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Long-term Monitoring of Shallow-water Coral and Fish
Communities at Scott Reef, Technical Report 2008



BROWSE FLNG DEVELOPMENT
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Long-term monitoring of shallow-water coral and fish communities at Scott Reef



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AIMS SRRP TECHNICAL REPORT PROJECT 1 - 2009

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Preamble

Scope of Works

The Australian Institute of Marine Science (AIMS) entered into a contract (No. 4600001754) with Woodside Energy Limited (WEL), as agent for the Browse Joint Venture Partners (JVP), on 28 February 2008, to undertake a three year research program at Scott Reef. For the purpose of this report, this research program is known as the Scott Reef Research Project (SRRP).

The research within the SRRP is divided among three projects, and each project is required to submit an annual technical report to WEL and the Browse JVP as part of their contractual requirements. This technical report for 2009 summarises the methods used and the results to date for Project 1: Understanding the shallow-water coral and fish communities. The report presents the current and future methods of data collection and analysis to be employed in this project, and most of results to date, in the context of AIMS' monitoring of coral and fish communities at Scott Reef since 1994. This technical report follows a standard scientific format agreed with WEL. Additionally, the report includes responses to specific questions provided by WEL; these questions in the format supplied are as follows.

PROJECT 1

1.1 Long Term Monitoring

- *What is the status of the biological communities at Scott Reef?*
- *Have any major mortality events or processes been seen at Scott Reef?*
- *Have the biological communities changed in the last 12 months; if so, what are the drivers?*
- *What has been the temperature regime at Scott Reef in the last 12 months; where there any bleaching alerts, temperature anomalies and any associated bleaching of corals?*
- *What were the rates of sedimentation in the last 12 months; how did they vary among sites and how do they compare to other reefs?*

1.2 Coral Demography

- *What were the rates of growth and survival of corals at Scott Reef in the last 12 months, what were the possible drivers of variation in growth and survival, and how do the rates of growth and survival compare with corals at other reefs?*

1.3 Genetic Connectivity of Coral and Fish

- *Please provide a summary of the methodology, i.e. in three paragraphs*
- *Based on published data could input of larvae from Scott Reef maintain fish populations at Rowley Shoals and vice versa?*

1.4 Coral Reproduction and Recruitment

- *What species of spawning and brooding coral reproduced last Autumn?*
- *What species of spawning and brooding coral reproduced last Spring?*
- *What is the relative 'significance' of the reproductive periods during Autumn and Spring each year?*
- *Do any species reproduce only during the Autumn or Spring periods?*
- *How do the patterns of reproduction in corals during the last year compare to previous years?*
- *What were the rates of coral recruitment at Scott Reef following the reproductive period last Autumn; how do these rates of coral recruitment compare to previous years, and do they indicate that the coral communities have/are recovering from previous disturbances?*

Specific Response to WEL Questions

1.1 Long Term Monitoring

- *What is the status of the biological communities at Scott Reef?*

Benthic communities

The cover of hard corals at Scott Reef in 2008 was moderate to high, similar to that prior to the mass-bleaching in 1997, although the cover of soft corals remains at approximately half that prior to the bleaching. On average, the total cover (\pm S.E.) of hard corals in 2008 was 37% (\pm 1), compared to 42% (\pm 2) in 1997, whereas the cover of soft corals was 4% (\pm 1), well below that (8% \pm 1) in 1997. The recovery of hard corals and the changes in cover ten years after the bleaching varied among the permanent monitoring locations at Scott Reef. The initial (1998-2004) increases in coral cover were most rapid at locations (SL1, SL2, SL3, SL4) least affected by the bleaching, and slowest at the worst affected locations (SS1, SS2). However, in more recent years (2004-2008), the locations with the fastest (SL1, SL2, SS1, SS2) or slowest (SL3, SL4) increases in cover differed from those shortly (1998-2004) after the bleaching. Different patterns of change among the locations ten years after the bleaching reflect both the severity of the bleaching and the localised impact of cyclones.

Significant differences in the structure of benthic communities at locations across Scott Reef, as defined by the percentage cover of the most abundant benthic groups (e.g. branching *Acropora*, coralline and turfing algae, massive corals, sponges), have been evident since monitoring commenced in 1994. These differences in community structure are related to the different physical conditions at locations, but have remained through periods of impact and recovery from disturbances. Thus, community structure differed significantly among locations and through time, and clearly separated according to the following periods: pre-bleaching (1994-1997), severe bleaching impact (1998-2001), recovery and localised cyclone disturbance (2003-2005), further recovery and localised cyclone disturbance (2006-2008).

In 2008, ten years after the bleaching and following two cyclones, benthic communities at Scott Reef were approaching their pre-bleaching structure. The structure of benthic communities throughout the post-bleaching period was increasingly similar to their pre-bleaching state, and by 2008 communities were statistically as similar to their pre-bleaching structure as they were to the most recent surveys (2003-2005). Indeed, community structures before (1994-1997) the bleaching and in 2008 were characterised by most of the same benthic groups; coralline and turfing algae, massive coral and encrusting coral. The most notable exception between the periods were an increased cover of tabulate corals and coralline and turfing algae in 2008, and a lower cover of soft corals and branching corals. The higher cover of tabulate corals and lower cover of branching corals may reflect the successional changes in the community structure following bleaching and cyclone disturbance, both of which disproportionately impact the branching corals. However, in the absence of further disturbances the cover of branching corals would be expected to increase further, due to their high rates of growth, local recruitment, and ability to outcompete (overtop) other benthic organisms. The extent to which branching corals again dominate at many sites across Scott Reef, and the benthic communities return to their previous cover and structure, depends on the regime of disturbance in the future. In particular, the frequency and severity of cyclone disturbances and whether communities are again exposed to extreme seawater temperatures.

Fish Communities

Although 10 years have passed since the 1998 bleaching at Scott Reef, the fish communities are different to their previous (pre-bleaching) composition. The fish assemblages have been undergoing change since 1998 and distinct pre- and post-bleaching fish assemblages are apparent, with a third interim group reflecting the early bleaching period and, to a lesser degree, the impact of Cyclone Fay in 2004. The shift away from the pre-bleaching community suggests that it may be some time before the structure of that earlier period returns. This pattern of change differs to that of the benthic communities, which have undergone a more recent shift towards pre-bleaching structure.

The structures of fish communities at Scott Reef in 2008 also largely reflect the differences in habitat and exposure to hydrodynamic factors such as oceanic waves, tidal intrusions and wind fetch. There is a clear separation in community structure among locations according to oceanographic conditions; SL2 separates out most significantly, then SL1 and SL3, then SL4 and SS1, and then SS2. Notwithstanding the importance of location, major differences in species composition and abundance were associated with the varying rates of coral recovery following the 1998 bleaching event and the passing of the category five Cyclone Fay in 2004. The 1998 coral bleaching event is the major overlying influence observed during 15 years of monitoring.

Abundances of fish species that are heavily dependent on hard coral for food and/or shelter were low during the initial post-bleaching phase (1998-2004) but show signs of increasing with the cover of hard corals (2005-2008). In contrast, the increasing abundance of species with a dietary preference for algae after the bleaching (1998-2004) has declined since 2004, become a decline, following a corresponding decrease in algae. In general, many of the larger, more mobile fish species have continued to increase in abundance over the monitoring period and now are more abundant than prior to the bleaching; smaller more site attached fish species displayed a more complicated pattern of change that can vary according to their habitat preferences. In 2008, the numbers of the larger, more mobile fishes are greater than in any previous year. Such an increase may be related to the increase in algal cover following the bleaching and thus the greater provision of food items for various species. However, the removal of sharks from this ecosystem through heavy fishing pressure may also be related to this increase, and a more detailed analysis of these interactions is warranted.

- *Have any major mortality events or processes been seen at Scott Reef?*

Benthic Communities

Major mortality events at Scott Reef in the last decade are currently limited to the widespread impacts of bleaching from elevated water temperatures in 1998, and some more localised physical damage from Cyclone Fay in April 2004 and Cyclone George in March 2007.

Recent cyclone disturbances at Scott Reef had more localised and heterogeneous impacts on coral communities than did the temperature induced mass-bleaching in 1998, which caused massive decreases in coral cover across the entire reef system and other reefs in the region. However, the different patterns of change among communities in the last ten years reflect the impacts of cyclones, in addition to initial differences in community structure, the impact from bleaching and spatial differences in the rates of larval supply. The impact of cyclones on coral communities at Scott Reef varied according to their exposure to cyclonic winds and waves. In 2004, Category 5 Cyclone Fay passed directly over Scott Reef, and there were subsequent decreases in mean coral cover at locations SL2, SS1 and SS2. Two years later (2006), Cyclone George passed to the south of Scott Reef, again having a variable impact on the coral communities; smaller relative increases in coral cover at locations SL3 and SL4 between 2004

and 2008 were probably due to the impacts of Cyclone George, which is supported by the patterns of growth and survival of tagged colonies. Nonetheless, throughout the cycles of cyclone disturbance, the mass-bleaching remains the most influential event determining the current cover of hard corals at Scott Reef; the locations (SL2, SS1, SS2) with the greatest absolute and relative decreases following the bleaching had not returned to their pre-bleaching cover in 2008, whereas the least affected locations (SL1, SL3, SL4) had returned to a similar or greater coral cover. These changes in coral cover show the extent to which disturbances that occurred a decade ago have an ongoing influence on the current structure of coral communities.

The dominant families of hard coral at Scott Reef displayed different patterns of impact and recovery following the mass-bleaching and cyclone disturbances, but ten years after the bleaching their relative abundances were approaching those prior to the disturbance. By 2008, the mean cover of the Acroporidae and Pocilloporidae had increased to 18% (± 2) and 4% (± 1) respectively, whereas the Poritidae had increased in mean cover to 9% (± 2); the cover of Acroporidae had returned to 65% of that prior to the bleaching, whereas the cover of the Poritidae and Pocilloporidae was similar or greater than (>90%) that prior to the bleaching.

Following the bleaching in 1998, the cover of all benthic groups at all locations across Scott Reef decreased by at least a half, with the exception of the turfing and coralline algae that increased in cover. The structural changes in the hard coral communities were driven by the relative changes in the abundances of the dominant families (Acroporidae, Poritidae, Faviidae), from communities previously dominated by branching *Acropora* (47%) and other branching corals (9%), to communities with a lower coral cover in which massive corals had the highest (45%) relative abundance. Between 2001 and 2004, there were few changes in the benthic community at Scott Reef. Turfing and coralline algae remained the dominant benthic group at all locations, and the cover of soft corals and sponges remained low. However, decreases in the cover of algae since the bleaching were matched by increases in coral cover, which were similar for the branching *Acropora*, other branching corals, tabulate, foliaceous, and massive corals. Consequently, the branching *Acropora* had returned to 21% of its previous cover, whereas the massive corals and tabulate corals had returned to 59 and 100% of their previous cover, respectively; the other groups had returned to between 30 and 40% of their previous cover.

By 2008, communities continued to return to their previous structure, but the cover of turfing and coralline algae was still higher than that prior to the bleaching and there was an increased cover of tabulate corals and sponges. Following small increases between 2004 and 2008, the cover of soft corals was approximately half that prior to the bleaching. Similarly, there were small increases and decreases in the cover of branching *Acropora* and other branching corals at sites across Scott Reef, and the groups had returned to between 25% and 47% of their cover prior to the bleaching, respectively. The massive corals (e.g. Poritidae, Faviidae) continued to increase in cover at some sites, but with small decreases at other sites; their cover in 2008 reached approximately 60% of that prior to the bleaching. Of all benthic groups, the most notable changes between 2004 and 2008 were the increases in cover of tabulate corals and sponges. Tabulate corals were largely composed of species of *Acropora* with table or corymbose growth forms, and had increased at most sites to a mean cover of 5%, compared to <1% prior to the bleaching. Sponges also had large relative increases in cover at most sites, to a mean cover of 3%, compared to <1% prior to the bleaching.

Fish Communities

The 1998 coral bleaching event represents the major overlying influence on fish assemblages at Scott Reef during 15 years of monitoring. The fish assemblages at Scott Reef are now very different to those prior to the disturbance, irrespective of location. Major differences in species composition and abundance were associated with the varying rates of coral recovery following the 1998 bleaching event and, to a lesser extent, the passing of the category five Cyclone Fay in 2004. The impact of the bleaching on fish communities typically lagged by 12 - 18 months after the bleaching and a pattern of increasing difference has been maintained throughout the subsequent monitoring period. This trend contrasts with the trajectory of change demonstrated by the benthic assemblage which is more towards a pre-bleaching state.

The fish assemblages at Scott Reef during the 1994 to 1999 period were distinguished from all other periods by greater numbers of *Chromis ternatensis* and *Amblyglyphidodon curacao*, whereas the 2001 to 2006 period was distinguished by the lethinid *Monotaxis grandoculis*. Species that distinguished the 2007 to 2008 period included the snapper *Lutjanus gibbus*, the damselfish *Chromis xanthurus* and the surgeonfish *Acanthurus nigricauda*.

In general, many of the larger, more mobile fish species have continued to increase in abundance over the monitoring period and in 2008 are more abundant than prior to the bleaching; smaller more site attached fish species displayed a more complicated pattern of change that can vary according to their habitat preferences. Abundances of fish species heavily dependent on hard coral for food and/or shelter were low during the post-bleaching phase (1998-2004) but have increased in parallel with the cover of hard corals (2005-2008). In contrast, the increasing abundance of species with a dietary preference for algae after the bleaching (1998-2004) has since (>2004) become a decline, following the corresponding decrease in algae. Similarly, the increased abundance of tabulate corals at some sites across Scott Reef may result in an increased abundance of fish species in the future that utilise these corals for habitat.

Although there was some evidence of an impact of Cyclone Fay at certain locations (SL2, SS1 and SS2), there was surprisingly little change in the fish communities at Scott Reef following the Cyclone. It is common for major disturbances to have less affect on communities that have already undergone major changes from earlier disturbances. Many of the coral species most susceptible to cyclone damage were removed following the bleaching, and had not recovered. Consequently, the fine scale habitat that strongly influences the fish communities had already been altered by the bleaching, such that there was little difference between the pre- and post-cyclone fish communities. Had the mass-bleaching not occurred in 1998, then Cyclone Fay would have had a far more dramatic affect on the fish and coral communities at Scott Reef.

- *Have the biological communities changed in the last 12 months; if so, what are the drivers?*

There have been no major disturbances or changes in the biological communities at Scott Reef in the last 12 months. In the last year, the coral communities have continued to recover from the mass-bleaching in 1998 and more recent and localised impacts of Cyclone Fay in 2004 and Cyclone George in 2007. Although absolute quantification of the annual trends awaits completion of the LTM data analysis, apparent changes in the benthic communities in the last 12 months were a further decrease in the cover of coralline and turfing algae, small increases in the cover of soft corals, branching corals and massive corals, and larger relative increases in the cover of tabulate corals and sponges. The fish assemblages at Scott Reef in 2008 have maintained their post-bleaching composition and an obvious shift towards a pre-bleaching

state has not occurred, however, there is evidence that the assemblages are continually changing. The trajectory of change for each location is mainly away from the initial pre-bleaching structure. This post-bleaching composition is maintained at the overall reef level and also for each location individually. Certain fish species that are more reliant on hard coral (e.g. *Chromis ternatensis*) have continued to increase as the cover of hard coral cover increases, whereas numbers of herbivorous species, e.g. *Plectroglyphidodon lacrymatus*, have continued to decrease through 2008 as the contribution of algal cover has similarly decreased. Total abundances of the larger, more mobile fish species are higher in 2008 than in any of the previously studied years.

- *What has been the temperature regime at Scott Reef in the last 12 months; where there any bleaching alerts, temperature anomalies and any associated bleaching of corals?*

Water temperatures in shallow (ca 9 m) waters at Scott Reef in 2007 and 2008 followed a seasonal cycle of higher temperatures in autumn (April/May) and lower temperatures in late winter (August/September). Although there was minimal variation in mean daily water temperature among locations in 2008, temperatures were consistently 0.5°C lower at SL3 throughout most of 2007 and the summer of 2007/2008. The cooler temperatures at SL3 are a consequence of the regular tidal incursions of cooler oceanic water between West Hook and Sandy Islet (Steinberg et al. 2003; Bird et al. 2004). The cooler temperatures at this location may have ecological significance in relation to the susceptibility of corals to bleaching.

No bleaching alerts were issued for Scott Reef in the last 12 months, but NOAA issued bleaching watches in February and November 2008. Mean daily water temperatures exceeded the NOAA bleaching threshold of 31°C for Scott Reef at all six locations in autumn 2008. The prolonged periods (13 to 28 days) in which water temperature exceeded this threshold are relevant in terms of the development of thermal threshold limits based on in situ temperature or remotely derived data. No bleaching of corals was observed at Scott Reef during any of the four field trips in 2008, with the possible exception of a few colonies within the north Scott lagoon in October.

- *What were the rates of sediment deposition in the last 12 months; how did they vary among sites and how do they compare with other reefs?*

Mean sedimentation rates in shallow water at Scott Reef between February and April 2008 ranged from a low of 0.45 mg cm⁻² d⁻¹ at SL2 to a high of 1.25 mg cm⁻² d⁻¹ at SL1. Future analysis of sediment samples will investigate the amount of variation among locations and the physical and biological content of the sediment.

These sediment rates are at the lower extent of the range (< 1 to 10 mg cm² d⁻¹) expected at reefs not subjected to stresses from human activities (e.g. Rogers 1990). These rates are consistent with mean deposition rates at clear water sites in north-western Australia and New Guinea where mean deposition rates were 1.4 mg cm² d⁻¹ and 1.0 mg cm² d⁻¹, respectively, and are comparable to those recorded at reef locations in Jamaica and the U.S. Virgin Islands where values ranged from 0.1-1.6 mg cm² d⁻¹ (Dodge et al. 1974; Simpson 1988).

1.2 Coral Demography

- *What were the rates of growth and survival of corals at Scott Reef in the last 12 months, what were the possible drivers of variation in growth and survival, and how do these rates of growth and survival compare with corals at other reefs?*

The mean rates of survival and growth of *Acropora spicifera* colonies at Scott Reef in the last year (June 2007 to June 2008) were similar to the previous year, and varied according to their exposure to cyclone disturbance and susceptibility of their different size classes. Differences in growth and survival among locations and size classes were consistent over the two year study period, reflecting the impact of Cyclone George in March 2007. Because Cyclone George occurred at the end of one survey period (June 2006 to June 2007), and shortly before the next (June 2007 to May 2008), its impacts were evident over two survey intervals.

Colonies at locations SL3 and SL4 were worst impacted by Cyclone George, having low rates of growth and survival, particularly the largest size classes. The survival of colonies at SL3 ranged from 10 to 90% yr⁻¹, between 2006 and 2008, and growth ranged from a mean decrease in diameter of -4 cm to a mean increase of 6 cm yr⁻¹, depending on size class. Similarly, the survival of colonies at SL4 ranged from 15 to 90% yr⁻¹ between 2006 and 2008, and the growth rates of colonies ranged from a mean decrease in diameter of -14 cm to a mean increase of 4 cm yr⁻¹, depending on size class. At both SL3 and SL4, the larger colonies were most susceptible to the wave energy generated by the cyclone, and had the lowest rates of survival and a high incidence of negative growth following injury and the loss of live tissue. At both locations the rates of survival for colonies > 25 cm diameter were <30% yr⁻¹ between the 2006 and 2007, and 2007 and 2008 surveys. The low rates of survival for the largest (> 25 cm) colonies between June 2007 and June 2008, several months after the cyclone (March 2007), were due to the eventual mortality of injured colonies.

Location SL1, and particularly SL2, were more sheltered from the impact of Cyclone George than SL3 and SL4, and had higher rates of growth and survival that were similar across the size classes. The survival of colonies of all sizes classes over the two year period ranged between 75 and 90% yr⁻¹ at SL1, and was > 94% yr⁻¹ at SL2; rates of growth ranged between 2.5 and 5.5 cm yr⁻¹ at SL1, and between 4.5 and 10.1 cm yr⁻¹ at SL2.

Preliminary data and literature searches indicate that the rates of growth and survival of *Acropora spicifera* at Scott Reef in the absence of cyclones are particularly high, and similar across size classes. In contrast, the survival of corals at reefs exposed to more localised anthropogenic disturbances (e.g. overfishing, degraded water quality) is generally lower and more size-specific, with smaller corals having lower rates of survival than larger corals (e.g. Hughes 1996). This size-specific survival may be due to the disproportionate impact of algal competition and sedimentation on the smallest corals; whereas Scott Reef has a low abundance of macroalgae and low rates of sedimentation. Thus, in contrast to other published results, the mean rates of survival for small colonies at Scott Reef over several years may prove to be higher than for larger colonies, which are more susceptible to physical damage associated with cyclone disturbance. Data collection over several years is required to confirm these initial patterns of growth and survival, and their responses to different disturbance regimes and the increasing density of corals as communities continue to recover from the bleaching.

1.3 Genetic Connectivity of Coral and Fish

- *What genetic approaches are being used to quantify patterns of connectivity among fish populations (summarise in three paragraphs)?*

Genetic studies have important practical and theoretical advantages over other methods for inferring patterns of connectivity. Genetic tools utilise the inherent differences in the DNA sequences of individual genomes that accumulate through selection or drift when gene flow is restricted. Well-developed theoretical models utilise either gene frequencies (e.g. allozyme and microsatellite data), or genealogical relationships of specific DNA sequences (e.g. mitochondrial DNA sequences), to measure the spatial distribution of genetic variation, allowing assessment of the genetic similarity of populations, subpopulations or individuals. This allows for estimation of the extent of genetic mixing, and thus provides an effective method to investigate the influence of dispersal and subsequent recruitment on the distribution of molecular variants.

There are many different molecular tools that can be applied for maximum benefit to different biological questions. The overall study, which seeks to contrast and compare both fish and coral components, will utilise microsatellite markers that have several attributes that make them the marker of choice for addressing ecological questions. When adequate sample sizes are used (between 30 and 60 individuals), detecting population differentiation within and among reefs and systems using an Analysis of Molecular Variance has strong statistical power, as well as for applying a model-based clustering method to infer the most likely number of populations in the data set. If the level of population division is sufficiently large, recent migrants will also be identified using assignment tests. In addition to microsatellites, mitochondrial DNA (mtDNA) markers are also being utilised in the fish study to complement the microsatellite data. mtDNA data are useful for providing a evolutionary context for the ecological analyses of the microsatellites by delineating deeper patterns of genetic structure (e.g. evolutionary significant units, cryptic species identification) and reconstructing past demographic processes (for example bottlenecks, population size expansions).

Two fish species that differ in life histories and behaviour are being used as representative models in this study. *Chromis margaritifer* is a common pomacentrid that lives in close association with live branching corals and is more abundant in exposed slope habitats. This species lays demersal eggs and once hatched, larvae live in the pelagic environment for between 30 and 36 days. This mode of reproduction is common in these reefs, and the pelagic larval duration is relatively high for fish that associated with live coral. Therefore, *C. margaritifer* will provide a good representation of many coral reef fish that have a relatively high potential for long-distance dispersal. *Cheilodipterus artus* is a common apogonid cardinal fish which broods its eggs in its mouth before releasing larvae that spend about three weeks in the plankton before they settle. These apogonids live in more sheltered water in lagoons, congregate in schools under reef overhangs, and are patchier in their distribution compared with *C. margaritifer*. In addition, adult cardinal fish have strong homing behaviour to their diurnal resting sites. Therefore, the genetic structure of *C. artus* is likely to be representative of those coral reef fish with greater natal homing potential. The expectation is that the apogonid will exhibit increased genetic structure compared to the pomacentrid.

- *Based on AIMS' results and published data, to what extent does larvae exchanged between Scott Reef and the Rowley Shoals contribute to the maintenance of their fish populations?*

Genetic data from a brooding and a broadcast spawning coral at Scott Reef and the Rowley Shoals showed that the majority of larvae of both species were retained on their natal reef or

reef patch (Underwood et al. 2007; Underwood et al. 2009; Underwood in press). The conclusion is that short-term recovery of these coral communities after severe disturbance requires input of larvae from viable communities kilometres to a few tens of kilometres away. Therefore, the isolated reef systems of northwest Australia clearly rely on their own production of coral larvae for the ecological maintenance of populations. It seems that oceanographic mechanisms of retention, a propensity for coral larvae to settle within a few days (Gilmour et al. in press), and reduction in numbers of larvae through predation and dilution in the open ocean, mean that successful long-distance dispersal of coral larvae over hundreds of kilometres is rare.

In contrast to coral larvae, the larvae of coral reef fish typically have longer obligate pelagic larval durations (PLD), as well as an ability to influence their own dispersal trajectories through more advanced swimming, sensory and feeding capabilities. These biological characteristics will affect the routine and rare dispersal distances of larvae, but so far, no research has been published on patterns of connectivity of fish among the offshore reefs of northwest Australia. Estimates of water particle transport from satellite tracked drifters and mean current speeds, show that dispersal of particles between Scott Reef and Rowley Shoals takes about a month (Gilmour et al. in press). Therefore, for species with relatively short PLD's, it is unlikely that larvae exchanged between Scott Reef and Rowley Shoals make significant contributions to recruitment and maintenance of populations at these systems. With respect to species with longer PLD's, the pattern of connectivity is more complex and less predictable. Considerable evidence from the literature indicates that larvae of many fish species, including those with relatively long PLD's, self-recruit back to their source populations (Swearer et al. 1999; Cowen et al. 2000; Swearer et al. 2002). The primary biological mechanism of retention seems to be the ability of larvae to migrate vertically, actively swim against currents and to sense and swim towards home reefs, thereby increasing rates of self-recruitment. In addition, there are physical mechanisms that retain larvae in the vicinity of natal reefs including; island wake effects, tidally driven vertical mixing of water, topographic complexity of coastlines, and coastal boundary layers of reduced flow-speeds near the shore, which all increase residence times of water particles (and potentially larvae) near reefs (Largier 2003). However, the ability of fish larvae to feed on the plankton, to sense and swim to reefs from many kilometres away, and a putative ability to delay metamorphosis, increases the chances that larvae may successfully disperse between Scott Reef and Rowley Shoals. Such long-distance transport between systems is likely to be important for gene exchange and hence patterns of genetic diversification over intermediate to long-term time scales (more than hundreds of years), but the strength and regularity of such connections relevant to the maintenance of populations over ecological time scales (years to tens of years) of is currently unknown.

Congruent with these predictions, preliminary sequence data collected by AIMS on two species of coral reef fish suggests genetic mixing has limited genetic diversification and geographic structuring among reefs and systems at Scott Reef and Rowley Shoals. The inference is that significant larval exchange between Scott Reef and Rowley Shoals occurs over intermediate to long-term time scales. However, these sequence data are influenced primarily by historical patterns of gene flow, and provide little information on contemporary patterns of dispersal that influence population maintenance, which will be addressed by future analysis of microsatellite markers.

1.4 Coral Reproduction and Recruitment

- *What species of spawning and brooding coral reproduced last autumn?*

Participation in mass-spawning was inferred by *in situ* determination of gamete maturity, based on visual observations of gamete pigmentation and size. In 2008, the majority of colonies and species that were sampled haphazardly were inferred to spawn in autumn (86% of all colonies, and 83% of all surveyed species). In the genus *Acropora*, the majority of colonies and species were also inferred to spawn in autumn (84% of colonies and 81% of *Acropora* species).

Of the species and colonies that were predicted to spawn in autumn, the proportion that spawned in March versus April was uncertain. It was assumed that colonies with large and pigmented eggs would have spawned during March, whereas those with unpigmented eggs would have spawned in April. However, a rapid visual survey conducted in early April suggested that many of the colonies that were expected to spawn in April had already spawned. With the exception of the brooding corals *A. brueggemanni*, *A. palifera*, and *Seriatopora hystrix*, none of the corals that were examined in April had visible eggs. Therefore, many of the 86% of colonies and 83% of species that were predicted to spawn in autumn were likely to have spawned in March. This pattern of egg development and spawning was unusual, because it indicates that at least some colonies spawned unpigmented eggs, or that eggs became pigmented closer (< 3 weeks) to the time of spawning than expected, in contrast to most findings.

