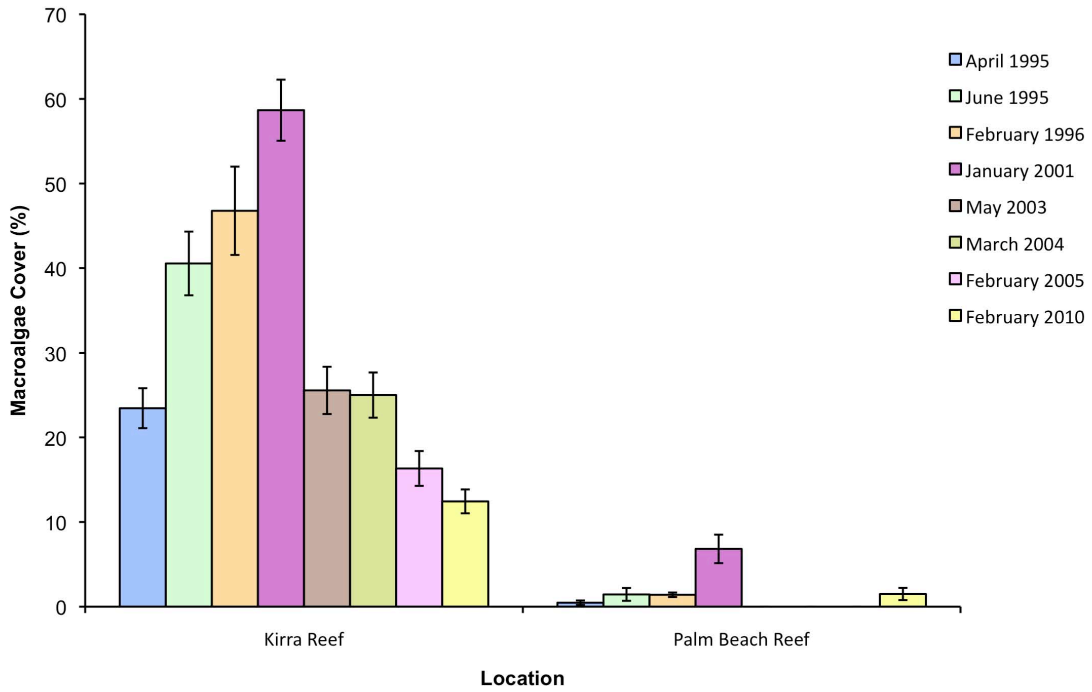


Figure 3.3 Mean cover of **macroalgae** (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

Table 3.1 Results of two-way nested ANOVA of macroalgae cover for differences between monitoring events (i.e. years) and locations (i.e. reefs). Numbers in **bold** represent a significant result at the p <0.005 level.

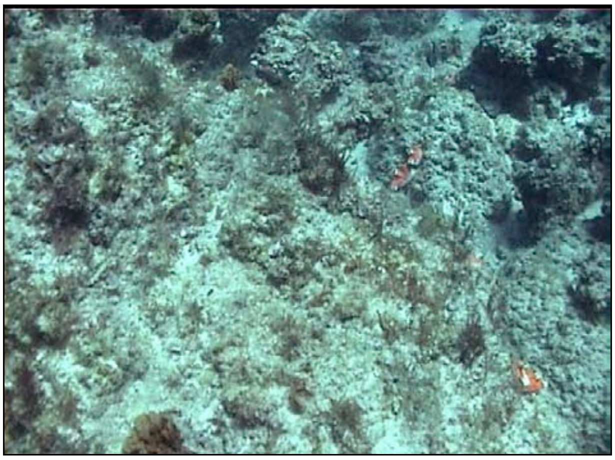
	Effect	Df effect	MS effect	F	p-level
Event	Fixed	7	21.207	5.026	**0.001**
Location	Fixed	1	1224.301	289.860	**0.000**
Site (event*location)	Random	35	4.250	6.212	**0.000**
Error		631	0.684		

Turf Algae

The cover of turf algae (Figure 3.4) at both Kirra Reef and Palm Beach Reef has varied considerably between monitoring events. In February 2010, turf algae cover at Kirra Reef was greater than that recorded in April 1995, February 1996 and January 2001, but lower than the peak cover reported in surveys from March 2004 (Figure 3.5, Table 3.2, Tukey's HSD tests, α = 0.05). In contrast, turf cover at Palm Beach Reef in February 2010, was the lowest recorded since the commencement of monitoring; cover was significantly lower than that recorded in June 1995, February 1996 and February 2005 (Figure 3.5, Tukey's HSD tests, α = 0.05).

Figure 3.4

Areas of Kirra Reef support little macroalgae but have a moderate cover of turf algae (February 2010).



Turf algae cover is typically lower at Kirra Reef then at Palm Beach Reef, however turf cover did not differ between Kirra Reef and Palm Beach Reef, or among sites at each reef in February 2010 (Figure 3.5, Tukey's HSD tests, α = 0.05).

Table 3.2 Results of two-way nested ANOVA of turf algae cover for differences between monitoring events (i.e. years) and locations (i.e. reefs). Numbers in **bold** represent a significant result at the p <0.005 level.

	Effect	Df effect	MS effect	F	p-level
Event	Fixed	7	22.005	1.725	0.135
Location	Fixed	1	395.666	30.985	**0.000**
Site (event*location)	Random	35	12.859	15.630	**0.000**
Error		631	0.823		

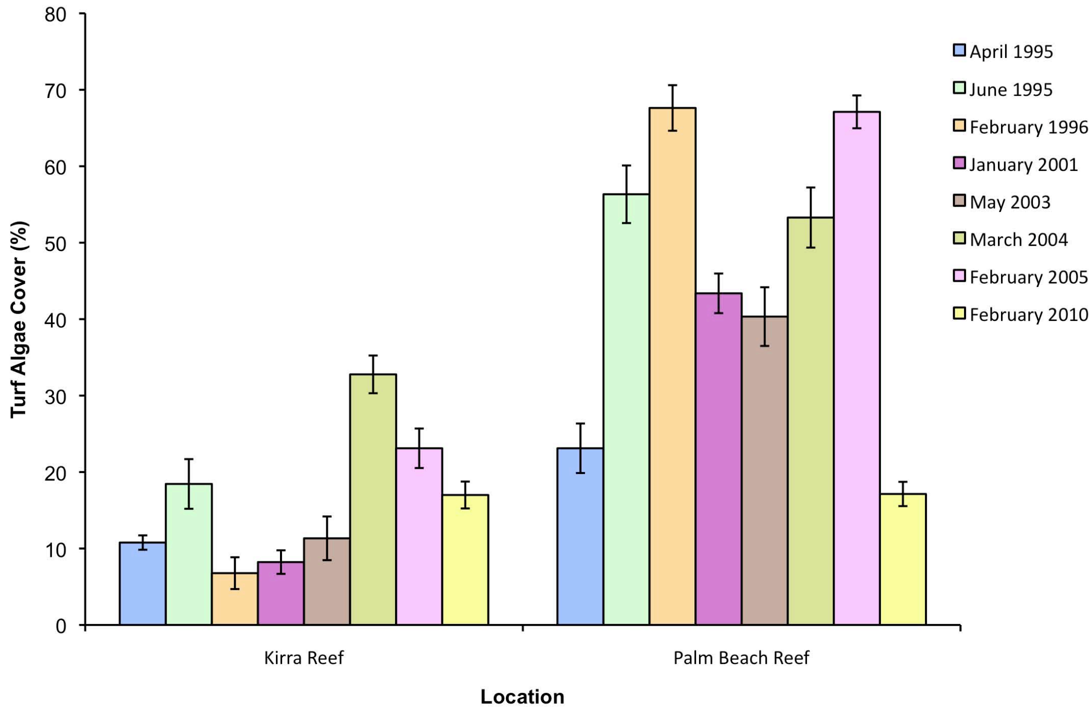


Figure 3.5 Mean cover of turf algae (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

3.2 Benthic Macro-Invertebrates

Sponges

The cover of sponges at Kirra Reef has declined significantly since peaking in March 2004, and is currently comparable to that recorded during baseline studies (i.e. April & June 1995) (Figure 3.7, Tukey's HSD tests, α = 0.05). In contrast, sponge cover at Palm Beach Reef has remained at a level that is significantly above that recorded during baseline studies (April 1995) (Figure 3.7, Table 3.3, Tukey's HSD tests, α = 0.05). As in 2005, the cover of sponge at Kirra Reef in February 2010 was lower than that recorded at Palm Beach Reef. There were no differences in sponge cover between sites within each location during the present monitoring event (Tukey's HSD tests, α = 0.05).

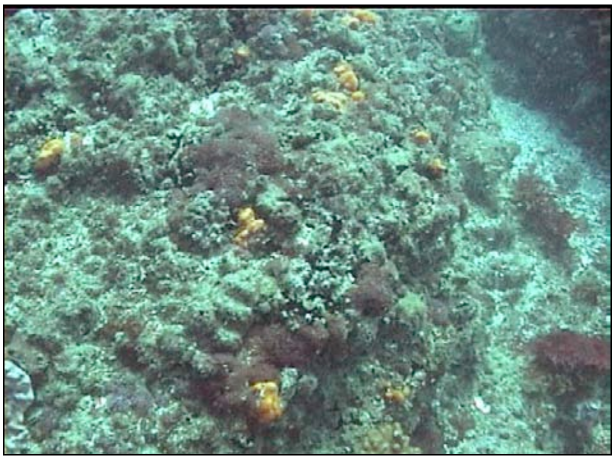


Figure 3.6

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

Sponge cover has varied more over time (i.e. between monitoring events) at Kirra Reef then at Palm Beach Reef. As for macroalgae cover, this variance is likely to be an indicator of greater ecological stress at Kirra Reef (refer, Warwick & Clarke 1993; Chapman et al 1995).

