FINAL REPORT

Australian Government
Great Barrier Reef
Marine Park Authority

Coral disease outbreak monitoring program — *Implications for management*





Allison S. Paley, David Abrego, Jessica Haapkyla
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Published by the Great Barrier Reef Marine Park Authority January 2013

ISBN 978 1 921682 77 3 (ebook: pdf)

National Library of Australia Cataloguing-in-Publication entry

Coral disease outbreak monitoring program [electronic resource]: implications for management / Allison S. Paley ... [et al.]

ISBN 978 1 921682 77 3 (ebook: pdf)

Other authors: David Abrego, Jessica Haapkyla and Bette L. Willis.

Corals--Diseases--Queensland--Great Barrier Reef.
Corals--Ecology--Queensland--Great Barrier Reef.
Corals--Queensland--Great Barrier Reef.
Great Barrier Reef (Qld.)

Paley, Allison S.
Great Barrier Reef Marine Park Authority.

593.609943

This publication should be cited as:
Paley, A.S., Abrego, D., Haapkyla, J., Willis, B.L. 2013, Coral disease outbreak monitoring program: implications for management, Great Barrier Reef Marine Park Authority, Townsville.

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1.0. EXECUTIVE SUMMARY

Seasonal environmental anomalies regularly affect the health of coral communities on the Great Barrier Reef (the Reef), particularly warm sea temperature anomalies in summer and low salinity anomalies following coastal run-off during the wet season. Such events can have severe impacts on corals, particularly those living in near shore habitats, causing stress that is typically manifested as bleaching and increasing their susceptibility to disease. During the 2008/2009 summer, seasonal anomalies occurred in both the northern and central sectors of the Reef. Thermal stress in the northern sector caused a moderate patchy bleaching event and freshwater inundation in the central sector caused a low salinity bleaching event. Selected reef sites, which form part of a long-term program to monitor coral disease annually on the Reef, were re-surveyed following reports of bleaching to evaluate the impacts of thermal and salinity stress on the prevalence of coral bleaching and disease in these two regions.

In the northern sector, bleaching observed late in the summer (March) was generally moderate (not exceeding 27 per cent of colonies) and consisted mostly of patchy bleaching, consistent with a lower likelihood of subsequent mortality than white, or whole-colony, bleaching. There was little change in coral cover, and coral disease prevalence remained low (between zero and three per cent of surveyed colonies) and comparable to observations from these sites made in previous years. Thermal bleaching in this region did not result in large-scale coral mortality or reef degradation, although two notable exceptions were No Name Reef and Day Reef, where coral cover significantly declined and disease prevalence was higher than average (Day Reef). Although major changes to coral community structure were not identified, regular surveying should continue at Day Reef and No Name Reef to monitor potential long-term impacts associated with thermal stress from the 2008–2009 summer.

In the central sector, salinity declined markedly in late February, resulting in five- to 10-fold increases in the abundance of the coral disease atramentous necrosis at Nelly Bay and Geoffrey Bay sites on Magnetic Island. Salinity stress resulted in severe bleaching (up to 85 per cent of colonies surveyed), followed by declines in hard coral cover of approximately 50 per cent at near shore reef sites in Picnic Bay and Middle Reef. Although overall disease prevalence remained low and comparable to previous records from the long-term monitoring program, disease abundance was probably higher than values recorded at Picnic Bay and Middle Reef sites in late March 2009 because the peak of the epizootic was not sampled.

Given the inherent difficulty in following seasonal environmental impacts through (typically) annual monitoring programs, a response-based action plan is needed to appropriately monitor changes in coral communities on the Reef. Such an action plan should include collaboration between frequent Reef users and trained reef monitors to target areas of particular concern or sensitivity.

Table 1: Summary of impacts associated with the 2008–2009 bleaching and salinity events by sector and reef region showing dominant coral families affected. Severity of impact categorised on a scale from minimal to severe (minimal: 0–3 per cent of colonies affected; moderate: 4–35 per cent; intermediate: 36–65 per cent; severe: 66–100 per cent of colonies affected). See figures referenced for detailed data. Significant impacts are **bolded**. *****: data from J. Haapkyla (Haapkyla et al. 2011)

Impact type	Sector	Reef	Extent of impact	Per cent of colonies affected	Dominant family	Most affected family	Fig. references
Thermal bleaching	Northern	Maxwell Reef	Moderate	24	Acroporidae	Acroporidae	4.1.1 4.1.4 4.3.2
		Martin Reef	Minimal	3	Poritidae	Acroporidae	
		Linnet Reef	Moderate	7	Poritidae	Poritidae	
		Lizard Island	Moderate	27	Acroporidae	Acroporidae	
		Macgillivary Reef	Moderate	14	Acroporidae	Acroporidae	
		North Direction Island	Moderate	15	Acroporidae	Acroporidae	
		No Name Reef	Moderate	14	Acroporidae	Acroporidae	
		Yonge Reef	Moderate	22	Acroporidae	Acroporidae	
		Day Reef	Moderate	18	Acroporidae	Acroporidae	
Salinity bleaching	Central	**Magnetic Island**	**Severe**	**86**	**Acroporidae**	**Acroporidae**	4.5.1 4.5.3 4.7.4
		Middle Reef	**Intermediate**	**54**	**Poritidae**	**Poritidae**	
		Orpheus Island	Minimal	3	Acroporidae	Poritidae	
		Kelso Reef	Minimal	3	Acroporidae	Pocilloporidae	
		Little Kelso Reef	Minimal	2	Acroporidae	Acroporidae	
		Davie Reef	Moderate	7	Acroporidae	Pocilloporidae	
		Knife Reef	Moderate	8	Acroporidae	Faviidae	
		Fork Reef	Moderate	5	Faviidae	Faviidae	
		Dip Reef	Moderate	8	Acroporidae	Acroporidae	
Disease prevalence	Northern	Maxwell Reef	Minimal	<1	Acroporidae	Acroporidae	4.2.1 4.2.3 4.3.2
		Martin Reef	Minimal	<1	Poritidae	Poritidae	
		Linnet Reef	Minimal	<1	Poritidae	Pocilloporidae	
		Lizard Island	Minimal	2	Acroporidae	Acroporidae	
		Macgillivary Reef	Minimal	<1	Acroporidae	Acroporidae	
		North Direction Island	Minimal	2	Acroporidae	Acroporidae	
		No Name Reef	Minimal	1	Acroporidae	Pocilloporidae	
		Yonge Reef	Minimal	3	Acroporidae	Acroporidae	
		Day Reef	**Moderate**	**8**	**Acroporidae**	**Acroporidae**	
	Central	**Magnetic Island**	**Intermediate**	**~3 / 45 colonies per 25m^2***	**Acroporidae**	**Acroporidae**	4.4.1 4.6.1 4.6.2 4.6.3 4.7.4
		Middle Reef	Moderate	4	Poritidae	Poritidae	
		Orpheus Island	Moderate	5	Acroporidae	Pocilloporidae	
		Kelso Reef	Moderate	5	Acroporidae	Pocilloporidae	
		Little Kelso Reef	Moderate	5	Acroporidae	Pocilloporidae	
		Davie Reef	Moderate	4	Acroporidae	Pocilloporidae	
		Knife Reef	Moderate	8	Acroporidae	Pocilloporidae	
		Fork Reef	Moderate	7	Faviidae	Pocilloporidae	
		Dip Reef	Minimal	<1	Acroporidae	Pocilloporidae	

2.0. INTRODUCTION

Coral reefs are affected annually by seasonal processes such as increases in oceanic temperatures, coastal run-off and strong winds. On the Great Barrier Reef (the Reef), annual rises in seawater temperature of only 1–2 ^{o}C above the usual summer maxima, combined with high light, has sometimes resulted in coral bleaching, i.e. the loss or expulsion of endosymbiotic zooxanthellae (Donner et al. 2005; Berkelmans 2009). Frequent or severe bleaching can lead to a reduction in reproductive capacity, growth, disease resistance and/or survivorship of affected corals, even at large geographic scales (Hoegh-Guldberg 1999; Michalek-Wagner and Willis 2001; Douglas 2003; Muller et al. 2008). Mass coral bleaching episodes in recent decades have been attributed to rising ocean temperatures and led many to speculate that future climate change could lead to long-term coral reef degradation (Glynn 1991; Brown 1997; Hoegh-Guldberg 1999; Wellington et al. 2001; Sheppard 2003; Hoegh-Guldberg et al. 2007). During the 1998 mass bleaching event on the Reef, 53 per cent of coral colonies from Magnetic Island and the Palm Islands were affected by bleaching to some degree (Marshall and Baird 2000). Some coral taxa were affected more greatly than others; the coral *Acropora hyacinthus* suffered 36 per cent mortality overall across the reef, with some locations seeing up to 70 per cent mortality of this coral (Pelorus Island, Palm Islands) (Marshall and Baird 2000).

While thermal stress has been identified as a major factor leading to coral bleaching (Jones et al.1998), monsoonal wet seasons in the tropical north (October to April) periodically deliver a deluge of freshwater to inner-shelf reefs, through flood plumes and terrestrial run-off, resulting in rapid reductions in seawater salinity (Van Woesik et al. 1995). Low salinity stress is another threat known to cause extensive coral bleaching and potential widespread mortality (Hedley 1925; Rainford 1925; Goreau 1964; reviewed in Glynn 1993). Humphrey et al. (2008) suggested that understanding the implications of increasing terrestrial run-off of freshwater, nutrients and sediments is one of the most pressing concerns for management of the Reef (see also Hutchings and Haynes 2005; Hutchings et al. 2005). In the past 150 years, expanding agriculture, coastal development and industry have led to greater inputs of freshwater (McCulloch et al. 2003), nutrients (Furnas 2003), sediments (Furnas 2003; McCulloch et al. 2003), and agrochemicals (Haynes and Johnson 2000; Haynes and Michalek-Wagner 2000) into inshore reef habitats. On the Reef, flood plumes generally remain within 20 kilometres of the coast (Humphrey et al. 2008; Chao 1988). However, in the absence of typical strong south-easterly winds, flood plumes have been known to extend to some of the mid- and outer-shelf portions of the Reef (Devlin and Brodie 2005). Some corals are more severely affected by changes in water quality than others; Van Woesik et al. (1995) found that the freshwater plume resulting from tropical cyclone Joy (1990/1991) had severe impacts on communities of acroporid and pocilloporid corals in the Keppel Islands, but in contrast, colonies with massive morphology (such as *Porites* and faviid species) generally exhibited only partial bleaching and recovered rapidly.