- *What species of spawning and brooding coral reproduced last spring?*

In October 2007, 59% of species sampled haphazardly participated in the spring spawning event (based on those species with adequate replication). Of the species sampled rigorously, 70% had between 20-80% of their colonies predicted to spawn in October. These species were also predicted to spawn in November, but the proportion of colonies was far lower, and none were likely to spawn exclusively during November. Less than 12% of colonies of any species were predicted to spawn in November, with the exception of *A. monticulosa*, for which 25% of colonies were predicted to spawn in November and 35% in October.

- *What is the relative 'significance' of the reproductive periods during autumn and spring each year?*

Based on the developmental stage of coral eggs within colonies sampled during 2008, the dominant coral spawning period at Scott Reef is autumn (March / April), with a secondary, lesser spawning event in spring (October / November). Research prior to 2008 also indicates that the greatest proportion of species and colonies participate in the autumn spawning, with the spring event being a minor, secondary event.

Estimates of the percentage of colonies and species participating in any spawning event are biased by non-random sampling design. Alternately, a random sampling design provides sufficient replication to elucidate patterns of reproduction in only the most common species. Thus, future work will combine data obtained from our stratified sampling design of reproduction in the most abundant coral species with measures of their percentage cover, to provide a quantitative estimate of the relative 'significance' of spawning events during autumn (March – April) and spring (September – November).

- *Do any species reproduce only during the autumn or spring periods?*

None of the 31 species that have been sampled with sufficient replication (>10 colonies) seem to spawn exclusively in spring, with the possible exception of *A. millepora*. Of all the species sampled, 83% appear to spawn solely in autumn, and 16% spawn in both autumn and spring. However, the participation by colonies and species in the spring spawning is not fully understood, and may involve only a small proportion of colonies, during only some years. Thus, a reasonable understanding of the participation in the spring spawning will require sufficient replication of colonies over several years.

Previous sampling of *Acropora* over consecutive years indicates that some populations may participate in both spawning events during some years. There is evidence that populations of at least five species of *Acropora* participate in both autumn and spring spawning events, but it is not known whether individual colonies participate in one or both of these events. During spring 2008, replicate colonies of species thought to spawn exclusively in spring or autumn, or during spring and autumn, were tagged to provide insights into whether populations and individuals spawn once or twice a year. Additionally, analyses of these samples may indicate whether two oogenic cycles are routinely initiated in some colonies twice a year, but only one set of eggs fully matures and is spawned.

Corals at Scott Reef whose larvae are brooded internally (brooders), rather than develop externally (spawners), are likely to have multiple gametogenic cycles throughout the year. Although the proportion of brooding species at Scott Reef is relative small, some (e.g. *Acropora bruegmanni*, *Seriatopora hystrix*) can have a high percentage cover that changes dramatically through cycles of disturbance and recovery. Regular sampling and histological analysis of the most abundant brooding corals will provide further insights into their periods of reproduction. In addition, some common spawning corals (e.g. *Porites*) may also reproduce outside the times of mass-spawning, and ongoing sampling and microscopic analyses of gamete development will provide insights into any exceptional patterns of reproduction, and the relative 'significance' of spawning events during any one period.

- *How do the patterns of reproduction in corals during the last year compare to previous years?*

Based on these data and those collected in October 2007, all species of *Acropora* participated in the autumn spawning, and no species spawn exclusively in spring (with the possible exception of *A. millepora*). However, there is evidence that populations of at least five species of *Acropora* participate in both autumn and spring spawning events. It is not known whether individual colonies participate in one or both of these events. Of the 25 colonies from 16 species of non-*Acropora* scleractinian corals sampled (families Faviidae, Merulinidae, Oculinidae, and Pectiniidae), all but one colony were expected to spawn in autumn. Seasonal differences are evident between the two major spawning periods at Scott Reef, however further sampling is required to determine the role of taxonomic, spatial, and temporal variability in gametogenesis, gamete maturation, and gamete release.

Causes for variable patterns of reproduction are likely to be multi-factorial, involving a combination of species-specific responses to a variety of conditions including lunar cycles, insolation, water temperature, day length, sunset time, and previous participation rates during earlier spawning events. Further research is required to determine the role of biological and environmental cues in spawning timing and synchronicity.

- *What were the rates of coral recruitment at Scott Reef following the reproductive period last autumn; how do these rates of coral recruitment compare to previous years, and do they indicate that the coral communities have/are recovering from previous disturbances?*

The rates of larval supply and recruitment at Scott Reef have continued to increase since the 1998 bleaching event, with a particularly large increase in 2008. The mean rates (\pm S.E.) of recruitment at Scott Reef have increased from < 0.3 (± 0.2) recruits plate⁻¹ yr⁻¹ one year after the bleaching (1999), to 2.3 (± 1.5) in 2003, and 70.4 (± 57) in 2008. On average, the rates of recruitment ten years after the bleaching in 2008 had exceeded the mean (\pm S.E.) pre-bleaching rate of 53 recruits plate⁻¹ yr⁻¹ in 1997. The rapid increases in recruitment in recent years (>2004) probably reflect the maturation and rapid increases in colony size from approximately five years after the bleaching. After 2003, there was a corresponding increase in the number of colonies of adult size and rapid increases in the percentage cover of hard corals. Given their greater number of polyps, the largest coral colonies are known to make a disproportionately high contribution to reproductive output and therefore, rates of recruitment.

Although the mean rate of recruitment in 2008 had surpassed that prior to the bleaching, this was not the case at all locations and considerable spatial variation in recruitment across Scott Reef persists. By far the highest mean (\pm S.E.) rates of recruitment in 2008 were 354 (± 52) recruits plate⁻¹ yr⁻¹ at location SL1 at the lagoon side of east hook which has consistently had the highest recruitment of all locations both before and after the bleaching event. The high level of recruitment at location SL1 reflect the easterly flow of water through the channel between north and south Scott Reef, and the eddy on the lagoonal side of east hook that entraps larvae generated from more westerly locations. By comparison, there were much smaller increases in recruitment at all other locations after 2003, and by 2008 the mean rates of recruitment (\pm S.E.) at locations SL2, SL3, SL4 and SS1 ranged between 5 and 35 ($\pm <5$) recruits plate⁻¹ yr⁻¹. The rates of recruitment in 2008 were similar or greater than those prior to the bleaching at all locations, with the exception of location SS2 on the outer slope of North Scott Reef; at SS2 the mean (\pm S.E.) rate of recruitment in 2008 was 1.6 (± 0.4) recruits plate⁻¹ yr⁻¹, which was less than 20% of that prior to the bleaching.

Recruitment rates in 2008 indicate that communities at most locations across Scott Reef are continuing to recover from the bleaching in 1998, and that more rapid increases in percentage cover may occur in the future. Given that recruitment rates have returned to a similar level to those prior to the bleaching at all locations (except SS2), then cover would also be expected to return to pre-bleaching levels within years.

Executive Summary

This report summarises the current status of the coral and fish communities at Scott Reef based on the research by AIMS in 2008 under the contract with WEL (No. 4600001754) and is set in the context of monitoring by AIMS commenced in 1994. In particular, the recovery of communities since the mass-coral bleaching in 1998 is discussed, as is the effect of periodic cyclone disturbance on their trajectories of recovery. The report also discusses the progress of research into the patterns of connectivity of coral and fish communities within Scott Reef, and communities at other reef systems in the region. Finally, some preliminary data are presented for the coral communities in the deep water lagoon at south Scott Reef, and variation in water temperatures and rates of sedimentation.

The general conclusions of this report are:

- ▶ The coral communities at Scott Reef are continuing to recover from the system-wide impact of mass-bleaching in 1998 and the more localised impact of two subsequent cyclones, with the cover of hard corals at some locations similar to that prior to the bleaching.
- ▶ The structure of benthic communities differs from that prior to the bleaching, with half the cover of soft corals, a higher abundance of tabulate corals and a lower abundance of branching corals.
- ▶ The fish communities are also responding to the changes in habitat arising from coral bleaching and cyclones, with the abundance of large fish at locations now similar or greater than that prior to the bleaching, but with the abundance of small fish varying among locations and through time.
- ▶ The current structure of fish communities differs from that prior to the bleaching, and some fish species that are strongly associated with groups of hard corals or algae have decreased or increased in abundance relative to these benthic groups.
- ▶ Preliminary data suggest that tabulate corals at Scott Reef have high rates of growth and survival, which are reduced during periodic cyclone disturbance that disproportionately impact the larger colonies.
- ▶ Patterns of genetic connectivity of corals among locations at Scott Reef and other reef systems in the region suggest these systems are largely self-seeded, and rely on the local production of larvae to maintain communities and facilitate recovery from disturbance.
- ▶ Sequence data show a lack of geographic structure in two coral reef fish species, suggesting that larvae are not only capable of dispersing the 400km between Scott Reef and Rowley Shoals, but do so over intermediate to longer time frames. However, these preliminary data do not shed light on contemporary patterns of connectivity that will be determined in future analyses.
- ▶ Most species and individual corals at Scott Reef participate in a mass-spawning in autumn (March/April) each year, with a comparatively small number of species and individuals participating in a second mass-spawning in spring (October/November), but there is evidence of populations of several species participating in both spawning events.
- ▶ Rates of larval supply and recruitment of corals are now similar to those prior to the bleaching, at all but one location, reflecting the maturation of colonies that had recruited following the bleaching and suggesting more rapid increases in coral cover in future years in the absence of disturbances.

- ▶ There have been no anomalies in water temperature at Scott Reef over the past year, and rates of sedimentation were very low.
- ▶ Preliminary data indicate that the deep-water coral communities at the south Scott Reef lagoon are very different to the shallow water communities and may have regional significance. A total of 51 scleractinian coral species from 27 genera and 11 families were recorded, including 8 new records for Scott Reef, 5 new records for Western Australia and 2 new records Australia-wide.
- ▶ The combination of data being collected in the SRRP Project 1 provides an excellent basis on which to compare the dynamics of coral and fish communities at other reefs, and determine the extent to which current ecological paradigms (e.g. from the Great Barrier Reef) apply to the Scott Reef system.

1 Introduction

1.1 Long Term Monitoring

Natural disturbances play important roles in the processes that influence the structure and dynamics of marine communities (Sousa 1984; Pickett and White 1985) and in the case of coral reef habitats, may be critical for the maintenance of species diversity (Connell 1978; Karlson and Hurd 1993; Jones and Syms 1998). Extreme disturbances may result in altered community composition through the elimination of species, whereas moderate levels of disturbances may promote local diversity by reducing the abundance of competitively dominant species and allowing inferior competitors to persist (Connell 1978; Petraitis et al. 1989).

Among the most common natural disturbances to Australian coral reefs are predation by *Acanthaster planci* starfish and waves associated with cyclones. Historically, coral reef communities have been resilient to cycles of impact and recovery from these major disturbances over periods of years to decades (Connell 1997). However, since Connell's review in 1997, there is global concern that the increasing scale, frequency and diversity of disturbances to which coral reef communities are exposed will reduce their resilience and cause widespread degradation. Many of the most significant threats to coral reefs in the future have emerged only in the last ten years, as a consequence of climate change, such as predicted increases in sea-water temperature, ocean acidification, outbreaks of coral disease, and an increase in severity and/or frequency of cyclone disturbances. Should this combination of disturbances cause major impacts to coral reef communities at frequencies of less than a decade, then the periods of recovery are unlikely to be sufficient to maintain current levels of abundance and diversity. A dramatic example of the cumulative effects of multiple disturbances is evident on coral reefs in the Caribbean, where the combination of overfishing, urchin disease and cyclones have caused a "coral-algal phase shift", whereby communities are now characterised by much lower levels of coral and a persistent state of high algal cover. There is now global concern that the combination of climate change, overfishing and degraded water quality are causing dramatic declines in the health and integrity of coral reef ecosystems, associated losses of biodiversity, and decreases in their social, ecological and economic values (Hughes et al. 2000; McManus et al. 2000; Pratchett et al. 2008).

Long-term studies that quantify the impact and recovery from major disturbances are invaluable to our understanding of the resilience of coral reef ecosystems in a changing world. In particular, studies that allow discrimination between the impacts of natural and anthropogenic disturbances on coral and fish communities provide insights into the periods of recovery, and the extent to which these periods vary according to the synergisms between natural and anthropogenic disturbances. However, decreases in the numbers of coral reefs free of local anthropogenic impacts (e.g. over-fishing, degraded water quality) means there are fewer case studies with which to compare the periods of recovery following impacts from natural (e.g. cyclones) or global (e.g. elevated water temperatures) disturbances. Therefore, studies at Scott Reef quantifying the local impacts of cyclone disturbance and the wide-spread impact of mass-coral bleaching in the last decade provide valuable insights into the resilience of coral reef communities in the absence of some major anthropogenic stressors affecting coral reefs world-wide (e.g. commercial or recreational fishing, degraded water quality); however, traditional fishing of some animals (e.g. species of sea cucumber, *Trochus* and sharks) at Scott Reef has been intense.

The Scott Reef system is ideally suited to studies of the impacts of cyclones and elevated water temperatures on coral communities because its distance from the mainland means it is not exposed to many of the anthropogenic stressors affecting other reefs around the world, such as degraded water quality from terrestrial runoff. However, the coral communities at Scott Reef are exposed to a high frequency (< decades) of cyclonic activity and were exposed to elevated water temperatures causing mass-coral bleaching in 1998. Since 1994, long-term monitoring of the coral and fish communities has quantified their resilience to this cycle of disturbances, in the absence of other localised stressors.

Since monitoring at Scott Reef began in 1994, disturbances to the system have been associated with extreme water temperatures in 1998, and periodic cyclones. Seawater temperatures at Scott Reef rarely exceed 31°C at 16m depth, whereas for two months (March and April) in 1998 temperatures remained between 30 and 32°C. As a result, there was a catastrophic mortality of corals across all study sites at Scott Reef, and in a range of habitats and depths down to 20m. In contrast, cyclone disturbances at Scott Reef tend to have more localized and heterogeneous impacts, but also occur more frequently. On average, at least one cyclone develops in the region of Scott Reef each year. Since monitoring commenced in 1994, there were major impacts to coral communities in March 2004 from Cyclone Fay (Gilmour 2004; Gilmour and Smith 2006), and there has since been four other cyclones that passed within the vicinity of Scott Reef (Table 1). Category 5 Cyclone Fay passed directly over Scott Reef in March 2004, at which time it had a central pressure of 905 hPa and wind speeds of over 300 km per hour. Tropical Cyclones Raymond and George passed within 50km of Scott Reef in January 2005 and March 2007, respectively (Fig. 1, Fig. 2 & Fig. 3).

Category 2 Cyclone George passed Scott Reef on 6th March 2007, with maximum wind speed of 92 km h⁻¹; Category 1 Cyclone Raymond developed close to Scott Reef but with maximum winds speeds of < 60 km h⁻¹. Cyclones Clare and Glenda passed in the vicinity (80 to 150 km) of Scott Reef in January and March of 2006, respectively. Of all these cyclones, Cyclone Fay and Cyclone George are thought to have had at least a moderate impact on the coral communities at Scott Reef, with little impact from the other cyclones. As each of these cyclones passed below Scott Reef the wind direction would predominantly be from the west or south. For this reason,, the locations that were likely to have been affected most by the associated increase in waves were the relatively exposed SL3, SL4 and SSI locations.

Table 1 Cyclones that have passed in the vicinity of Scott Reef since 2004

Year	Month	Day	Cyclone	Central Pressure (hPa)	Maximum wind speed (km/h)	Min dist. Scott Reef (km)
2004	March	21	Fay	905	300	0
2005	January	1	Raymond	995	56	< 50
2006	January	7	Clare	994	84	120
	March	27	Glenda	950	150	110
2007	March	6	George	976	92	< 50

Fig. 1 Track of category 5 Cyclone Fay along long the north-Western Australian coastline, and directly over Scott Reef in 2004. Insert, meteorological picture illustrating the scale of Cyclone Fay adjacent to Western Australia.

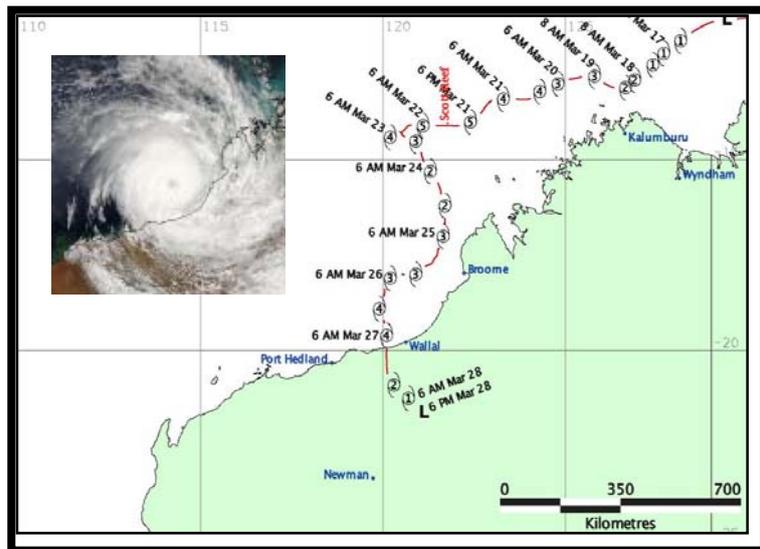


Fig. 2 Track of Tropical Cyclone Raymond in 2005.

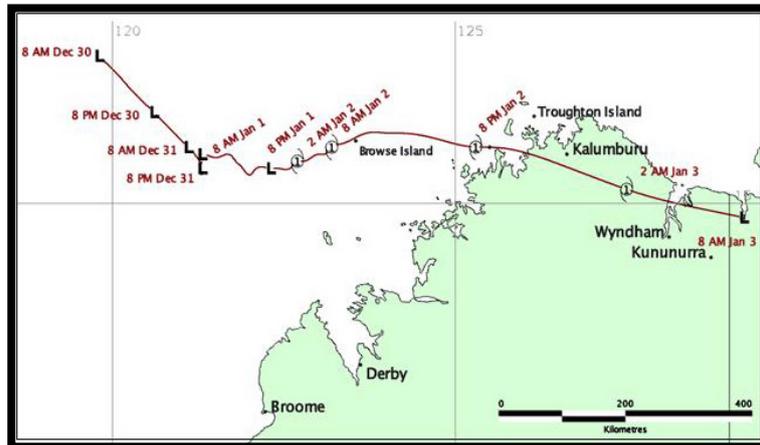
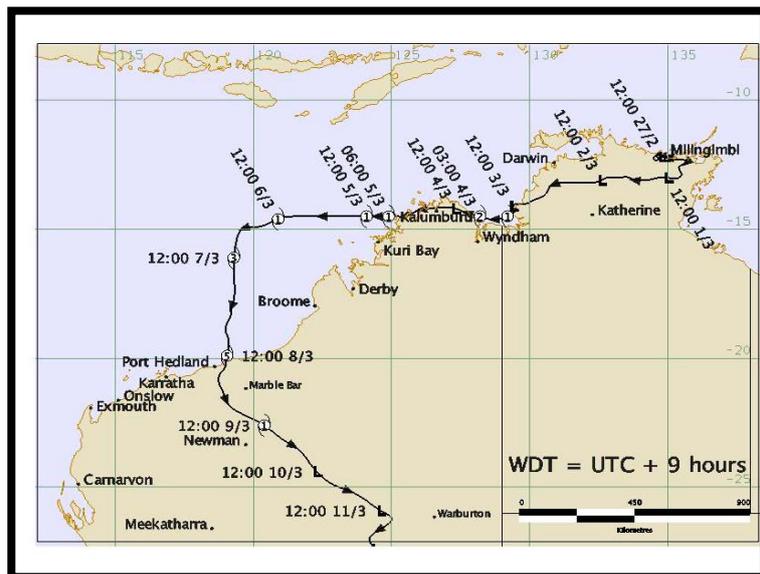


Fig. 3 Track of Tropical Cyclone George in 2007.



1.2 Coral Demography

Monitoring programs of coral reefs have traditionally quantified temporal changes in benthic cover as an indication of health, with high or increasing coral cover regarded as indicative of a healthy reef (e.g. Oliver et al. 1995). However, to adequately manage coral reefs it is necessary to know how and *why* coral cover changes through time (Hughes 1996; Connell 1997; Bellwood et al. 2004). This requires an understanding of population demography (structure and dynamics) through the collection of complementary data, which also enables inferences to be made about the future consequences of observed changes. Ideally, the number of individuals of different size-classes (population structure) is quantified through time, in addition to the rates of recruitment, growth and survival (vital rates) that underlie population structure (Caswell 1989; Ebert 1999). These data can then be incorporated into simple matrix models to provide a measure of population health (growth rate), and to project future changes under a variety of physical and biological conditions (e.g. Done 1987; Fong and Glynn 1998; Fong and Glynn 2000).

To provide insights into demographic causes of changes in coral cover and community structure at Scott Reef, relative to disturbance regimes, the vital rates of populations were quantified for two species of coral with contrasting life histories. *Acropora spicifera* and *Goniastrea* spp. were chosen because they are abundant at Scott Reef and have contrasting life histories that are characteristic of species with corymbose and massive growth forms, respectively. Several hundred colonies of each species were tagged at sites across Scott Reef, and their rates of growth and survival quantified for different colony size classes. The rates of recruitment and size-structure of colonies within study sites were also quantified. In addition to providing insights into the causes of observed changes in coral cover for the different groups of corals, these data will be combined into models that provide estimates of the relative 'health' of each population, the relative importance of different colonies to population maintenance, and the likely changes in population structure in the future under a range of hypothetical disturbances regimes.

1.3 Genetic Connectivity

The current lack of spatially and temporally explicit knowledge of dispersal represents the most critical scientific gap in the understanding required for the effective management of marine systems (Gerber et al. 2003; Sale et al. 2005). In the Timor Sea in northwest of Australia, this knowledge gap is particularly limited. Although long-distance transport of larvae among the isolated coral reef systems in this region seems feasible based on coarse calculations of mean current speeds and pelagic larval durations, considerable evidence from studies elsewhere indicates that larvae of many marine species self-recruit to their source populations (Jones et al. 1999; Swearer et al. 1999; Cowen et al. 2000; Swearer et al. 2002; Largier 2003; Taylor and Hellberg 2003; Jones et al. 2005; Johnson and Black 2006; Almany et al. 2007; Gerlach et al. 2007).

A genetic study of two species of hard corals showed that recruitment to Scott Reef and Rowley Shoals is predominantly local (Underwood et al. 2007; Underwood et al. 2009). Significant genetic subdivision for both species between systems (>100 km), and between (>10 km) or within reefs (<10 km), indicated that many reefs or reef patches are demographically independent for both a brooding and broadcast spawning coral. Because these patterns of genetic structure were not only strong, but were also consistent between the two species of corals that differed in reproductive mode, these results are likely to be applicable to many hard corals in this region. The primary implication is that short-term recovery of these coral communities after severe disturbance requires the input of larvae from viable communities that are only kilometres to a few tens of kilometres away. In addition, genetic divergence in

the broadcast spawner between the coastal (Dampier Archipelago and Ningaloo Reef) and offshore (Scott Reef and Rowley Shoals) zones cannot be adequately explained by geographic distance, indicating that transport of larvae between these zones via large-scale oceanic currents is rare even over multiple generations (Underwood in press). These results also suggest that the coastal and offshore coral systems of northwest Australia will have to rely on their own genetic diversity to adapt to environmental change in the next few decades to centuries.

In contrast to coral larvae, fish larvae have more developed swimming and sensory capabilities, and it is unknown how this will affect their scales of routine and rare dispersal. Therefore, the extent of genetic and demographic connectivity in two species of coral reef fish within and among the isolated systems of northwest Australia is being investigated. This will involve an assessment of the ways in which the different life history and behavioural characteristics of these two fish influence their dispersal. The secondary objective is to compare and contrast these patterns with the corals, and utilising the oceanographic and ecological data from other Scott Reef projects, develop a multidisciplinary model of connectivity within and beyond Scott Reef.

1.4 Coral Reproduction and Recruitment

Many species of Indo-Pacific corals participate in mass spawning or multi-specific spawning events that involve the synchronous release of their gametes over a few nights each year (Harrison and Wallace 1990; Baird et al. 2000; Guest et al. 2002; Carroll et al. 2006; Mangubhai and Harrison 2006; Nozawa et al. 2006). On reefs around Australia, most research into broadcast-spawning corals was initially conducted on the Great Barrier Reef where many corals spawn their gametes over a few consecutive nights each year (Harrison et al. 1984; Willis et al. 1985). Synchronous spawning was subsequently reported for reefs off Western Australia (Simpson 1991; Babcock et al. 1994), and further studies identified more species participating in mass spawning events. However, further studies also identified differences in the times of spawning on in- and offshore reefs and the tendency for 'split-spawning' to occur over consecutive months during some years (Harrison et al. 1984; Willis et al. 1985; Simpson 1991). In addition, quantification of cycles of gametogenesis in an increasing number of colonies and species provided evidence of spawning at times other than during the main nights of mass spawning, over a more protracted period, and more than once a year in a few species (e.g., (Wallace 1985; Harrison and Wallace 1990; Stobart et al. 1992; Wolstenholme 2004).

On the east coast of Australia, mass spawning of corals occurs predominately in October and November (Harrison et al. 1984; Willis et al. 1985) with a small proportion of coral species spawning outside of these months (Wolstenholme 2004). On the west coast, mass spawning occurs primarily in March and April (Simpson 1991; Babcock et al. 1994), however recent research has found consistent evidence of biannual spawning at several reefs in north Western Australia (Gilmour et al. 2007b; Rosser and Gilmour 2008). At Scott Reef, mass-spawning occurs predominately in autumn, with a secondary multi-specific spawning event recorded in spring (Gilmour et al. 2007b). The proportion of species and colonies that participate in these two spawning events at Scott Reef during the late spring remains poorly understood and it is unclear whether separate colonies within a species participate in biannual spawning or whether biannual spawning occurs only at the level of the population. Similarly, there is no knowledge of the times of planula release by many common species of brooding corals which are periodically abundant and play a key role in community structure and dynamics.

Future sampling at Scott Reef will quantify the relative participation by colonies and species in the autumn and spring mass-spawning events, and provide insights into the times of planulae production by brooding corals. Information about the times of reproduction for the spawning

and brooding corals will also be combined with data on the abundance of different species, to provide estimates of the relative 'significance' of the two mass-spawning periods and of reproductive output during other periods of the year.

The potential for coral larvae produced during mass-spawning events to facilitate the recovery of communities following major disturbances is determined by the rates of larval supply, recruitment, and post-recruitment survival. For example, recovery of a community following a disturbance may be slow, even with high rates of larval supply and recruitment, if post-recruitment survival is low; conversely, recovery would also be slow under favourable conditions and high rates of post-recruitment survival, if the rates of larval supply and recruitment are low. Quantifying the importance of recruitment and post-recruitment processes in determining the rates of recovery of coral communities requires a combination of biological and physical data, detailing the magnitude of the disturbance, the degree of connectivity to communities not affected by the disturbance, the changes in physical conditions, and the vital rates of the communities after the event (e.g. recruitment, growth, survival). However, insights into the relative importance of recruitment and post-recruitment processes can be obtained by simultaneously quantifying variation in coral cover and recruitment over different spatial scales; doing so also provides greater understanding of observed rates of recovery for communities, and the extent to which the reefs are 'self-seeded' and reliant on surviving individuals to restock communities.