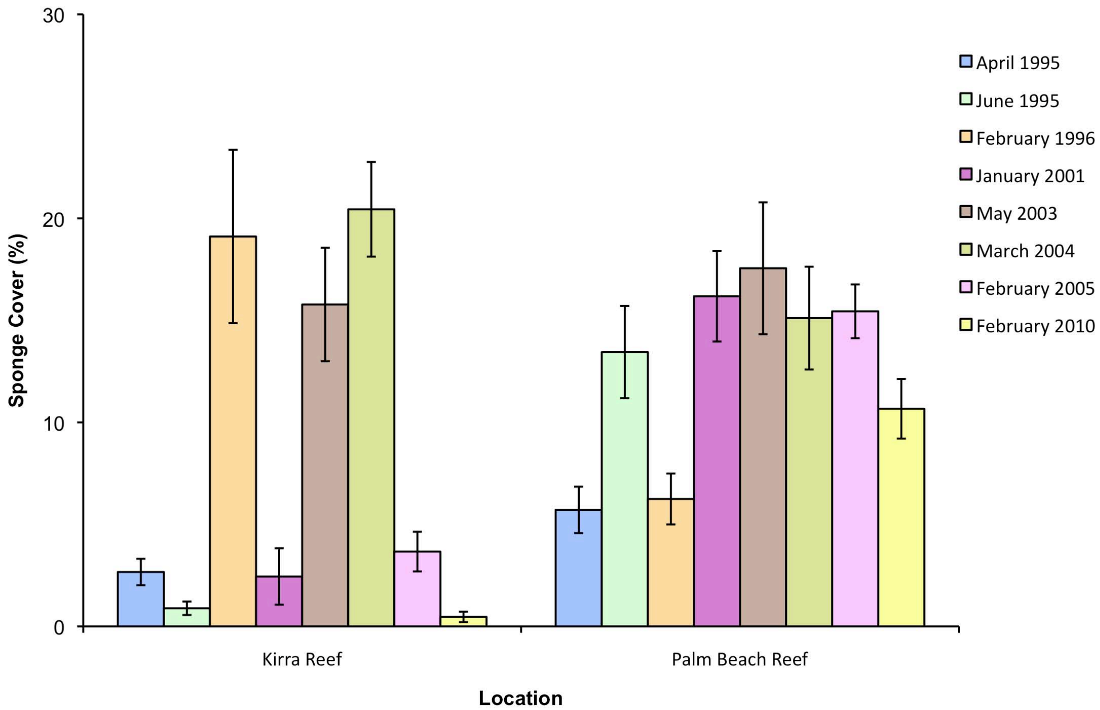


Figure 3.7 Mean cover of **sponges** (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

Table 3.3 Results of two-way nested ANOVA of sponge cover for differences between monitoring events (i.e. years) and locations (i.e. reefs). Numbers in **bold** represent a significant result at the p <0.005 level.

	Effect	Df effect	MS effect	F	p-level
Event	Fixed	7	10.667	1.337	0.263
Location	Fixed	1	163.490	20.469	**0.000**
Site (event*location)	Random	35	8.038	6.431	**0.000**
Error		631	1.250		

Ascidians

The abundance of ascidians (*Pyura* sp.) at both Kirra Reef and Palm Beach Reef has increased consistently since May 2003 (Figure 3.9, Table 3.4, Tukey's HSD tests, α = 0.05). However in February 2010, ascidian abundance at both reefs still remained lower than that reported during the baseline studies in 1995, and the survey in 2001 (Figure 3.9, Table 3.4, Tukey's HSD tests, α = 0.05). Both reefs have experienced significant inter-annual variation in the number of *Pyura* sp. over the period of monitoring. The number of *Pyura* sp. did not vary between reefs, or among sites within reefs, in February 2010 (Figure 3.9, Tukey's HSD tests, α = 0.05).

Figure 3.8

Ascidians (*Pyura* sp.) were again abundant at Kirra Reef in February 2010.

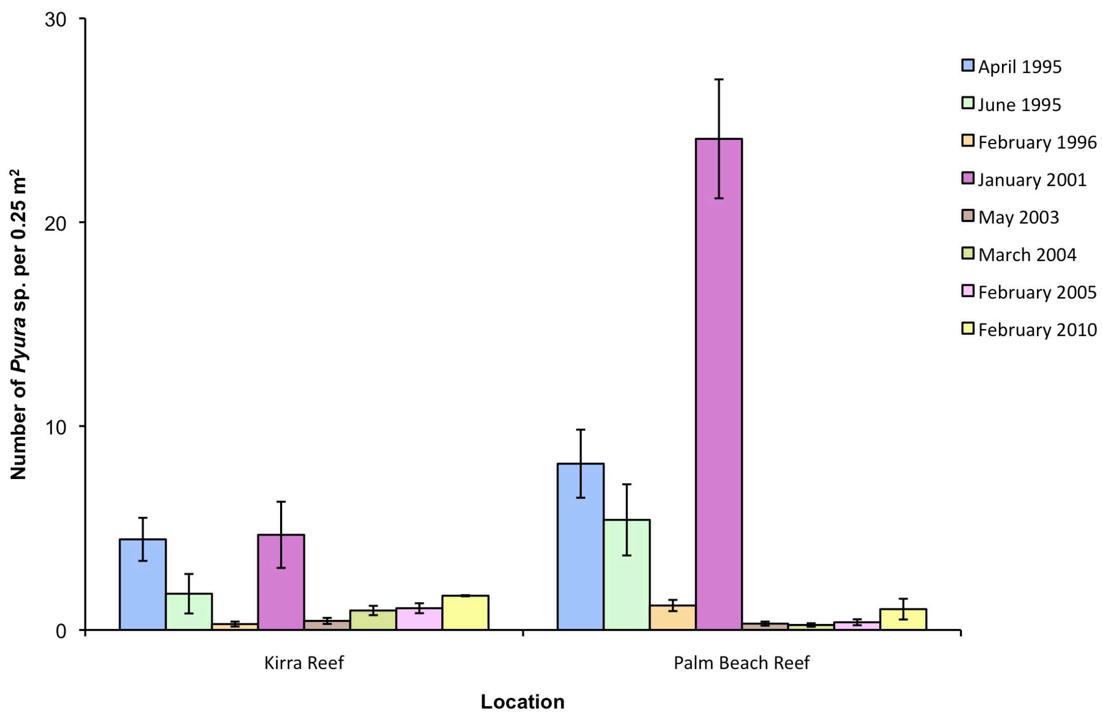


Figure 3.9 Mean density of **ascidians** (*Pyura* sp.) per 0.25 m^2 (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

Hard Corals

The cover of hard coral is typically quite low at both Kirra Reef and Palm Beach Reef (i.e. < 5%), however very little hard coral was recorded at Kirra Reef in February 2010 (Figure 3.10). Hard coral cover at Kirra Reef is very patchy, and therefore, has never been significantly greater than zero (Figure 3.10, Table 3.4, Tukey's HSD tests, α = 0.05). Consequently, the low cover of hard coral at Kirra Reef in the most recent survey cannot be interpreted as a decline in cover over the period of monitoring.

Overall, the cover of hard coral at Kirra Reef is generally lower than that at Palm Beach Reef, and the presence of occasional large colonies at Palm Beach Reef is likely responsible for the perceived high inter-annual variation at this location (Figure 3.10).

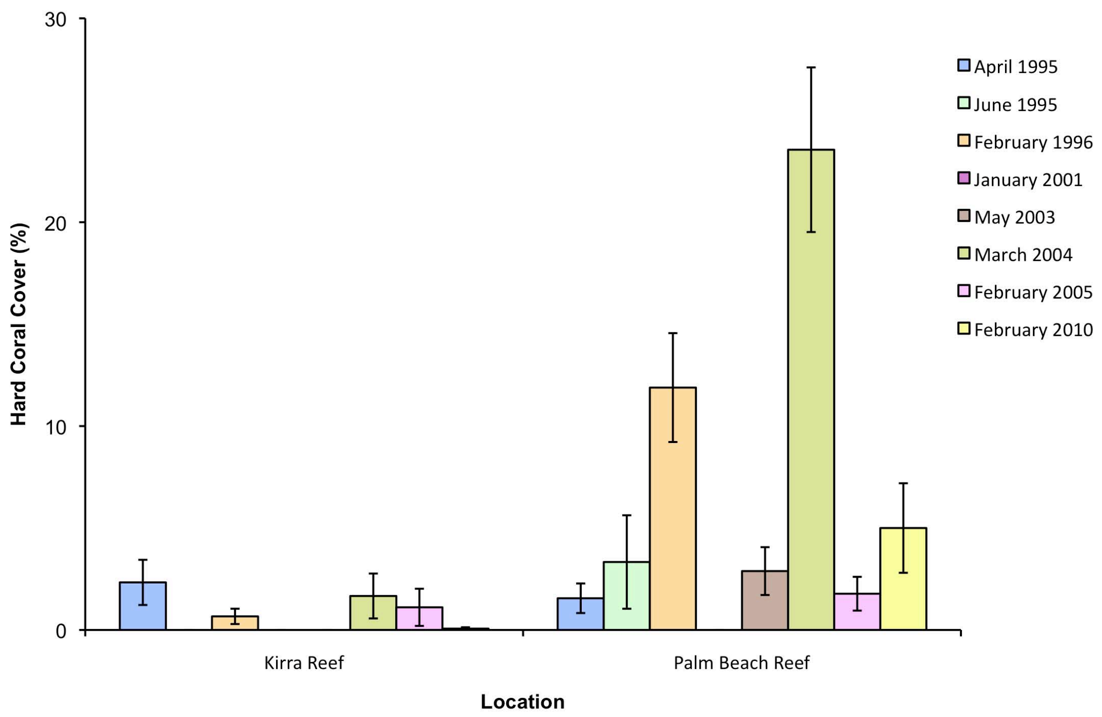


Figure 3.10 Mean cover of **hard corals** (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

Table 3.4 Results of two-way nested ANOVA of hard coral cover for differences between monitoring events (i.e. years) and locations (i.e. reefs). Numbers in **bold** represent a significant result at the p <0.005 level.

	Effect	Df effect	MS effect	F	p-level
Event	Fixed	7	21.809	8.482	**0.000**
Location	Fixed	1	53.283	20.705	**0.000**
Site (event*location)	Random	35	2.587	3.579	**0.000**
Error		631	0.723		

Soft Corals

The cover of soft coral has declined at Kirra Reef, but not at Palm Beach Reef, since May 2003 (Figure 3.11, Table 3.5, Tukey's HSD tests, α = 0.05). No soft coral was recorded at Kirra Reef in February 2010 (Figure 3.11).