Coral bleaching is not the only threat challenging the resilience of coral reefs. Other threats, such as coral disease, may act to augment the impacts of coral bleaching (Willis et al. 2004; Miller et al. 2006; Muller et al. 2008; Brandt et al. 2009). Higher coral disease prevalence has been linked with warmer sea surface temperatures (Gil-Agudelo and Garzon-Ferreira 2001; Kuta and Richardson 2002; Boyett et al. 2007; Bruno et al. 2007; Sato et al. 2009), and not surprisingly, mass coral bleaching events have been followed by disease outbreaks (Miller et al. 2006).

Until recently, it was thought that coral disease has had little impact on coral populations on the Great Barrier Reef, however, comparatively few studies have specifically targeted coral disease on the Reef, which has undoubtedly contributed to the fallacy that disease has played a minor role in the dynamics of coral communities in this region (Willis et al. 2004). The identification of several new coral diseases on the Reef in recent years, including brown band disease (Willis et al. 2004) and atramentous necrosis (Jones et al. 2004), highlights the potential for emerging diseases on the Reef. Bleaching makes corals more susceptible to disease, and in turn, coral disease exacerbates the deleterious impacts of bleaching (Brandt et al. 2009). When combined, coral disease and bleaching cause greater harm to coral colonies than either can accomplish independently (Brandt et al. 2009). For these reasons, the impact bleaching may have on a reef should not be measured based on bleaching severity alone, but combined with monitoring of disease prevalence and changes to community structure (e.g. hard coral cover).

In February of 2009, two events impacted the Reef in the northern and central sectors: (1) a moderate thermal anomaly occurred on mid- and outer-shelf reefs in the northern sector, as predicted by the ReefTemp model, and bleaching in response to warm thermal stress was reported; and (2) heavy rainfall and accompanying freshwater run-off caused bleaching in response to low salinity stress on inner-shelf reefs in the central sector. Records from January 2009, collected as part of a long-term monitoring program of disease prevalence across the Reef for the past five years (B. Willis, unpubl. data), enabled a comparative study of disease prevalence, coral cover and bleaching severity before and after the events in these two reef regions.

The aim of this study is to evaluate and report on the extent of (i) coral disease, (ii) bleaching severity, and (iii) change in coral cover, as an indicator of coral recovery and mortality, at sites in the northern and central sectors of the Great Barrier Reef that were exposed to temperature and salinity stress during the 2008–2009 summer. This information will provide baseline data on the impacts of warm thermal anomalies and low salinity events on coral communities of the Great Barrier Reef Marine Park to enable development of management strategies which enhance the recovery of reefs affected by coral disease outbreaks and/or coral mortality.

RESEARCH METHODS

3.1. Sampling scheme

To monitor the impacts of (1) a moderate thermal anomaly in the northern sector, and (2) freshwater inundation from coastal run-off in the central sector of the Reef, coral bleaching severity, coral cover and disease prevalence were surveyed within two latitudinal sectors of the Reef from January to August 2009 (Fig. 3.1.1). To investigate spatial variability in these three parameters, three haphazardly selected reefs were surveyed within each of three cross-shelf positions (inner-, mid-, and outer-shelf) in both sectors. These cross-shelf positions represent a gradient of decreasing terrestrial influence and increasing wave exposure from inner- to outer-shelf positions. At each reef, two sites were randomly selected within the north-west sheltered, back-reef zone. At each site, we haphazardly placed three 20 x 2 metre belt transects parallel to depth contours along the upper slope between 3 and 6 metres in depth.

Within each belt transect, all scleractinians, gorgonians, alcyonaceans and hydrocorals were recorded and examined for signs of the following diseases: black band disease, brown band disease, skeletal eroding band, white syndromes, atramentous necrosis, growth anomalies and other cyanobacterial infections. Recent cases of tissue loss, which were inconsistent with predation, were classified as suspected cases of white syndromes and recorded as ‘other’. All scleractinians were identified to genus level. Coral colonies of the genus *Acropora* were further divided into growth morphologies as follows: tabular, corymbose, clumping, bushy, digitate or staghorn. Colonies showing signs of bleaching were recorded as either patchy bleached (diffuse areas of white bleaching consistent with thermal or salinity stress, but not including sharply demarcated, unusual patterns of bleaching consistent with pathogen-induced bleaching), pale bleached (pale overall appearance particularly on branch tips and areas directly exposed to light) or bleached (completely white bleached with intact living tissue). Along transects, line intercept data were collected to estimate per cent coral cover by calculating the fraction of the 20 transect that was intercepted by each of the coral taxa, as well as sand, bare substratum, algae and crustose coralline algae (after English et al. 1997).

Data from surveys were entered into a long-term database (Microsoft Access), created for an ongoing program to monitor coral disease prevalence and per cent coral cover annually since 2004 in three sectors of the Reef. For some reef regions, data on coral cover prior to 2009 have been included here to show temporal changes in per cent coral cover over time spans greater than the scope of the current study.

Water quality (salinity in ppt (parts per thousand)), temperature and the prevalence of atramentous necrosis on plating *Montipora* colonies were monitored in Geoffrey and Nelly Bays of Magnetic Island at four–six week intervals between December 2007 and October 2009 by J. Haapkyla (Haapkyla et al. 2011). These data will be presented here to enable discussions of disease prevalence, coral bleaching and changes in hard coral cover in relation to the rapid decline in salinity that occurred following near shore flooding and subsequent coastal run-off in the central sector of the Reef during the 2009 summer. Disease prevalence surveys were conducted every fortnight using belt transects as described above. Five replicate transects were laid at depths of 4 metres for a total of 10 transects surveyed across the two bays during each sampling period. Water temperature was monitored using Odyssey data recording system temperature loggers, which were deployed on star pickets underneath a sediment trap at each site and retrieved every two months. At each sampling time, a water sample was collected in close proximity to each site surveyed and measured using a hand-held Reichert r^2-mini refractometer.

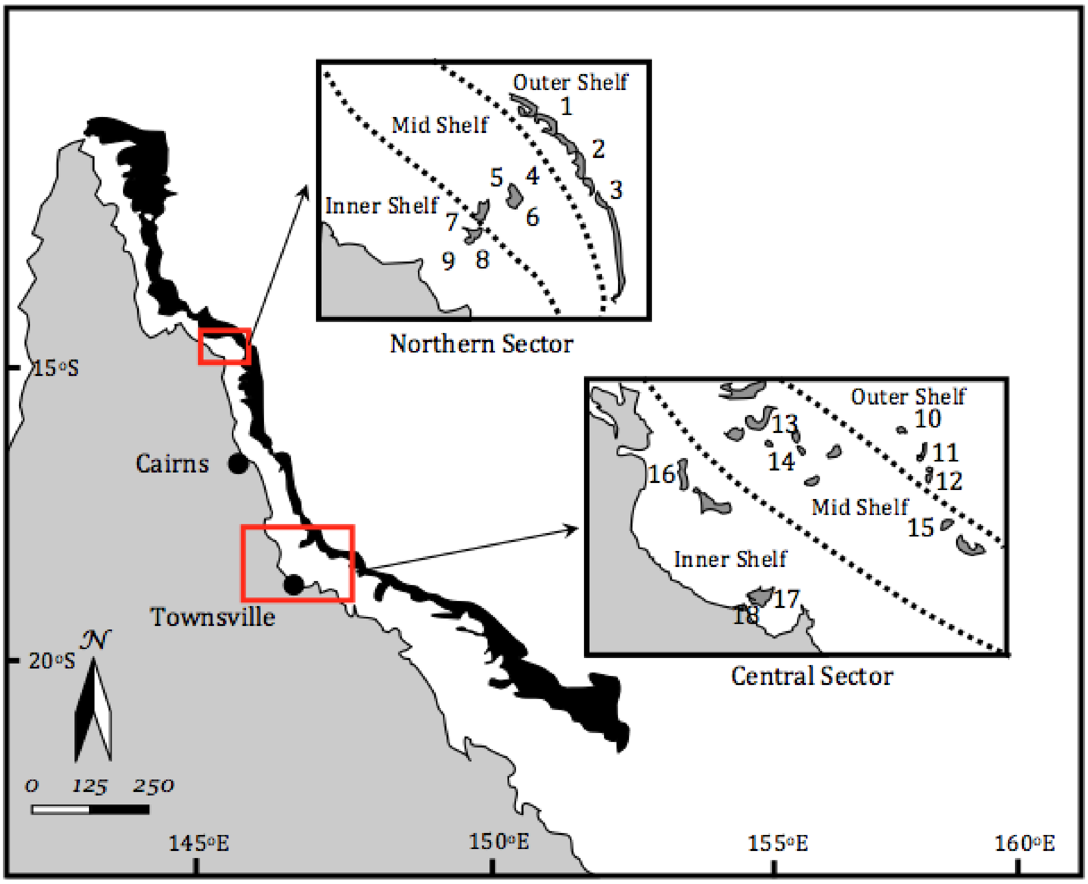


Fig. 3.1.1: Reefs surveyed for coral bleaching, coral cover and disease prevalence in two latitudinal sectors of the Great Barrier Reef. Reefs numbered as follows: (1) Day Reef, (2) Yonge Reef, (3) No Name Reef, (4) Macgillvary Reef, (5) Lizard Island, (6) North Direction Island, (7) Martin Reef, (8) Linnet Reef, (9) Maxwell Reef, (10) Dip Reef, (11) Knife Reef, (12) Fork Reef, (13) Kelso Reef, (14) Little Kelso Reef, (15) Davies Reef, (16) Orpheus Island, (17) Magnetic Island, and (18) Middle Reef.