Changes in coral cover and rates of coral recruitment have been quantified across Scott Reef over ten years, through a series of disturbances regimes. Most notably, there were large and comparable decreases in coral cover and recruitment across Scott Reef following the mass-bleaching event in 1998, and changes in cover and recruitment though cyclone disturbances were weakly correlated at the scale of individual locations. The data indicate that the Scott Reef system is largely self-seeded, and that even over distances of a few tens of kilometres coral communities rely heavily on the local abundance of adults for the supply of recruits; these conclusion are supported by studies of larval ecology (Gilmour et al. in press) and genetics (Underwood et al. 2007; Underwood et al. 2009).

Because the Scott Reef system is largely self-seeded and the mass-bleaching (1998) reduced coral cover by approximately 80%, the rates of coral recruitment during six years (<2004) after the bleaching event were much reduced compared with pre-bleaching levels (Gilmour et al. 2006). However, more than six years after the bleaching many of the new colonies recruited during this period have grown to size to become effective spawners. Thus, coral cover and recruitment are expected to increase rapidly, and further sampling has been conducted to quantify this relationship. Additionally, further changes in coral cover and rates of recruitment provide more data to investigate the spatial scales at which coral cover and recruitment are correlated, providing better insights into patterns of larval dispersal and connectivity within the Scott Reef system.

1.5 Deep Water Communities

The South Scott Reef lagoon is dominated by extensive areas of high cover coral communities at depths of 30-70 metres. These deep water communities are ecologically significant as they represent a large proportion of the known deep water coral reefs in the Australian North-West Marine Bioregion. The deep water coral communities at Scott Reef are also significant in providing two new taxonomic records for Australia and two new records for Western Australia. In addition, the deep water assemblages may represent potential refugia for the maintenance of the shallow water communities at Scott Reef that are impacted by disturbances, including the effects of tropical cyclones and warm water coral bleaching.

As the deep water (> 30 m) habitats at Scott Reef are beyond the limits of scientific diving, a video grab system was developed to document the coral communities. The video grab system allowed highly targeted, minimal-impact sampling of corals in deep water habitats for laboratory analysis.

2 Materials and Methods

2.1 Long Term Monitoring

Benthic communities

In 1994, a long-term benthic monitoring program was established to assess spatial and temporal changes within reef slope communities across Scott Reef. Eighteen monitoring sites were established along the reef slopes (9 m depth) at six locations (Heyward et al. 1997). Most were located in relatively sheltered areas of low water turbidity and not exposed to oceanic swells; two outer reef locations are exposed to the open ocean (SS1, SS2). Additionally, some of the sheltered locations (i.e. SL3, SL4) are likely to be bathed in more oceanic waters than others (SL1, SL2), as a result of their proximity to deepwater passages (Fig. 4). At each location, the three sites were separated by approximately 300 m, and at each site were five permanent 50 m transects, were deployed along the 6 to 9 m depth contour, marked at 10 m intervals and separated by approximately 10 m.

To quantify changes in cover of benthic organisms, permanent transects were surveyed annually between 1994 and 2000, and again in 2001, 2004 and 2008. During each survey, a tape was laid along each transect and the substrata filmed using a video camera held at a distance of 30 cm. The video footage was analyzed using a point sampling technique (Ninio et al. 2000), whereby the footage for each transect was paused at 40 regular intervals and the organism or substrata beneath each of five fixed points assigned to a benthic life-form category. The hard and soft corals were identified to genera and divided among growth forms.

Fish communities

To provide a relative description of the fish communities at Scott Reef, the total number of fish species were summarised from taxonomic surveys of the communities at the reef slope, lagoon and outer-reef margin at the Rowley Shoals, Scott and Ashmore Reef systems (Allen and Russel 1986; Allen 1993; Hutchins et al. 1995; Ceccarelli et al. 2001; WAM 2006). Surveys were conducted using a semi-quantitative visual survey method during a 45 minute swim along a zig-zag course of approximately 250m within a depth range of 0-12 m. Three different observers carried out complementary tasks, recording all the observed fish species and the abundance counts for each species during each swim.

To quantify the changes in the fish communities at Scott Reef, permanently marked transects were visited during the same period (October-January) during 12 surveys between 1994 and 2008. Reef fishes from a list of 210 species (including species from Acanthuridae; Chaetodontidae; Labridae; Lethrinidae; Lutjanidae; Pomacentridae; Scaridae; Serranidae; Siganidae and Zanclidae that occur in the Indo-Pacific region) were counted on fixed transects using underwater visual census (Heyward et al. 1995). Two transect widths were used: 50 × 1 m belts for the Pomacentridae and 50 × 5 m belts for the remaining families.

Multivariate analyses of benthic and fish communities

Counts of fishes were summed to site level and converted to densities (number of fish, 250m⁻²) to account for the difference in transect width for the large mobile versus small sedentary species. The percentage contribution of each of twelve benthic life-form categories was averaged to site level (Abiotic, Branching *Acropora*, Branching non-*Acropora*, Coralline/Turf Algae, Encrusting Coral, Foliose Coral, Massive Coral, Other Coral, Soft Coral, Sponge, Submassive Coral, Tabulate Coral). Thus, for both the fish and benthic databases there were three replicates (sites) for each location, on each sampling occasion (year). For ordination analyses, the density of each fish species and percentage contribution of each life-form category in each replicate were Log₁₀ and square-root transformed, respectively. The means of the transformed values for each location and year combination were then calculated and used to construct respective Bray-Curtis similarity matrices, which were subjected to non-metric multidimensional scaling (nMDS) ordination (Clarke and Gorley 2006).

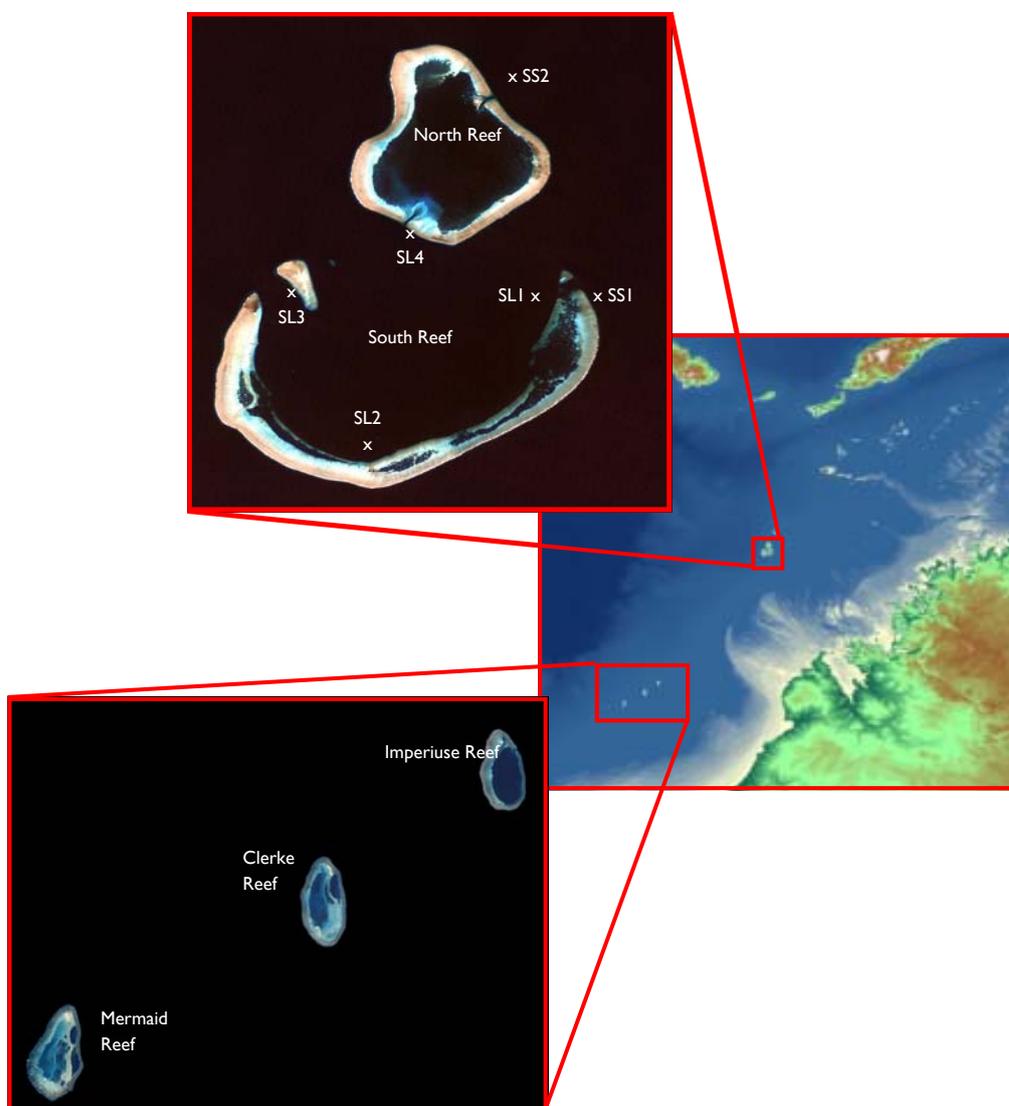


Fig. 4 Study sites at Scott Reef and Rowley Shoals. Note that sites SS3 and SS4 are located at Seringapatam Reef and are not shown.

Using the replicate data and again computing Bray-Curtis similarities on the transformed values, two-way crossed Analysis of Similarities (ANOSIM) were employed with factors being location (6 levels) and year category (4 levels: 1994-1997, 1998-2001, 2003-2006 and either 2007-2008 in the case of fish, or 2008 for corals). For each ANOSIM test, the null hypothesis that there were no significant differences among groups was rejected when the significance level (P) was $< 5\%$, which, for comparison only, is equivalent to a P value < 0.05 in ANOVA terminology. The extent of any significant differences produced by this test was determined using the R -statistic value, which can range from +1, i.e. all samples within each group are more similar to each other than to any of the samples from other groups, down to approximately zero, when the similarities within and between groups are the same. When pairwise ANOSIM comparisons detected that fish compositions differed significantly among locations and/or among year categories, Similarity Percentages (SIMPER) was used to identify which species (fish) and life-form categories (benthos), typified and distinguished the groups.

2.2 Coral Demography

Approximately 1000 colonies of *Acropora spicifera*, and of two species of *Goniastrea*, were tagged at two sites at four locations (SL1, SL2, SL3 & SL4) across Scott Reef. Colonies of *A. spicifera* were first tagged in 2006 and colonies from two species of *Goniastrea* first tagged in 2008. Two species of *Goniastrea* were included in the study because the density of any one of the species alone was insufficient for appropriate replication. However, the two species chosen were *Goniastrea edwardsii* and *G. retiformis*, which are closely related, have the same growth forms, and probably very similar life histories. Colonies were surveyed and photographed annually in May or June, yielding information on survival, growth and injury (after colony images have been digitized). Additionally, permanent transects and quadrats were established at each site to quantify the rates of recruitment, population structures and community interactions. At each site at each location, 3 to 4 permanent quadrats and transects were constructed from stainless steel wire and secured to the substrate with push mounts. Each 6 x 3 m quadrat was equally divided with wire into 48 sub-quadrats (75 x 50 cm) and photographed annually. Along the length of each quadrat a permanent transect (30m) was established, within which the size structure of *Acropora spicifera* and the two species of *Goniastrea* are quantified within a width of 50 cm for colonies < 10 cm length, and a width of 200 cm for colonies > 10 cm in length. The percentage cover of benthic organisms along the permanent transect will also be quantified using the standard long-term monitoring methods.

The mean rates of recruitment, growth and survival of colonies for populations (vital rates) will be combined in simple matrix models to produce estimates of population health and the importance of different sized colonies to population maintenance, under different levels of disturbances (sites and years). The vital rates of different populations will be combined with their size-structures to project likely changes in population size and percentage cover in the future, and to infer the likely recovery times (resilience) following different disturbances. Community interactions among dominant benthic organisms and study species within permanent quadrats will be interpreted relative to the population dynamics and used to supplement the results of demographic and long-term monitoring data.

2.3 Genetic Connectivity of Coral and Fish

There are great practical difficulties involved with tracing movements of large numbers of small propagules with high mortality rates throughout the wide expanses of the pelagic environment. As a consequence, there is absence of direct, empirical data detailing patterns of larval dispersal or retention, and most dispersal studies have utilised a range of indirect, interpretative and aggregative methods (Swearer et al. 2002). Genetic studies on larval dispersal have important practical and theoretical advantages over other methods, and have

been consistently employed to explore these questions since the advent of molecular markers. These methods utilise the inherent differences in the DNA sequences of individual genomes that accumulate through selection or drift when gene flow is restricted. Well-developed theoretical models utilise either gene frequencies (e.g. allozyme and microsatellite data), or genealogical relationships of specific DNA sequences (e.g. mitochondrial DNA sequences), to measure the spatial distribution of genetic variation, allowing assessment of the genetic similarity of populations and subpopulations (Hellburg et al. 2002). This allows for estimates of genetic mixing, and thus provides an effective method to investigate the influence of dispersal and subsequent recruitment on the distribution of molecular variants (Palumbi 2003).

There are many different molecular tools that can be applied for maximum benefit to different biological questions (Sunnucks 2000). Microsatellite markers, which consist of tandemly repeated nucleotide sequences, have several attributes that make them most suitable for ecological studies (Estoup and Angers 1998). Between 30 and 60 specimens from at least six sites from each of Scott Reef and Rowley Shoals will be genotyped with microsatellites. Population differentiation and levels of gene flow within and among reefs will be calculated in an AMOVA framework. A model-based clustering method will be used to infer the most likely number of populations in the data set. If the level of population division is sufficiently large, recent migrants will be identified using assignment and exclusions tests. In addition to microsatellites, mitochondrial DNA (mtDNA) markers will also be utilised in the fish study to compliment the microsatellite data. mtDNA data are useful for providing an evolutionary context for the ecological analyses of the microsatellites by delineating deeper patterns of genetic structure (e.g. evolutionary significant units, cryptic species identification) and reconstructing past demographic processes (for example bottlenecks, population size expansions) (Moritz 1994).

Two species that differ in life histories and behaviour are being studied. *Chromis margaritifer* is a common damselfish that lives in close association with live branching corals and is more abundant in exposed slope habitats. This species lays demersal eggs and once hatched, larvae live in the pelagic environment for between 30 and 36 days. This mode of reproduction is common, and the pelagic larval duration is relatively high for fish species that associate with live coral. Therefore, *C. margaritifer* will provide a good model for many coral reef fish that have a relatively high potential for long-distance dispersal. *Cheilodipterus artus* is a common cardinal fish that broods its eggs in its mouth before releasing larvae into the water column for duration of about 21 days. These fish live in much more sheltered water in lagoons, congregate in multi-specific schools under reef overhangs, and are patchier in their distribution compared with *C. margaritifer*. In addition, adults have strong homing behaviour to their diurnal resting sites (Marnane 2000). These fish feed off the reef at night, and may therefore provide a crucial ecological role in bringing nutrients from the pelagic environment back onto the reef. Therefore, this cardinal fish may be representative of coral reef fish with greater natal homing potential, and levels of genetic subdivision are likely to be greater for *C. artus* compared with *C. margaritifer*. The only relevant study conducted so far supports this hypothesis, and suggested that swimming speed and behavioural ability to home to natal sites may differ between these fish (Gerlach et al. 2007).

In April 2008, a total of 580 individuals of each species were collected from 14 sites for *Chromis margaritifer*, and 12 sites for *Cheilodipterus artus*, at Scott Reef and Rowley Shoals (Fig. 4). Sample sizes per site ranged from between 30 and 60 individuals for each species at each site. In addition to *Cheilodipterus artus*, *Cheilodipterus quinquelineatus* also occurs at Scott Reef and Rowley Shoals, and is impossible to distinguish these sister species underwater. Therefore, some *C. quinquelineatus* were incidentally collected (Table 2), and these samples are being utilised to compliment the *C. artus* data. DNA was extracted from all individuals

collected (more than 1280) with a high throughput DNA extraction protocol (Ivanova et al. 2006). Quality and quantity of DNA was ascertained through gel electrophoresis and spectrometry. In addition to the genetic tissue collections, data on sex, reproductive status and size of each fish were also recorded, and whole samples have been frozen for otolith examination. These data will yield invaluable information about early life history characteristics of the fish, such as pelagic larval duration, age and growth.

Table 2 GPS locations, sample sizes and site habitat of *Chromis margaritifer*, *Cheilodipterus artus* and *C. quinquelineatus* at Rowley Shoals and Scott Reef.

Site	Habitat	GPS	<i>Chromis margaritifer</i>	<i>Cheilodipterus artus</i>	<i>Cheilodipterus quinquelineatus</i>
SL1	lagoon	14° 04.917' S 121° 56.831' E	50	60	-
SL3	lagoon	14° 04.142' S 121° 46.601' E	41	47	9
SL4	slope	14° 01.459' S 121° 51.720' E	50	31	23
SL6	lagoon	17° 08.303' S 119° 39.620' E	14	31	20
SS1	slope	14° 04.576' S 121° 58.554' E	49	63	-
SS2	slope	13° 55.305' S 121° 54.864' E	37	50	-
SS3	slope	13° 37.927' S 122° 01.259' E	32	-	-
SS4	slope	13° 41.893' S 122° 02.431' E	35	-	-
RS1	slope	17° 03.774' S 119° 38.885' E	52	-	-
RS1	lagoon	17° 04.201' S 119° 38.596' E	-	50	19
RS2	slope	17° 08.303' S 119° 39.620' E	44	-	-
RS2	lagoon	17° 08.272' S 119° 39.216' E	-	57	-
RS3	slope	17° 15.285' S 119° 21.667' E	53	-	-
RS3	lagoon	17° 17.405' S 119° 22.196' E	-	50	26
RS4	slope	17° 23.389' S 119° 22.248' E	38	-	-
RS4	lagoon	17° 18.748' S 119° 22.074' E	-	39	3
RS5	slope	17° 30.552' S 118° 57.933' E	47	-	-
RS5	lagoon	17° 32.568' S 118° 57.870' E	-	49	-
RS6	slope	17° 39.445' S 118° 55.321' E	44	-	-
RS6	lagoon	17° 35.335' S 118° 58.155' E	-	60	-
Total			586	587	100

In order to explore whether these fish populations have been isolated for long enough to develop distinct genetic lineages, sequences of the Hypervariable Mitochondrial Control Region I (D-loop) were targeted. For the cardinal fish, these were universal primers CR-A and CR-E (Lee et al. 1995); for the damselfish, the forward primer dLoopF (developed by Bay et al. 2006) was used together with the universal reverse primer CR-E. PCR reactions were conducted in 25µL reactions (0.2 units Fisher Biotech Tth DNA polymerase Taq, 2.5µL of 10X PCR Buffer, 2.5 mM MgCl₂, 2.5 µL of 10 uM dNTP's, 0.4 mM of each primer, 20 ng template DNA). Amplification using the polymerase chain reaction (PCR) was conducted with a cycling profile of an initial 2 min denaturing step at 94°C, then 35 cycles of 30 s at 94°C, 45 s at 48°C and 60 s at 72°C followed by a 10 min terminal extension phase at 72°C. PCR products were cleaned up with Axygen PCR cleanup kit and sequenced in the forward and reverse reaction. Using this procedure, a 394 bp product was amplified in 53 cardinal fish, and a 292 bp product was amplified in 52 damselfish. Four or five individuals were sequenced from most sites. Forward and reverse sequences were aligned with the program Sequencher 4.8, and haplotype and nucleotide diversity were assessed using the program MEGA v4 (Tamura et al. 2007).

A phylogenetic analysis was also conducted with MEGA v4 using the Neighbor-Joining method and the evolutionary distances were computed using the Maximum Composite Likelihood method and are in the units of the number of base substitutions per site (Tamura et al. 2004). A bootstrap consensus tree was inferred from 500 replicates (Felsenstein 1985). Branches corresponding to partitions reproduced in less than 50% bootstrap replicates were collapsed. The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test (500 replicates) are shown next to the branches (Felsenstein 1985). All positions containing gaps and missing data were eliminated from the dataset. This analysis is preliminary and requires validation with more sophisticated evolutionary models.

In order to explore the finer scale patterns of recent connectivity of these coral reef fish, development of microsatellite DNA markers are currently under way. A microsatellite library has been completed for the damsel fish *C. margaritifer*. Initially, recombinant plasmids were produced by ligating restriction fragments from genomic DNA into the Hind III site of pUC19 plasmid. The fragments were enriched for four microsatellite motifs (AAC, CATC, TACA, TAGA). Ligation products were introduced into *E. coli* strain DH5 α (ElectroMaxJ, Invitrogen) by electroporation. To isolate colonies for sequencing, cells from the glycerol stock were spread on BluO-gal/IPTG/ampicillin-LB agar plates, X-gal/IPTG/ampicillin-LB agar plates, and positive colonies were picked and PCR products were amplified with standard PCR procedures. More than 50% of clones were enriched for microsatellites in each library. 96 clones have been sequenced from these libraries, and primers designed for 20 loci. Fourteen reliably amplified and polymorphic products have been obtained and tested on high resolution agarose gel electrophoresis. Collection of data for this species will therefore commence shortly. Progress has also been made in the development of microsatellite markers for the second species *C. artus*. Four microsatellite libraries have been enriched with different repeat motifs (AAC, CATC, TACA, TAGA) and if successful, sequencing from these libraries will commence shortly.

2.4 Coral Reproduction and Recruitment

Pre-Spawning Visual Survey

The reproductive state of corals at Scott Reef was assessed by *in situ* visual examination of gamete development at five locations (SL1, SL2, SL3, SL4, SS2). Replicate colonies of the dominant spawning and brooding corals were sampled in February 2008, prior to the predicted major spawning in autumn.

Colonies were randomly selected adjacent to the long term monitoring transects, identified to species, and then fractured to allow visual examination of eggs within the polyps. Only large colonies (> 20 cm) were examined to ensure that colonies were sexually mature. All branches were selected from the colony centre to avoid the sterile, actively growing colony margins. For each colony, reproductive state (egg presence and colour) was scored for three fragments and used to infer predicted spawning times. Colonies were scored according to the following criteria:

- | | |
|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Score 1 | Large pigmented (red or pink) eggs were clearly visible within polyps, indicating that colonies will spawn following the next full moon, and within one month; |
| Score 1/2 | Unresolved egg state (between states 1 and 2) indicating that colonies will spawn following the next full moon or two full moons, and within one or two months; |
| Score 2 | Large unpigmented (white or cream) eggs were clearly visible within polyps, indicating colonies will spawn following two full moons and within two months; |
| Score 3 | Small unpigmented (white or cream) eggs were visible within polyps, indicating colonies are unlikely to spawn for several months; |
| Score 4 | No eggs were visible within polyps, indicating that colonies had recently spawned, or will not spawn for many months. |

Pre-Spawning Sampling Survey

Adjacent to the permanent quadrats, replicate colonies of *Acropora spicifera* were photographed *in situ*, before a minimum of three branch fragments were collected from the central region of each colony. Fragments of other *Acropora* and non-*Acropora* species were also collected for laboratory analyses. Additional samples were collected from deepwater locations (>30m) with a Van Veen grab to enable preliminary comparison of reproductive ecology between shallow and deep water species.

All specimens were fixed in 10% formalin & seawater, then decalcified using a progressive protocol of increasingly concentrated hydrochloric acid (3-4 days at 1% HCL, 3-4 days at 5% HCL, 2-3 weeks at 10% HCL). After decalcification, specimens were transferred to 70% ethanol for analysis and long term storage.

From each decalcified colony, five polyps were randomly selected from each of the three branches and dissected under a Leica MS205 stereo microscope to derive estimates of fecundity and egg size. Oocyte maximal and medial diameters were measured using Leica Application Suite version 3.1 software, and the geometric mean for each oocyte was calculated as the square root of the maximal x medial diameter. Polyp fecundity was recorded as the number of oocytes per polyp.

Post-Spawning Rapid Visual Assessment

In early April 2008, several weeks prior to the predicted late April spawning period, a rapid visual assessment of the reproductive state of scleractinian corals was conducted at Scott Reef alongside the Surface Supply Breathing Apparatus (SSBA) study. Survey methodology utilised the pre-spawning visual survey technique but was limited to three study locations.

Future Data Analysis

Further sampling will occur prior to the spring spawning period in October / November 2008. Future data analyses will determine the size at sexual maturity of *A. spicifera* by scoring gamete development in small size class colonies. Size at sexual maturity and size-specific fecundity will be determined by correlation of colony dimensions with fecundity per cm².

Size frequency distributions of target species will be determined from digital photography taken of the sampling area (photographs taken at one metre intervals). Colony dimensions will be calculated using Image J software Version 1.38. Random point count software will be used to determine the percentage cover and relative contributions of target species to the community assemblage. Estimates of the total proportion of corals that participate in the mass-spawning events will be derived from the combination of reproductive data and percentage cover of sampled colonies. Histological analyses on the brooding corals *Acropora palifera*, *A. brueggemanni*, and *Seriatopora hystrix* will be utilised to examine cycles of gametogenesis and planula development.

Recruitment of corals

The rates of recruitment of corals at Scott Reef were quantified from 1996 to 1999, and in 2002, 2003, 2006 and 2008, at six monitoring locations (SL1, SL2, SL3, SL4, SS1 & SS2). At each of the locations, six terracotta settlement plates (110mm x 110mm x 10mm) were deployed at each of the three sites separated by 50 m on the reef slope (18 plates location⁻¹ year⁻¹). The six plates were spaced haphazardly, approximately 1 m apart, and attached to the reef (see Mundy 2000) two weeks prior to the predicted mass coral spawning in autumn and collected

eight weeks later. After collection, the settlement plates were bleached and the remnant skeletons of coral recruits counted using a stereo-dissection microscope.

2.5 Physical Data

Water temperature was recorded at six shallow monitoring locations (SL1, SL2, SL3, SL4, SS1 and SS2) at Scott Reef. A single Odyssey water temperature logger was attached to the first star picket (9 m depth) of the first monitoring site at each location. During the initial February field trip, a single logger was sealed in a plastic zip-lock bag before being attached to the star picket with stainless steel wire and cable ties. Each logger was programmed to continuously log water temperature at 60 minute intervals until subsequent retrieval within a year. Loggers were retrieved from three locations (SL1, SL3, SS2) after they had recorded temperature between March 2007 and April 2008.

Sedimentation rates at Scott Reef were derived from the deployment of sediment traps at four lagoon locations (SL1, SL2, SL3, SL4) and two outer-ref locations (SS1 and SS2). Sediment traps were deployed for two months between February and May 2008 and will be processed on each subsequent sampling occasion. Sediment traps were constructed from hollow cylindrical lengths of PVC plumbing tubing that was 700 mm long with an internal diameter of 110 mm (Fig. 5). The bottom of each trap was sealed with a screw type PVC cap and the internal baffle system at the entrance of each trap was composed of seven 150 mm lengths of PVC tube with an internal diameter of 30 mm, joined together and screwed into the top of the trap so that each baffle sat flush with the outer entrance of the trap (Fig. 5). The baffle system was designed to prevent larger organisms from occupying the traps (e.g. fish, crustaceans and octopus), and contaminating the sediment load. At each location, 5 sediment traps were secured with stainless steel wire and cable ties to vertically oriented star pickets at 10m intervals along the first transect at the first site at monitoring locations. Each trap was attached to the star picket so the opening was 80 cm above the substrate.

Upon retrieval of the traps, the sediment and water are passed through a 1 mm sieve to remove any large organic material (e.g. fish and crabs). The retained water containing the sediment is mixed thoroughly to homogenise the sample and four 60 ml replicate sub-samples are extracted with a syringe and vacuum filtered through pre-weighed (5 decimal places) polycarbonate 0.4 μm membrane filters (Fig. 6). Each filter was then placed in a labelled petri-dish and transported to the laboratory frozen. Petri-dishes were placed in an oven overnight at 60°C and then cooled in a dessicator unit before re-weighing the filter to determine the dry weight of sediment (mg). The rate of sediment deposition ($\text{mg cm}^{-2} \text{d}^{-1}$) for each sub-sample was calculated using the weight and volume of water sampled, area of the entrance of the trap and the number of days the trap was deployed.