Palm Beach Reef typically supports a greater cover of soft coral than Kirra Reef; it also appears to experience greater temporal variation in soft coral cover (Figure 3.11, Table 3.5, Tukey's HSD tests, α = 0.05). However, the high inter-annual variation at Palm Beach Reef likely reflects the patchy distribution of soft corals at this location and the occasional survey of large colonies.

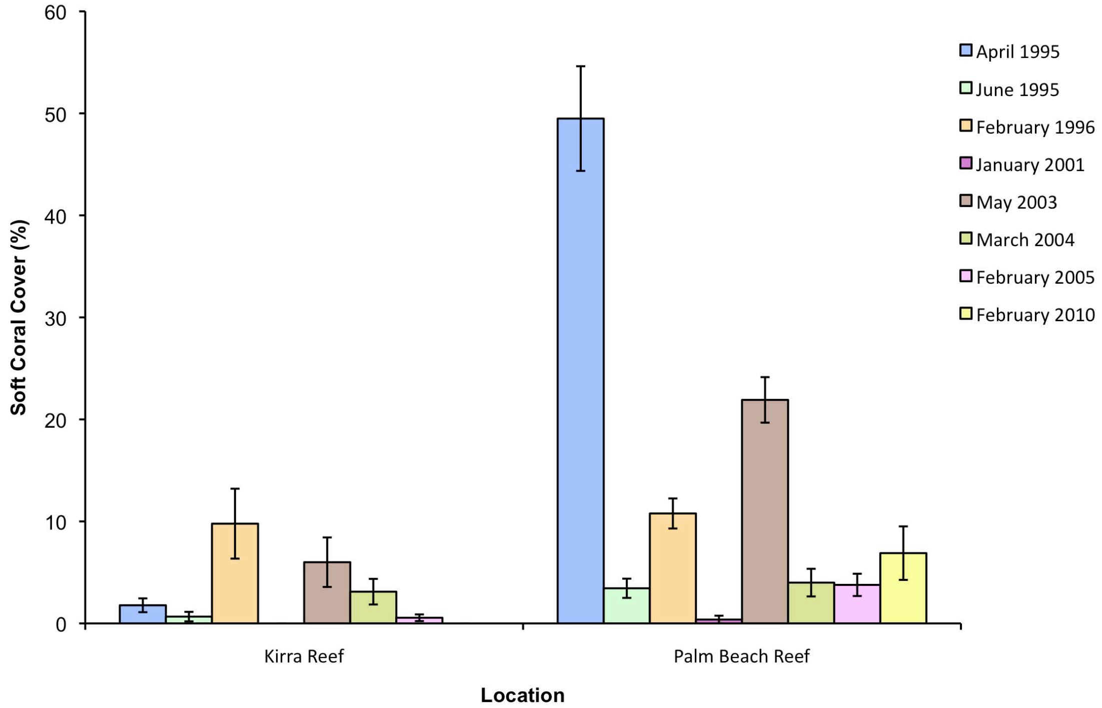


Figure 3.11 Mean cover of **soft corals** (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

Table 3.5 Results of two-way nested ANOVA of soft coral cover for differences between monitoring events (i.e. years) and locations (i.e. reefs). Numbers in **bold** represent a significant result at the p <0.005 level.

	Effect	Df effect	MS effect	F	p-level
Event	Fixed	7	38.968	4.835	**0.000**
Location	Fixed	1	214.130	26.541	**0.000**
Site (event*location)	Random	35	8.122	9.995	**0.000**
Error		631	0.813		

Crinoids

The abundance of crinoids at Kirra Reef has declined considerably since February 2005 (Figure 3.13, Table 3.6, Tukey's HSD tests, $\alpha = 0.05$). However, crinoid abundance in February 2010 still remained above the low-point of zero reported in January 2001 (Figure 3.13). At Palm Beach Reef, crinoid numbers have shown a trend of steady decline since monitoring began in April 1995 (Figure 3.13, Table 3.6, Tukey's HSD tests, $\alpha = 0.05$).

Figure 3.12

Crinoids (feather stars) were relatively rare at Kirra Reef in February 2010.

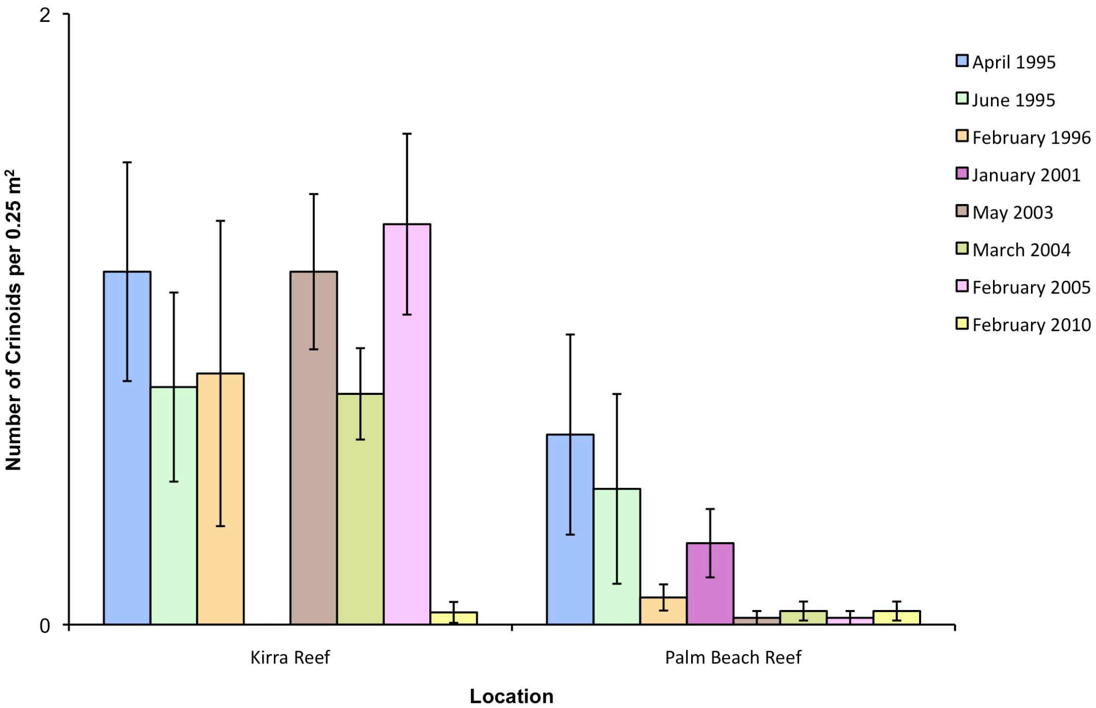


Figure 3.13 Mean number of **crinoids** per 0.25 m^2 (± 1 SE) within monitored quadrats at Kirra Reef and Palm Beach Reef on each monitoring event.

Table 3.6 Results of two-way nested ANOVA of Crinoid density / 0.25 m^2 for differences between monitoring events (i.e. years) and locations (i.e. reefs). Numbers in **bold** represent a significant result at the p <0.005 level.

	Effect	Df effect	MS effect	F	p-level
Event	Fixed	7	1.446	1.728	0.134
Location	Fixed	1	0.422	0.503	0.482
Site (event*location)	Random	35	0.843	5.172	**0.000**
Error		631	0.696		

3.3 Fishes

The number of fish species recorded at Kirra Reef in February 2010 was within the range reported in previous monitoring events (Figure 3.14), however, this was considerably lower than that recorded on the last monitoring event (i.e. February 2005). Fish species richness has fluctuated more between monitoring events at Kirra Reef than at Palm Beach Reef. In February 2010, fish species richness was lower at Kirra Reef than Palm Beach Reef (Figure 3.14).

The fish assemblage of Kirra Reef in February 2010 was comprised of species from all trophic levels, including detritivores, planktivores, herbivores and carnivores (Appendix B). As in previous monitoring events, the assemblage was dominated by herbivores and planktivores. Yellowtail, three-bar porcupine fish, Australian mado, stripeys, sweep and wobbegong sharks were very abundant and remained dominant components of the fish community (Figure 3.15 & Figure 3.16, Appendix B). Sawtail surgeons, silver trevally, blue-spotted maskrays, round batfish and leaping bonito were recorded at Kirra Reef for the first time in February 2010 (Figure 3.17 & Figure 3.18, Appendix B). Though several species that had previously been common were not present, these included oldwife, moray eels, damselfish and moon wrasse (Appendix B).

Moon wrasse, neon damsels, sergeant majors, clownfish, large-scale palma, Australian mado, rabbitfish and yellowtail were abundant at Palm Beach in February 2010. Yellowtail have not been recorded at Palm Beach Reef since May 2003. The complete list of species recorded from this and previous monitoring events is presented in Appendix B.