3.2. Bleaching and disease prevalence comparisons

As moderate thermal bleaching in the northern sector and low salinity bleaching in the central sector were unrelated events, the data for these two sectors will be analysed separately as follows.

Northern sector The prevalence of corals showing signs of bleaching and in each bleaching severity category (patchy, pale or bleached) at the survey sites were compared graphically between January (17–24 January) and March (16–22 March) 2009. Disease prevalence, total mean per cent hard coral cover (estimated from line intercept data), and the per cent of colonies in each coral family that were bleached, diseased and healthy were also compared between January and March 2009 for northern sector sites. Additionally, surveys from the Lizard Island lagoon in August were added to graphical comparisons of bleaching severity, disease prevalence and hard coral cover for this site.

Central sector Mid-, outer- and inner-shelf reefs in the central sector were surveyed during the summer of 2009. Mid- and outer-shelf reefs were surveyed only once in January (22–28 January), while inner-shelf sites were surveyed up to three times between March and August 2009 (Magnetic Island sites 6–11 March, 18 May; Middle Reef 7 June and 21–26 August 2009). To investigate longer term patterns in bleaching severity, disease prevalence and per cent hard coral cover, data from inner-shelf positions were graphed separately and compared with data collected by J. Haapkyla between December 2007 and October 2009 (Haapkyla et al. 2011). Patterns in water temperature, salinity and the prevalence of atramentous necrosis on plating *Montipora* colonies from inner-shelf reefs at Magnetic Island between December 2007 and October 2009 were investigated graphically, with an emphasis on samples/surveys taken around 28 February 2009, when rapid changes in salinity were observed (Haapkyla et al. 2011). Mean per cent coral cover at Magnetic Island sites determined from surveys in the current study was also compared with data collected from March 2008 through September 2009 by J. Haapkyla (Haapkyla et al. 2011).

Cross-shelf patterns in bleaching severity in the central sector during the summer of 2009 were assessed by comparing the total per cent of colonies showing signs of bleaching and the per cent of corals in each bleaching severity category (patchy, pale or bleached) between inner- and mid-shelf reef positions. In addition, bleaching severity at inner-shelf sites was compared between March and August 2009. Disease prevalence and total mean per cent hard coral cover were compared among mid-shelf sites surveyed in January, and among inner-shelf sites surveyed between March and August 2009. Colony condition (bleached, diseased, healthy) by family was compared among mid-shelf sites surveyed in January, and between March and April surveys of inner-shelf sites in 2009.

RESULTS

4.1. Thermal bleaching in the northern sector

In the summer of 2009, the per cent of corals showing signs of bleaching increased by between four-fold and 200-fold at the nine reefs surveyed in the northern sector. Per cent bleaching increased from levels ranging between zero and four per cent at all sites in January, to levels greater than 20 per cent at some sites in March (Fig. 4.1.1). Within the Lizard Island lagoon, the per cent of bleached corals increased from one per cent to greater than 25 per cent between January and March (Fig. 4.1.2). In August, coral bleaching was almost absent, with less than 0.25 per cent of colonies showing signs of bleaching (Fig. 4.1.2).

In March, a high per cent of bleached colonies were categorised as patchily bleached (between 30 and 85 per cent of the bleached colonies), and a comparatively small per cent of colonies were categorised as white bleached (between five and 20 per cent of bleached colonies) (Fig. 4.1.3). Bleached corals belonged primarily to the family Acroporidae, with between 30 and 80 per cent of corals belonging to this family (Fig. 4.1.4). Other coral groups that comprised a substantial portion of the bleached colonies observed belonged to the coral families Faviidae and Pocilloporidae (Fig. 4.1.4).

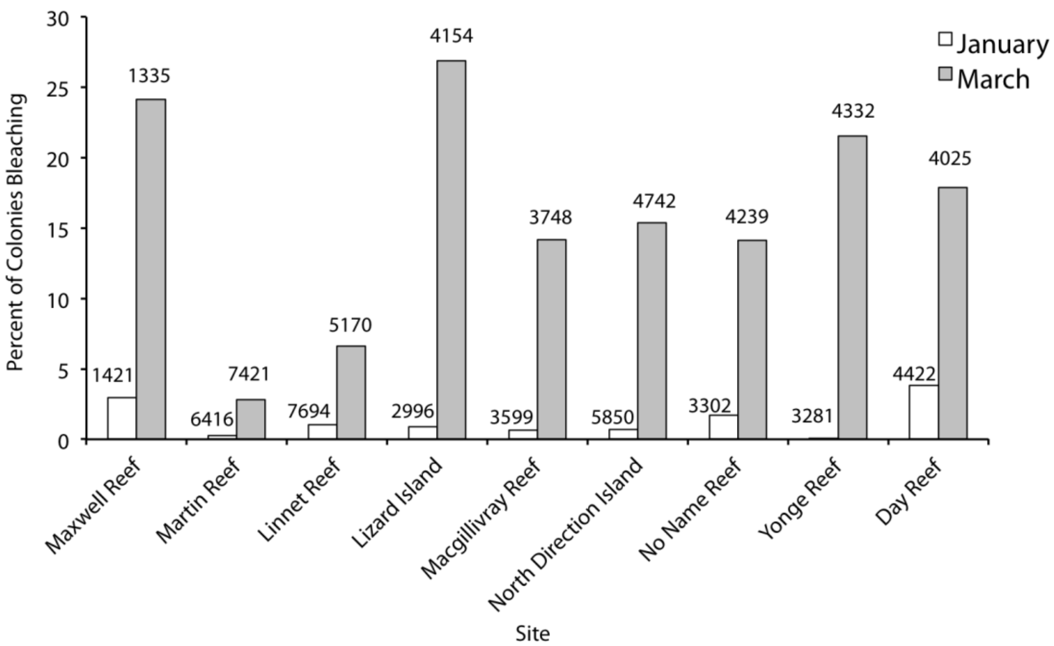


Fig. 4.1.1: Overall per cent of corals showing signs of bleaching on three inner-, mid- and outer-shelf reefs in the northern sector of the Great Barrier Reef in January and March 2009. Sample sizes shown above bars.

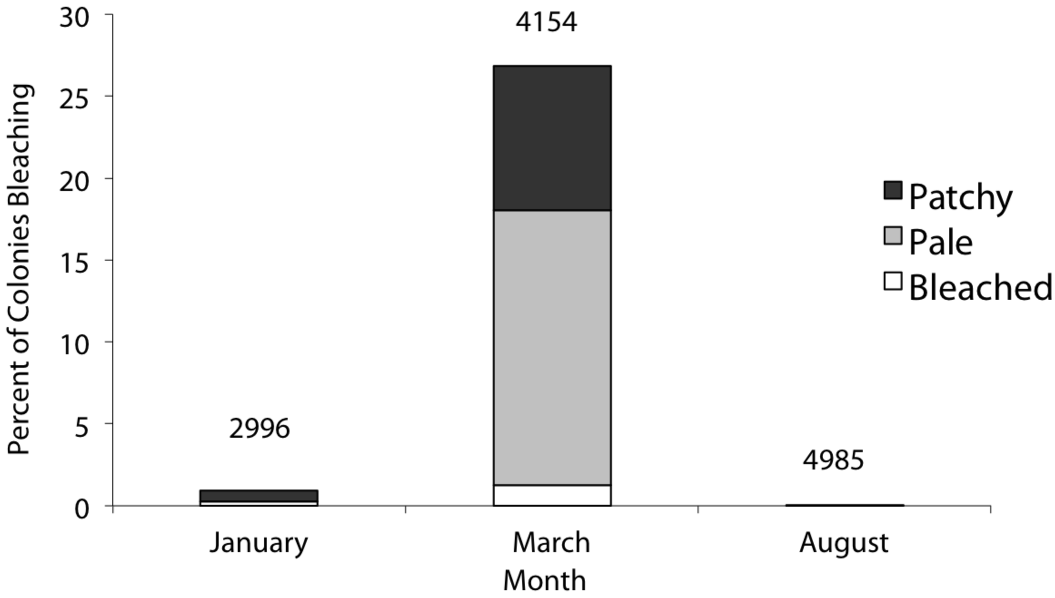
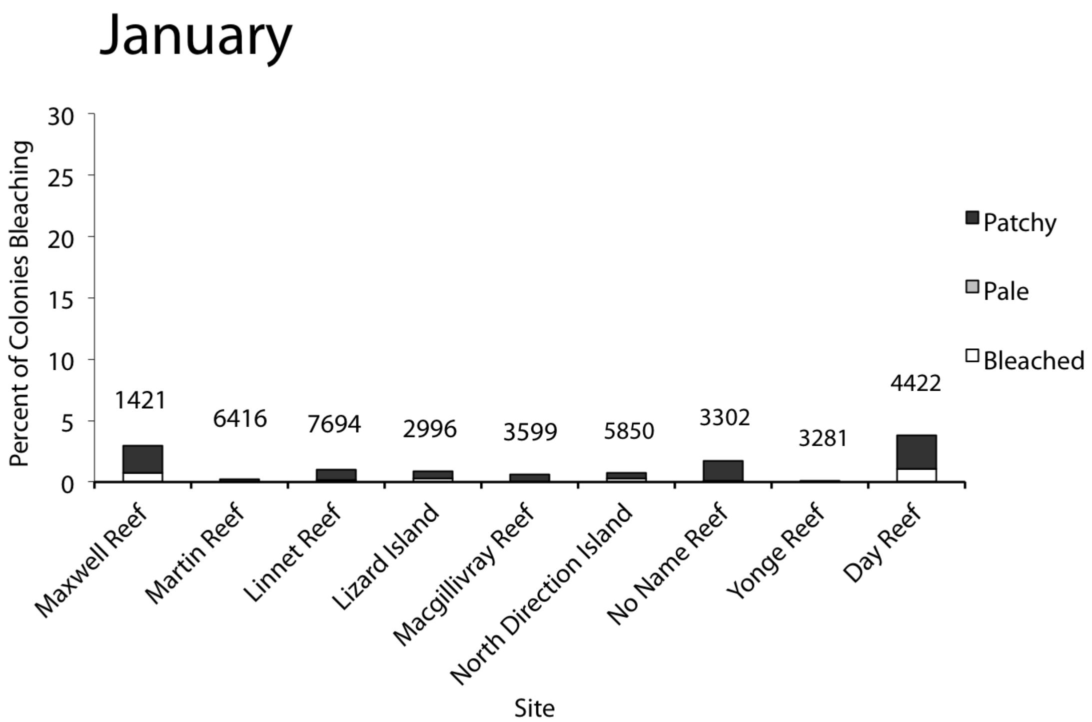