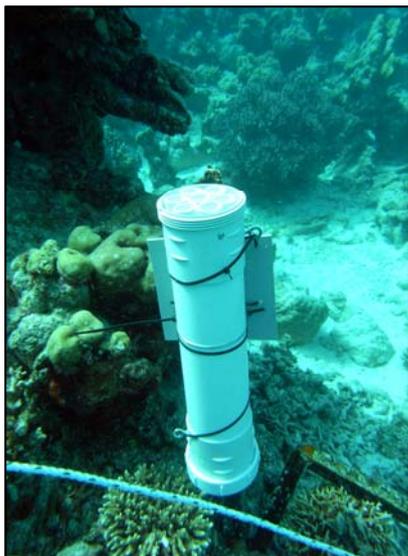


Fig. 5 Sediment trap attached to star picket



Fig. 6 Sediment filtration manifold

2.6 Deep Water Communities

To investigate the deep-water coral communities in the south Scott lagoon, a low-light video camera with live feed was mounted above a Van Veen benthic grab. The video grab was deployed in February 2008 at 69 sites at South Scott lagoon, which ranged in depth from 30-70m (Fig. 7). Sampling sites were selected both randomly and in a stratified design to capture a range of deep water habitats. The video grab system enabled accurate, small-scale sampling of specific coral colonies and the capture of digital images of the deep water coral communities.

Colony samples obtained using the grab were preserved for taxonomic, histological, and genetic analyses. Taxonomic specimens were preserved in bleach (calcium hypochlorite 700g/kg; 250g per 10 litres), then dried, wrapped in paper, and transported to the laboratory. Reproductive specimens were preserved in 10% formalin & seawater, and will be processed according to the protocol developed for shallow water coral samples or using histology techniques. Genetic specimens were preserved in alcohol (99.6% analytical grade) and stored in scintillating vials for future analyses.

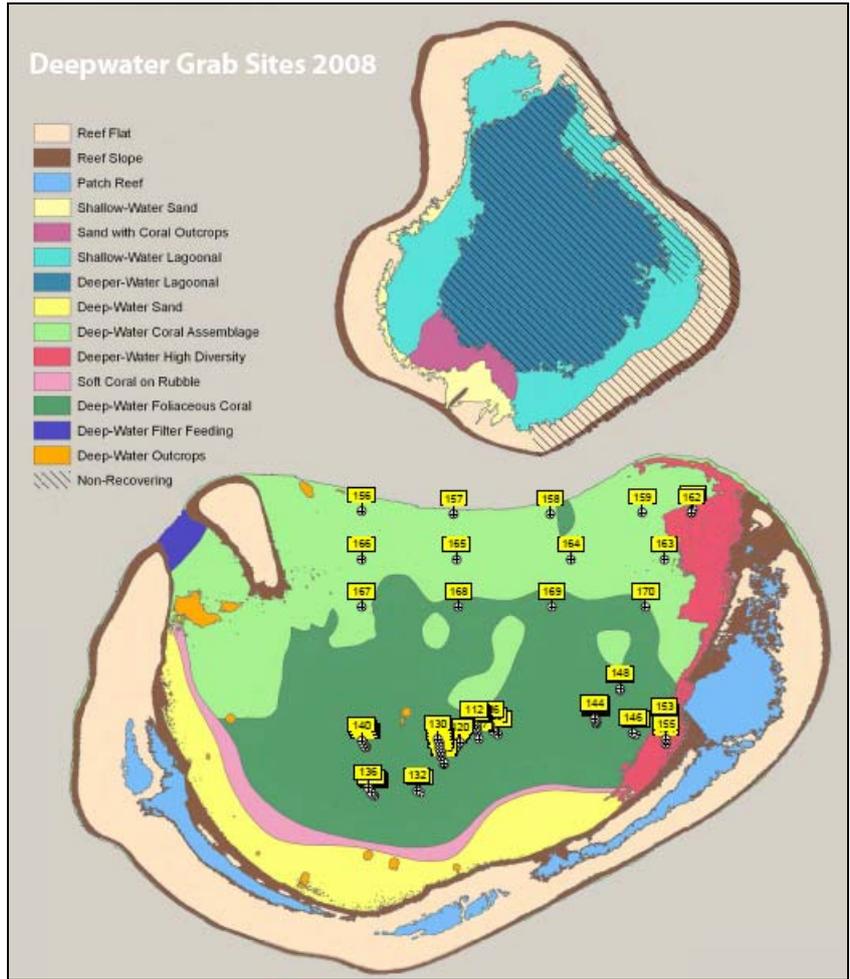


Fig. 7 Deep water grab sites at South Scott lagoon in 2008

3 Results and Discussion

3.1 Long Term Monitoring

Benthic communities: hard and soft corals

The cover of hard corals at Scott Reef is now similar to that prior to the bleaching (1997), although the cover of soft corals remains at approximately half that prior to the bleaching. On average, the total cover (\pm S.E.) of hard corals in 2008 was 37% (\pm 1), compared to 42% (\pm 2) in 1997, whereas the cover of soft corals was 4% (\pm 1), well below that (8% \pm 1) in 1997 (Fig. 8).

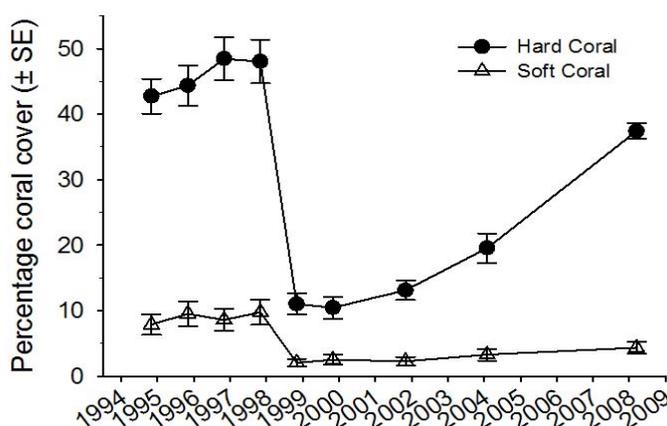


Fig. 8 Changes in the mean cover of hard and soft corals at all monitoring sites across Scott Reef. Mass-coral bleaching occurred in 1998.

The recovery of hard corals and the changes in cover ten years after the bleaching varied among the locations at Scott Reef (Fig. 9). The initial (1998-2004) increases in coral cover were most rapid at the locations (SL1, SL2, SL3 & SL4) least affected by the bleaching, and slowest at the worst affected locations (SS1 & SS2). However, in more recent years (2004-2008) there was a different pattern of change; the locations with the fastest (SL1, SL2, SS1 & SS2) or slowest (SL3 & SL4) increases in cover differed from those shortly after the bleaching (Fig. 9).

Different patterns of change among the locations ten years after the bleaching reflect their different community structures, rates of larval supply and exposures to cyclones. The impact of cyclones on coral communities at Scott Reef varied according to their exposure to the resulting winds and waves. In 2004, Category 5 Cyclone Fay passed directly over Scott Reef, and there were subsequent decreases in mean coral cover at locations SL2, SS1 and SS2 (Fig. 9). Two years later (2006), Cyclone George passed to the south of Scott Reef, again having a variable impact on the coral communities; the smaller relative increases in coral cover at locations SL3 and SL4 between 2004 and 2008 were probably due to the impacts of Cyclone George, which is supported by the patterns of growth and survival of tagged colonies.

Cyclone disturbances at Scott Reef had more localised and heterogeneous impacts on coral communities than did the temperature induced mass-bleaching in 1998, which caused massive decreases in coral cover across the entire reef system. Indeed, throughout the cycles of cyclone disturbance, the mass-bleaching remains the most influential event determining the current cover of hard corals at Scott Reef; the locations (SL2, SS1, SS2) with the greatest absolute and relative decreases following the bleaching had not returned to their pre-bleaching cover in 2008, whereas the least affected locations (SL1, SL3, SL4) had returned to a similar or greater coral cover (Fig. 9). These changes in coral cover reflect the extent to which disturbances that occurred many years ago can influence the current structure of coral communities (Hughes 1989).

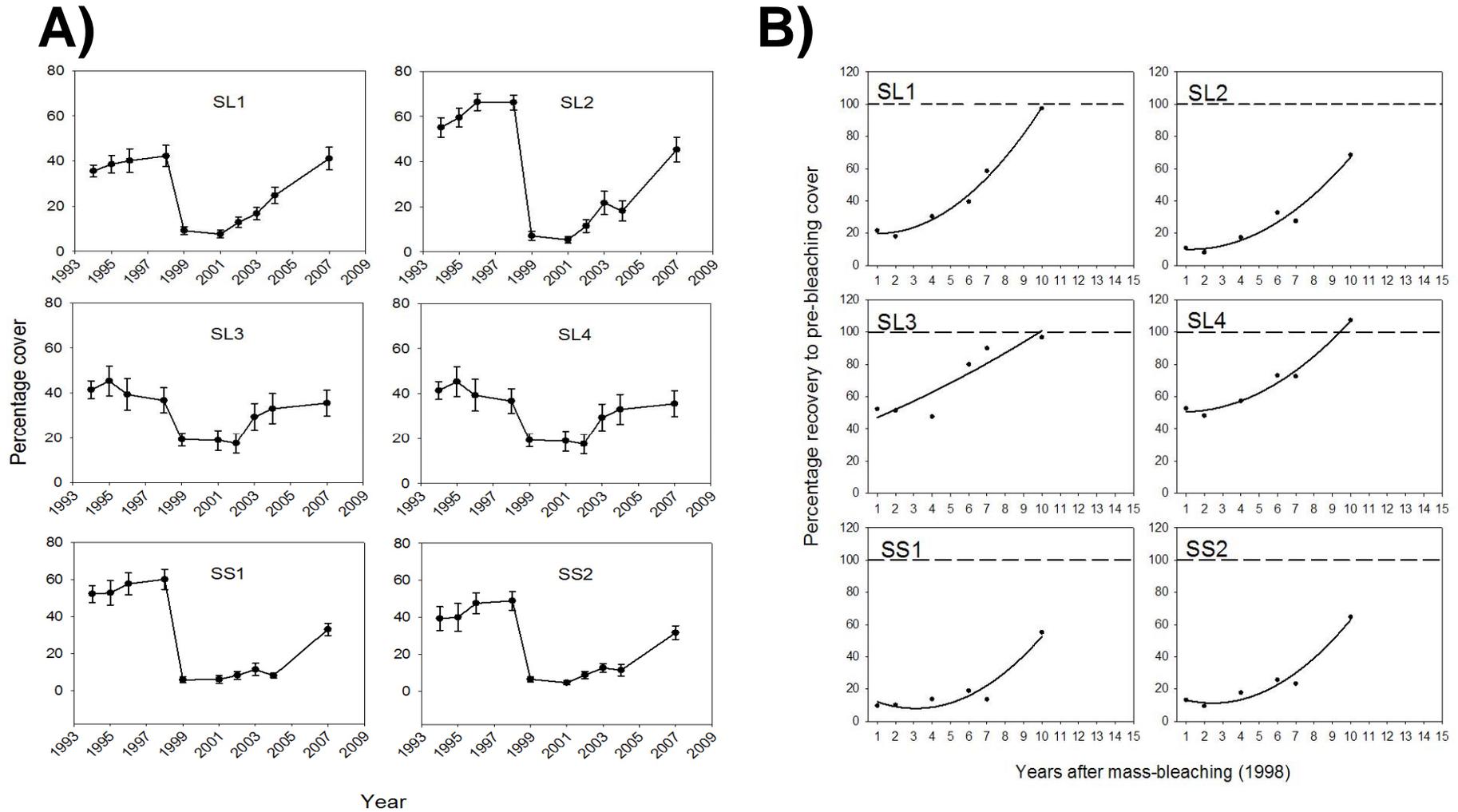


Fig. 9 Absolute changes in percentage cover of hard corals at locations across Scott Reef; the bleaching occurred in 1998, Cyclone Fay in 2004 and Cyclone George in 2006. B) Percentage recovery of hard coral cover to pre-bleaching levels (1997) through time at locations across Scott Reef; recovery is at 100% when mean coral cover is that same as that prior to the bleaching in 1997.

Benthic communities: families of hard coral

The dominant families of hard coral displayed different patterns of impact and recovery from the mass-bleaching in 1998, but ten years later their relative abundances were approaching those prior to the disturbance (Fig. 10). Prior to the bleaching (1997), the family with the highest mean coral cover (\pm S.E.) was the Acroporidae ($27\% \pm 5$), followed by the Poritidae ($10\% \pm 1$) and Pocilloporidae ($4\% \pm 1$). Following the bleaching, the Acroporidae and Pocilloporidae had the largest relative ($>80\%$) decreases in cover, compared to a smaller (56%) relative decrease for the Poritidae; the Acroporidae and Pocilloporidae were also initially slow to recover, with little increase in cover three years later, while there were larger relative increases in the cover of the Poritidae over the same period (Fig. 10). The Poritidae were least susceptible to the bleaching because many colonies suffered partial- rather than whole-colony mortality and the re-growth of survivors resulted in the initial increases in cover (Brown and Suharsono 1990; Loya et al. 2001).

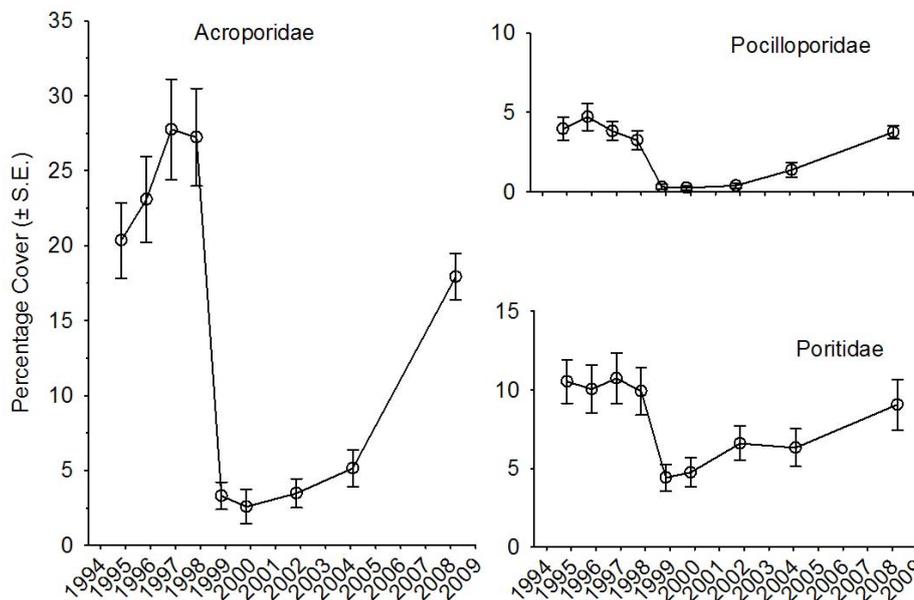


Fig. 10 Changes in the mean cover of the dominant families of hard corals at all monitoring sites across Scott Reef. Mass-coral bleaching occurred in 1998.

More than three years after the bleaching the increases in cover were more rapid for the Acroporidae than for the Pocilloporidae and Poritidae (Fig. 10). By 2008, the mean cover of the Acroporidae and Pocilloporidae had increased to $18\% (\pm 2)$ and $4\% (\pm 1)$ respectively, whereas the Poritidae had increased mean cover to $9\% (\pm 2)$. Ten years after the bleaching, the cover of Acroporidae had returned to 65% of that prior to the bleaching, whereas the cover of the Poritidae and Pocilloporidae was similar or greater than ($>90\%$) that prior to the bleaching. The more recent changes in the cover of the Acroporidae and Pocilloporidae provide examples of how the recovery of these families from major disturbances can accelerate through time, due to comparatively high recruitment and rapid growth (Harrison and Wallace 1990; Halford et al. 2004). Additionally, the ability of the Acroporidae to outcompete (overtop) other species of corals, such as those in the families Poritidae and Pocilloporidae, means they are expected to again become the dominant coral across the Scott Reef system in the absence of additional disturbances.

Compared with the hard corals, the recovery of soft corals was far slower, reaching approximately half their pre-bleaching cover by the final survey. By far the most abundant (>80% cover) species of soft coral were in the family Alcyoniidae, which have had high levels of impact following bleaching events. The Alcyoniidae tend to grow slowly and maintain populations through asexual propagation rather than sexual recruitment, yet there was limited potential for recovery by asexual propagation following the bleaching because most colonies were killed. The high rates of mortality of the Alcyoniidae, and their slow growth and low rates of sexual recruitment, suggest populations are particularly vulnerable to predicted increases in sea-water temperatures, which may become evident in their reduced contribution to communities on coral reefs.

Benthic communities: community structure

The structure of benthic communities at Scott Reef was defined by the percentage cover of the dominant benthic groups, including Abiotic, Branching *Acropora*, Branching non-*Acropora*, Coralline/Turf Algae, Encrusting Coral, Foliose Coral, Massive Coral, Other Coral, Soft Coral, Sponge, Submassive Coral and Tabulate Coral. Since monitoring commenced in 1994, there have been significant differences in the structure of benthic communities across Scott Reef (Figs. 11, 12), due to the different physical conditions at their respective locations. These differences remained throughout the monitoring period, even through the cycles of impact and recovery from disturbances, such that community structure differed significantly both among locations and through time (Two-way ANOSIM; $P=0.1\%$).

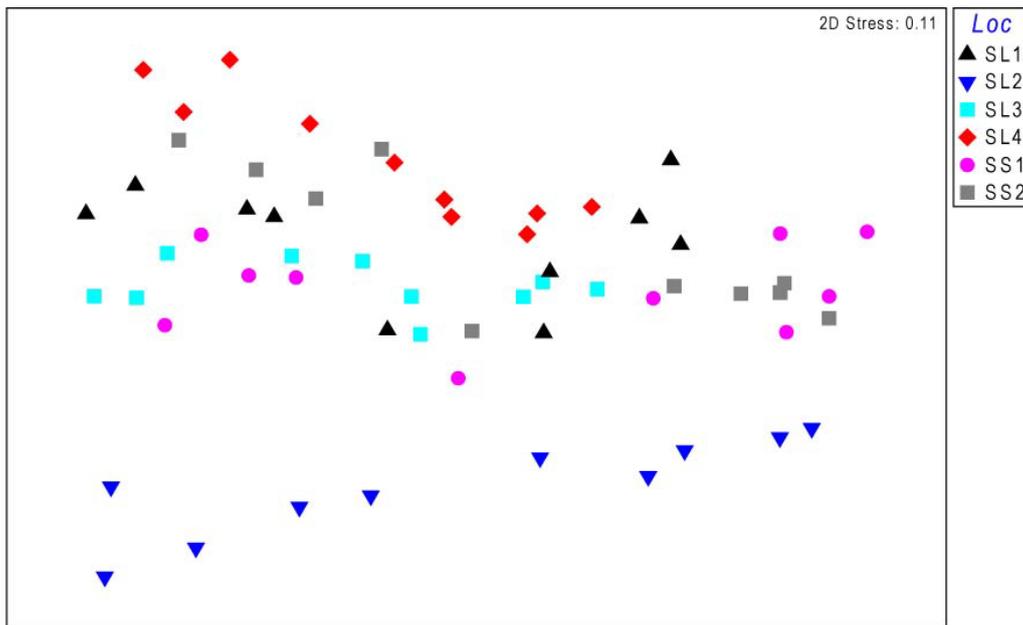


Fig 11. Non-metric multidimensional scaling (nMDS) ordination illustrating the differences in structure of benthic communities at locations (Loc) across Scott Reef, for each survey year between 1994 and 2008.

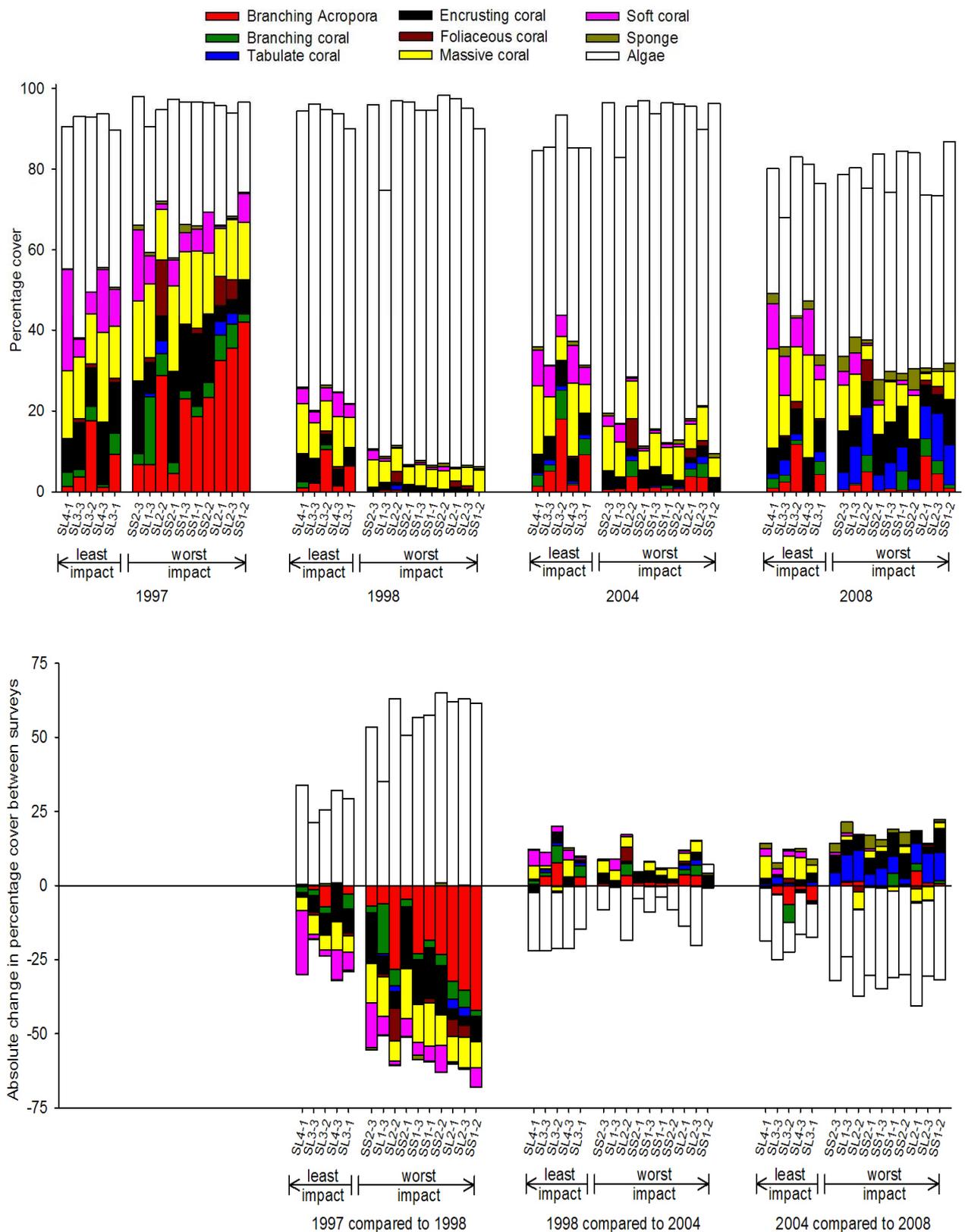


Fig. 12 Temporal variation in percentage cover of benthic groups at sites at Scott Reef; Algae group is predominantly turfing and coralline algae, and not macroalgae. Sites are in order of increasing impact following the bleaching. B) Absolute changes in percentage cover of benthic groups at sites between selected surveys: 1997 compared to 1998; 1998 compared to 2004; 2004 compared to 2008.

Table 3. Degree of similarity and significance of differences in the structure of benthic communities between periods of impact and recovery across Scott Reef. Global significance levels (%) and *R*-statistic values (brackets) are for pairwise comparisons of community structure (percentage cover of benthic categories) in a one-way ANOSIM test. Differences in community structure are significant at a level of <5%. *R* values range from 1, when all samples within each of the groups are more similar to each other than to any of the samples from other groups, to approximately 0, when average similarities within and between groups are the same.

Period	1994 to 97	1998 to 01	2003 to 05
1998 to 01	0.1% (0.903)		
2003 to 05	0.1% (0.753)	0.1% (0.147)	
2008	0.1% (0.488)	0.1% (0.721)	0.1% (0.413)

The significant changes in community structure across Scott Reef clearly separated according to the different periods of disturbance, which are summarised as: pre-bleaching (1994-1997), severe bleaching impact (1998-2001), recovery and localised cyclone disturbance (2003-2005), further recovery and localised cyclone disturbance (2006-2008) (Fig. 13 a, b; Table 3). A similar pattern was evident at each of the locations, although more specific changes in community structure were due to the varying impact of the bleaching and the differing exposure of locations to the localised impact of cyclone disturbances (Fig. 13 c-h). Cyclone Fay in 2004 affected locations SL2, SS1 and SS2 the worst, then SL3 and SL4, then SL1. Cyclone George in 2006 had less severe and more localised impacts, slowing the recovery of communities at SL3 and SL4 and causing a side-ways shift in community structure up to 2008, whereas at the other locations the impact was less and they displayed a large shift towards the pre-bleaching state up to 2008.

The cover of all benthic groups decreased by at least a half (hard corals, soft corals, sponges) following the mass-bleaching in 1998, with the exception of the turfing and coralline algae that increased in cover (\pm S.E.) from 37% (\pm 2) in the years prior to the bleaching to 75% (\pm 4) the year after (Fig. 12). The colonisation of available space by algae following the bleaching did not include the fleshy macroalgae, whose cover was < 1% at all locations both before and after the bleaching. Changes in the relative abundance of the Acroporidae, Poritidae and Faviidae drove the structural changes in the hard coral communities at different sites, from communities previously dominated by branching *Acropora* (47%) and other branching corals (9%), to communities with a lower coral cover in which massive corals had the highest (45%) relative abundance (Fig. 12). Indeed, it was the sites with the highest cover of branching corals that were worst affected by the bleaching and underwent the largest changes in community structure. Thus, changes in the structure of benthic communities following the bleaching were characterised by an increased cover of coralline and turfing algae, and a reduced cover of branching, submassive, encrusting and soft corals (Table 4). The increased cover of coralline and turfing algae, and the increased relative cover of massive corals, characterised the post-bleaching communities (Table 4).