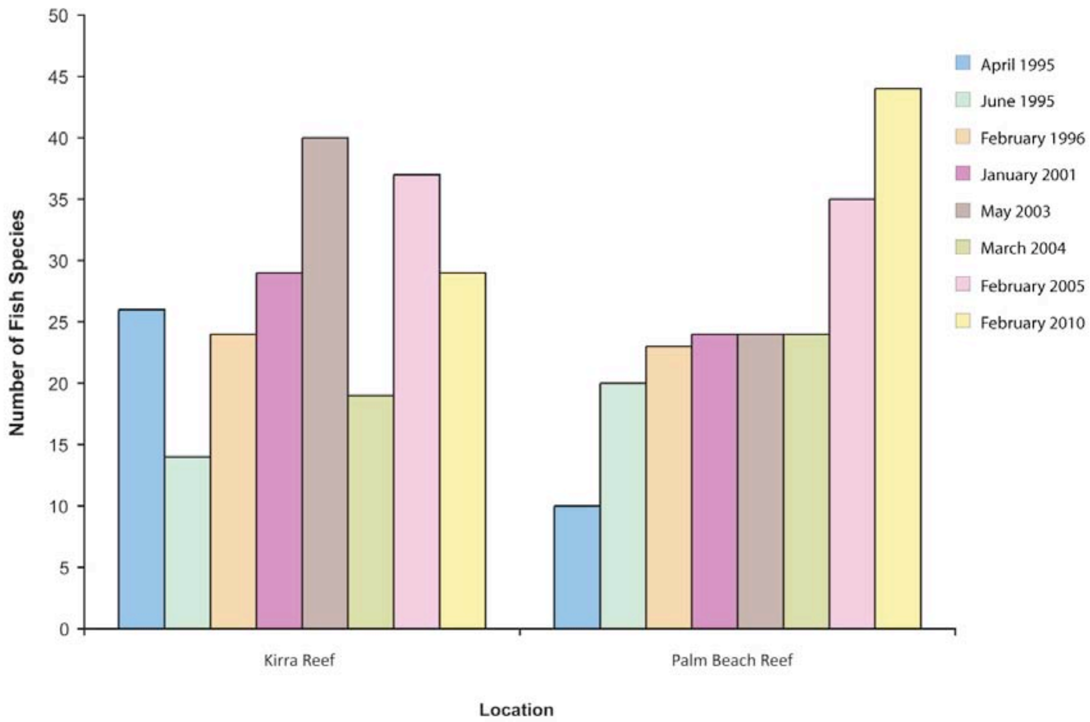


Figure 3.14 Number of **fish** species recorded at Kirra Reef and Palm Beach Reef on each monitoring event.

Figure 3.15

Yellowtail and sweep were abundant at Kirra Reef in February 2010.

Figure 3.16

Three-bar porcupine fish were again common at Kirra Reef in February 2010.

Figure 3.17

Leaping bonito were recorded at Kirra Reef for the first time in February 2010.

Figure 3.18

Blue-spot maskrays were abundant over the sands adjacent to Kirra Reef in February 2010.

4 Discussion

4.1 Changes to the Ecological Condition of Kirra Reef

The greatest ecological change to the condition of Kirra Reef has been the loss of large areas of hard substrate that supported benthic flora and fauna, as a consequence of burial of the reef by sand. However, there have also been subtle changes to the flora and fauna of the remaining reef, which likely result from an interaction between the reduced depth of seabed surrounding the reef, and subsequent enhanced levels of physical disturbance, abrasion and sedimentation associated with greater wave action. The area of reef emergent from the sand has increased prior to the most recent monitoring event (February 2010), and the rocky outcrops that are currently exposed support a rich benthic assemblage. However, this assemblage exhibits signs of ongoing stress and physical disturbance, including a declining trend in the cover of macroalgae and soft coral, and enhanced temporal variability (i.e. lower stability) of sessile benthic invertebrate and fish assemblages, relative to those at Palm Beach Reef.

Benthic Flora

On the emergent outcrops, the cover of macroalgae has declined from a peak in January 2001, and is currently the lowest recorded since monitoring began in April 1995. A decline in macroalgae has also been recorded at the monitoring program's comparative location at Palm Beach over the same period, although this decline has not been as great in magnitude. Furthermore, the cover of macroalgae has varied more over time at Kirra Reef than at Palm Beach Reef. The variable cover of macroalgae at Kirra Reef may be an indicator of ecological stress, as stressed assemblages typically experience lower biological stability and exhibit higher levels of temporal and spatial variability (Warwick & Clarke 1993; Chapman et al 1995). It is considered likely that increased wave action at Kirra Reef has contributed to the decline in macroalgae cover. In our 2005 report (frc environmental 2005), we predicted that: "unless the bed level adjacent to the reef drops, there would be a permanent shift in the dominant macroalgal taxa". Despite the higher bed level and reduced extent of Kirra Reef in recent years, this does not yet appear to have taken place. This finding suggests that the macroalgal assemblage at Kirra Reef may be more resilient than anticipated, however, it is likely that further chronic physical disturbance (i.e. wave action, abrasion and sedimentation) will to continue to reduce macroalgae cover and decrease the stability of this assemblage. Indeed, increased sediment deposition has been shown to reduce algal diversity (Hatcher et al. 1989), abundance, recruitment, growth, survival and seasonal regeneration (Umar et al. 1998, Cheshire et al. 1999). In addition to the decline in cover, there has also been an apparent loss of vertical structure in the macroalgal communities of Kirra Reef. Increased suspended solids levels can reduce the vertical structure of algal communities, from three dimensional to a more two dimensional environment (Saiz-Salinas & Urkaiga-Alberdi 1999). This results from a reduction in the average daily amount of light available to the macroalgae for photosynthesis, and subsequent impacts upon productivity and growth. The decrease in the extent of Kirra Reef, may have also concentrated fish grazing pressure over the remaining reef. Such increases in grazing pressure from fish and mobile invertebrates have been shown to contribute to a reduction in algal abundance (Jompa & McCook 2002; McCook 1997). However given the intensity of physical disturbance experienced by Kirra Reef, the relative influence of grazing on macroalgae cover is likely to be low.

The cover of turf algae at both Kirra Reef and Palm Beach Reef has varied considerably over time. Turf cover has typically been relatively low at Kirra Reef and high at Palm Beach Reef, however in February 2010, cover was quite consistent between the two reefs. Patterns in the cover of turf algae are believed to follow macroalgae dynamics, and subsequent levels of substrate and light availability. This is because turf algae are better able to withstand sediment deposition, and can more rapidly re-colonise available substrate, than canopy-forming macroalgae (Airoldi 1998, Irving & Connell 2002). However, the relationship between algal dynamics, physical disturbance, water quality and herbivore grazing activity is complex, and turf cover can exhibit extreme temporal variability as a consequence of the spatial interaction of these top-down and bottom-up processes (e.g. Russ 2003; Mumby 2006; Bellwood et al 2006; Hughes et al 2007; Albert et al 2008; Hoey & Bellwood 2008; Mumby 2009).

Benthic Macro-Invertebrates

The cover of sponges at Kirra Reef has declined in recent years, but is currently comparable to that recorded during baseline studies. The abundance of crinoids has also declined, and is now considerably below the level reported from baseline surveys. In contrast, the abundance of ascidians (*Pyura* sp) has increased, but still remained lower than that reported during the baseline studies. The cover of hard and soft coral at Kirra Reef is both very low and very patchy, and therefore, cannot be said to have increased or decreased over time.

An increase in suspended solids may benefit some sessile, filter feeding invertebrates, by increasing the density of available food particles; and negatively impact other filter feeders, by clogging filter mechanisms (Nybakken 1993). It is likely that invertebrates that are less tolerant of physical buffering and elevated suspended solids (e.g. sponges and corals) would be impacted more severely than those that are more resilient (e.g. armoured ascidians, such as *Pyura* sp.). This corresponds with the patterns of change that have been observed in the benthic assemblages of Kirra Reef. Increased water velocities may also contribute to conditions that favour some filter-feeding invertebrates. Decreased water depth around the reef and increased proximity to the surf zone are likely to increase water velocity and turbulence around the remaining reef habitat, reducing boundary layer effects. Boundary layers act as a buffer to water movement, and reducing these can lead to increased availability of water-borne food items to filter feeders attached to the reef (Holland et al 1986, cited in Trager et al 1990). Increases in sedimentation rates can also affect the settlement, growth rates and survival of hard corals (Dodge & Vaisnys 1977, Rogers 1990). The deposition of sand and any increase in turbidity around Kirra Reef are likely to negatively impact hard coral cover on Kirra Reef. However, the relatively low initial abundance and slow rates of growth are likely to contribute to a lag in detecting any such impacts.

The cover of sponges has varied more over time at Kirra Reef than at Palm Beach Reef. As for macroalgae, this enhanced variability in population abundance is likely to be indicative of ecological stress, and has been observed in many communities following various forms of perturbation (Warwick & Clarke 1993). Survey monitoring has shown that sand volumes have reduced in the Kirra Beach and nearshore area over recent years, and this reduction is expected to continue as the sand build-up disperses northward of Kirra (TRESBP 2010). Ongoing changes in the physical extent of reef outcrops is likely to result in variable diversity and abundance of benthic flora and fauna and fish until a new equilibrium is reached. As the sand disperses, periods of high physical disturbance (i.e. wave action, abrasion and sedimentation) are expected to continue to reduce sponge cover and decrease the stability of the benthic invertebrate assemblage, with a lag in biological responses. However, once sand levels reach an equilibrium, benthic community structure is also expected to reach an equilibrium (although seasonal variations are still expected to occur in response to ambient conditions).

Fishes

The reduction in the area of exposed reef habitat at Kirra Reef has had a direct impact on the overall abundance of fish, however the reef continues to support a high diversity of reef fish, and pelagic (i.e. non-reef associated) fish. This indicates that Kirra Reef continues to provide valuable ecosystem services.

There is a high degree of inter-annual variability in the composition of the fish assemblage at Kirra Reef. This temporal variability is thought to be characteristic of stressed populations and has been observed in many assemblages following various forms of perturbation (see above, refer Chapman et al. 1995, Warwick & Clarke 1993). This inter-annual variability is likely to reflect temporal variability in the physical habitat provided by the reef complex, which may be a partial consequence of reef burial and re-exposure. Indeed, the diversity, quality and areal extent of fish habitat have been shown to be some of the most important factors influencing reef fish distribution, abundance, biomass and diversity (Bellwood & Hughes 2001; Friedlander et al. 2003). These changes in community dynamics are thought to reflect the greater availability of food and shelter, increased niche differentiation and lower intra-specific competition in structurally complex heterogeneous habitats. However, the fish community at Kirra Reef is also likely to be significantly affected by variation in local hydrodynamic processes. That is, the biomass of reef fish can decrease with exposure to waves and strong currents, and conversely abundance and diversity can increase following calm periods (e.g. Friedlander et al. 2003). Variation in local hydrodynamics may follow seasonal weather patterns or episodic storm events, however it is also likely to follow patterns of reef burial and re-exposure.