Fig. 4.1.2: Per cent of corals that were patchy bleached, pale bleached or white bleached at Lizard Island in the northern sector of the Great Barrier Reef in January, March and August of 2009. Sample sizes shown above bars.



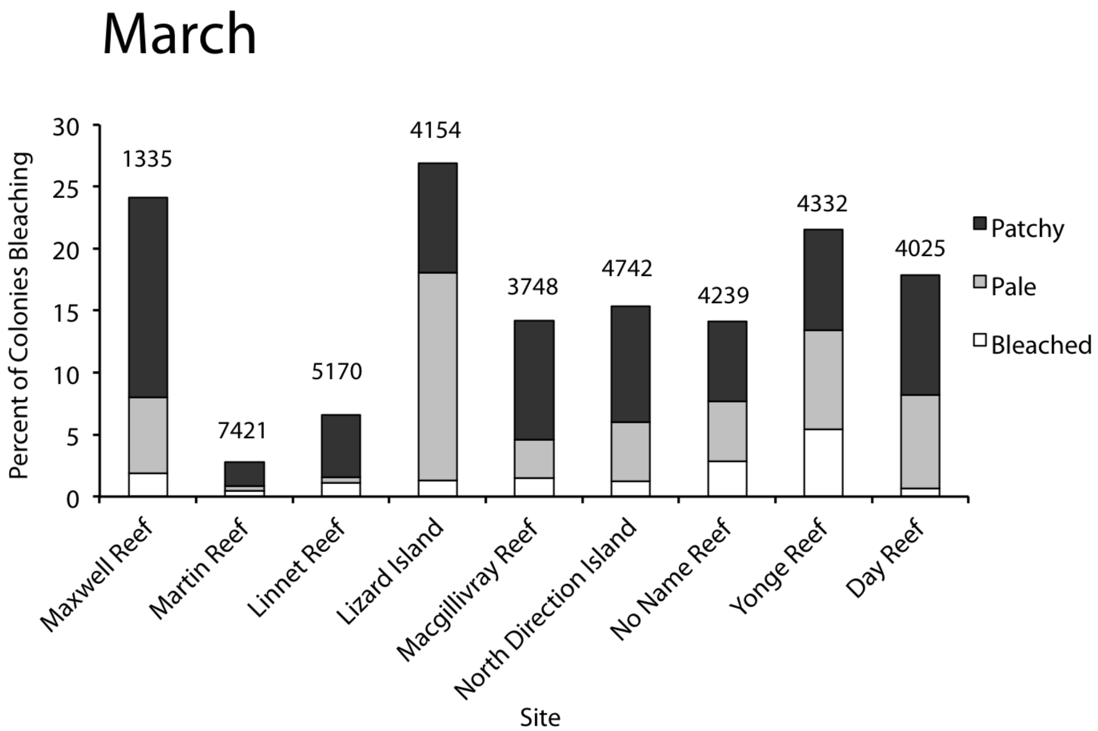


Fig. 4.1.3: Per cent of corals that were patchy bleached, pale bleached or white bleached on three inner-, mid- and outer-shelf reefs in the northern sector of the Great Barrier Reef in: a) January, and b) March 2009. Sample sizes shown above bars.

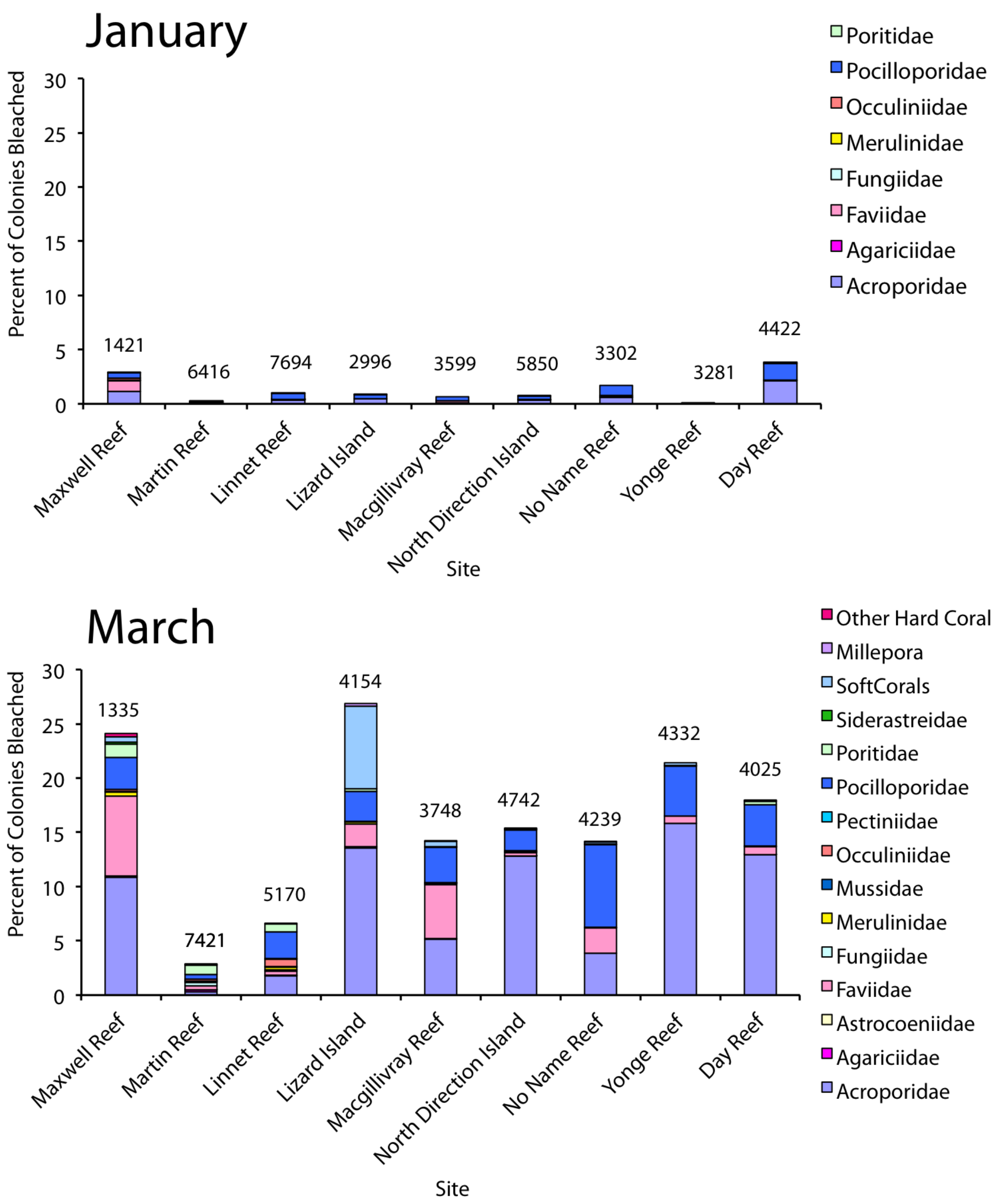


Fig. 4.1.4: Overall per cent of corals showing signs of bleaching by family in three inner-, mid- and outer-shelf reefs in the northern sector of the Great Barrier Reef in: a) January, and b) March 2009. Sample sizes shown above bars.