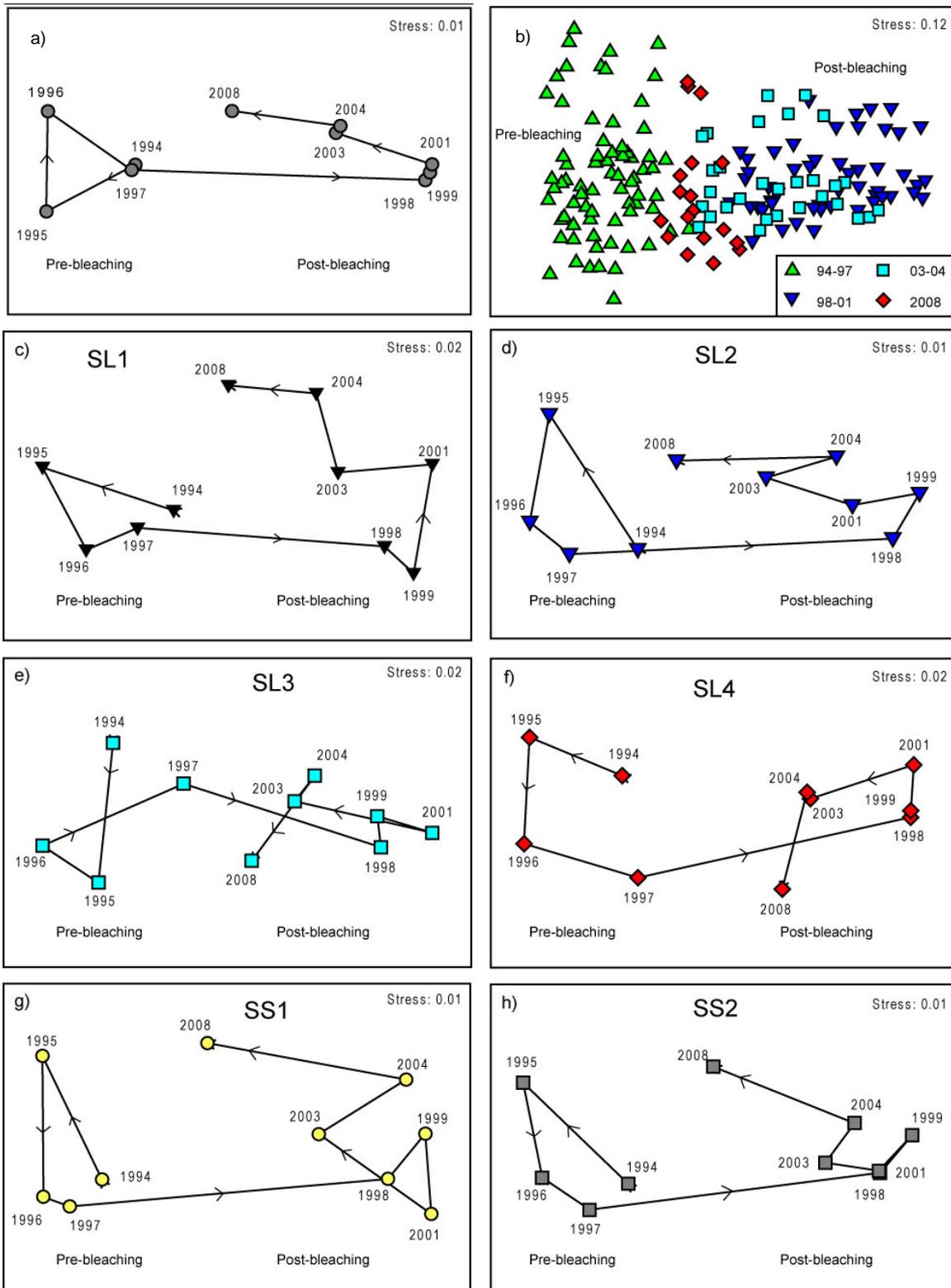


Fig. 13 Non-metric multidimensional scaling (nMDS) ordinations of community structure at Scott Reef between 1994 and 2008. Ordinations for (a) the benthic composition in each year averaged across all locations (b) for all samples coded for year group and (c to h) for each of the six locations separately.

Table 4 Groups of benthic organisms that best *characterise* community structure at locations across Scott Reef (grey boxes) and *distinguish* changes in community structure from one period to the next (white boxes). Groups that *characterise* community structure are most representative across all locations at Scott Reef, as opposed to those that may have high percentage cover at some/most locations. Groups that *distinguish* community structure are those which have the largest changes in percentage cover between periods, from one period (row) to the next (column); the period in which the benthic group increases in cover is in brackets. Within each box, benthic groups are presented in decreasing order of importance, with those that most characterise a community, or those most distinguishing changes in communities, at the top of the list.

Year	1994 to 1997	1998 to 2001	2003 to 2005	2008
1994 to 1997	Abiotic Massive coral Coralline turf algae Encrusting coral Branching non Acropora			
1998 to 2001	Coralline turf algae (98-01) Abiotic (94-97) Branching non Acropora (94-97) Submassive (94-97) Encrusting (94-97) Branching Acropora (94-97) Soft coral (94-97)	Coralline turf algae Massive coral Abiotic		
2003 to 2005	Coralline turf algae (03-05) Abiotic (94-97) Branching non Acropora (94-97) Branching Acropora (94-97) Submassive (94-97) Soft coral (94-97)	Abiotic (03-05) Soft coral (03-05) Encrusting coral (03-05) Coralline turf algae (98-01) Branching Acropora (03-05) Tabulate coral (03-05)	Coralline turf algae Massive coral Encrusting coral Abiotic	
2008	Coralline turf algae (2008) Tabulate coral (2008) Branching Acropora (94-97) Soft coral (94-97) Abiotic (94-97) Branching non Acropora (94-97)	Coralline turf algae (98-01) Tabulate coral (2008) Abiotic (2008) Encrusting coral (2008) Submassive (2008) Branching Acropora (2008)	Coralline turf algae (03-05) Tabulate coral (2008) Abiotic (2008) Soft coral (2008) Submassive (2008)	Coralline turf algae Abiotic Encrusting coral Massive coral Submassive Tabulate Sponge

In 2004 there had been few changes in the benthic communities at Scott Reef. Changes in community structure between 1998-2001 and 2003-2005 were the least significant of all the monitoring periods (Table 3), and the communities were characterised by the same benthic groups (Table 4). Turfing and coralline algae remained the dominant benthic group at all locations (Fig. 12), with a mean (\pm S.E.) cover of 65% (\pm 4), and the mean (\pm S.E.) cover of soft corals ($3\% \pm 1$) and sponges ($<1\%$) remained low. The relative decreases in the cover of algae since the bleaching were however matched by increases in coral cover, which were similar for the branching *Acropora* (2%), other branching corals (1%), and tabulate (1%), foliaceous (1%) and massive (3%) corals. Consequently, the branching *Acropora* had returned to only 21% of its previous cover, whereas the massive corals and tabulate corals had returned to 59 and 100% of their previous cover, respectively; the other groups had returned to between 30 and 40% of their previous cover (Fig. 12).

Ten years after the bleaching the benthic communities continued to return to their previous structure, but the cover of turfing and coralline algae was still higher than that prior to the bleaching and there was an increased cover of tabulate corals and sponges. Turfing and coralline algae remained the dominant benthic group at all sites (Fig. 12, Table 4), with a mean (\pm S.E.) cover of 43% (\pm 2). Small increases in the cover of soft corals between 2004 and 2008 were important in distinguishing the communities from the previous period (Table 4), but the mean (\pm S.E.) cover of soft corals ($4\% \pm 1$) remained low and had returned to approximately half (52%) that prior to the bleaching. Similarly, there were small increases and decreases in the cover of branching *Acropora* and other branching corals at sites across Scott Reef (Fig. 12), to a mean (\pm S.E.) cover of between 2 and 3% (± 1) respectively; the cover of branching *Acropora* and other branching corals had returned to 25% and 47% of that prior to the bleaching, respectively. The massive corals (e.g. Poritidae, Faviidae) continued to increase in cover at some sites, but with small decreases at other sites. On average, the mean (\pm S.E.) cover of massive corals had reached 10% (± 2), which was approximately 60% of that prior to the bleaching. Of all benthic groups, the most notable changes between 2004 and 2008 were the increases in cover of tabulate corals and sponges, and both groups characterised the structure of the benthic communities at the final survey (Fig. 12, Table 3). Tabulate corals were largely composed of species of *Acropora* with table or corymbose growth forms, and had increased at most sites to a mean (\pm S.E.) cover of 5% (± 1), compared to $<1\%$ prior to the bleaching. Sponges also had large relative increases in cover at most sites, to a mean cover of 3% (± 1), compared to $<1\%$ prior to the bleaching. The current structure of benthic communities at Scott Reef is distinguished from that prior to the bleaching by the increased cover of coralline algae, turfing algae, and tabulate corals, and a decreased cover of branching *Acropora*, soft corals and branching non-*Acropora* (Table 4). However, the communities in 2008 were as similar to those prior to the bleaching as in any previous survey, and as similar to the pre-bleaching communities as they were to the community structure in 2003-2005 (Table 3).

As with the changes in the total cover of hard corals, the changes in the cover of specific coral growth forms reflected the exposure of sites to the different regimes of disturbance. For example, the small changes in the abundance of branching corals and the large increases in the abundance of tabulate corals in recent years (>2004) may reflect a combination of successional recovery following the bleaching and the local impacts of cyclone disturbance. At most of the sites least affected by the bleaching, the cover of branching corals had decreased in recent years, rather than the further increases that were expected. However, these sites (e.g. locations SL3, SL4) were also among those most exposed to recent (2006) cyclone disturbances that impact branching corals; the increases in the cover of massive corals over the same period were also largest at these sites (Fig. 12). In contrast, the largest increases in the cover of the tabulate corals and sponges were at the sites worst affected by the bleaching, where the decreases in the cover of branching corals were most significant. Thus, the increases in the cover of tabulate corals may reflect the successional changes in the

community structure following major disturbances; with few branching *Acropora* and branching corals surviving the bleaching, recruitment may have been dominated by the tabulate growth forms which occupied the available space. In the absence of further disturbances, however, the abundances of branching corals would be expected to increase, due to their high rates of growth, local recruitment, and ability to outcompete other corals or sponges. Such successional changes in the cover of branching corals are exemplified by the brooding coral *Acropora bruegmanni*, which was the dominant species prior to the bleaching. *A. bruegmanni* is particularly susceptible to disturbances such as elevated water temperatures and cyclones, but has very high rates of growth and local recruitment, and is capable of crowding and overtopping other benthic organisms. The extent to which branching corals again dominate at many sites across Scott Reef, and the benthic communities return to their previous cover and structure, depends on the regimes of disturbance in the future. In particular, the frequency and severity of cyclone disturbances and whether communities are again exposed to extreme water temperatures arising from climate change.

Fish communities: characteristics

The effects of the 1998 bleaching event and 2004 cyclone were presented in an analysis of 10 years (1994 to 2003) of annual monitoring of fish assemblages at Scott and Seringapatam Reefs (Smith et al. 2004). These results demonstrated that the fish assemblages at Scott Reef five years after the 1998 bleaching were very different from those prior to the bleaching. The spatial structure of the fish communities was initially maintained and impacts from the bleaching typically lagged by 12 - 18 months. Although there were significant reductions in abundances of species that were heavily dependent on hard coral for food and/or shelter, such as the chevroned butterflyfish (*Chaetodon trifascialis*), there were increases in abundances of species with a dietary preference for algae, such as the jewel damselfish (*Plectroglyphidodon lacrymatus*). Species that did not display any marked changes in abundance were often most common at locations least impacted by the bleaching.

Five years after the 1998 coral bleaching, the fish assemblages on five of the seven surveyed locations still differed from their pre-impact structures, although signs of recovery were evident. Such differences in species composition were mainly due to changes in the relative abundances of species within the Chaetodontidae (butterflyfishes) and Pomacentridae (damselfishes), two families whose species exhibit a close association with the benthos. The pattern of recovery of the fish communities are therefore linked to that of the corals, and both are likely to continue to increase to pre-1998 levels in the absence of additional disturbances.

Although the recovery of the benthic communities at Scott Reef was slowed by Cyclone Fay in 2004, there was surprisingly little change in the fish communities (Smith et al. 2004). Only species on the exposed sites showed an obvious shift from pre-cyclone community, which was largely due to an increase in several damselfishes; most significantly, juvenile sized *Chrysiptera rex* and *Pomacentrus philippinus*. The juveniles were too small to include in the January 2004 (pre-cyclone) count, so the shift in abundances of damselfishes may be due to a strong recruitment event prior to the cyclone, rather than any affect of the cyclone. Many of the coral species with a growth form most susceptible to cyclone damage had not recovered from the bleaching. Consequently, the fine scale structure of coral habitats that strongly influences the fish communities had changed little before and after the cyclone, resulting in correspondingly small changes in the fish communities. Had the mass-bleaching not occurred in 1998, then Cyclone Fay might have had a far more dramatic affect on the fish and coral communities at Scott Reef.

The structure of fish communities and their changes through time were quantified at reef slope habitats at Scott Reef during regular surveys from 1995 to 2001 (Gilmour et al. 2007a). The species compositions of communities at Scott Reef differed to those at Rowley Shoals, located 300 km to the south (Fig. 4). The main species responsible for such differences were the damselfishes *Pomacentrus lepidogenys* and *Chrysiptera rex* that were abundant at Scott Reef but absent from the Rowley Shoals. Species richness was higher at Scott Reef (721) than at either Ashmore Reef (568) or the Rowley Shoals (569), however, there were slightly more families of fishes at the Rowley Shoals and Ashmore than at Scott Reef (Fig. 14; Appendix 1). A recent survey of fish at the Rowley Shoals and Scott Reef did not add to these numbers (WAM 2006), however further surveys at Ashmore Reef may yield additional species from that region.

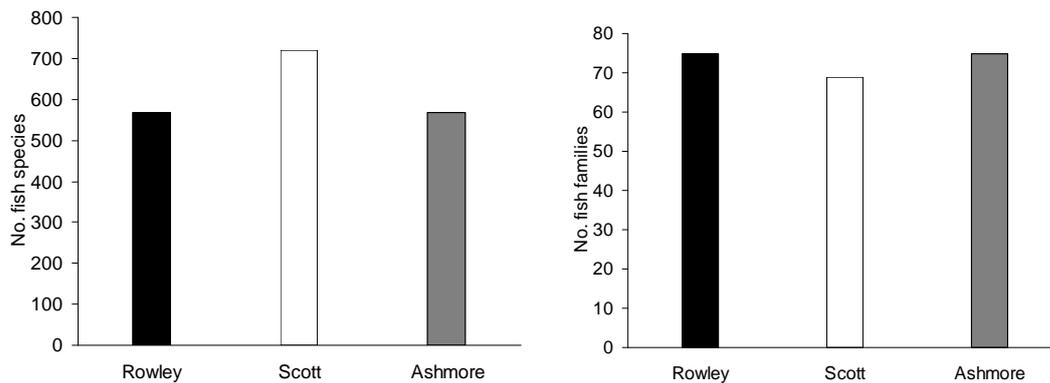


Fig. 14 Total fish species and familial richness of fishes at the Rowley Shoals, Scott Reef and Ashmore Reef.

The mean abundances of the family Pomacentridae (damselfishes) demonstrated a sequential decreasing trend between 1995 and 1999, followed by an increase to 2008 (Fig. 15). In contrast, the mean abundances of the larger more mobile reef fish demonstrates an increasing trend since 1995 (Fig. 16), regardless of the changes in benthic cover following the bleaching. Further monitoring of the fish communities and subsequent analyses that take into account the different trophic categories of fish species will lead to a better understanding of the factors relating to this increase. Reef fish communities are broadly composed of corallivores, coral dwellers, herbivores, omnivores, invertivores, piscivores and planktivores, all with different resource requirements. Corallivorous fishes can be broadly divided into obligate or facultative corallivores. Obligate species are considered to have a diet consisting of at least 80% coral, whereas the level of reliance on coral shown by facultative species varies greatly between individuals and between locations, making it difficult to assess the level of coral dependence for many these species. It may also be relevant that Scott Reef has very low numbers of sharks as a result of heavy fishing pressure, and the removal of these apex predators may have an effect on the predator-prey relationships of the larger reef fish species.

Fish communities: species composition

On the ordination plot for reef fishes recorded at six locations at Scott Reef between 1994 and 2008, the points formed very discrete groups according to location (Fig. 17a). Samples from the most protected location (SL2) formed a group at the bottom of the plot, whereas those from the more exposed locations (SS1, SS2) formed a group at the top. When these samples were coded according to time-period, those from the pre-bleaching period lay to the left of the plot and those from the post-bleaching period lay in the middle and those from

2008 formed a group to the right (Fig. 17b). At the year level, there was a clear separation of the points into a group containing all those from 1994-1999 on the left and all those from subsequent years on the right (Fig. 17c). This pattern was also reflected at each location separately (Fig. 18). The lines overlain on each plot indicate that the fish species composition from 2001 onwards is different to that occurring prior to 2001, irrespective of location. Cyclone Fay in 2004, affected the benthic community at SL2, SS1 and SS2 more than other localities (see previous section), and this is reflected in the sharp shift in trajectory for 2004 on the ordinations for these locations (Fig. 18 b,e,f).

Fig. 15 Mean abundance (95 C.I.) of pomacentrid fishes at Scott reef between 1994 and 2008.

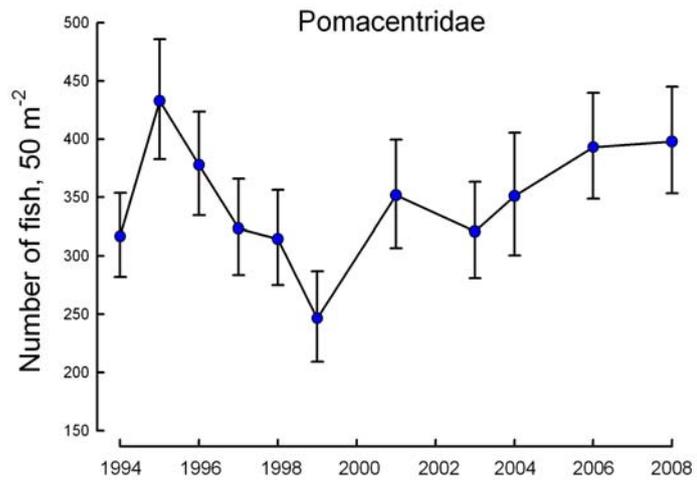
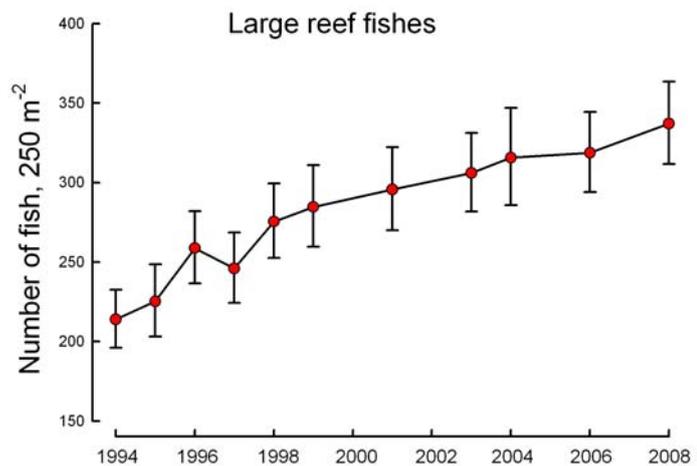


Fig. 16 Mean abundance (95 C.I.) of large reef fishes at Scott Reef between 1994 and 2008.



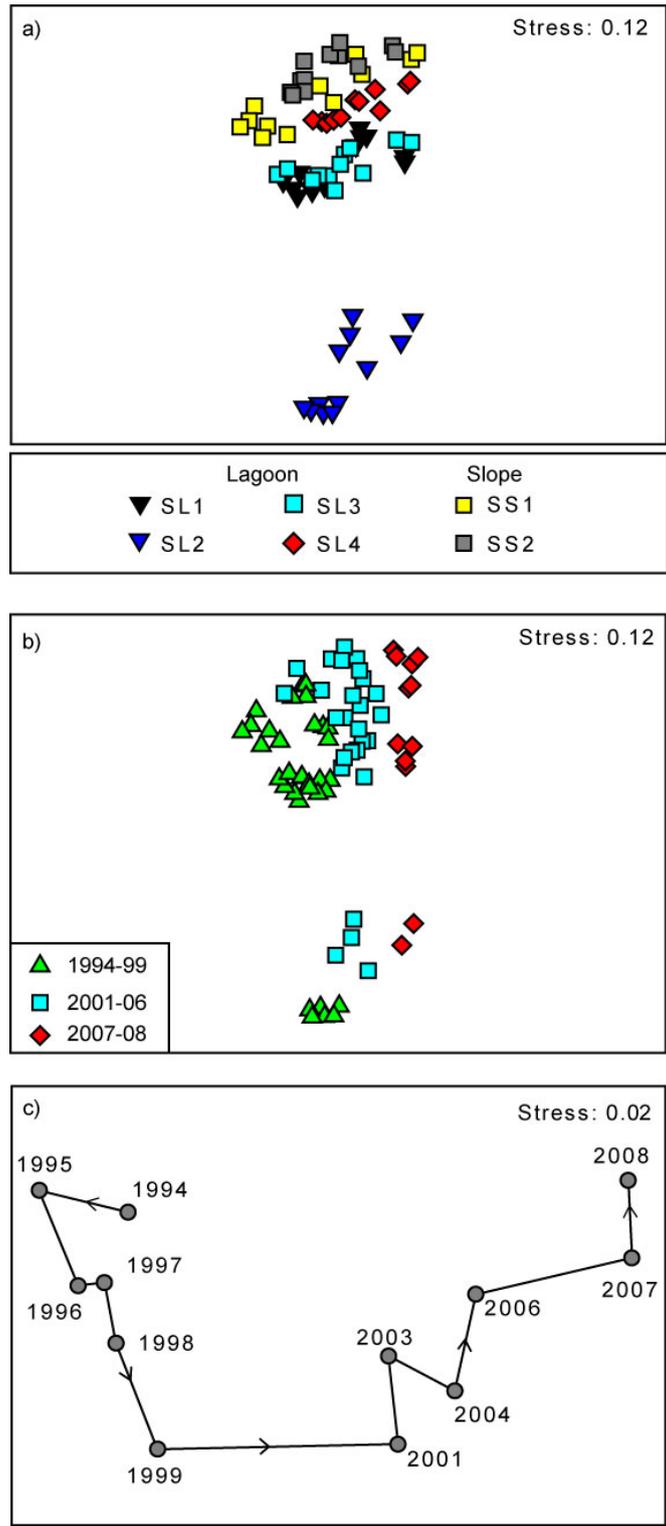


Fig. 17 Non-metric multidimensional scaling (nMDS) ordinations of the species compositions of fish assemblages at six locations at Scott Reef between 1994 and 2008 coded separately for (a) location and (b) year groups and (c) ordination of the species composition in each year averaged across all locations.

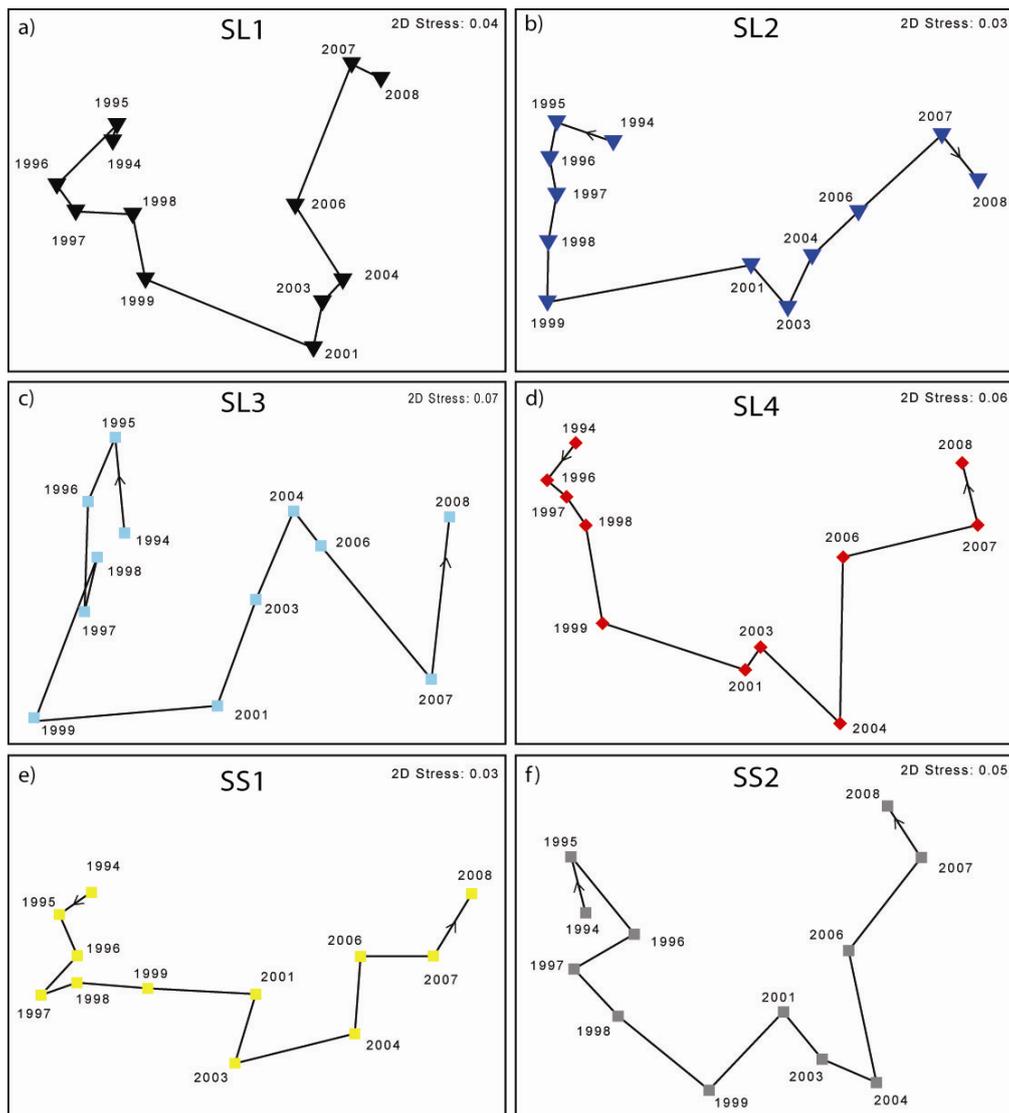


Fig. 18 Non-metric multidimensional scaling (nMDS) ordinations of the species compositions of fish assemblages at each of the six locations at Scott Reef between 1994 and 2008.

Two-way crossed ANOSIM demonstrated that the species compositions of fishes differed significantly among locations and among periods (both $P = 0.1\%$), with the Global R -statistic being greater for location (0.865) than period (0.596). Pair-wise tests showed that the fish assemblages at each location were significantly different from that at each other location (all $P = 0.1\%$). The R -statistic values for pair-wise comparisons between the samples at the different locations varied greatly (0.591 to 1.000). For example, the fish assemblage at SL2 differed to the greatest extent from all other locations, with the R -statistic being *ca* 1.000 for each respective comparison. In contrast, the R -statistics for comparisons between the faunas at locations with similar degrees of exposure were lower, e.g. 0.591 for SL1 vs SL4 and 0.644 for SS1 vs SS2. Pair-wise comparisons demonstrated that the fish assemblages in each period were significantly different to other periods (all $P = 0.1\%$), with the R -statistic for pair-wise tests ranging from 0.341 in the case of 2001/06 vs 2007/08 to 0.755, for 1994/99 vs 2007/08 (Table 5). ANOSIM demonstrated statistically that although each location has its own unique suite of fish species there is an underlying progressive change in species composition from the pre-bleaching to initial post-bleaching through to the most recent time-period.

SIMPER was used to identify the species that characterised each location and time-period and those species most responsible for the differences among these groups. *Pomacentrus phillipinus* was a characteristic species at each location and the same was true for *Pomacentrus lepidogenys* at all but SL2 (Table 6). The fauna at SS2, one of the more exposed locations, was distinguished from that at each other location by greater densities and frequencies of occurrence of *Chromis weberi*, whereas that at SL2, the most protected location, was distinguished from all other locations by greater numbers of *Neoglyphidodon nigroris*, *Stegastes nigricans* and *Dascyllus aruanus*). The fauna at SL4 was distinguished from those at all other locations by relatively greater numbers of *Amblyglyphidodon aureus*. The damselfishes *Pomacentrus phillipinus*, *Pomacentrus lepidogenys* and *Pomacentrus vaiuli* were characteristic of each time-period and the same was true for the surgeonfish group *Ctenochaetus* spp. (Table 7). The fish assemblages at Scott Reef during the 1994 to 1999 period were distinguished from all other periods by greater densities of species such as *Chromis ternatensis* and *Amblyglyphidodon curacao*, whereas the 2001 to 2006 period was distinguished by the lethrinid *Monotaxis grandoculis*. Species that distinguished the 2007 to 2008 period included the snapper *Lutjanus gibbus*, the damselfish *Chromis xanthurus* and the surgeonfish *Acanthurus nigricauda* (Table 7).