A continued reduction in the abundance, richness and diversity of fish at Kirra Reef would be expected if there are further decreases in habitat availability. However, given that the areal extent of the Reef has been greatly reduced in recent years, it is likely that the fish assemblage of Kirra Reef is somewhat more resilient than anticipated (see frc environmental 2005). That being said, several species that are dependent on the presence of reef habitat (i.e. oldwife, moray eels, damselfish and moon wrasse), and that had previously been common at Kirra Reef, were not encountered in February 2010. Logically, this suggests that periods of chronic reef burial may reduce the overall diversity of reef-associated species. However, the overall condition of the fish assemblage at Kirra Reef is likely to be reflective of the complex interaction between physical disturbance (i.e. sedimentation, wave action, and abrasion), food availability and competition, and local weather and sea conditions. Fish abundance and diversity are likely to be lowest following periods of severe weather, which create unfavourable conditions for many species, and may further exacerbate the affects of sedimentation.

4.2 Impacts of the Sand Bypassing System on Kirra Reef

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

- *Tweed River Entrance Sand Bypassing Project Permanent Bypassing System Environmental Impact Statement / Impact Assessment Study*, prepared by Hyder Consulting, Paterson Britton & Partners Pty Ltd and WBM Oceanics Australia Joint Venture in June 1997;

- *Impact Assessment Review Report for Tweed River Entrance Sand Bypassing Project Permanent Bypassing System*, prepared by the Queensland Department of Environment in March 1998; and
- *Report on Historic Changes at Kirra Beach*, prepared by P.K. Boswood and R. J. Murray of the then Queensland Department of Environment in March 1997.

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

The current extent of Kirra Reef, and that present throughout much of this decade, is quite different to that of the late 1980s / early 1990s. In February 2010, the areal extent of Kirra Reef approximated that encountered on the 2004 and 2005 monitoring events. When this is compared with the historical extent of the reef, as presented in the 'Report on Historic Changes at Kirra Beach', it is apparent that the current extent of the reef more closely approximates that recorded in 1930 and 1935. That is, as in 2005, the current extent of Kirra Reef is broadly in accordance with predictions made in the EIS. The burial and subsequent re-exposure of large sections of Kirra Reef between the February 2005 and 2010 monitoring events, together with recent surveyed trending of reduced sand volumes at Kirra, suggests that the rugosity and extent of the reef may have not have reached a physical equilibrium. The continued decline, and inherent variability, of floral and faunal assemblages over this period also indicates that the reef may not yet have achieved ecological stability. Ongoing monitoring of the physical and ecological dynamics of Kirra Reef will be required to determine the magnitude of variation in seabed height, benthic cover and biodiversity that will characterise the reef complex in the longer-term.

4.3 Impacts of Storms & Seasonality on Kirra Reef

The benthic flora and fauna assemblages of Kirra Reef are likely to be highly susceptible to the influence of storms, and associated wave action. This is because the currently exposed reef (i.e. the rocky substrate available for colonisation) is surrounded by deposited sand that has both reduced the depth of water, and brought the surf zone seaward and closer to the reef. The availability of refuge habitats (from wave action, sedimentation etc.), such as crevices and overhangs has also been reduced, as many of these features have been either buried or filled. Given that more reef was exposed in February 2010 than over the period since the last monitoring event (i.e. February 2005), the inherent susceptibility of the reef is expected to be lower than it has been. However, the potential for storm driven disturbance is still expected to be higher than it was over the preceding six decades.

As in February 2005, it is likely that during storm events, when waves are larger, waves would break across Kirra Reef resulting in enhanced levels of physical disturbance, abrasion and sedimentation for benthic assemblages. Storms disturbance can cause local reductions in the species richness and abundance of coral (Woodley et al. 1981; Massel & Done 1993; Hughes 1994; Connell et al.1997) and alter fish assemblages indirectly through habitat modifications (Kaufman 1983; Jones & Syms 1998) or directly by increasing mortality (Lassig 1983). However, there is relatively little known about how increases in the frequency and intensity of storms may impact on the broader assemblage of sessile invertebrates on coral reefs (Moran & Reaka Kudla, 1991; Lugo et al., 2000). Though, increased storm severity is likely to affect organisms through wind-driven wave action, as breaking waves can impose significant forces on marine habitats (Denny 1983). The hydrodynamic forces produced by wave action are an important source of disturbance in intertidal habitats, inflicting damage through direct physical impact and abrasion (Paine & Levin 1981; Denny 1983; Shanks & Wright 1986; Bell & Denny 1994). Furthermore, the frequency and magnitude of storms can also determine the community structure of subtidal reefs (Ebeling et al. 1985).

The bio-diversity of sessile benthic invertebrate assemblages on coral reefs is particularly sensitive to physical disturbance. Regimes of elevated physical disturbance, resulting from enhanced exposure or susceptibility to storms and associated wave action (as on Kirra Reef), can lead to a decrease in the diversity of cryptic sessile invertebrate assemblages (Walker et al 2008). 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), any such disturbance-driven reductions in biodiversity have the potential to impact negatively on the future health and productivity of reef ecosystems (Walker et al. 2008). It is therefore likely, that storm and wave action (and associated sedimentation and abrasion) are now very important in shaping the benthic assemblages of Kirra Reef. The influence of this physical disturbance is likely manifest in the reduction of macroalgae and soft coral cover at Kirra Reef, and in the increased temporal variability (i.e. lower stability) of sessile benthic invertebrate and fish assemblages relative to Palm Beach Reef. That being said, Kirra Reef still affords habitat to a range of flora and fauna, and is therefore still likely to support many important marine ecological functions and ecosystem services in the Gold Coast region.

The impacts of increased wave action and sedimentation on the flora and fauna present at Kirra Reef are likely to be greatest during and immediately following storm conditions, however such 'pulse' impacts would be expected to have lasting influences on the composition and stability of benthic assemblages. Partitioning the influence of storm and wave driven disturbance from that of the operation of the TRESBP would require a much more powerful, and temporarily replicated, experimental design, to be implemented periodically to follow such poor weather events. However, it is quite likely that the restored coastal sand supply of the TRESBP interacts with storm driven disturbances and natural seasonal patterns of coastal zone transport, to result in seasonal variation in the extent to which Kirra Reef is covered by sand. That is, whilst the sand bypass relies on the net northerly transport of sand, it is likely that sand is also moved on-and offshore at Kirra Reef in response to seasonal weather and sea conditions.

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

The exposed reef at Kirra currently covers only a small area of that present in 1995 (i.e. prior to the operation of the TRESBP). Consequently, the greater part of hard substrate has been lost from the reef complex. Logically, this has dramatically reduced the abundance of benthic reefal assemblages, and is also likely to have substantially decreased habitat diversity across Kirra Reef.

Large volumes of sand were delivered by the TRESBP in the initial years of the operation, to clear the Tweed entrance bar and to restore the badly eroded southern Gold Coast beaches. A reduction in the level of sand delivery by the TRESBP since 2005 was anticipated to more closely mirror the natural movement of sand along the coast, and subsequently reduce the amount of sand covering Kirra Reef. However, due to persistent calm weather conditions, the natural northwards movement of sand has been slower than predicted, leading to the prolonged accumulation of excess sand volumes in the southern Gold Coast beaches. Survey monitoring has shown that excess sand volumes have dispersed from the Kirra area over recent years, and this is expected to continue under the current level of sand delivery by the TRESBP (TRESBP 2010). This reduction in sand volumes resulted in an increase in exposed reef area prior to this monitoring event (February 2010) and progressive uncovering of the reef is expected to continue as the excess sand continues to disperse. Given that the areal extent of the reef has been greatly reduced in recent years (i.e. prior to February 2010), it is likely that the floral and faunal assemblages of Kirra Reef are more resilient than anticipated.

Ongoing reductions in sand levels at Kirra Reef are likely to result in variable diversity and abundance of benthic flora and fauna and fish until a new equilibrium is reached. During times of increased physical disturbance, flora and fauna diversity is likely to decrease, although it is likely that in many respects, observable change in floral and faunal communities lag behind actual physical disturbance. However, sand levels at Kirra Reef are predicted to become similar to levels prior to construction of the Tweed River training walls in the future. Once this occurs, communities are expected to become similar to those recorded prior to construction of the training walls, in the absence of other (new) forms of disturbance. The timeframe for the 'recovery' of communities to this state is currently unknown, and will depend on ambient environmental conditions once sand levels stabilise. Ongoing monitoring will provide insight into the rate of 'recovery' of communities.

5 References

Airoldi, L. 1998, 'Role of disturbance, sediment stress, and substratum retention on spatial dominance in algal turf', *Ecology*, 79(8): 2759-2770.

Andrewartha, H. G. & Birch, L. C. 1954, *The Distribution and Abundance of Animals*, The University of Chicago Press, Chicago.

Albert S, Udy J, Tibbetts I. 2008 'Responses of algal communities to gradients in herbivore biomass and water quality in Marovo Lagoon, Solomon Islands.' *Coral Reefs* 27:73-82.

Bell, E. C. & Denny, M. W. 1994, 'Quantifying "wave exposure": a simple device for recording maximum velocity and results of its use at several field sites', *Journal of Experimental Marine Biology & Ecology,* 181: 9-29.

Bellwood D, Hughes T, Hoey A. 2006 'Sleeping functional group drives coral-reef recovery.' *Current Biology* 16:2434-2439.

Baronio, M. A. & Bucher, D. J, 2008, 'Artificial crevice habitats to assess the biodiversity of vagile macro-cryptofauna of subtidal rocky reefs'. *Marine and Freshwater Research*, 59: 661-670.

Cannon, L. R., Goeden, G. B. & Campbell, P. 1987, 'Community patterns revealed by trawling in the inter-reef regions of the Great Barrier Reef', *Memoirs of the Queensland Museum*, 25(1): 45-70.

Chapman, M. G., Underwood, A. J. & Skilleter, G. A. 1995, 'Variability at different spatial scales between a subtidal assemblage exposed to the discharge of sewage and two control assemblages' *Journal of Experimental Marine Biology and Ecology*, 189:103-122.

Cheshire, A. C., Miller, D. J. & Stewart, R. 1999, 'Effect of dispersed sediment plumes from beach sand replenishment dredging on recruitment of phaeophycean algae to rocky reefs in Gulf St. Vincent, South Australia' in *The Impact of Sand Dredging on Benthic Community Structure at the Port Stanvac Dredge Site* 2: 1-39. Department of Environmental Biology, University of Adelaide.