4.2. Disease prevalence in the northern sector following thermal stress

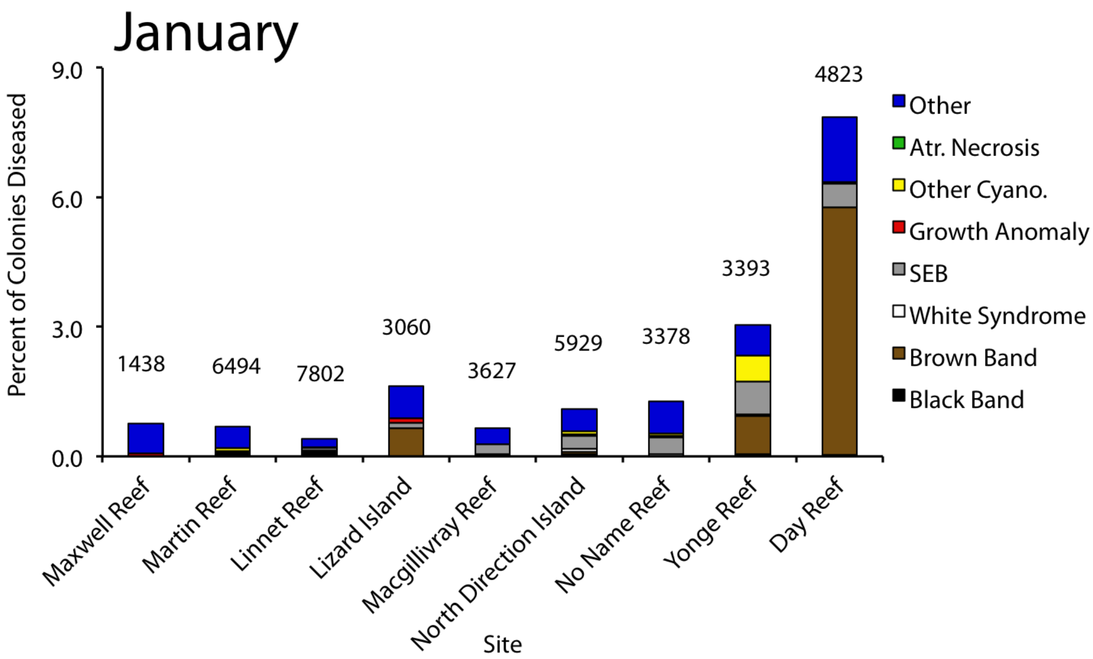
In the following sections, the general term disease will refer to conditions that are known or suspected to be infectious, i.e. black band disease, brown band disease, white syndromes, skeletal eroding band, atramentous necrosis, other cyanobacterial infections and growth anomalies. In addition, a category called ‘other’ is included, which comprised patterns of recent tissue loss that were less clearly interpreted but, because there were no obvious signs of predators, lesions were categorised as potential white syndromes.

The percentage of colonies affected by disease in the northern sector remained low following thermal stress. Overall, between 0.5 and three per cent of all colonies surveyed had signs of disease, with the exception of Day Reef, where between seven and eight per cent of colonies had disease signs in January and March (Fig. 4.2.1). At Day Reef, approximately 75 per cent of diseased colonies had brown band disease in January, with the remaining 25 per cent being suspected cases of white syndromes (20 per cent; coded as other) or skeletal eroding band (five per cent) (Fig. 4.2.1).

In March, skeletal eroding band became the dominant disease present at Day Reef (30 per cent of colonies with disease), while colonies with brown band declined to 15 per cent (Fig. 4.2.1). Another 15 per cent of colonies were infected with black band disease, 15 per cent had other cyanobacterial infections and the remaining 25 per cent were cases of suspected white syndromes (Fig. 4.2.1.). At sites where brown band disease was present and/or the dominant form of infection in January, diseases such as skeletal eroding band or cases of suspected white syndromes became dominant in March (Fig. 4.2.1).

Within the Lizard Island lagoon, the per cent of colonies with signs of disease declined by nearly 50 per cent between January and March (from 1.7 to 0.9 per cent) but remained relatively constant between March and August (Fig. 4.2.2). Initially, brown band disease accounted for nearly 40 per cent of diseased colonies, whereas no colonies had brown band disease in March and only eight per cent of colonies did in August (Fig. 4.2.2). In contrast, five per cent of diseased colonies had skeletal eroding band in January, which increased to nearly 40 per cent in March and August (Fig. 4.2.2). Fifty per cent of colonies recorded as diseased had lesions suspected to be caused by white syndromes throughout the survey period (Fig. 4.2.2).

The Acroporidae was the family most susceptible to disease, with greater than 80 per cent of corals with signs of disease belonging to this family in January and March 2009 (Fig. 4.2.3). The families Poritidae and Pocilloporidae were the next most susceptible families (Fig. 4.2.3).



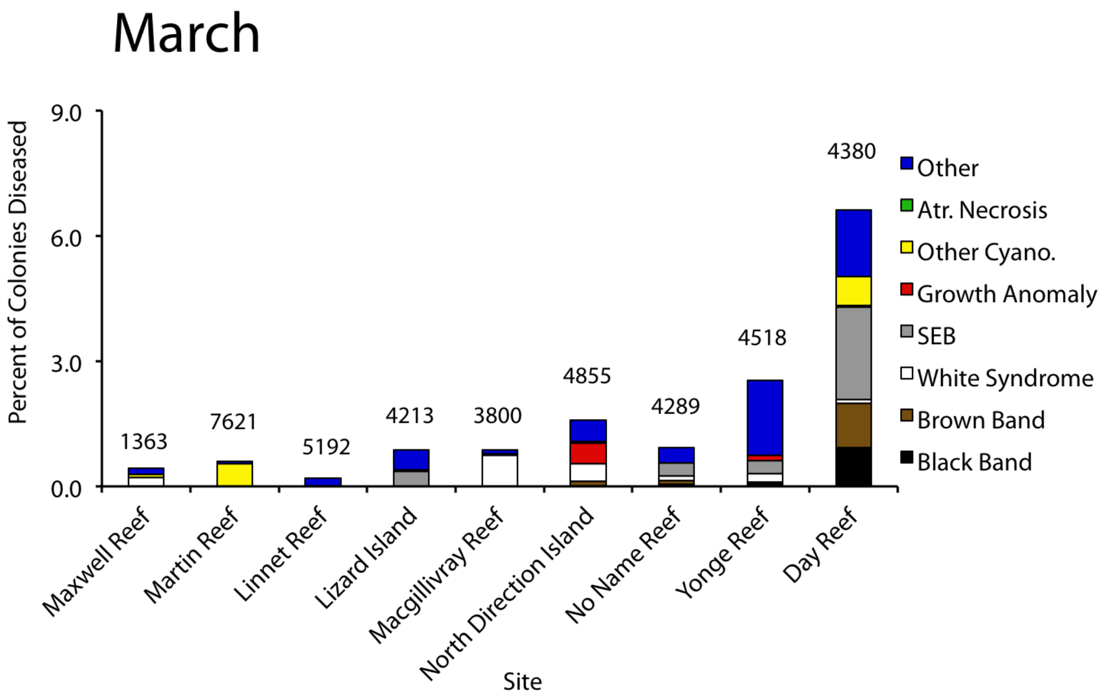


Fig. 4.2.1: Per cent of corals affected by seven diseases at each of three inner-, mid- and outer-shelf reefs in the northern sector of the Great Barrier Reef in: a) January, and b) March 2009. Sample sizes shown above bars.

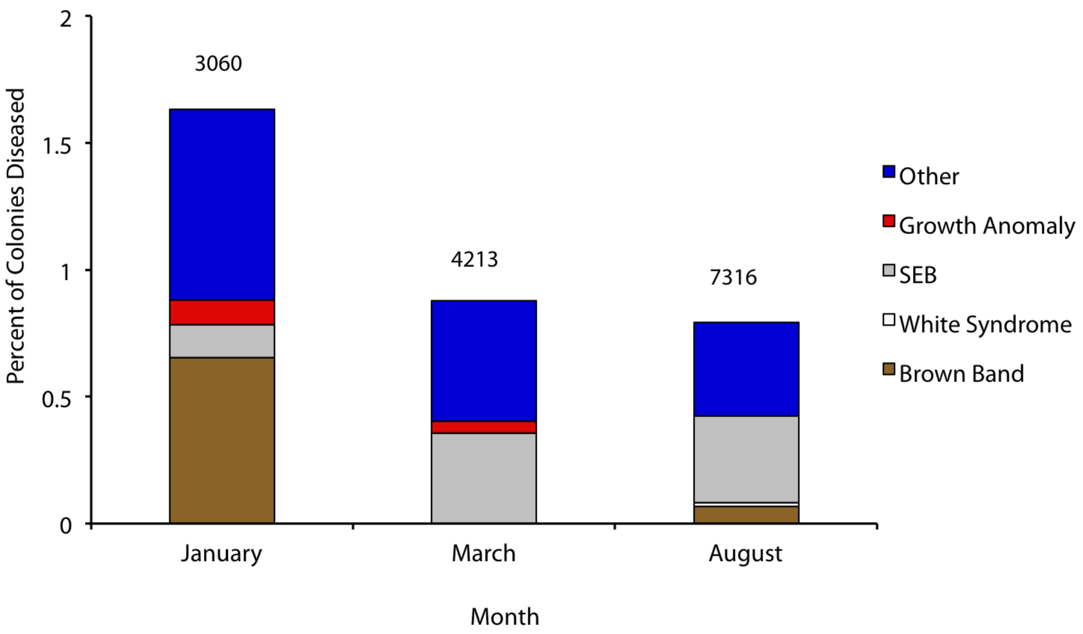
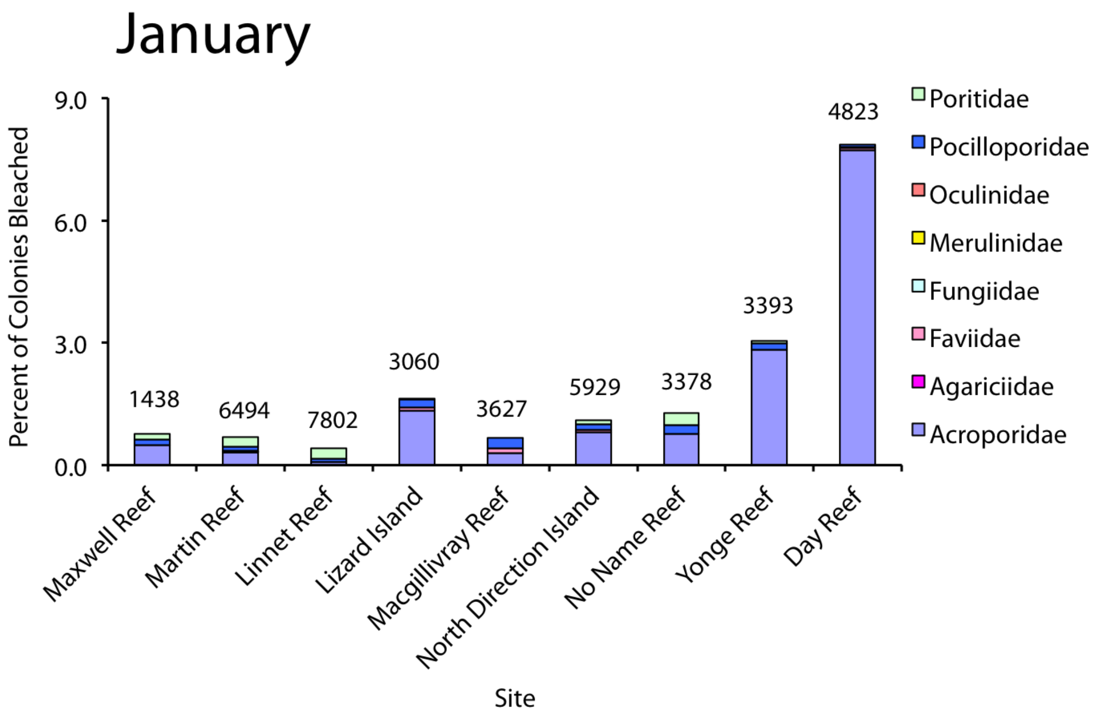


Fig. 4.2.2: Per cent of coral colonies affected by disease from the Lizard Island lagoon sites in January, March and August 2009. Sample sizes shown above bars.