Table 5. Global significance levels (%) and R-statistic values (brackets) for pairwise comparisons in a two-way ANOSIM test carried out on data for fish species at Scott Reef between 1994 and 2008.

Period	1994 to 1999	2001 to 2006
2001 to 2006	0.1 (0.597)	
2007 to 2008	0.1 (0.755)	0.1 (0.341)

The use of MDS ordination and ANOSIM demonstrated that the fish assemblages at Scott Reef were influenced by location and by the time-periods in which the surveys were undertaken. The influence of location is likely to be related to the different types of benthic cover (see previous section) and the physical conditions at the respective locations. Although the separation of the fauna according to location was maintained throughout the monitoring period, there was a pronounced tendency for the faunas to change sequentially according to year and to form groups according to period. This trend was particularly apparent on the ordinations for each of the six locations separately. The fish communities at Scott Reef have been undergoing change since the 1998 bleaching event and distinct pre- and post-bleaching fish assemblages are apparent, with a third interim group reflecting the early bleaching period and impact of Cyclone Fay. Ordination also showed that there were temporal changes in the structure of fish communities at Scott Reef within the 1994 to 1998 period (pre-bleaching), however, the magnitude of these changes appears small in relation to those that occurred after 1999 (post-bleaching). Further analyses of the temporal changes in fish assemblages in the pre-bleaching period will determine whether these changes are significant, and if so, the drivers of these changes will be explored, e.g. impact of earlier cyclones. There was a lag in the effect of bleaching on the fish communities, with those shortly after the bleaching (1999) being similar to those before the bleaching (1994 to 1998), however, over time the disparity between pre- and post-bleaching communities increased. Although 10 years have passed since the 1998 bleaching at Scott Reef, the fish communities are still no closer to their earlier composition. This sequential shift away from the pre-bleaching community suggests that it may be some time before the structure of that early period returns, if at all. The distinction of pre- and post-bleaching assemblages parallel the results of a study of long-term changes in the cryptobenthic reef fish community at one location on the Great Barrier Reef (Bellwood et al. 2006). The pattern of change for fish assemblages at Scott Reef differs to that described previously for the benthic communities, which displayed a recent shift towards pre-bleaching structure. Analyses of data collected from further monitoring at Scott Reef will determine whether the fish assemblages continue tracking away from their initial structure, or, as with the benthic communities, make a shift towards a more pre-bleaching composition.

Table 6. Species identified by SIMPER as typifying the reef fish assemblages at the six locations (shaded boxes) and distinguished between the fish assemblages at each pair of those locations (non-shaded boxes). For each pairwise comparison between locations, the species that distinguish between the fauna at one location from that at another location are indicated by the initials of that location. Within each box, species are presented in decreasing order of importance, with those that most characterise a community, or those most distinguishing changes in communities, at the top of the list.

Location	SL1	SL2	SL3	SL4	SS1	SS2
SL1	<i>Pomacentrus philippinus</i> <i>Pomacentrus lepidogenys</i> <i>Pomacentrus vaiuli</i> <i>Chrysiptera rex</i> <i>Chromis ternatensis</i> <i>Chromis atripes</i> <i>Chlorurus sordidus</i>					
SL2	<i>Stegastes nigricans</i> ^{SL2} <i>Chromis atripes</i> ^{SL1} <i>Neoglyphidodon nigroris</i> ^{SL2} <i>Pomacentrus adelus</i> ^{SL2} <i>Dascyllus aruanus</i> ^{SL2} <i>Chromis margaritifer</i> ^{SL1} <i>Pomacentrus amboinensis</i> ^{SL2} <i>Pomacentrus vaiuli</i> ^{SL1}	<i>Pomacentrus adelus</i> <i>Pomacentrus moluccensis</i> <i>Amblyglyphidodon curacao</i> <i>Plectroglyphidodon lacrymatus</i> <i>Pomacentrus philippinus</i> <i>Stegastes nigricans</i> <i>Zebbrasoma scopas</i>				
SL3	<i>Pomacentrus adelus</i> ^{SL3} <i>Chromis margaritifer</i> ^{SL3} <i>Chromis amboinensis</i> ^{SL1} <i>Chromis xanthurus</i> ^{SL3} <i>Chromis lepidolepis</i> ^{SL3} <i>Chlorurus bleekeri</i> ^{SL1} <i>Ctenochaetus strigosus</i> ^{SL3}	<i>Chromis margaritifer</i> ^{SL3} <i>Chromis atripes</i> ^{SL3} <i>Chromis lepidolepis</i> ^{SL3} <i>Neoglyphidodon nigroris</i> ^{SL2} <i>Stegastes nigricans</i> ^{SL2} <i>Dascyllus aruanus</i> ^{SL2} <i>Amblyglyphidodon curacao</i> ^{SL2} <i>Chromis xanthurus</i> ^{SL3}	<i>Pomacentrus lepidogenys</i> <i>Chromis margaritifer</i> <i>Pomacentrus philippinus</i> <i>Pomacentrus vaiuli</i> <i>Chromis ternatensis</i> <i>Chromis lepidolepis</i> <i>Chromis atripes</i>			
SL4	<i>Pomacentrus moluccensis</i> ^{SL1} <i>Chromis ternatensis</i> ^{SL1} <i>Chromis amboinensis</i> ^{SL1} <i>Amblyglyphidodon aureus</i> ^{SL4} <i>Amblyglyphidodon curacao</i> ^{SL1} <i>Dascyllus trimaculatus</i> ^{SL4} <i>Chromis xanthurus</i> ^{SL4}	<i>Pomacentrus adelus</i> ^{SL2} <i>Neoglyphidodon nigroris</i> ^{SL2} <i>Stegastes nigricans</i> ^{SL2} <i>Chromis margaritifer</i> ^{SL4} <i>Pomacentrus moluccensis</i> ^{SL2} <i>Dascyllus aruanus</i> ^{SL2} <i>Pomacentrus amboinensis</i> ^{SL2} <i>Chromis atripes</i> ^{SL4} <i>Chromis lepidolepis</i> ^{SL4} <i>Amblyglyphidodon aureus</i> ^{SL4}	<i>Pomacentrus adelus</i> ^{SL3} <i>Chromis ternatensis</i> ^{SL3} <i>Pomacentrus moluccensis</i> ^{SL3} <i>Amblyglyphidodon aureus</i> ^{SL4} <i>Pomacentrus amboinensis</i> ^{SL3} <i>Ctenochaetus strigosus</i> ^{SL3} <i>Chrysiptera rex</i> ^{SL3}	<i>Pomacentrus lepidogenys</i> <i>Pomacentrus philippinus</i> <i>Chrysiptera rex</i> <i>Pomacentrus vaiuli</i> <i>Chromis xanthurus</i> <i>Chromis margaritifer</i>		
SS1	<i>Pomacentrus moluccensis</i> ^{SL1} <i>Chromis ternatensis</i> ^{SL1} <i>Amblyglyphidodon curacao</i> ^{SL1} <i>Chromis lepidolepis</i> ^{SL1} <i>Chlorurus bleekeri</i> ^{SL1} <i>Chromis xanthurus</i> ^{SS1} <i>Chromis margaritifer</i> ^{SS1} <i>Zebbrasoma veliferum</i> ^{SL1}	<i>Pomacentrus adelus</i> ^{SL2} <i>Chromis margaritifer</i> ^{SS1} <i>Stegastes nigricans</i> ^{SL2} <i>Neoglyphidodon nigroris</i> ^{SL2} <i>Amblyglyphidodon curacao</i> ^{SL2} <i>Pomacentrus amboinensis</i> ^{SL2} <i>Chromis atripes</i> ^{SS1} <i>Dascyllus aruanus</i> ^{SL2} <i>Acanthurus nigricans</i> ^{SS1}	<i>Pomacentrus adelus</i> ^{SL3} <i>Chromis lepidolepis</i> ^{SL3} <i>Pomacentrus moluccensis</i> ^{SL3} <i>Chromis amboinensis</i> ^{SS1} <i>Pomacentrus amboinensis</i> ^{SL3} <i>Forcipiger flavissimus</i> ^{SS1}	<i>Chromis lepidolepis</i> ^{SL4} <i>Chromis weberi</i> ^{SS1} <i>Chromis amboinensis</i> ^{SS1} <i>Chromis ternatensis</i> ^{SS1} <i>Amblyglyphidodon aureus</i> ^{SL4} <i>Acanthurus nigrofuscus</i> ^{SS1}	<i>Pomacentrus lepidogenys</i> <i>Pomacentrus philippinus</i> <i>Pomacentrus vaiuli</i> <i>Chromis margaritifer</i> <i>Chrysiptera rex</i> <i>Plectroglyphidodon lacrymatus</i> <i>Acanthurus nigricans</i>	
SS2	<i>Pomacentrus moluccensis</i> ^{SL1} <i>Chromis weberi</i> ^{SS2} <i>Chromis ternatensis</i> ^{SL1} <i>Chromis atripes</i> ^{SL1} <i>Chromis lepidolepis</i> ^{SL1} <i>Chromis margaritifer</i> ^{SS2} <i>Amblyglyphidodon curacao</i> ^{SL1} <i>Chlorurus bleekeri</i> ^{SL1} <i>Chaetodon kleinii</i> ^{SS2}	<i>Pomacentrus adelus</i> ^{SL2} <i>Chromis margaritifer</i> ^{SS2} <i>Pomacentrus moluccensis</i> ^{SL2} <i>Amblyglyphidodon curacao</i> ^{SL2} <i>Stegastes nigricans</i> ^{SL2} <i>Neoglyphidodon nigroris</i> ^{SL2} <i>Pomacentrus amboinensis</i> ^{SL2} <i>Dascyllus aruanus</i> ^{SL2} <i>Chrysiptera rex</i> ^{SS2} <i>Chromis weberi</i> ^{SS2}	<i>Pomacentrus adelus</i> ^{SL3} <i>Pomacentrus moluccensis</i> ^{SL3} <i>Chromis ternatensis</i> ^{SL3} <i>Amblyglyphidodon curacao</i> ^{SS2} <i>Forcipiger flavissimus</i> ^{SS2} <i>Chrysiptera rex</i> ^{SS2} <i>Pomacentrus amboinensis</i> ^{SL3}	<i>Chromis weberi</i> ^{SS2} <i>Amblyglyphidodon aureus</i> ^{SL4} <i>Chromis lepidolepis</i> ^{SL4} <i>Chromis atripes</i> ^{SL4} <i>Acanthurus nigrofuscus</i> ^{SS2} <i>Chromis margaritifer</i> ^{SS2} <i>Chaetodon kleinii</i> ^{SS2}	<i>Chromis amboinensis</i> ^{SS1} <i>Chromis weberi</i> ^{SS2} <i>Chromis ternatensis</i> ^{SS1} <i>Chromis atripes</i> ^{SS1} <i>Chaetodon kleinii</i> ^{SS2} <i>Chromis xanthurus</i> ^{SS2}	<i>Chrysiptera rex</i> <i>Pomacentrus lepidogenys</i> <i>Pomacentrus philippinus</i> <i>Chromis margaritifer</i> <i>Pomacentrus vaiuli</i> <i>Plectroglyphidodon lacrymatus</i> <i>Chromis xanthurus</i>

Table 7 Species identified by SIMPER as typifying the fish assemblages of reefs in the three time-periods (shaded boxes) and distinguished between the fish assemblages for each pair of those periods (non-shaded boxes). For each pairwise comparison between periods, the species that distinguish between the fauna of one from that of another are indicated by the initials of that period.

Period	1994 to 1999	2001 to 2006	2007 to 2008
1994 to 1999	<i>Pomacentrus lepidogenys</i> <i>Pomacentrus philippinus</i> <i>Pomacentrus vaiuli</i> <i>Ctenochaetus</i> spp. <i>Chromis ternatensis</i> <i>Plectroglyphidodon lacrymatus</i> <i>Chlorurus sordidus</i> <i>Scarus niger</i> <i>Chaetodon trifasciatus</i>		
2001 to 2006	<i>Chromis ternatensis</i> ^{94/99} <i>Chromis weberi</i> ^{01/06} <i>Amblyglyphidodon curacao</i> ^{94/99} <i>Pomacentrus moluccensis</i> ^{94/99} <i>Monotaxis grandoculis</i> ^{01/06} <i>Acanthurus nigrofuscus</i> ^{01/06} <i>Scarus schlegeli</i> ^{01/06}	<i>Pomacentrus philippinus</i> <i>Pomacentrus lepidogenys</i> <i>Chrysiptera rex</i> <i>Pomacentrus vaiuli</i> <i>Ctenochaetus</i> spp. <i>Plectroglyphidodon lacrymatus</i> <i>Chlorurus sordidus</i> <i>Acanthurus nigricans</i>	
2007 to 2008	<i>Chromis ternatensis</i> ^{94/99} <i>Amblyglyphidodon curacao</i> ^{94/99} <i>Lutjanus gibbus</i> ^{07/08} <i>Plectroglyphidodon lacrymatus</i> ^{94/99} <i>Chaetodon punctofasciatus</i> ^{94/99} <i>Chromis xanthurus</i> ^{07/08} <i>Monotaxis grandoculis</i> ^{07/08} <i>Acanthurus nigricauda</i> ^{07/08}	<i>Lutjanus gibbus</i> ^{07/08} <i>Plectroglyphidodon lacrymatus</i> ^{01/06} <i>Monotaxis grandoculis</i> ^{01/06} <i>Acanthurus nigrofuscus</i> ^{01/06} <i>Acanthurus nigricauda</i> ^{07/08} <i>Chromis ternatensis</i> ^{07/08} <i>Chromis xanthurus</i> ^{07/08}	<i>Pomacentrus philippinus</i> <i>Pomacentrus lepidogenys</i> <i>Chrysiptera rex</i> <i>Pomacentrus vaiuli</i> <i>Ctenochaetus</i> spp. <i>Chromis margaritifer</i> <i>Chromis xanthurus</i> <i>Acanthurus nigricans</i> <i>Chaetodon trifasciatus</i>

Fish communities: abundance of individual species

Some fishes display characteristic associations with benthic communities. In general, fish heavily dependent on hard coral for food and or shelter are expected to decline when coral cover declines, and species that utilise algae as their primary food source will increase when the coral cover is replaced by algae. For example the numbers of the coral associated butterflyfish *Chaetodon trifascialis* decreased after the bleaching event in 1998, remained low until 2002, and then increased between 2003 and 2008 following the increase in cover of hard corals (Fig. 19). The damselfish species *Chromis ternatensis* is most common on the outer slope locations and requires live coral for shelter. Its response to the bleaching event was delayed by 12 months, which indicates a gradual reduction in numbers over that period. However, there was an increasing trend in numbers since 2003, largely reflecting the recovery of coral habitat (Fig. 20). In contrast, the numbers of the territorial herbivorous damselfish *Plectroglyphidodon lacrymatus* increased following the bleaching and reached a peak in 2003 before declining to 2008 (Fig. 21). The initial increasing trend may reflect a period when algal cover and food was high following the bleaching, and/or a reduction in competition increased suitable habitat. The latter trend of decreasing abundance may reflect the shift from an algal dominated substrate to one in which hard corals have increased in cover, reducing the space for the farming of the 'algal gardens' that this species defends (Ceccarelli et al. 2001).

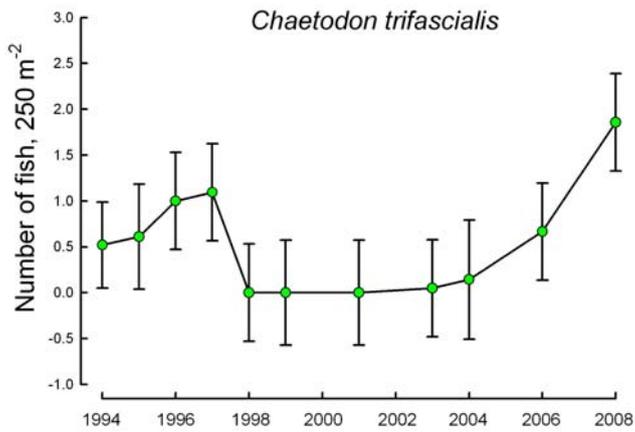


Fig. 19 Mean abundance values of *Chaetodon trifascialis* between 1994 and 2008.

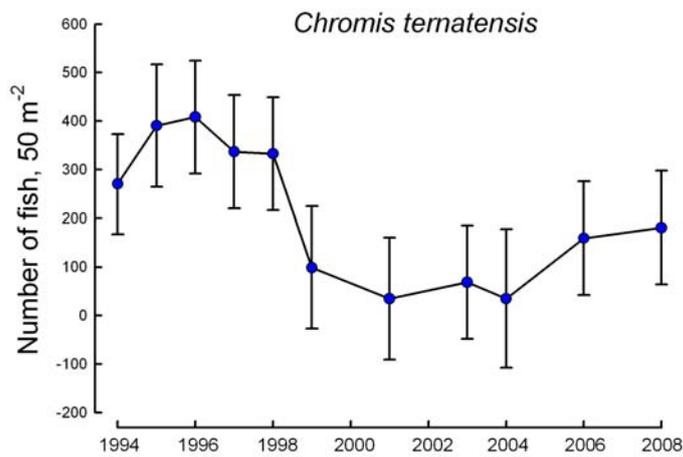


Fig. 20 Mean abundance values of *Chromis ternatensis* between 1994 and 2008.

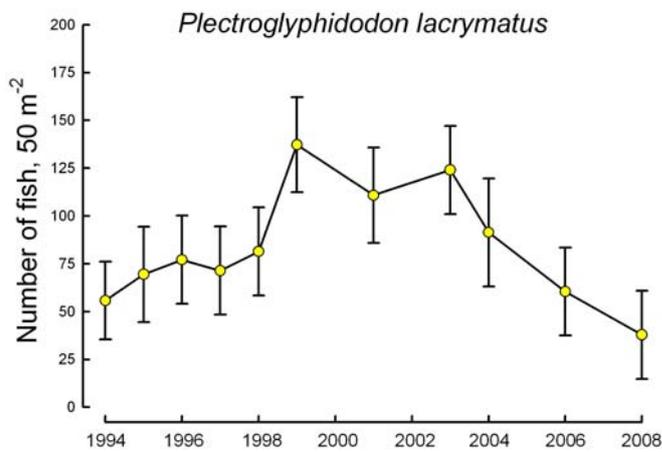


Fig. 21 Mean abundance values of *Plectroglyphidodon lacrymatus* between 1994 and 2008.

3.2 Coral Demography

The rates of survival and growth of *Acropora spicifera* colonies varied according to their exposure to cyclone disturbance and susceptibility of their different size classes (Fig. 22). Differences in growth and survival of *A. spicifera* among locations and size classes were consistent over the two year study period, reflecting the impact of Cyclone George in March 2007. Because Cyclone George occurred at the end of one survey period (June 2006 to June 2007), and shortly before the next (June 2007 to May 2008), its impacts were evident over the two years. In general, colonies at locations SL3 and SL4 were the worst impacted by Cyclone George, consistently having the lowest rates of growth and survival, and survival was lowest for the largest size classes. In contrast, colonies at location SL2 were sheltered from the impacts of the cyclone and had high rates of growth and survival for all size classes (Fig. 22).

Colonies at locations SL3 and SL4 had low rates of survival (40 to 65% yr⁻¹) between 2006 and 2008, and comparatively low rates of growth, reflecting their exposure to the impacts of Cyclone George (Fig. 22). In particular, the larger (> 15cm) colonies were most susceptible to the wave energy generated by the cyclone, and had the lowest rates of survival and a high incidence of negative growth following injury and the loss of live tissue (Fig. 22). The longer-term consequences of injury to larger colonies following the cyclone (May 2007) was evident in their low (< 30% yr⁻¹) rates of survival the following year (Fig. 22). In contrast, locations SL1, and particularly SL2, were comparatively sheltered from the impact of Cyclone George, and therefore had higher rates of growth and survival that were similar across the different size classes (Fig. 22). The survival of colonies of all sizes classes over the two year period ranged between 75 and 90% yr⁻¹ at SL1, and was > 94% yr⁻¹ at SL2; rates of growth ranged between 2.5 and 5.5 cm yr⁻¹ at SL1, and between 4.5 and 10.1 cm yr⁻¹ at SL2 (Fig. 22).

These initial data on growth and survival of a corymbose species at Scott Reef provide valuable insights into the demography of corals when exposed to 'natural' regimes of disturbance. The annual rates of growth and survival at locations not exposed to cyclone disturbance were high, and similar across size classes. In contrast, the survival of corals at reefs exposed to more localised anthropogenic disturbances (e.g. overfishing, degraded water quality) are more size-specific, with smaller corals having lower rates of survival than larger corals (Hughes 1984). However, anthropogenic stressors are characteristically associated with increased growth of algae and sedimentation, both of which may disproportionately impact smaller corals. In contrast, reefs such as Scott Reef have much lower abundances of algae and sedimentation, with disturbances more commonly in the form of periodic cyclones. The contrasting impact of cyclone disturbance was evident in the reduced rate of growth and survival of the largest colonies, whereas the growth and survival of the smallest size classes remained relatively high (Fig. 22). Thus, from these preliminary data, mean rates of survival for small colonies over several years may prove to be higher than for larger colonies. Data collection over several years is required to confirm these initial patterns of growth and survival, and their responses to different disturbance regimes. In particular, the variation in the demographic traits of different size classes will be quantified with the continued increase in the cover and density of corals, because existing patterns may vary with an increased interaction among individuals (e.g. Tanner 1996).

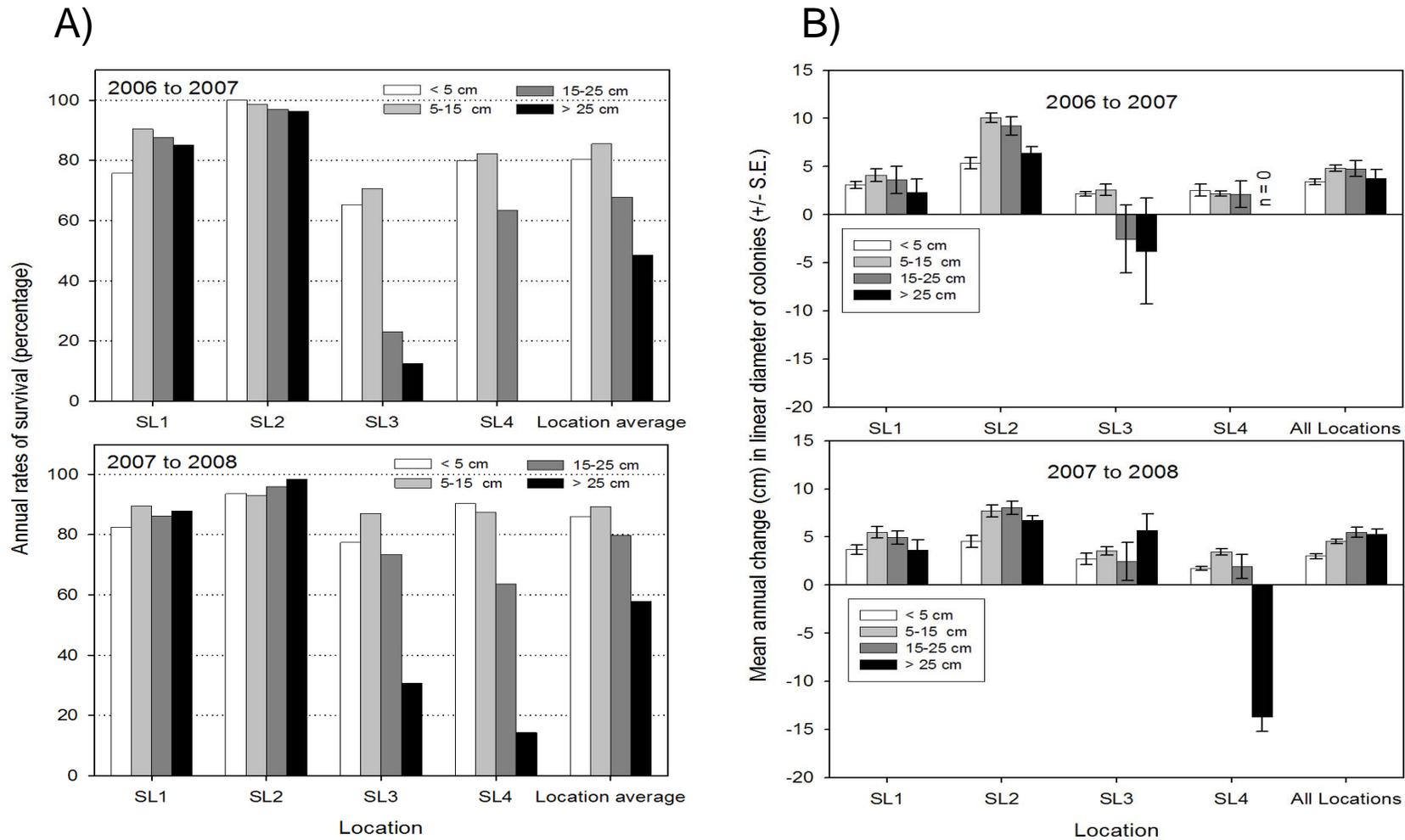


Fig. 22 A) Annual rates of survival and B) growth for size classes (linear diameter) of *Acropora spicifera* at locations across Scott Reef. Rates of growth are the mean annual changes in the linear diameter (cm) of colonies between surveys conducted in May/June each year; mean negative rates of growth reflect decreases in size of colonies and/or the amount of live tissue on colonies following disturbance and injury.

3.3 Genetic Connectivity of Coral and Fish

Genetic structure and variation of the cardinal fish

Preliminary phylogenetic analysis of the cardinal fish *Cheilodipterus artus* indicates a very strong genetic split (> 20% sequence divergence) into two clades (Fig. 23). The underlying variation is high (134 out of 387 sites were variable and a nucleotide diversity of 0.122) and the tree has strong bootstrap support. These clades correspond closely to the different habitats sampled; one clade consists almost entirely of individuals from slope sites at Scott Reef (indicated by squares in figure 23), and the other clade consists almost entirely of individuals from lagoon sites at Scott Reef and Rowley Shoals (indicated by triangles in Fig. 23). However, there is some overlap, with two individuals from Rowley Shoals lagoon in the “slope” clade, and two individuals from Scott Reef slope in the “lagoon” clade. Given the strength of genetic differentiation between clades, together with the co-occurrence of a small number of individuals from different clades at the same site, the most parsimonious explanation is that we have uncovered two cryptic species that have been previously identified as *C. artus*. Detailed morphological confirmation of this hypothesis is currently being tested. The alternative but less plausible hypothesis is that these two clades are currently in the process of speciation, with behavioural characteristics limiting hybridization between the two clades. Analysis with microsatellite markers will also shed further light on this issue.

Irrespective of whether these two clades are different species or not, from a management perspective, this preliminary data from the cardinal fish suggest significant levels of genetic mixing among reefs and between systems at Rowley Shoals and Scott Reef. Within the “lagoon clade”, although genetic structure is relatively deep (i.e. old), there is clearly no geographic structure underlying these patterns; many individuals from Scott Reef and Rowley Shoals are closely related. Further, the high levels of genetic variation within each clade (between 3% and 6% nucleotide divergence) suggest that these populations have not been highly isolated in the past. Therefore, it appears that the larvae of these cardinal fish are capable of dispersing the 400km between systems, and do so regularly at least in the context of intermediate to longer term time frames. However, it is not clear from these data whether self-recruitment back to natal reefs drives population replenishment in these fish over ecological time scales. Microsatellite data are required to elucidate these contemporary patterns of connectivity.