Connell, S. D. 2003, 'Negative effects overpower the positive of kelp to exclude invertebrates from the understorey community', *Oecologia*, 137: 97-103.

Connell JH, Hughes TP, Wallace CC, 1997 ‘A 30-year study of coral abundance, recruitment, and disturbance at several scales in space and time.’ *Ecological Monographs*, 67, 461–488.

Denny, M. W. 1983, ‘A simple device for recording the maximum force exerted on intertidal organisms’, *Limnology & Oceanography,* 28: 1269-1274.

Diaz MC, Rutzler K. 2001 ‘Sponges: an essential component of Caribbean coral reefs.’ *Bulletin of Marine Science*, 69, 535–546.

Dodge, R. E. & Vaisnys, J. R. 1977, 'Coral populations and growth patterns: responses to sedimentation and turbidity associated with dredging', *Journal of Marine Research*, 35: 715-730.

Done, T. J. 1982, 'Patterns in the distribution of coral communities across the central Great Barrier Reef', *Coral Reefs*, 1: 95-107.

Ebeling, A. W., Laur, D. R. & Rowley, R. J. 1985, ‘Severe storm disturbances and reversal of community structure in a southern California kelp forest’, *Marine Biology*, 84: 287-294.

Edwards, R. A. & Smith, D. A. 2005, ‘Subtidal assemblages associated with a geotextile reef in south-east Queensland, Australia’, *Marine and Freshwater Research*, 56: 133-142.

Fellegara, I. 2008, ‘Ecophysiology of the marginal, high-latitude corals (Coelenterata: Scleractinia) of Moreton Bay, QLD, Ph.D Thesis, University of Queensland.

Fisheries Research Consultants 1991, *Survey of the Intertidal and Subtidal Rocky Reefs of the Sunshine Coast*, Unpublished report for the Queensland National Parks and Wildlife Service.

Fisheries Research Consultants 1995a, *Tweed River Entrance Sand Bypassing Project Monitoring Study of the Impacts of Stage 1 (A) Nourishment on Kirra Reef*, May 1995 Unpublished report prepared for the Tweed River Entrance Sand Bypassing Project, New South Wales Public Works.

Fisheries Research Consultants 1995b, *Tweed River Entrance Sand Bypassing Project Monitoring Study of the Impacts of Stage 1 (A) Nourishment on Kirra Reef*, June 1995, Unpublished report prepared for the Tweed River Entrance Sand Bypassing Project, New South Wales Public Works.

Fisheries Research Consultants 1996, *Tweed River Entrance Sand Bypassing Project, Monitoring Study of the Impacts of Stage 1(A) Nourishment on Kirra Reef*, Unpublished report prepared for the Tweed River Entrance Sand Bypassing Project, New South Wales Public Works.

frc environmental 2001, Tweed River Entrance Sand Bypassing Project, Monitoring of Kirra Reef, January 2001, unpublished report prepared for Brown and Root.

frc environmental 2003, *Tweed River Entrance Sand Bypassing Project, Kirra Reef Ecological Monitoring 2003,* unpublished report prepared for Department of Infrastructure Planning & Natural Resources.

frc environmental 2004, *Tweed River Entrance Sand Bypassing Project, Kirra Reef Ecological Monitoring 2004,* unpublished report prepared for Department of Infrastructure Planning & Natural Resources.

frc environmental 2005, *Tweed River Entrance Sand Bypassing Project, Kirra Reef Ecological Monitoring 2005,* unpublished report prepared for Department Lands.

Friedlander A. M., Brown, E. K., Jokiel, P. L., Smith, W. R. & Rodgers, K. S. 2003, ‘Effect of habitat, wave exposure, and marine protected area status on coral reef fish assemblages in the Hawaiian archipelago’, *Coral Reefs* 22: 291-305.

Grigg, R. W. & Maragos, J. E. 1974, 'Recolonisation of hermatypic corals on submerged lava flows in Hawaii', *Ecology*, 55: 387-395.

Guzman, H. M. & Cortes, J. 1989, 'Growth rates of eight species of scleractinian corals in the eastern Pacific (Costa Rica)', *Bulletin of Marine Science*, 44: 1186-1194.

Harriott, V. J. 1998, ‘Growth of the staghorn coral *Acropora formosa* at Houtman Abrolhos, Western Australia’, *Marine Biology*, 132:319-325.

Harriott, V. J., Banks, S. A, Mau, R. L., Richardson, D. & Roberts, L. G. 1999, ‘Ecological and conservation significance of the subtidal rocky reef communities of northern New South Wales, Australia, *Marine and Freshwater Research*, 50: 299-306.

Hatcher, B., Johannes, R. & Robertson, A. 1989, ‘Review of research relevant to the conservation of shallow tropical marine ecosystems’, *Oceanogr. Marine Biology Annual Review*, 27:337-414.

Hoey A, Bellwood D. 2008 ‘Cross-shelf variation in the role of parrotfishes on the Great Barrier Reef.’ *Coral Reefs*: 37-47.

Hollingsworth, P. 1975, *Environmental Investigation Report: Crown Reserve - R68 Currumbin Creek*, City of the Gold Coast, Land Administration Commission, unpublished report.

Hughes TP, 1994 'Catastrophes, phase shifts, and large scale degradation of a Caribbean coral reef.' *Science*, 265, 1547–1551.

Hughes T, Rodrigues M, Bellwood D, Ceccarelli D, Hoegh-Guldberg O, McCook L, Moltschaniwskyj N, Pratchett M, Steneck R, Willis B. 2007 'Phase shifts, herbivory, and the resilience of coral reefs to climate change.' *Current Biology* 17: 360-365.

Huston, M. A. 1994, *Biological Diversity: The Coexistence of Species on Changing Landscapes*, Cambridge University Press, Cambridge.

Hyder Consulting Pty Ltd, Patterson Britton & Partners Pty Ltd & WBM Oceanics Australia Joint Venture 1997, *Tweed River Entrance Sand Bypassing Project, Permanent Bypassing System, Environmental Impact Statement – Impact Assessment Study,* report no. 9706236-4D June.

Irving, A. D. & Connell, S. D. 2002, 'Interactive effects of sedimentation and microtopography on the abundance of subtidal turf algae', *Phycologia*, 41(5): 517-522.

Jompa, J. & McCook, L. J. 2002, 'Effects of competition and herbivory on interactions between a hard coral and a brown alga', *Journal of Experimental Marine Biology and Ecology*, 271(2002): 25-39.

Jones GP, Syms C, 1998 'Disturbance, habitat structure and the ecology of fishes on coral reefs.' *Australian Journal of Ecology*, 23, 287–297.

Kaufman LS, 1983 'Effects of Hurricane Allen on reef fish assemblages.' *Coral Reefs*, 2, 43–47.

Lassig BR, 1983 'The effects of a cyclonic storm on coral reef fish assemblages.' *Environmental Biology of Fishes*, 9, 55–63.

Lesser MP, 2006 'Benthic–pelagic coupling on coral reefs: feeding and growth of Caribbean sponges.' *Journal of Experimental Marine Biology and Ecology*, 328, 277–288.

Lopez-Victoria M, Zea S, Wei E, 2006 ‘Competition for space between encrusting excavating Caribbean sponges and other coral reef organisms.’ *Marine Ecology Progress Series*, 312, 113–121.

Lough, J. M. & Barnes, D. J. 2000, 'Environmental controls on growth of the massive coral Porites', *Journal of Experimental Marine Biology and Ecology*, 245: 225-243.

Lugo AE, Rogers C, Nixon S, 2000 ‘Hurricanes, coral reefs and rainforests: resistance, ruin and recovery in the Caribbean.’ *Ambio*, 29, 106–114.

Malcolm, H. A., Smith, S. D. A & Jordan, A., 2009, ‘Using patterns of reef fish assemblages to refine a Habitat Classification System for marine parks in NSW, Australia, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 20: 83-92.

Massel SR, Done TJ, 1993 ‘Effects of cyclone waves on massive coral assemblages on the Great Barrier Reef: meteorology, hydrodynamics and demography.’ *Coral Reefs*, 12, 153–166.

McCook, L. J. 1997, ‘Effects of herbivory on zonation of *Sargassum* spp. within fringing reefs of the central Great Barrier Reef’, *Marine Biology,* 129(4):713-722.

McCook, L. J., Jompa, J. & Diaz-Pulido, G. 2001, ‘Interactions between corals and benthic algae: Variability and mechanisms’, *Proceedings of the 16th Annual Conference of the Australian Society for Phycology and Aquatic Botany,* pp. 26.

Moran DP, Reaka Kudla ML, 1991 ‘Effects of disturbance: disruption and enhancement of coral reef cryptofaunal populations by hurricanes.’ *Coral Reefs*, 9, 215–224.

Mumby P. 2006 ‘The impact of exploiting grazers (Scaridae) on the dynamics of Caribbean coral reefs.’ *Ecological Applications* 16: 747-769.

Mumby P. 2009 ‘Phase shifts and the stability of macroalgal communities on Caribbean coral reefs.’ *Coral Reefs* 28: 761-773.

Murphy, H. M & Jenkins, G. P. 2010 ‘Observational methods used in marine spatial monitoring of fishes and associated habitats: a review’, *Marine and Freshwater Research*, 61: 236-252.

Nybakken, J.W. 1993, *Marine Biology: An Ecological Approach*, Harper Collins College Publishing, New York, p 247.

Paine, R. T. & Levin, S. A. 1981 ‘Inter-tidal landscapes: Disturbance and the dynamics of pattern’, *Ecological Monographs,* 51: 145-178.

Parker, P. 1995 'Structure of Reef Fish Assemblages at Julian Rocks, Northern New South Wales', Masters Thesis, Griffith University.

Parker, P. G. 1999 'Fish assemblages at Julian Rocks and the adjacent waters of northern New South Wales, Australia', *Australian Zoologist*, 31: 134-160.

Pawlik JR, Steindler L, Henkel TP, Beer S, Ilan M, 2007 'Chemical warfare on coral reefs: sponge metabolites differentially affect coral symbiosis in situ.' *Limnology and Oceanography*, 52, 907–911.