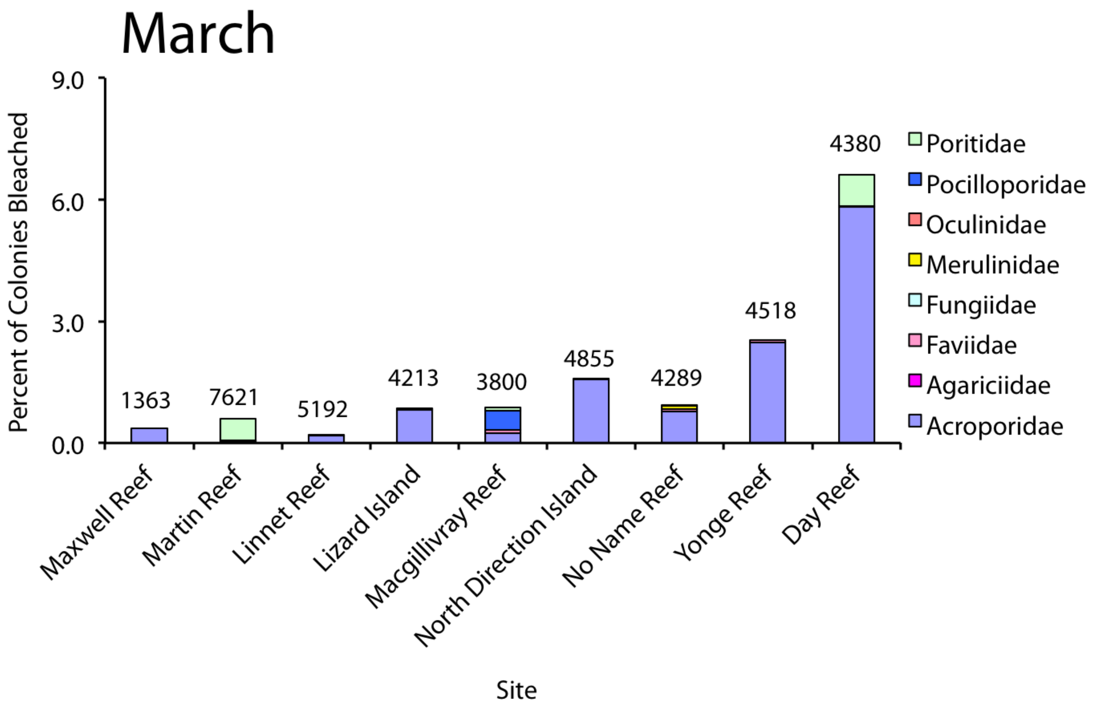
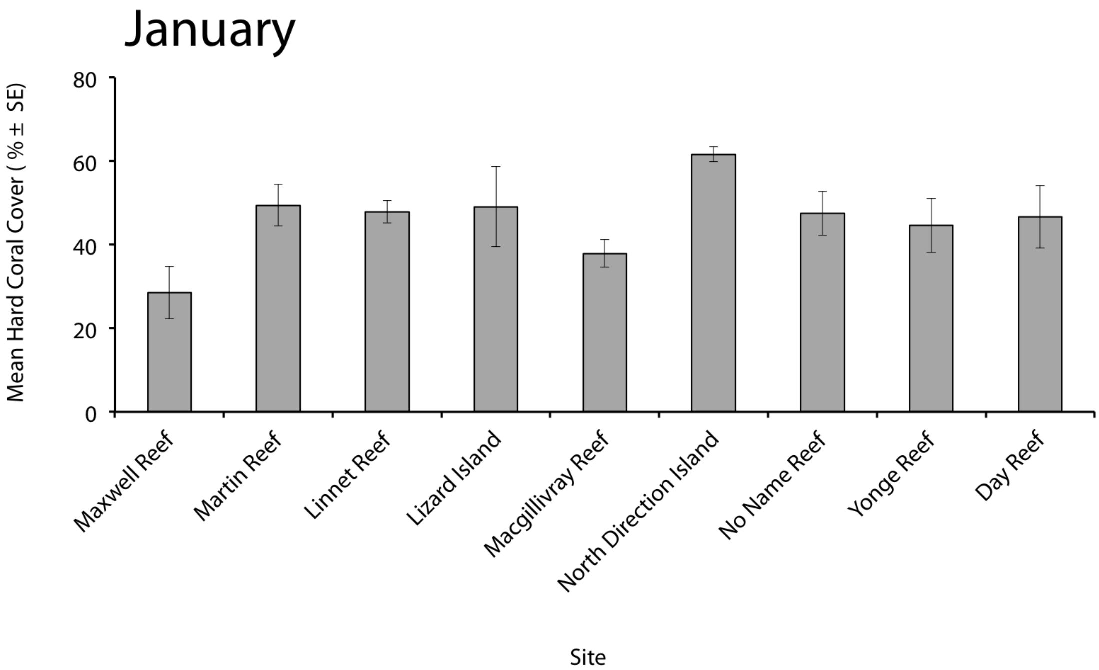


Fig. 4.2.3: Per cent of corals affected by disease by family on three inner-, mid- and outer-shelf reefs in the northern sector of the Great Barrier Reef in: a) January, and b) March 2009. Sample sizes shown above bars.

4.3. Temporal variation in per cent hard coral cover in northern sector

Mean per cent hard coral cover varied between 30 and 60 per cent among the nine sites, with cover remaining generally similar between January and March 2009 at each site. The exceptions were No Name reef, where coral cover declined 19 per cent, from 49 to 30 per cent, and Day Reef, where mean coral cover declined 13 per cent, from 46 to 33 per cent in the span of two months (Fig. 4.3.1). No consistent pattern in per cent hard coral cover among inner, mid- and outer-shelf reefs was detected. Overall, mean per cent coral cover at North Direction Island, a mid-shelf reef, was higher (~60 per cent) than at all other sites (Fig. 4.3.1).

Species in the family Acroporidae dominated coral assemblages at these sites, followed by species in the families Poritidae, Faviidae and Pocilloporidae, in declining order of per cent cover (Fig. 4.3.2). At Martin Reef, an inner-shelf reef, Poritidae was the dominant coral family present and at Linnet Reef (inner-shelf), corals in the families Acroporidae and Poritidae dominated and were equally represented (Fig. 4.3.2).



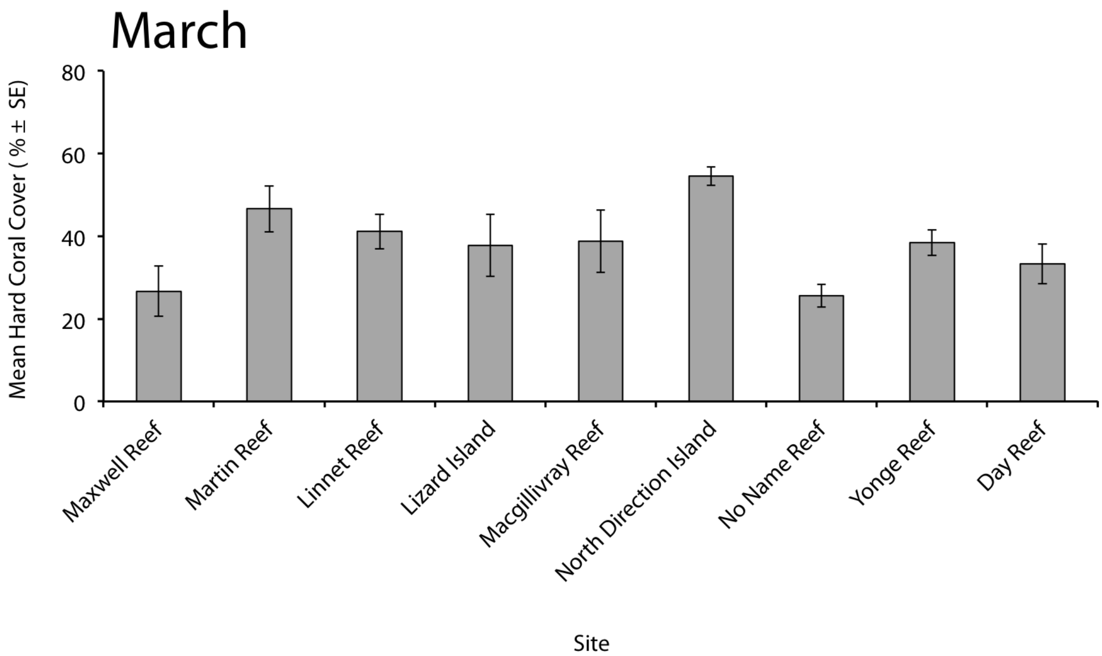
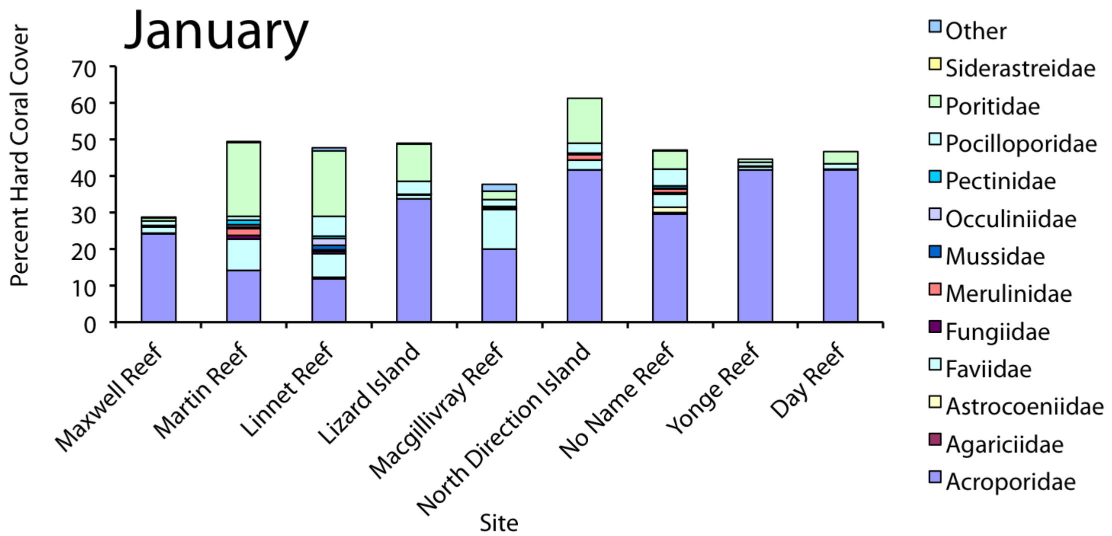