Genetic structure and variation of the damselfish

In the damselfish, *Chromis margaritifer*, both the universal primers and the modified primers appeared to amplify a region of the genome that is unlikely to be the targeted control region and is probably an unknown nuclear gene, making phylogenetic inferences difficult. Further, variation was low (60 out of 282 sites were variable, and a nucleotide diversity of 0.008). As a result, the phylogenetic tree does not have strong bootstrap support (Fig. 24). Therefore, inferences from this analysis are particularly tentative. However, the phylogenetic analysis indicates little underlying geographic structure to genetic relationships among individuals from different sites at Scott Reef and Rowley Shoals (Fig. 24). Therefore, it appears that like the cardinal fish, gene flow among reefs and systems has historically been strong enough to limit major genetic diversification of populations. Microsatellites are required to test this inference, and to assess patterns of contemporary genetic connectivity.

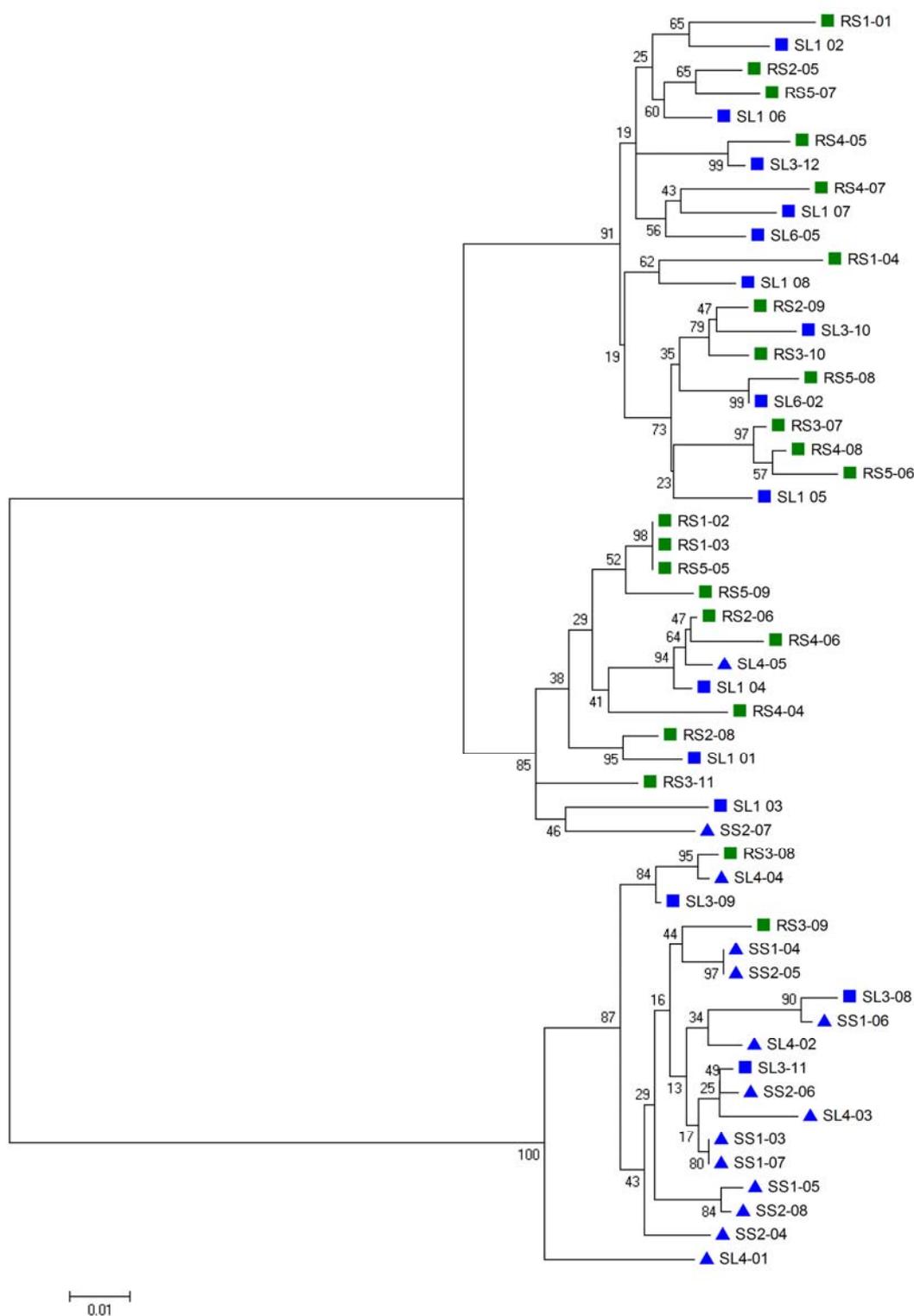


Fig. 23 A Neighbour-Joining bootstrap consensus tree showing genetic relationships among individuals for the cardinal fish *Cheilodipterus artus*. The percentages of replicate trees in which the associated taxa clustered together in the bootstrap test (500 replicates) are shown next to the branches. The tree is drawn to scale, with branch lengths in the same units as those of the evolutionary distances used to infer the phylogenetic tree. The evolutionary distances were computed using the Maximum Composite Likelihood method and are in the units of the number of base substitutions per site. The blue triangles are Scott Reef outer reef slope sites, the blue squares are Scott Reef Lagoon sites, and the red squares are Rowley Shoals lagoon sites.

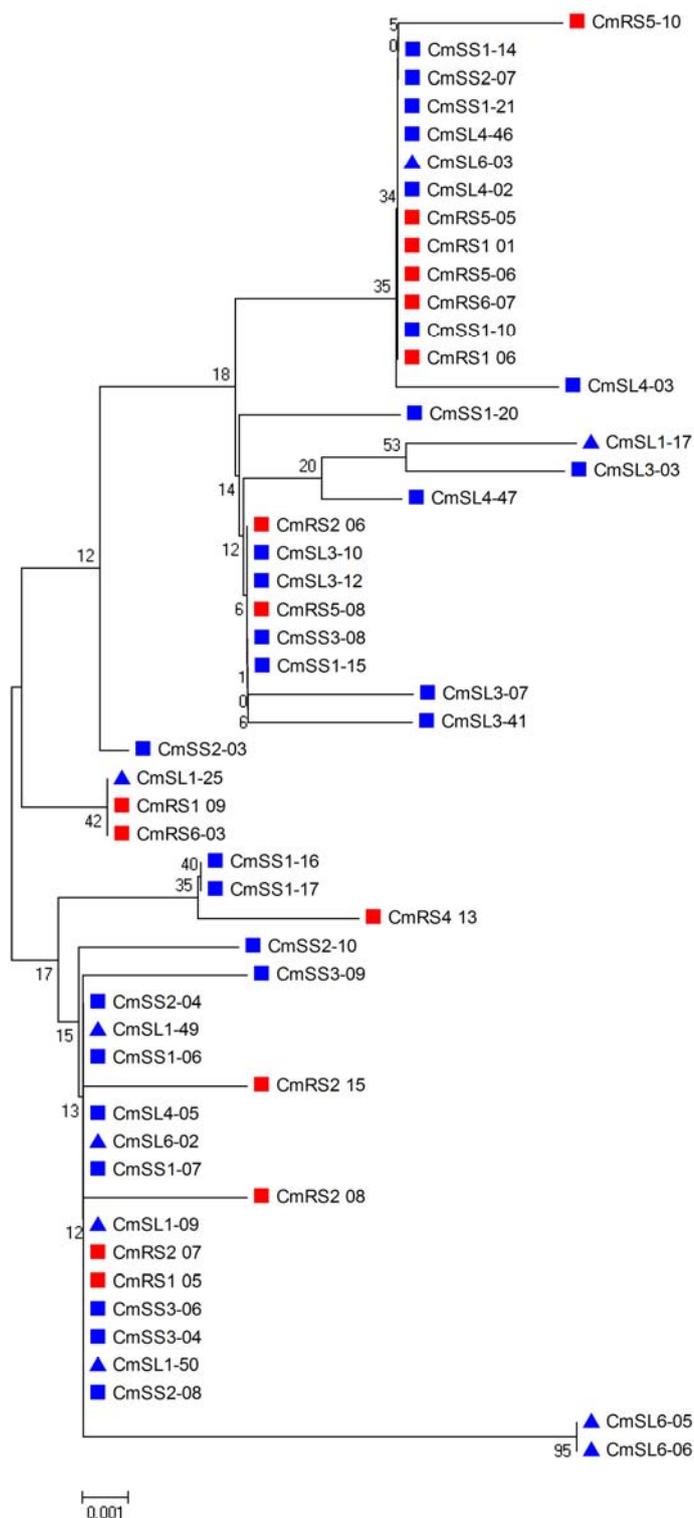


Fig. 24 A Neighbour-Joining bootstrap consensus tree showing genetic relationships among individuals for the damselfish *Chromis margaritifer*. The percentages of replicate trees in which the associated taxa clustered together in the bootstrap test (500 replicates) are shown next to the branches. The tree is drawn to scale, with branch lengths in the same units as those of the evolutionary distances used to infer the phylogenetic tree. The evolutionary distances were computed using the Maximum Composite Likelihood method and are in the units of the number of base substitutions per site. The blue triangles are Scott Reef lagoon sites, the blue squares are Scott Reef slope sites and the red squares are Rowley Shoals slope sites.

3.4 Coral Reproduction and Recruitment

Pre-Spawning Visual Survey

The developmental stage of coral eggs during March 2008 provides further support that autumn is the dominant coral spawning period at Scott Reef. In total, 220 colonies from 48 species of scleractinian corals (16 genera, eight families) were scored at 5 locations across Scott Reef (Table 8), of which 86% of all colonies, and at least 83% of all species were expected to spawn in autumn. In the *Acropora* genus, a total of 195 colonies from 32 species were sampled, of which 84% of colonies and 81% of species were expected to spawn in autumn.

Based on these data and those collected in October 2007 (Gilmour et al. 2007b), all species of *Acropora* participate in the autumn spawning, and no species spawn exclusively in spring, with the possible exception of *A. millepora*. However, there is evidence that populations of at least five species of *Acropora* participate in both autumn and spring spawning events (Table 10), but it is not known whether individual colonies participate in one or both of these events. Of the 25 colonies from 16 species of non-*Acropora* corals sampled (families Faviidae, Merulinidae, Oculinidae, and Pectiniidae), all but one colony were expected to spawn in autumn.

Of the species and colonies predicted to spawn in autumn, the proportion spawning in March versus April was uncertain. Based on previous data, it was initially assumed that colonies with large and pigmented eggs (Score 1) spawned during March, whereas those with weakly pigmented (Score 1/2), or unpigmented (Score 2), eggs spawned in April (Table 8 & 9). However, a rapid visual survey conducted in early April 2008 suggested that many of the colonies expected to spawn after the full moon in April had already spawned; most of these probably had weakly pigmented eggs and were Scored 1/2 during the March survey. Approximately 110 colonies of locally dominant *Acropora* species were visually surveyed for eggs at locations SL3, SL4, and SSI in April, and with the exception of the brooding corals (*A. brueggemanni*, *A. palifera*, and *Seriatopora hystrix*) none had visible eggs. The key drivers behind the spawning by corals with weakly pigmented eggs remains to be determined, and is rarely reported in the literature. This early spawning may be linked to oceanographic conditions or comparatively cool water temperature leading up to the spawning in 2008. Environmental variables including sea surface temperatures, solar insolation, lunar cycles, and photo period are known to influence gamete development and release times (van Woesik et al. 2006). The spawning of unpigmented eggs has occasionally been documented, indicating that egg pigmentation is not an entirely reliable proxy for gamete maturity and spawning time.

Table 8 Reproductive state of *Acropora* colonies at Scott Reef prior to the spawning event in March 2008, showing the number of colonies scored at different stages of gametogenesis. Score 1 = pink or red eggs, Score 2 = large white or cream eggs, Score 3 = small white or cream eggs, Score 4 = no visible eggs, Score 1/2 = unresolved egg state (between 1 and 2). For colonies where *in situ* scoring could not be determined, a voucher sample was collected for later analysis. All species that were scored as 1, 2, or 1/2 were inferred to have spawned in the March spawning event based on the absence of eggs in these species in early April. A rapid assessment conducted in early April indicated that many of the colonies with eggs assigned a score of either 1/2 or 2, may have spawned following the full moon in March, and not in April as expected.

Species	Location SL1					Location SL2					Location SL3					Location SL4					Location SS2					Locations All Sites					Total Scored Vouchers (n)	
	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4	1	1/2	2	3	4		
Acropora																																
<i>A. abrolhosensis</i>									1																1						1	
<i>A. aculeus</i>																																3
<i>A. anthocercis</i>			1																2						3						3	1
<i>A. brueggemanni</i>										2																2					2	9
<i>A. carduus</i>			1			1																			1	1					2	
<i>A. cerealis</i>			6					1	1				1					5					5					18	1		19	3
<i>A. cytherea</i>			3					1	4				2					2					2					10	4		14	4
<i>A. digitifera</i>			1					2					1												4						4	1
<i>A. echinata</i>																																1
<i>A. florida</i>								2	3																2			3			5	4
<i>A. gemmifera</i>			3					6					6					3					2					20			20	4
<i>A. grandis</i>									1																1						1	1
<i>A. granulosa</i>						1												1							1			1			2	
<i>A. humilis</i>			1					4					4					3					1					13			13	1
<i>A. hyacinthus</i>			2					1	2				3					3					2					11	2		13	1
<i>A. indonesia</i>								1	1																1			1			2	3
<i>A. intermedia</i>								1																	1						1	2
<i>A. latistella</i>			2																				1					3			3	5
<i>A. loripes</i>															1										1						1	
<i>A. microclados</i>			4						1				1												5			1			6	6
<i>A. microphthalma</i>			1					2	1				1										1					5	1		6	6
<i>A. millepora</i>									1																			1			1	2
<i>A. monticulosa</i>													1															1			1	1
<i>A. muricata</i>									3																3			3			3	2
<i>A. nasuta</i>			3					3	2				4					5					1					16	2		18	4
<i>A. pallifera</i>															1										1						1	11
<i>A. polystoma</i>													3															3			3	2
<i>A. samoensis</i>			2					3																	5						5	
<i>A. spicifera</i>			4					3					1										7					15			15	
<i>A. subglabra</i>								4																	4						4	
<i>A. subulata</i>			1						3														1					2	3		5	2
<i>A. tenuis</i>			3					2	4				3					2					2					12	4		16	3
<i>A. valenciennesi</i>									2																			2			2	1
<i>A. valida</i>													1										2					3			3	3
<i>A. vaughani</i>																																1
Total colonies			38			2		36	3		2		31	1		1		27					27			5		159	31		195	96
Total species																															32	28

Table 10 Participation by selected *Acropora* species in multi-specific spawning events in autumn (March / April) and/or spring (October / November).

Species	autumn	spring
<i>A. spicifera</i>	x	
<i>A. millepora</i>		x
<i>A. digitifera</i>	x	
<i>A. tenuis</i>	x	x
<i>A. florida</i>	x	x
<i>A. valida</i>	x	
<i>A. gemmifera</i>	x	x
<i>A. humilis</i>	x	
<i>A. hyacinthus</i>	x	x
<i>A. cytherea</i>	x	x

Pre-spawning sampling surveys

Samples from 121 colonies of *Acropora spicifera*, 96 colonies of *Acropora spp.* (28 species) and 82 colonies of non-*Acropora* species (32 species from the families Acroporidae, Agariciidae, Faviidae, Merulinidae, Oculinidae, Pectiniidae, Pocilloporidae, Siderastreidae) were collected for laboratory analyses of fecundity and oocyte size. Laboratory work and data analyses are ongoing, however samples that have been analysed for fecundity and oocyte size are summarised below (Table 11).

Recruitment of corals

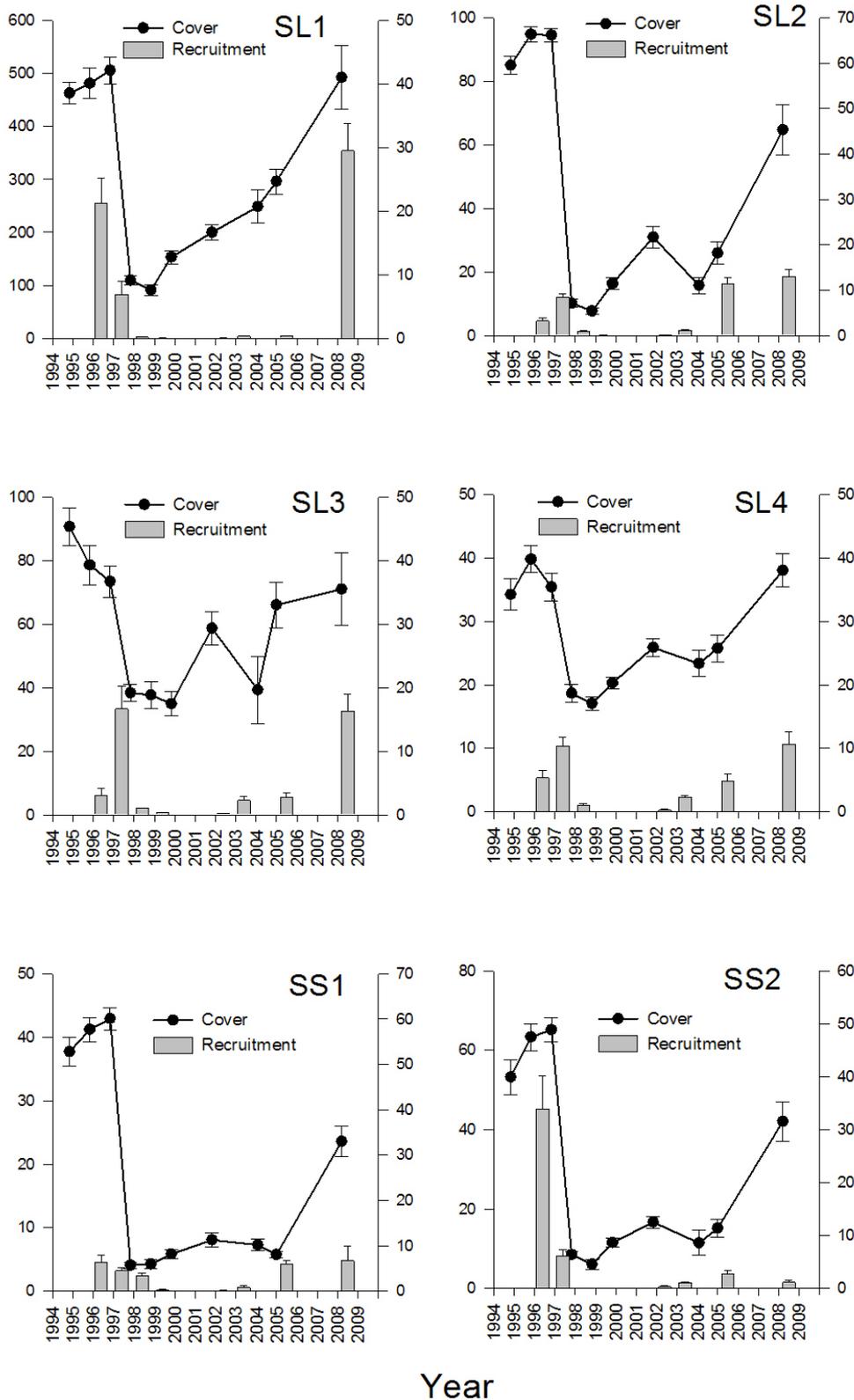
The rates of recruitment at Scott Reef have continued to increase since the 1998 bleaching, with a particularly large increase in 2008 (Fig. 25). The mean rates (\pm S.E.) of recruitment at Scott Reef have increased from < 0.3 (± 0.2) recruits plate⁻¹ yr⁻¹ one year after the bleaching (1999), to 2.3 (± 1.5) in 2003, and 70.4 (± 57) in 2008. On average, the rates of recruitment in 2008, ten years after the bleaching, had exceeded the mean (\pm S.E.) pre-bleaching rate of 53 recruit's plate⁻¹ yr⁻¹ in 2007. The rapid increases in recruitment in recent years (>2004), compared with those shortly after (< 2004) the 1998 bleaching, probably reflect the maturation and rapid increases in colony size from approximately 5 years after the bleaching. Thus, after 2003, there was a corresponding increase in the number of colonies of adult size (Smith et al. 2006), and rapid increases in the percentage cover of hard corals. The largest coral colonies are known to make a disproportionately high contribution to reproductive output, because the numbers of polyps in a colony increases exponentially with size (Hall and Hughes 1996).

Although the mean rate of recruitment in 2008 had surpassed that prior to the 1998 bleaching, this was not the case at all locations and there was considerable spatial variation in recruitment across Scott Reef. By far the highest mean (\pm S.E.) rates of recruitment in 2008 were 354 (± 52) recruits plate⁻¹ yr⁻¹ at location SL1, which was more than four times that prior to the bleaching or that at any other location at Scott Reef. Additionally, location SL1 consistently had the highest recruitment of all locations before and after the bleaching event. By comparison, there were much smaller increases in recruitment at all other locations after 2003, and by 2008 the mean rates of recruitment (\pm S.E.) at locations SL2, SL3, SL4 and SS1 ranged between 5 and 35 ($\pm <5$) recruits plate⁻¹ yr⁻¹. The rates of recruitment in 2008 were similar or greater than those prior to the bleaching at all locations, with the exception of location SS2; at SS2 the mean (\pm S.E.) rate of recruitment in 2008 was 1.6 (± 0.4) recruits plate⁻¹ yr⁻¹, which was less than 20% of that prior to the 1998 bleaching.

Table 11 Polyp fecundity, fecundity per cm², and oocyte geometric mean diameter of coral samples, Scott Reef 2008.

Species	Polyp Fecundity	Polyp Fecundity	Maximal	Maximal	Medial	Medial	Geometric	Geometric	Colonies	Eggs
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	N	N
<i>Acropora aculeus</i>	4.86	0.16	137.15	1.77	106.59	1.82	120.30	1.70	3	356
<i>Acropora anthocercis</i>	5.55	0.25	170.52	6.17	115.67	4.13	139.75	4.89	1	147
<i>Acropora cerealis</i>									1	0
<i>Acropora cytherea</i>	5.36	0.16	183.58	2.24	135.85	1.46	156.95	1.58	3	398
<i>Acropora digitifera</i>	4.28	0.22	579.35	12.79	467.16	8.20	514.05	6.83	1	110
<i>Acropora echinata</i>									1	0
<i>Acropora gemmifera</i>	4.93	0.17	139.93	1.68	108.75	1.17	122.76	1.23	3	342
<i>Acropora grandis</i>									1	0
<i>Acropora hyacinthus</i>	4.66	0.11	164.37	2.41	125.27	1.87	142.78	2.04	7	590
<i>Acropora indonesia</i>	6.73	0.22	543.47	11.35	372.09	6.43	444.16	7.47	2	348
<i>Acropora latistella</i>	5.01	0.14	376.99	10.64	247.88	6.85	302.83	8.14	4	496
<i>Acropora microclados</i>	5.59	0.19	198.80	3.93	149.40	2.85	171.44	3.20	4	392
<i>Acropora micropthalma</i>	1.00	0.00	466.93	32.85	392.70	34.84	427.95	33.23	1	4
<i>Acropora millepora</i>	5.56	0.20	155.88	2.17	122.14	1.27	136.89	1.33	2	280
<i>Acropora muricata</i>	4.68	0.29	123.47	2.45	64.94	1.51	89.09	1.74	2	103
<i>Acropora nasuta</i>									2	0
<i>Acropora polystoma</i>	5.59	0.26	217.51	5.26	142.20	2.37	174.45	3.12	1	148
<i>Acropora spicifera</i>	5.01	0.09	627.74	4.34	443.58	2.88	521.41	2.48	9	1081
<i>Acropora subulata</i>	6.88	0.22	179.08	2.22	138.33	1.70	156.76	1.78	2	356
<i>Acropora tenuis</i>	5.96	0.22	125.33	1.57	102.58	1.36	112.63	1.24	2	290
<i>Acropora valenciennesi</i>									1	0
<i>Acropora valida</i>	2.43	0.17	1149.88	35.98	370.56	15.57	632.33	13.43	1	53
<i>Goniastrea pectinata</i>									1	0
<i>Seriatopora hystrix</i>									1	0

Number of coral recruits per plate



Percentage Cover

Fig. 25 Changes in percentage cover and recruitment of hard corals at locations across Scott Reef. The mass-bleaching occurred in 1998, Cyclone Fay in 2004 and Cyclone George in 2007.

The low rates of recruitment at SS2 may be because the the corals that recolonised the location following belaching and cyclone disturbances have not yet reached reproductive size, although coral cover is now approaching that prior to the belaching. Alternately, the low rates of recruitment may be because it is the coral communities in shallow water and lagoon sites at North Scott that provide many of the recruits to SS2, and there has been little recovery of these communities since the bleaching.

Spatial variation in recruitment among the locations at Scott Reef is driven by the local abundance of adult colonies, the distances of larval dispersal, and the oceanographic conditions during the dispersal period. Rates of recruitment at each location are influenced by the abundance and size of adult colonies at those locations (< 10 kilometres). Additionally, there is increasing evidence that coral larvae at Scott Reef may settle out of the water column within a week of spawning and may routinely disperse over distances of approximately 10 kilometres (Underwood et al. 2009; Gilmour et al. in press). However, oceanographic conditions during this dispersal period certainly play an important role in determining the degree of connectivity among locations and reefs across the Scott Reef system. In particular, oceanographic conditions clearly disperse larvae from other lagoonal communities and supply the highest rates of recruitment to location SL1 at the inner west hook (Steinberg et al. 2006).

3.5 Physical Data

Temperature

Mean daily water temperatures ranged from a low of 25.7°C at SL3 on 9 August 2007 to a maxima of 31.4 °C at SL2 on 13 April 2008 (Fig. 26). There were bi-modal peaks in summer 2007/2008 with temperatures of *ca* 30°C at each location with an initial peak on 16 December 2007 and a secondary peak on 4 February 2008, and a period of lower water temperature (*ca* 28.5°C) in January 2008 (Fig. 26). A third peak occurred in late March/early April which was the warmest period during this time-series.

Water temperatures in shallow (*ca* 9 m) waters at Scott Reef in 2007 and 2008 followed a seasonal cycle of higher temperatures in autumn (April/May) and lower temperatures in late winter (August/September). Although there was minimal variation in mean daily water temperature among locations in 2008, temperatures were consistently 0.5°C lower at SL3 throughout most of 2007 and the summer of 2007/2008. The cooler temperatures at SL3 are a consequence of the regular tidal incursions of cooler oceanic water between West Hook and Sandy Islet (Steinberg et al. 2003; Bird et al. 2004). The cooler temperatures at this location may have ecological significance in relation to the susceptibility of corals to bleaching. Mean daily temperatures exceeded 31°C for consecutive periods during March/April 2008 at all locations, e.g. 13 days at SL4 and 28 days at both SL2 and SL3. These prolonged periods in which corals have been exposed to elevated temperatures may be significant in relation to the question of the development of thermal threshold limits for Scott Reef such as that developed by NOAA as part of their online bleaching alert system for Scott Reef.

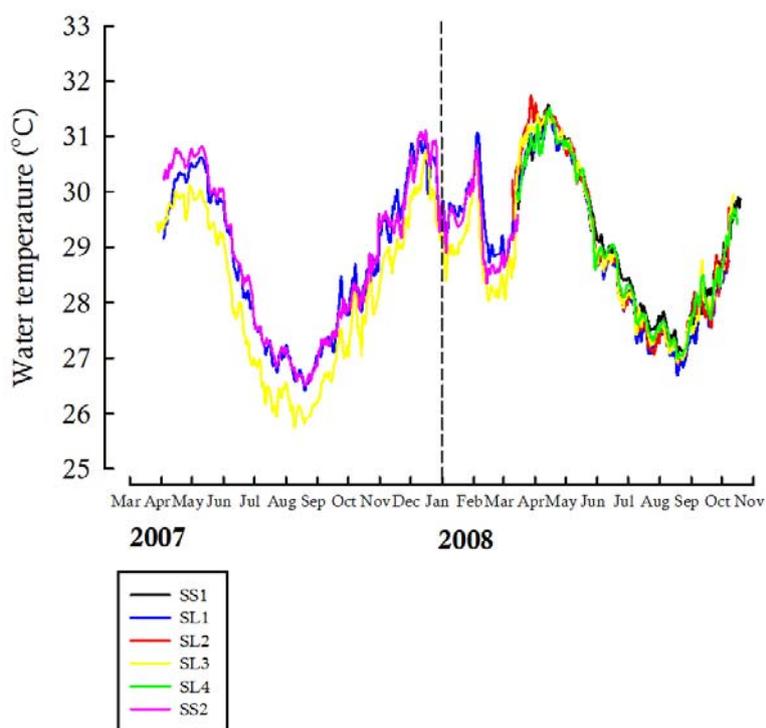


Fig. 26 Mean daily water temperatures at shallow (9m) locations at Scott Reef between April 2007 and October 2008.