Reef Check, 2010, data accessed online on 2nd March 2010, www.reefcheckaustralia.org/data.html.

Robinson, K. I. & Pollard, D. A.1982, 'Marine and estuarine reserves in Australia with particular reference to New South Wales', *Wetlands*, 2(1): 17 - 26.

Rogers, C. S. 1990, 'Responses of coral reefs and reef organisms to sedimentation', *Marine Ecology Progress Series,* 62:185-202.

Russ G. R. 2003 'Grazer biomass correlates more strongly with production than with biomass of algal turfs on a coral reef.' *Coral Reefs* 22: 63-67.

Rutzler K, 2002 'Impact of crustose clionid sponges on Caribbean reef corals.' *Acta Geologica Hispanica*, 37, 61–72.

Saiz-Salinas, J. I. & Urkaiga-Alberdi, J. 1999, 'Faunal responses to turbidity in a man-modified bay (Bilbao, Spain)'*, Marine Environmental Research*, 47:331 – 347.

Scheffers SR, Nieuwland G, Bak RPM, van Duyl FC, 2004 'Removal of bacteria and nutrient dynamics within the coral reef framework of Curacao (Netherlands Antilles).' *Coral Reefs*, 23, 413–422.

Shanks A. L. & Wright, W. G. 1986, 'Adding teeth to wave action: the destructive effects of wave-borne rocks on intertidal organisms', *Oecologia*, 69: 420-4281.

Smith, S. D. A., Rule, M. J., Harrison, M. & Dalton, S. J. 2008, 'Monitoring the sea change: Preliminary assessment of the conservation value of nearshore reefs, and existing impacts, in a high-growth, coastal region of subtropical eastern Australia', *Marine Pollution Bulletin*, 56: 525-534.

TRESBP 2010, *Tweed River Entrance Sand Bypassing Project – Project Updates,* [online] www.tweedsandbypass.nsw.gov.au, accessed February 2011.

Trager, G. C., Hwang, J. S. & Strickler, J. R. 1990, 'Barnacle suspension-feeding in variable flow', *Marine Biology*, 105:117-127.

Umar, M.J., McCook, L.J., & Price, I.R., 1998, 'Effects of sediment deposition on the seaweed *Sargassum* on a fringing coral reef', *Coral Reefs*, 17: 169-177.

Walker, S. J., Degnan, B. M., Hooper, J. N. A. & Skilleter, G. A. 2008,' Will increased storm disturbance affect the biodiversity of intertidal, nonscleractinian sessile fauna on coral reefs? *Global Change Biology*, 14: 2755-2770.

Warwick, R. M. & Clarke, K. R. 1993, 'Increased variability as a symptom of stress in marine communities' *Journal of Experimental Marine Biology and Ecology*, 172:215-216.

Woodley JD, Chornesky EA, Clifford PA et al., 1981 'Hurricane Allens impact on Jamaican coral reefs.' *Science*, 214, 749–755.

Wulff J, 2001 'Assessing and monitoring coral reef sponges: why and how?' *Bulletin of Marine Science*, 69, 831–846.

Zar, J. H. 1996, *Biostatistical Analysis*, Prentice Hall International, USA.

Appendix A Benthic Assemblage Data from Kirra and Palm Beach reefs in February 2010

Table A.1 Benthic assemblage data from Kirra and Palm Beach reefs in February 2010.

Location	Site	Replicate	% Macroalgae	% Turf algae	%Soft coral	%Hard coral	%Sponge	%Ascidians	%Barnacles	% Anemone	% Bare	# Crinoids	#Pyura sp.	#Echinoidea	#Tube worms	#Polychates	#Hydroids	#Zooanthids	#Bryozoan	#Cowrie	#Seastar
Palm Beach	1	1	5	25	10	5	10	0	0	0	45	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	2	0	15	5	0	20	30	0	0	30	0	0	0	0	0	0	0	0	1	0
Palm Beach	1	3	1	15	10	5	0	10	0	0	59	0	1	0	0	0	0	0	0	0	0
Palm Beach	1	4	0	10	0	0	15	5	0	0	70	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	5	0	5	10	30	5	5	0	0	45	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	6	5	10	0	5	20	10	0	25	25	0	0	1	0	0	0	0	0	0	0
Palm Beach	1	7	1	1	5	30	25	10	0	0	28	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	8	0	20	0	0	5	0	0	0	75	0	0	0	0	0	0	0	1	0	0
Palm Beach	1	9	0	5	80	0	10	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	10	0	40	0	5	25	5	0	0	25	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	11	5	10	0	0	15	5	0	0	65	0	0	0	0	0	0	0	0	0	1
Palm Beach	1	12	0	20	5	0	5	0	0	0	70	1	0	0	0	0	0	0	0	0	0
Palm Beach	1	13	30	10	0	0	5	0	0	0	55	0	0	0	0	0	0	0	0	0	0
Palm Beach	1	14	10	5	0	0	30	0	0	0	55	0	0	0	0	0	0	0	0	0	1
Palm Beach	1	15	0	5	0	90	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	1	0	30	0	0	10	5	0	0	55	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	2	0	20	5	0	15	20	0	0	40	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	3	0	10	0	0	0	10	0	0	80	0	0	1	0	0	0	0	0	0	0
Palm Beach	2	4	0	25	0	0	5	25	0	0	45	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	5	0	30	0	0	10	20	0	0	40	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	6	0	15	0	15	5	30	0	0	35	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	7	0	10	60	0	10	0	0	0	20	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	8	0	10	0	0	10	5	0	0	75	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	9	0	10	0	0	40	5	0	0	45	1	0	0	0	0	0	0	0	0	0
Palm Beach	2	10	0	20	0	0	30	5	0	0	45	0	9	0	0	0	0	0	0	0	0
Palm Beach	2	11	0	15	0	0	10	35	0	0	40	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	12	0	10	5	10	0	5	0	0	70	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	13	0	30	0	0	20	10	0	0	40	0	5	0	0	0	0	0	0	0	0
Palm Beach	2	14	0	15	0	0	20	5	0	0	60	0	0	0	0	0	0	0	0	0	0
Palm Beach	2	15	0	10	15	0	30	5	0	0	40	0	0	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	%Soft coral	%Hard coral	%Sponge	%Ascidians	%Barnacles	% Anemone	% Bare	# Crinoids	#Pyura sp.	#Echinoidea	#Tube worms	#Polychates	#Hydroids	#Zooanthids	#Bryozoan	#Cowrie	#Seastar
Palm Beach	3	1	0	25	0	0	5	30	0	0	40	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	2	0	5	5	10	0	0	0	0	80	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	3	5	20	5	0	0	15	0	0	55	0	15	1	0	0	0	0	0	0	0
Palm Beach	3	4	0	10	0	0	0	5	0	25	60	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	5	0	15	0	0	10	5	0	0	70	0	0	1	0	0	0	0	0	0	0
Palm Beach	3	6	0	10	5	0	15	20	0	0	50	0	0	1	0	0	0	0	0	0	0
Palm Beach	3	7	0	20	0	15	5	0	0	0	60	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	8	0	15	0	0	10	0	0	0	75	0	0	1	0	0	0	0	15	0	0
Palm Beach	3	9	0	40	0	0	5	0	0	0	55	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	10	0	10	70	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	11	5	40	0	0	5	0	0	0	50	0	0	0	0	0	0	0	0	0	0
Palm Beach	3	12	0	45	10	5	10	0	0	0	30	0	0	1	0	0	0	0	0	0	0
Palm Beach	3	13	0	10	5	0	0	5	10	0	70	0	1	0	0	0	0	0	0	0	0
Palm Beach	3	14	0	20	0	0	5	70	0	0	5	0	15	0	0	0	0	0	0	0	0
Palm Beach	3	15	0	30	0	0	5	0	0	0	65	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	1	0	0	0	0	0	0	5	0	95	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	2	0	0	0	0	0	0	20	0	80	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	3	0	0	0	0	0	0	15	0	85	0	0	0	1	0	0	0	0	0	0
Kirra Reef	KI3	4	0	15	0	0	0	0	10	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	5	0	5	0	0	0	0	5	0	90	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	6	0	0	0	0	0	0	25	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	7	0	0	0	0	0	0	10	0	90	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	8	0	10	0	0	0	0	15	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	9	1	5	0	0	0	0	15	0	79	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	10	5	15	0	0	0	0	5	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	11	0	10	0	0	0	0	20	0	70	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	12	0	0	0	0	0	0	15	0	85	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	13	10	5	0	0	0	0	5	0	80	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	14	0	10	0	0	0	0	15	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KI3	15	0	0	0	0	0	0	5	0	95	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	1	25	15	0	0	0	5	0	0	55	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO1	2	10	10	0	0	0	0	5	0	75	0	0	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	%Soft coral	%Hard coral	%Sponge	%Ascidians	%Barnacles	% Anemone	% Bare	# Crinoids	#Pyura sp.	#Echinoidea	#Tube worms	#Polychates	#Hydroids	#Zooanthids	#Bryozoan	#Cowrie	#Seastar
Kirra Reef	KO1	3	15	10	0	0	0	20	10	0	45	0	2	0	0	0	0	0	0	0	0
Kirra Reef	KO1	4	45	10	0	0	0	0	5	0	40	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	5	40	10	0	0	0	0	10	0	40	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	6	35	10	0	0	0	0	5	0	50	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	7	15	20	0	0	0	0	10	0	55	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	8	15	25	0	0	0	0	15	0	45	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	9	20	10	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	10	50	5	0	0	0	5	5	0	35	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO1	11	35	10	0	0	0	0	0	0	55	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	12	25	15	0	0	0	10	5	0	45	0	2	0	0	0	0	0	0	1	0
Kirra Reef	KO1	13	15	10	0	0	0	0	0	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	14	0	0	0	0	0	0	60	0	40	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO1	15	25	15	0	0	10	15	5	0	30	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO3	1	30	65	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO3	2	20	30	0	0	0	10	0	0	40	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KO3	3	15	20	0	0	0	25	0	0	40	0	9	0	0	0	0	0	0	0	0
Kirra Reef	KO3	4	20	30	0	0	0	0	15	0	35	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO3	5	15	15	0	0	0	10	10	0	50	0	4	0	0	0	0	0	0	0	0
Kirra Reef	KO3	6	10	40	0	0	0	5	15	0	30	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO3	7	10	15	0	5	0	30	10	0	30	0	4	0	0	0	0	0	0	0	0
Kirra Reef	KO3	8	20	20	0	0	0	5	5	0	50	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO3	9	25	15	0	0	0	15	10	0	35	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KO3	10	45	20	0	0	0	15	10	0	10	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO3	11	5	60	0	0	0	0	5	0	30	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KO3	12	30	40	0	0	0	20	5	0	5	0	6	0	0	0	0	0	0	0	0
Kirra Reef	KO3	13	10	70	0	0	0	1	0	0	19	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KO3	14	30	40	0	0	0	3	5	0	22	0	10	0	0	0	0	0	0	0	0
Kirra Reef	KO3	15	0	30	0	0	0	5	5	0	60	1	1	0	0	0	4	0	0	0	0
Kirra Reef	KN1	1	15	20	0	0	0	5	5	0	55	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	2	10	10	0	0	0	20	30	0	30	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	3	15	20	0	0	0	25	20	0	20	0	4	0	0	0	0	0	0	0	0
Kirra Reef	KN1	4	1	30	0	0	0	30	10	0	29	0	6	0	0	0	0	0	0	0	0