Fig. 4.3.1: Mean per cent coral cover (SE) at each of three inner-, mid-, and outer-shelf reefs in the northern sector of the Great Barrier Reef in: a) January, and b) March 2009.



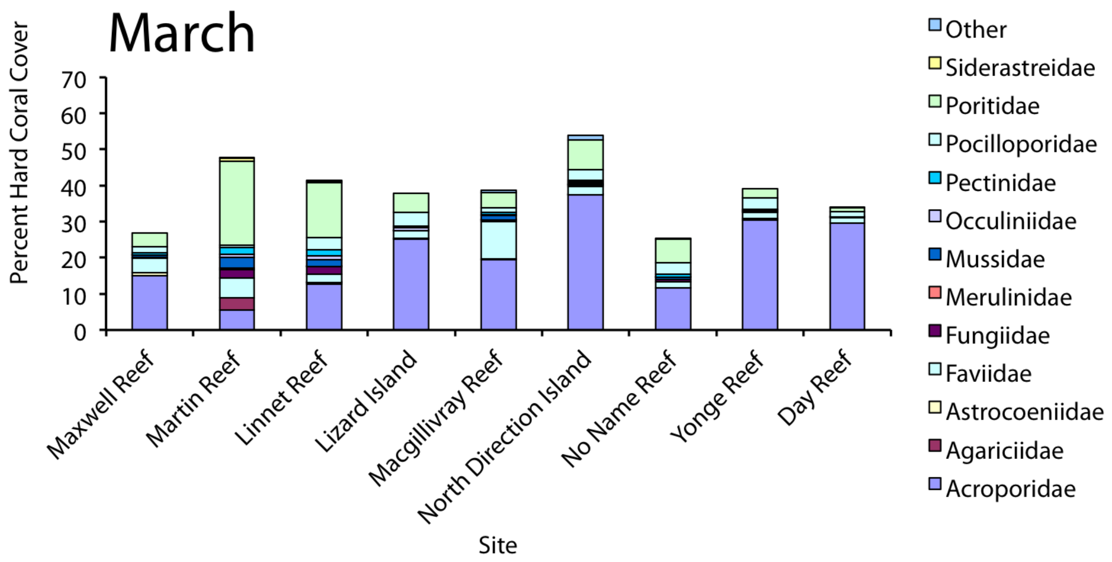


Fig. 4.3.2: Per cent hard coral cover by family on three inner-, mid- and outer-shelf reefs in the northern sector of the Great Barrier Reef in: a) January, and b) March 2009.

4.4. Temporal variation in water quality in the central sector

In the central sector, salinity declined dramatically on Magnetic Island inner-shelf reefs between January and March 2009, to as low as 20 ppt (as measured on 28 February 2009) (Fig. 4.4.1). A moderate warm anomaly in the annual sea temperature pattern was recorded at the height of freshwater run-off from coastal flooding on the mainland (Fig. 4.4.1). Coincident with this extreme salinity and moderate temperature anomaly, a 10-fold increase in the mean number of coral colonies infected with atramentous necrosis was detected in Geoffrey Bay and a five-fold increase was detected in Nelly Bay, Magnetic Island (Fig. 4.4.1). The mean number of diseased colonies declined rapidly when salinity returned to levels (~35 ppt) that are typically observed at times other than during the wet season in 2009 (Fig. 4.4.1).

Mean per cent hard coral cover at both sites declined between March 2008 and 2009, by as much as 50 per cent in Nelly Bay (from 60 to 30 per cent hard coral cover). Mean coral cover continued to decline after March 2009 in Geoffrey Bay, from an initial 40 per cent hard coral cover in March 2008 to 22 per cent in September 2009 (Fig. 4.4.2).

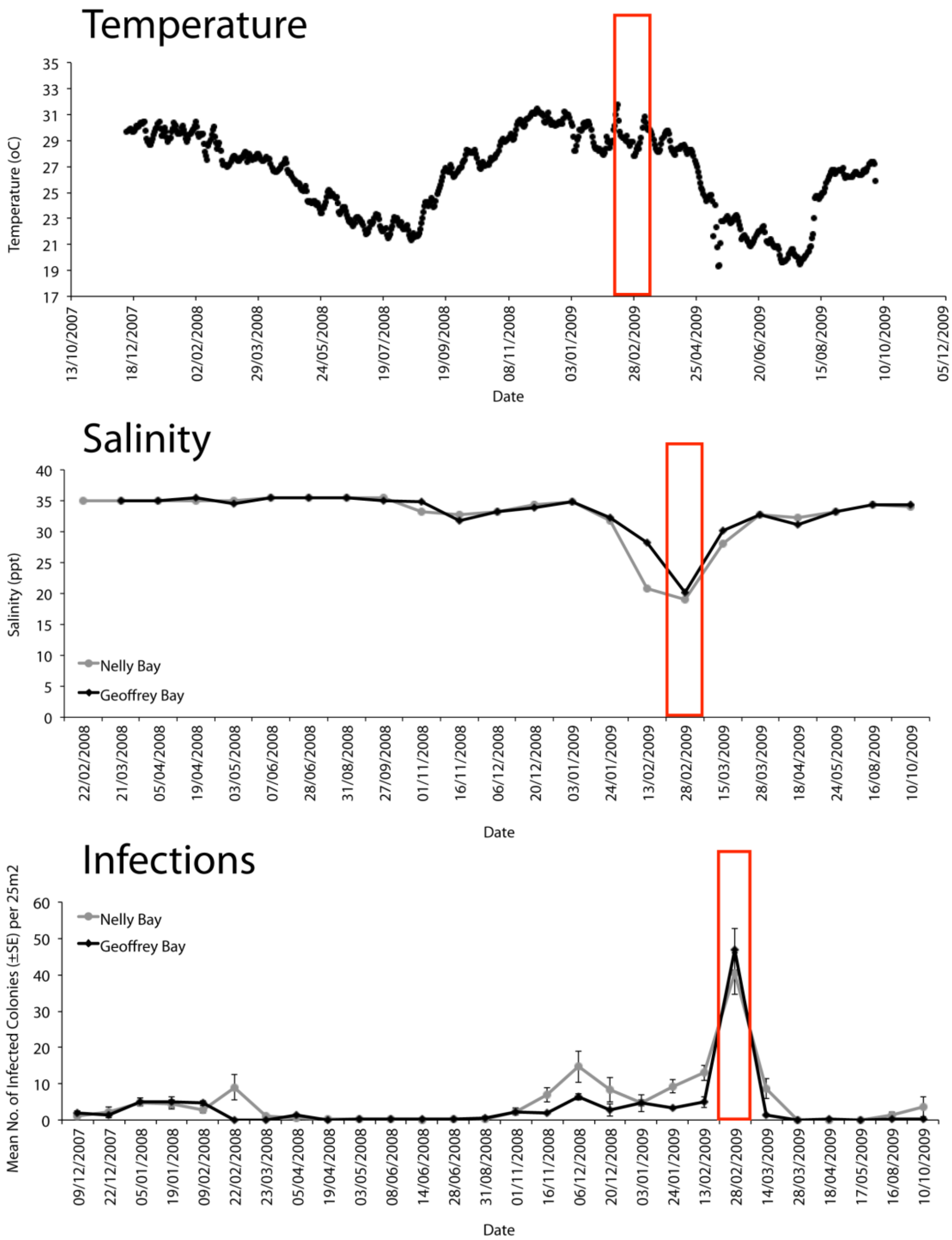


Fig. 4.4.1: Temporal patterns in mean (±SE) temperature, salinity and number of colonies infected with atramentous necrosis in Nelly and Geoffrey Bays, Magnetic Island between December 2007 and October 2009. Red boxes indicate measurements/samples taken on 28 February 2009. Data courtesy of J. Haapkyla