Sedimentation

Mean sedimentation rates at Scott Reef between February and April 2008 ranged from a low of $0.45 \text{ mg cm}^{-2} \text{ d}^{-1}$ at SL2 to a high of $1.25 \text{ mg cm}^{-2} \text{ d}^{-1}$ at SL1 (Fig. 27). Except for SL1 and SL4 all locations had sedimentation rates $< 1.0 \text{ mg cm}^{-2} \text{ d}^{-1}$.

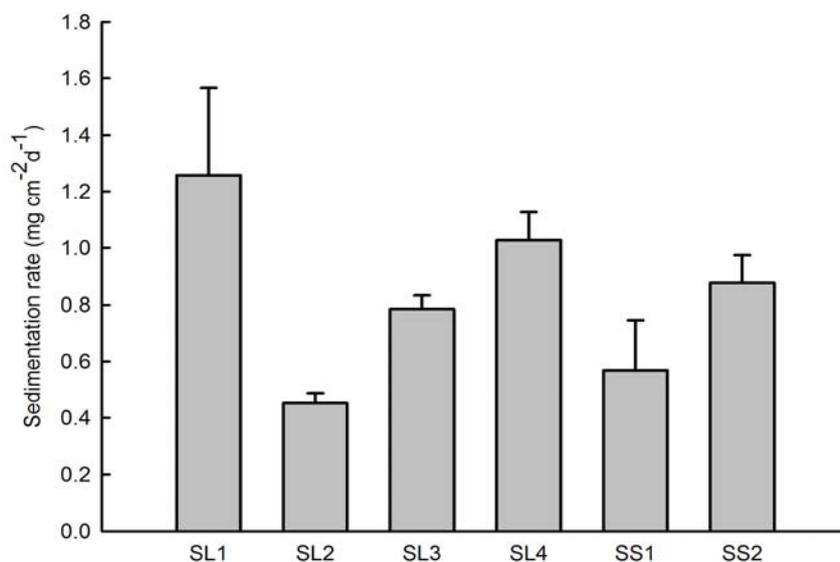


Fig. 27 Mean sedimentation rate ($\text{mg cm}^{-2} \text{ d}^{-1} \pm 1 \text{ S.E.}$) at six locations at Scott Reef between late February and late May 2008.

The mean sediment deposition rates recorded at Scott Reef between February and May 2008 are at the lower extent of the range (< 1 to $10 \text{ mg cm}^{-2} \text{ d}^{-1}$) expected at reefs not subjected to stresses from human activities (Rogers 1990). These rates are consistent with mean deposition rates at clear water sites in north-western Australia (Simpson 1988) and New Guinea (Kojis and Quinn 1984) where mean deposition rates during calm periods were $1.4 \text{ mg cm}^{-2} \text{ d}^{-1}$ and $1.0 \text{ mg cm}^{-2} \text{ d}^{-1}$, respectively. The mean deposition rates at Scott Reef are also consistent with those recorded at reef locations in Jamaica and the U.S. Virgin Islands where values ranged from 0.1 - $1.6 \text{ mg cm}^{-2} \text{ d}^{-1}$ (Dodge et al. 1974).

3.6 Deep Water Communities

In February 2008, 315 coral samples were collected from the deep lagoon habitats of Scott Reef for taxonomy, genetic and reproductive analyses. Preliminary taxonomic analyses of the deep water specimens have recorded a total of 51 scleractinian coral species from 27 genera and 11 families. These initial records of deep water taxonomic diversity at Scott Reef are likely to be significantly below true species diversity at depth due to the limited sampling regime and the inherent bias with the capture of coral species using the benthic grab. While the benthic grab has successfully captured many of the foliaceous and arborescent coral species, deep water video imagery has shown that many colonies of encrusting and massive species (e.g. Faviidae and Poritidae) are present at depth but have not been collected in grabs. It is therefore expected that additional or modified sampling regimes will result in an upward revision of species recorded from the deep lagoon habitats at Scott Reef.

Of the taxonomic records made in 2008, eight species are new records for Scott Reef, of which 5 are new records for Western Australia and two are new records Australia-wide (Appendix 2). Eleven species recorded from Scott Reef have been found only in the deep water habitats. Data from shallow water taxonomic surveys by Veron (1986), Done (1994), Wolstenholme (2004, Unpublished data), and McKinney (2007 unpublished data; 2008 unpublished data) were also rationalised to a common taxonomy and compiled to produce an aggregate species list of deep and shallow water corals at Scott Reef.

In addition to the deep water species records, 295 scleractinian coral species from 58 genera and 14 families have been recorded from the shallow water habitats at Scott Reef. In total, 306 coral species from 60 genera and 14 families have been recorded from both the deep and shallow habitats. Community composition in the deep water lagoon is markedly different to the shallow water habitats; shallow water coral communities are comprised of typical reef front, lagoon, and reef flat assemblages, while the deep water communities are dominated by extensive areas of foliaceous Agariciidae, Pectiniidae, Poritidae, and *Montipora* species, combined with fragile arborescent and plate-like *Acropora* species.

Scott Reef coral taxa are predominately widespread Indo-Pacific species that present clear affinities with the coral assemblages of Ashmore Reef and the Indonesian provinces to the north. In future analyses, non-parametric multi-dimensional scaling will be utilised to examine the relationship between the deep and shallow water communities at Scott Reef, and place these communities within the regional context of neighbouring oceanic and coastal reef systems.

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Appendices

Appendix I. Number of fish species recorded for each family at the Rowley Shoals and Scott Reef and Ashmore Reef systems (after Allen 1993; Hutchins et al. 1995)

Family	Common Name	Rowley Shoals	Scott/ Serinapatam Reefs	Ashmore Reef/ Cartier I.
Acanthuridae	Surgeonfishes	21	33	21
Antennariidae	Anglerfishes or Frogfishes	4	0	3
Apogonidae	Cardinalfishes	26	40	38
Atherinidae	Hardyheads or Silversides	3	2	0
Aulostomidae	Trumpetfishes	1	1	1
Balistidae	Triggerfishes	12	14	11
Belonidae	Longtoms or Needlefins	1	4	1
Blenniidae	Blennies	22	17	15
Bothidae	Lefteye flounders	3	1	2
Brotulidae	Eel-pouts	1	0	0
Bythitidae	Cuskeels	3	0	3
Caesionidae	Fusiliers	3	9	6
Callionymidae	Dragonets	3	2	2
Caracanthidae	Crouchers or Orbicular Velvetfishes	1	1	1
Carangidae	Trevallies	16	15	6
Carapidae	Pearlfishes	0	0	1
Carcharhinidae	Whaler sharks or Requiem sharks	5	5	2
Chaetodontidae	Butterflyfishes	27	37	24
Cirrhitidae	Hawkfishes	2	6	4
Clupeidae	Herrings and Sardines	0	2	1
Congridae	Conger Eels	0	0	5
Creediidae	Sand Burrowers	1	0	0
Dasyatididae	Stingrays	1	2	2
Diodontidae	Porcupinefishes	2	3	1
Echeneididae	Remoras	2	1	0
Elotridae	Gudgeons or Sleepers	3	0	2
Ephippidae	Batfishes	3	6	2
Exocoetidae	Flyingfishes	1	2	0
Fistulariidae	Flutemouths	2	1	1
Gerreidae	Mojarras	1	0	1
Ginglymostomatidae	Nurse Sharks	1	1	0
Gobiesocidae	Clingfishes	1	1	2
Gobiidae	Gobies	50	65	67
Grammistidae	Soapfishes	1	2	2
Haemulidae	Sweetlips	2	5	3
Hemiramphidae	Garfishes or Halfbeaks	0	1	2
Hemiscylliidae	Bamboo Sharks	0	1	1
Holocentridae	Squirrel fishes and Soldier fishes	18	19	14
Istiophoridae	Billfishes	1	2	1
Kraemeridae	Sanddarts	0	0	1
Kyphosidae	Drummers or Sea Chubs	4	6	2
Labridae	Wrasses	69	79	54
Lethrinidae	Emperors	14	21	6
Lutjanidae	Snappers	12	23	12
Malacanthidae	Sand Tilefishes	4	3	2
Microdesmidae	Worm fishes and Dartfishes	4	7	5

Family	Common Name	Rowley Shoals	Scott/ Seringapatam Reefs	Ashmore Reef/ Cartier I.
Mobulidae	Manta or Devil Rays	1	3	1
Monacanthidae	Leatherjackets	15	8	6
Moringuidae	Worm Eels	2	1	2
Mugilidae	Mulletts	0	0	1
Mugiloididae	Sand Perches and Weavers	2	3	4
Mullidae	Goatfishes	6	11	9
Muraenidae	Moreys	14	18	19
Mylobatidae	Eagle rays	1	3	1
Nemipteridae	Coral Breems	3	6	7
Nomeidae	Driftfishes	1	0	0
Notograptidae	Eel Blenny	0	0	1
Ophichthidae	Snake Eels	4	5	8
Orectolobidae	Wobbygongs	0	0	1
Ostraciidae	Boxfishes	3	2	1
Pempheridae	Sweepers	2	2	2
Pinguipedidae	Grubfishes	0	1	0
Platycephalidae	Flatheads	2	2	2
Plesiopidae	Longfins	3	1	3
Pleuronectidae	Righteye Flounders	1	0	1
Plotosidae	Eeltail Catfishes	1	1	0
Pomacanthidae	Angelfishes	11	14	11
Pomacentridae	Damselfishes	49	76	66
Priacanthidae	Bigeyes	1	1	1
Pseudochromidae	Dottybacks and Eel Blennies	7	10	10
Pseudogrammatidae	Basslet	2	1	1
Scaridae	Parrotfishes	24	31	13
Scombridae	Tunas and Mackerels	6	7	1
Scorpaenidae	Scorpionfishes	6	12	15
Serranidae	Rock cods or Groupers	34	41	19
Siganidae	Rabbitfishes	11	11	5
Soleidae	Soles	2	0	3
Solenostomidae	Ghost pipefishes	1	0	0
Sphyrnaidae	Barracudas	3	2	1
Stegastomatidae	Leopard Sharks	0	0	1
Syngnathidae	Pipefishes	10	8	3
Synodontidae	Lizardfishes	3	6	5
Tetraodontidae	Puffers	4	9	6
Tripterygiidae	Triplefins	4	4	7
Xenocoelidae	False Moreys	1	2	0
Zanclidae	Moorish Idol	1	2	1
Number of Families		75	69	75
Number species		569	721	568

Appendix 2. Shallow (<30m) and deep water (30-70m) corals recorded at Scott Reef, 1993-2008.

Species	Shallow	Deep	Combined	New Records
Acroporidae				
<i>Acropora abrolhosensis</i>	x		x	
<i>Acropora abrotanoides</i>	x		x	
<i>Acropora aculeus</i>	x		x	
<i>Acropora acuminata</i>	x		x	
<i>Acropora anthocercis</i>	x		x	
<i>Acropora aspera</i>	x		x	
<i>Acropora austera</i>	x		x	
<i>Acropora cf batunai</i>		x	x	Requires confirmation. Potential new record for Australia
<i>Acropora brueggemanni</i>	x		x	
<i>Acropora carduus</i>	x		x	
<i>Acropora caroliniana</i>	x		x	
<i>Acropora cerealis</i>	x		x	
<i>Acropora clathrata</i>	x		x	
<i>Acropora cytherea</i>	x		x	
<i>Acropora cf desalwyii</i>	x		x	Requires confirmation. Potential new record for Australia
<i>Acropora digitifera</i>	x		x	
<i>Acropora divaricata</i>	x		x	
<i>Acropora donei</i>	x		x	
<i>Acropora echinata</i>	x		x	
<i>Acropora elegans</i>		x	x	Requires confirmation. Potential new record for Australia
<i>Acropora elseyi</i>	x		x	
<i>Acropora exquisita</i>	x		x	
<i>Acropora florida</i>	x		x	
<i>Acropora gemmifera</i>	x		x	
<i>Acropora glauca</i>	x		x	
<i>Acropora grandis</i>	x		x	
<i>Acropora granulosa</i>	x		x	
<i>Acropora horrida</i>	x		x	
<i>Acropora humilis</i>	x		x	
<i>Acropora hyacinthus</i>	x		x	
<i>Acropora indonesia</i>	x		x	
<i>Acropora intermedia</i>	x		x	
<i>Acropora cf jacquelinae</i>		x	x	Requires confirmation. Potential new record for Australia
<i>Acropora kimbeensis</i>	x		x	
<i>Acropora kirstyi</i>	x		x	
<i>Acropora latistella</i>	x		x	
<i>Acropora listeri</i>	x		x	
<i>Acropora loisetteae</i>	x		x	
<i>Acropora longicyathus</i>	x		x	
<i>Acropora loripes</i>	x		x	
<i>Acropora lutkeni</i>	x		x	
<i>Acropora microclados</i>	x		x	
<i>Acropora microphthalma</i>	x		x	
<i>Acropora millepora</i>	x		x	
<i>Acropora monticulosa</i>	x		x	
<i>Acropora muricata</i>	x		x	
<i>Acropora nana</i>	x		x	
<i>Acropora nasuta</i>	x		x	

Species	Shallow	Deep	Combined	New Records
<i>Acropora palifera</i>	x		x	
<i>Acropora paniculata</i>	x		x	
<i>Acropora pichoni</i>		x	x	
<i>Acropora polystoma</i>	x		x	
<i>Acropora pulchra</i>	x		x	
<i>Acropora robusta</i>	x		x	
<i>Acropora samoensis</i>	x		x	
<i>Acropora secale</i>	x		x	
<i>Acropora selago</i>	x		x	
<i>Acropora spicifera</i>	x		x	
<i>Acropora striata</i>	x		x	
<i>Acropora subglabra</i>	x		x	
<i>Acropora subulata</i>	x		x	
<i>Acropora cf tenella</i>		x	x	Requires confirmation. Potential new record for Australia
<i>Acropora tenuis</i>	x		x	
<i>Acropora valenciennesi</i>	x		x	
<i>Acropora valida</i>	x		x	
<i>Acropora vaughani</i>	x		x	
<i>Acropora yongei</i>	x		x	
<i>Anacropora forbesi</i>		x	x	Requires confirmation
<i>Anacropora puertogalerae</i>	x		x	
<i>Astreopora cucullata</i>	x		x	
<i>Astreopora expansa</i>	x	x	x	
<i>Astreopora gracilis</i>	x		x	
<i>Astreopora incrustans</i>	x		x	
<i>Astreopora listeri</i>	x		x	
<i>Astreopora myriophthalma</i>	x		x	
<i>Astreopora ocellata</i>	x		x	
<i>Montipora aequituberculata</i>	x	x	x	
<i>Montipora angulata</i>	x		x	
<i>Montipora caliculata</i>	x		x	
<i>Montipora crassituberculata</i>	x	x	x	
<i>Montipora danae</i>	x		x	
<i>Montipora digitata</i>	x		x	New Record for Scott Reef
<i>Montipora efflorescens</i>	x		x	
<i>Montipora floweri</i>	x		x	
<i>Montipora foliosa</i>	x		x	
<i>Montipora foveolata</i>	x		x	
<i>Montipora grisea</i>	x		x	
<i>Montipora hispida</i>	x		x	
<i>Montipora hoffmeisteri</i>	x		x	
<i>Montipora incrassata</i>	x		x	
<i>Montipora informis</i>	x		x	
<i>Montipora millepora</i>	x		x	
<i>Montipora mollis</i>	x		x	
<i>Montipora monasteriata</i>	x		x	
<i>Montipora nodosa</i>	x		x	
<i>Montipora peltiformis</i>	x		x	
<i>Montipora spumosa</i>	x		x	
<i>Montipora tuberculosa</i>	x		x	
<i>Montipora turgescens</i>	x		x	
<i>Montipora turtlensis</i>	x		x	
<i>Montipora undata</i>	x		x	

Species	Shallow	Deep	Combined	New Records
<i>Montipora venosa</i>	x		x	
<i>Montipora verrucosa</i>	x		x	
Agariciidae				
<i>Coeloseris mayeri</i>	x		x	
<i>Gardineroseris planulata</i>	x		x	
<i>Leptoseris explanata</i>	x	x	x	
<i>Leptoseris foliosa</i>	x	x	x	
<i>Leptoseris gardineri</i>		x	x	New Record for WA
<i>Leptoseris hawaiiensis</i>	x		x	
<i>Leptoseris incrustans</i>	x		x	
<i>Leptoseris mycetoseroides</i>	x	x	x	
<i>Leptoseris papyracea</i>	x	x	x	
<i>Leptoseris scabra</i>	x	x	x	
<i>Leptoseris solida</i>	x		x	New Record for WA
<i>Leptoseris striata</i>		x	x	
<i>Leptoseris yabei</i>	x	x	x	
<i>Pachyseris rugosa</i>	x		x	
<i>Pachyseris speciosa</i>	x	x	x	
<i>Pavona bipartita</i>	x		x	
<i>Pavona cactus</i>	x	x	x	
<i>Pavona clavus</i>	x		x	
<i>Pavona decussata</i>	x		x	
<i>Pavona duerdeni</i>	x		x	
<i>Pavona explanulata</i>	x		x	
<i>Pavona frondifera</i>	x		x	New Record for WA
<i>Pavona maldivensis</i>	x		x	
<i>Pavona varians</i>	x	x	x	
<i>Pavona venosa</i>	x		x	
Astrocoeniidae				
<i>Stylocoeniella armata</i>	x		x	
<i>Stylocoeniella guentheri</i>	x		x	
Dendrophylliidae				
<i>Turbinaria frondens</i>	x		x	
<i>Turbinaria mesenterina</i>	x		x	
<i>Turbinaria peltata</i>	x		x	
<i>Turbinaria reniformis</i>	x		x	
<i>Turbinaria stellulata</i>	x		x	
Euphyllidae				
<i>Euphyllia ancora</i>	x		x	
<i>Euphyllia cristata</i>	x	x	x	
<i>Euphyllia glabrescens</i>	x		x	
<i>Physogyra lichtensteini</i>	x		x	
<i>Plerogyra sinuosa</i>	x		x	
Faviidae				
<i>Caulastrea furcata</i>	x	x	x	
<i>Caulastrea tumida</i>	x		x	
<i>Cyphastrea agassizi</i>	x		x	
<i>Cyphastrea chalcidicum</i>	x	x	x	
<i>Cyphastrea microphthalma</i>	x	x	x	
<i>Cyphastrea serailia</i>	x	x	x	
<i>Diploastrea heliopora</i>	x		x	
<i>Echinopora ashmorensis</i>	x		x	
<i>Echinopora gemmacea</i>	x		x	

Species	Shallow	Deep	Combined New Records
<i>Echinopora hirsutissima</i>	x		x
<i>Echinopora horrida</i>	x		x
<i>Echinopora lamellosa</i>	x	x	x
<i>Echinopora mammiformis</i>	x		x
<i>Favia danae</i>	x		x
<i>Favia fava</i>	x		x
<i>Favia helianthoides</i>	x		x
<i>Favia laxa</i>	x		x
<i>Favia lizardensis</i>	x		x
<i>Favia matthaii</i>	x		x
<i>Favia maxima</i>	x		x
<i>Favia pallida</i>	x		x
<i>Favia rotumana</i>	x		x
<i>Favia rotundata</i>	x		x
<i>Favia speciosa</i>	x		x
<i>Favia stelligera</i>	x		x
<i>Favia truncatus</i>	x		x
<i>Favites abdita</i>	x		x
<i>Favites chinensis</i>	x		x
<i>Favites complanata</i>	x		x
<i>Favites flexuosa</i>	x		x
<i>Favites halicora</i>	x		x
<i>Favites pentagona</i>	x		x
<i>Favites russelli</i>	x		x
<i>Favites stylifera</i>	x		x
<i>Goniastrea aspera</i>	x		x
<i>Goniastrea australensis</i>	x		x
<i>Goniastrea edwardsi</i>	x		x
<i>Goniastrea favulus</i>	x		x
<i>Goniastrea palauensis</i>	x		x
<i>Goniastrea pectinata</i>	x		x
<i>Goniastrea retiformis</i>	x		x
<i>Leptastrea aequalis</i>	x		x
<i>Leptastrea inaequalis</i>	x		x
<i>Leptastrea pruinosa</i>	x		x
<i>Leptastrea purpurea</i>	x		x
<i>Leptastrea transversa</i>	x		x
<i>Leptoria phrygia</i>	x		x
<i>Montastrea annuligera</i>	x		x
<i>Montastrea curta</i>	x		x
<i>Montastrea magnistellata</i>	x		x
<i>Montastrea valenciennesi</i>	x		x
<i>Oulophyllia bennettae</i>	x		x
<i>Oulophyllia crispa</i>	x		x
<i>Oulophyllia levis</i>	x		x
<i>Platygyra daedalea</i>	x		x
<i>Platygyra lamellina</i>	x		x
<i>Platygyra pini</i>	x		x
<i>Platygyra ryukyuensis</i>	x		x
<i>Platygyra sinensis</i>	x		x
<i>Platygyra verweyi</i>	x		x
<i>Plesiastrea versipora</i>	x		x

Species	Shallow	Deep	Combined	New Records
Fungiidae				
<i>Ctenactis crassa</i>	x	x	x	
<i>Ctenactis echinata</i>	x	x	x	
<i>Ctenactis albitentaculata</i>	x		x	New record for WA
<i>Fungia (Cycloseris) costulata</i>	x		x	
<i>Fungia (Cycloseris) vaughani</i>	x		x	
<i>Cantharellus noumeae</i>	x		x	
<i>Fungia concinna</i>	x	x	x	
<i>Fungia fungites</i>	x		x	
<i>Fungia granulosa</i>	x		x	
<i>Fungia horrida</i>	x	x	x	
<i>Fungia moluccensis</i>	x		x	New record for WA
<i>Fungia paumotensis</i>	x	x	x	
<i>Fungia repanda</i>	x	x	x	
<i>Fungia scutaria</i>	x		x	
<i>Fungia (Danafungia) scruposa</i>	x		x	
<i>Halomitra pileus</i>		x	x	New record for WA
<i>Heliofungia actiniformis</i>	x		x	
<i>Herpolitha limax</i>	x	x	x	
<i>Herpolitha weberi</i>	x	x	x	
<i>Lithophyllon mokai</i>	x		x	
<i>Lithophyllon undulatum</i>	x		x	
<i>Podabacia crustacea</i>	x		x	
<i>Podabacia motuporensis</i>	x		x	New record for WA
<i>Polyphyllia talpina</i>	x		x	
<i>Sandalolitha robusta</i>	x	x	x	
<i>Sandalolitha dentata</i>		x	x	New record for Australia
<i>Zoopilus echinatus</i>		x	x	New record for Australia
Merulinidae				
<i>Hydnophora exesa</i>	x	x	x	
<i>Hydnophora microconos</i>	x		x	
<i>Hydnophora pilosa</i>	x		x	
<i>Hydnophora rigida</i>	x	x	x	
<i>Merulina ampliata</i>	x		x	
<i>Merulina scabricula</i>	x		x	
<i>Scapophyllia cylindrica</i>	x		x	
Mussidae				
<i>Acanthastrea brevis</i>	x		x	
<i>Acanthastrea echinata</i>	x		x	
<i>Australomussa rowleyensis</i>	x	x	x	
<i>Lobophyllia hataii</i>	x		x	
<i>Lobophyllia hemprichii</i>	x	x	x	
<i>Symphyllia agaricia</i>	x		x	
<i>Symphyllia radians</i>	x		x	
<i>Symphyllia recta</i>	x		x	
<i>Symphyllia valenciennesii</i>	x		x	
Oculinidae				
<i>Galaxea astreata</i>	x		x	
<i>Galaxea fascicularis</i>	x		x	
<i>Galaxea horrescens</i>	x		x	
Pectiniidae				
<i>Echinophyllia aspera</i>	x	x	x	
<i>Echinophyllia echinata</i>	x	x	x	

Species	Shallow	Deep	Combined New Records
<i>Echinophyllia echinoporoides</i>	x		x
<i>Echinophyllia orpheensis</i>	x		x
<i>Mycedium elephantotus</i>	x	x	x
<i>Mycedium mancaoi</i>	x		x
<i>Mycedium robokaki</i>	x		x
<i>Oxypora glabra</i>	x		x
<i>Oxypora lacera</i>	x	x	x
<i>Pectinia alcicornis</i>	x		x
<i>Pectinia lactuca</i>	x		x
<i>Pectinia paeonia</i>	x		x
<i>Pectinia teres</i>	x		x
Pocilloporidae			
<i>Pocillopora damicornis</i>	x		x
<i>Pocillopora danae</i>	x		x
<i>Pocillopora eydouxi</i>	x		x
<i>Pocillopora meandrina</i>	x		x
<i>Pocillopora verrucosa</i>	x		x
<i>Pocillopora woodjonesi</i>	x		x
<i>Seriatopora hystrix</i>	x	x	x
<i>Stylophora mordax</i>	x		x
<i>Stylophora pistillata</i>	x	x	x
Poritidae			
<i>Alveopora allingi</i>	x		x
<i>Alveopora catalai</i>	x		x
<i>Alveopora fenestrata</i>	x		x
<i>Alveopora spongiosa</i>	x		x
<i>Alveopora tizardi</i>	x		x
<i>Alveopora verrilliana</i>	x		x
<i>Goniopora burgosi</i>	x		x
<i>Goniopora columna</i>	x		x
<i>Goniopora djiboutiensis</i>	x		x
<i>Goniopora lobata</i>	x		x
<i>Goniopora minor</i>	x		x
<i>Goniopora palmensis</i>	x		x
<i>Goniopora pendulus</i>	x		x
<i>Goniopora stutchburyi</i>	x		x
<i>Goniopora tenuidens</i>	x		x
<i>Porites annae</i>	x		x
<i>Porites cylindrica</i>	x		x
<i>Porites lichen</i>	x		x
<i>Porites lobata</i>	x		x
<i>Porites lutea</i>	x		x
<i>Porites monticulosa</i>	x		x
<i>Porites murrayensis</i>	x		x
<i>Porites nigrescens</i>	x		x
<i>Porites rus</i>	x		x
<i>Porites solida</i>	x		x
<i>Porites vaughani</i>	x	x	x
Siderastreidae			
<i>Coscinaraea columna</i>	x		x
<i>Coscinaraea exesa</i>	x		x
<i>Coscinaraea wellsi</i>	x		x
<i>Psammocora contigua</i>	x		x

Species	Shallow	Deep	Combined New Records
<i>Psammocora digitata</i>	x		x
<i>Psammocora explanulata</i>	x		x
<i>Psammocora haimeana</i>	x	x	x
<i>Psammocora nierstraszi</i>	x		x
<i>Psammocora obtusangula</i>	x		x
<i>Psammocora profundacella</i>	x	x	x
<i>Psammocora superficialis</i>	x		x
Total Species Recorded	295	51	306
Total Genera Recorded	58	27	60
Total Families Recorded	14	11	14
Total New Records for Scott Reef	8	2	8
Total New Records for WA	5	2	7
Total New Records for Australia	0	2	2