Location	Site	Replicate	% Macroalgae	% Turf algae	%Soft coral	%Hard coral	%Sponge	%Ascidians	%Barnacles	% Anemone	% Bare	# Crinoids	#Pyura sp.	#Echinoidea	#Tube worms	#Polychates	#Hydroids	#Zooanthids	#Bryozoan	#Cowrie	#Seastar
Kirra Reef	KN1	5	0	10	0	0	15	40	5	0	30	0	7	0	0	0	0	0	0	0	0
Kirra Reef	KN1	6	5	15	0	0	5	10	0	0	65	1	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	7	10	15	0	0	0	15	20	0	40	0	2	0	0	0	0	0	0	0	0
Kirra Reef	KN1	8	15	5	0	0	0	3	5	0	72	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	9	10	15	0	0	0	25	5	0	45	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	10	20	10	0	0	0	0	5	0	65	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN1	11	25	10	0	0	0	0	5	0	60	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN1	12	15	10	0	0	0	25	15	0	35	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	13	10	15	0	0	5	15	5	0	50	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN1	14	0	20	0	0	0	0	15	0	65	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN1	15	10	5	0	0	0	0	0	0	85	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN2	1	10	40	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN2	2	5	30	0	0	0	40	10	0	15	0	6	0	0	0	0	0	0	0	0
Kirra Reef	KN2	3	1	10	0	0	0	30	5	0	54	0	8	0	0	0	0	0	0	0	0
Kirra Reef	KN2	4	10	20	0	0	0	10	10	0	50	0	3	0	0	0	0	0	0	0	0
Kirra Reef	KN2	5	5	10	0	0	0	5	60	0	20	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KN2	6	0	30	0	0	0	0	5	0	65	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN2	7	5	15	0	0	0	0	10	0	70	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN2	8	10	20	0	0	0	10	5	0	55	0	2	0	0	0	0	0	0	0	0
Kirra Reef	KN2	9	5	10	0	0	0	0	10	0	75	0	0	0	0	0	0	0	0	0	0
Kirra Reef	KN2	10	5	5	0	0	0	10	5	0	75	0	9	0	0	0	0	0	0	0	0
Kirra Reef	KN2	11	10	20	0	0	0	0	5	0	65	1	0	0	0	0	0	0	0	0	0
Kirra Reef	KN2	12	5	20	0	0	0	30	5	0	40	0	4	0	0	0	0	0	0	0	0
Kirra Reef	KN2	13	15	5	0	0	0	5	5	0	70	0	1	0	0	0	0	0	10	0	0
Kirra Reef	KN2	14	10	5	0	0	0	10	5	0	70	0	1	0	0	0	0	0	0	0	0
Kirra Reef	KN2	15	5	65	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	0

Appendix B: Fish Relative Abundance Data for Kirra and Palm Beach reefs on all Monitoring Events

Table B.1 Fish species and their relative abundance in February 2010, and in previous monitoring events.

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

		Kirra Reef								Palm Beach Reef							
Scientific Name	**Common Name**	**Apr '95**	**Jun '95**	**Feb '96**	**Jan '01**	**May '03**	**Mar '04**	**Feb '05**	**Feb '10**	**Apr '95**	**Jun '95**	**Feb '96**	**Jan '01**	**May '03**	**Mar '04**	**Feb '05**	**Feb '10**
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	**				*			**								
Cheilodactylidae																	
Cheilodactylus fuscus	red morwong			**	**	**	**	*	**		**		**	**		**	**
Cheilodactylus vestitus	crested morwong			*				*	*				*			**	**
Chironemidae																	
Chironemus marmoratus	kelp fish				**	**		**									
Cirrhitidae																	
Cirrhitichthys sp.	hawkfish					**						*			**	**	
Dasyatidae																	
Dasyatis kuhlii	blue-spotted maskray								**								
Diodontidae																	
Dicotylichthys punctulatus	three-bar porcupine fish					**	*	***	**				*				
Diodon holacanthus	freckled porcupine fish	*		**													
Diodon hystrix	black-spotted porcupine fish					*											
Ephippidae																	
Platax orbicularis	round batfish								*								
Enoplosidae																	
Enoplosus armatus	old wife	***		**	***			**					**				

		Kirra Reef								Palm Beach Reef							
Scientific Name	**Common Name**	**Apr '95**	**Jun '95**	**Feb '96**	**Jan '01**	**May '03**	**Mar '04**	**Feb '05**	**Feb '10**	**Apr '95**	**Jun '95**	**Feb '96**	**Jan '01**	**May '03**	**Mar '04**	**Feb '05**	**Feb '10**
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													*			
Halichoeres sp.	striped wrasse			**	***	*			***				**		*	**	**
Labroides dimidiatus	cleaner wrasse			**	**	***	**	**	**		*	*	*	**	**	*	**
Notolabrus gymnogensis	crimson-banded wrasse					***	**										
Notolabrus sp.	wrasse	**								**	**	**					
Thalassoma lunare	moon wrasse					**	**	**				***	***	***	**	****	***
Thalassoma lutascens	yellow moon wrasse	**		**	**	***	*	**			**	***	***	***	**	**	***
Monocanthidae																	
Meuschenia trachylepis	yellow-tailed leatherjacket					*										**	
Monocanthus chinensis	fan-bellied leatherjacket	*		*	*				*		*	*				**	
Monodactylidae																	
Monodactylus argenteus	silver batfish					***					***		**	***			
Schuettea scalaripinnis	eastern pomfred								***	****	***	***					**
Mullidae																	
Parupeneus barberinoides	half-and-half goatfish				**			*								**	

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

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	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
Pomacentridae																	
Abudefduf begalensis	Bengal sergeant major					**		*						**	**	**	*
Abudefduf vaigiensis	sergeant major								*					***	*	**	***
Abudefduf saxatilis	five-banded sergeant major								**					***			*
Amphiprion sp.	clown fish	**	**	**		**						**		**			***
Chromis chrysura	robust puller			**											*		
Chromis nitida	barrier reef chromis			**								**					
Chrysiptera sp.	Demoiselle					**								**	*		**
Dascyllus trimaculatus	domino puller							*					*				
Parma microlepis	white ear puller		**	**	**					**	**	**	**		*	*	*
Parma oligolepis	large-scaled parma					**	**	**								*	***
Parma pollepis	banded parma							**								**	**
Pomacentrus australis	Australian damsel	**	**	**						**	**			**	**		
Pomacentrus coelestis	neon damsel					***		**						***		***	****
Stegastes gascoynei	coral sea gregory					**	*								**		**
Pomatomidae																	
Pomatomus saltatrix	tailor	****															
Rhinobatidae																	
Aptychotrema sp.	shovelnose ray	*															
Glaucostegus typus	giant shovelnose ray																*
Scorpaendiae																	
Centropogon australis	fortescue												*				
Pterois volotans	red firefish					*								*			

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	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
Scorpaena cardinalis	red scorpionfish					*								*			**
Synancia horrida	estuarine stonefish							**									
Scombridae																	
Cybiosarda elegans	leaping bonito								****								
Scomberomorus commerson	spanish mackerel																**
Scorpididae																	
Atypichthys strigatus	mado			**	***	***	*	***	***						***	***	***
Microcanthus strigatus	stripey	***	***	**	***	***	**	***	***	***	**	**	***		*		***
Scorpis lineolatus	sweep	***	***	**	**	**	*	**	**	***	***	**	****	**	**	**	***
Serranidae																	
Epinephelus fasciatus	black-tipped cod										**				*	***	**
Plectropomus maculatus	coral trout										*						
Siganidae																	
Siganus fuscescens	rabbit fish				***								***		***	***	***
Sillaginidae																	
Sillago analis	gold-lined whiting							**									
Sparidae																	
Acanthopagrus australis	yellow fin bream	***	***	**	***	***				***	**	**	**				***
Rhabdosargus sarba	tarwhine	***			**												*
Sphyraenidae																	
Sphyraena obtusata	striped sea pike	****	**	**	**	*		****						*			**
Syngnathidae																	
Sp. 1	pipefish	*															

		Kirra Reef								Palm Beach Reef							
Scientific Name	Common Name	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10	Apr '95	Jun '95	Feb '96	Jan '01	May '03	Mar '04	Feb '05	Feb '10
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				***												
Torquigener pleurogramma	toadfish	*	*		***							*					
Urolophidae																	
Urolophus sp.	stingaree	*	***	**	**	*		**									
Acanthuridae																	
Acanthurus grammoptilus	ring-tailed surgeon	**	**	**	**	**		**	**	**	**	***	**	**		**	**
Prionurus microlepidotus	sawtail surgeon								***							**	**
Apogonidae																	
Apogon cookii	cook's cardinal fish														**	**	*
Apogon doederleini	four lined cardinal fish							**	*				**		***	**	**