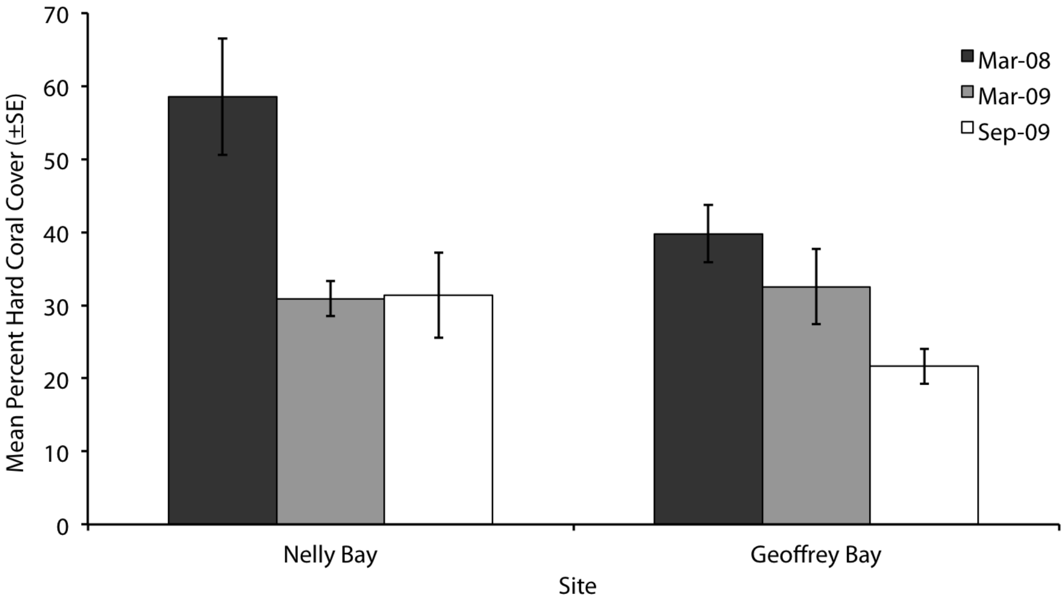


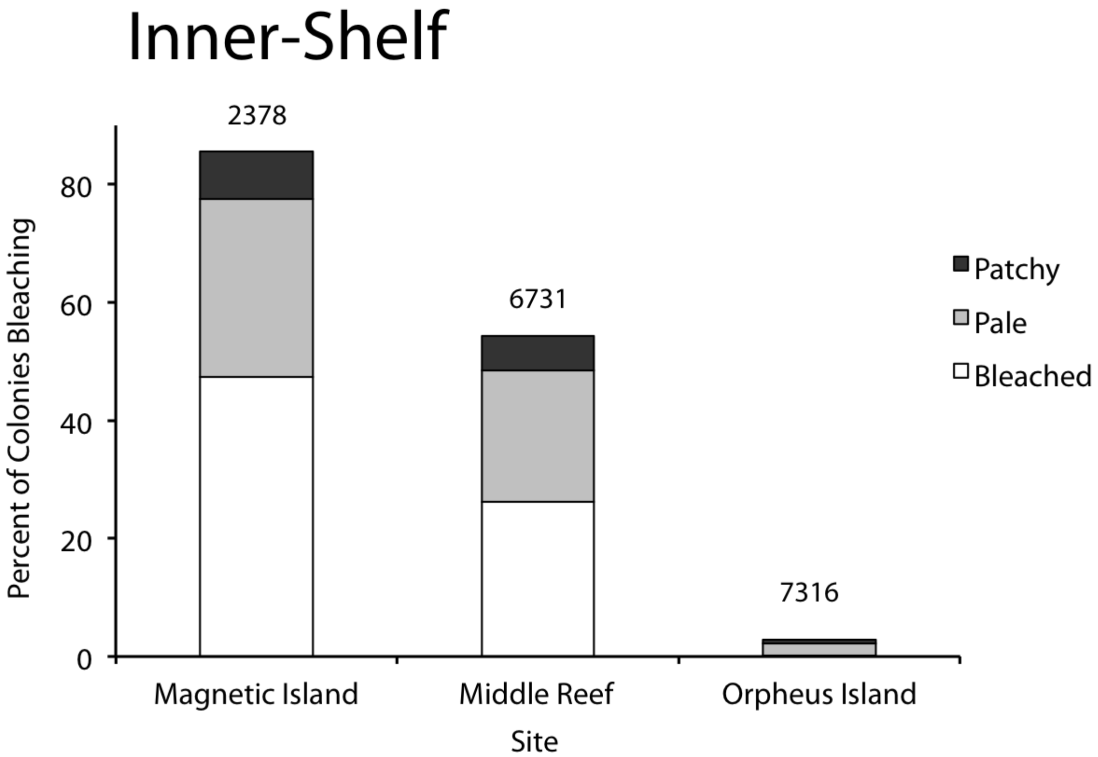
Fig. 4.4.2: Comparison of mean per cent hard coral cover (±SE) at two Magnetic Island sites in the central sector of the Great Barrier Reef from March 2008 through September 2009. Data courtesy of J. Haapkyla (see also Haapkyla et al. 2011).

4.5. LOW SALINITY BLEACHING IN THE CENTRAL SECTOR

Coral bleaching during the 2009 summer (January to March) was higher on inner-shelf, fringing reefs than on mid- and outer-shelf reefs of similar latitude, with inner-shelf sites at Magnetic Island having as much as 85 per cent of colonies showing signs of bleaching. Nearly 60 per cent of bleached colonies from Magnetic Island were white bleached compared with between three and nearly 10 per cent of colonies at mid- and outer-shelf reefs (Fig. 4.5.1).

Following the low salinity event in late February 2009 (see Fig. 4.4.1), the overall per cent of bleached colonies declined between March and August at Magnetic Island, but showed a slight increase between May/June and August at Middle Reef (Fig. 4.5.2). In the Palm Islands, bleaching was high in Pioneer Bay (50 per cent of colonies), but comparatively low at SE Pelorus and especially low at neighbouring Cattle Bay (less than five per cent of colonies showed signs of bleaching) in March (Fig. 4.5.2). Bleaching had declined by August at both Pioneer Bay and SE Pelorus sites, yet increased nearly 10-fold in Cattle Bay (Fig. 4.5.2).

On mid-shelf reefs, pocilloporid corals were the most susceptible to bleaching, with between 45 and 85 per cent of bleached corals belonging to this family (Fig. 4.5.3). Acroporids were the next most common group of bleached corals, followed by corals in the families Faviidae and Poritidae (Fig. 4.5.3). On inner-shelf reefs, bleached colonies were dominated by species in the family Acroporidae at Magnetic Island and Poritidae at Middle Reef (Fig. 4.5.4).



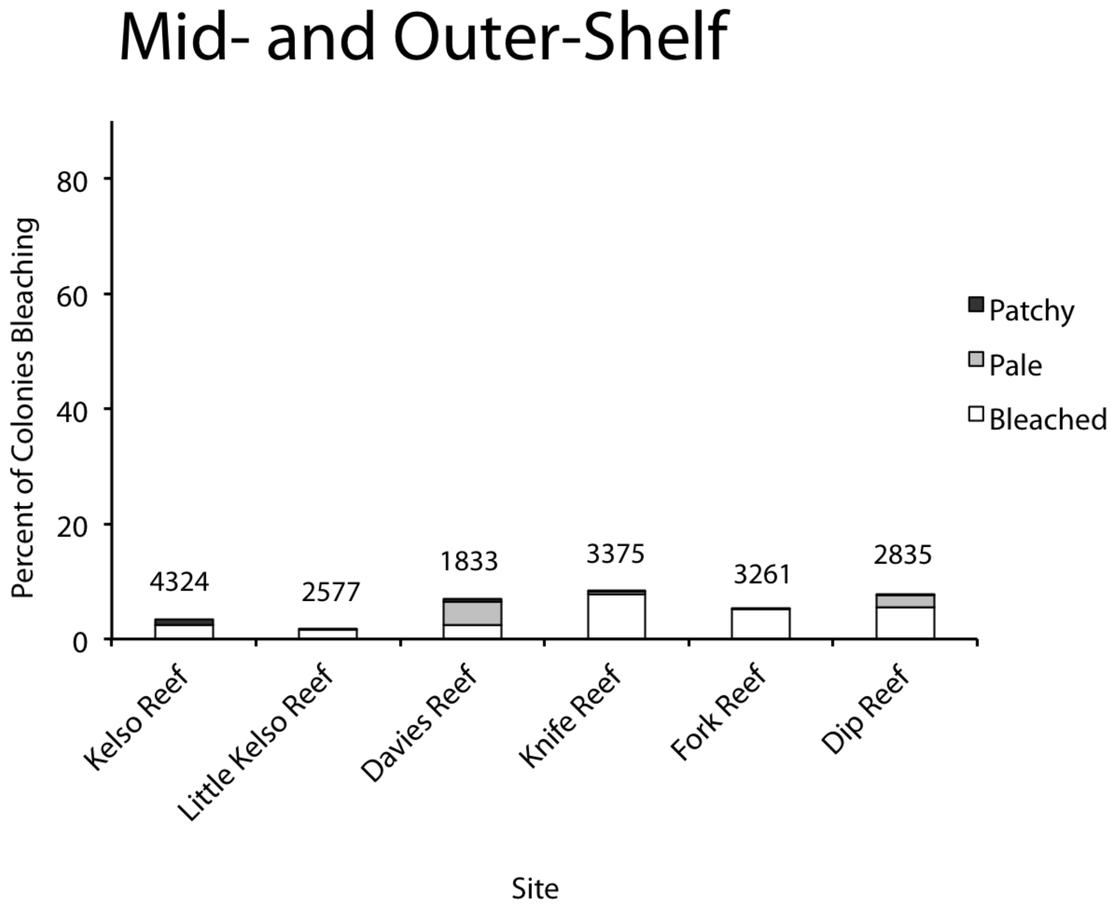
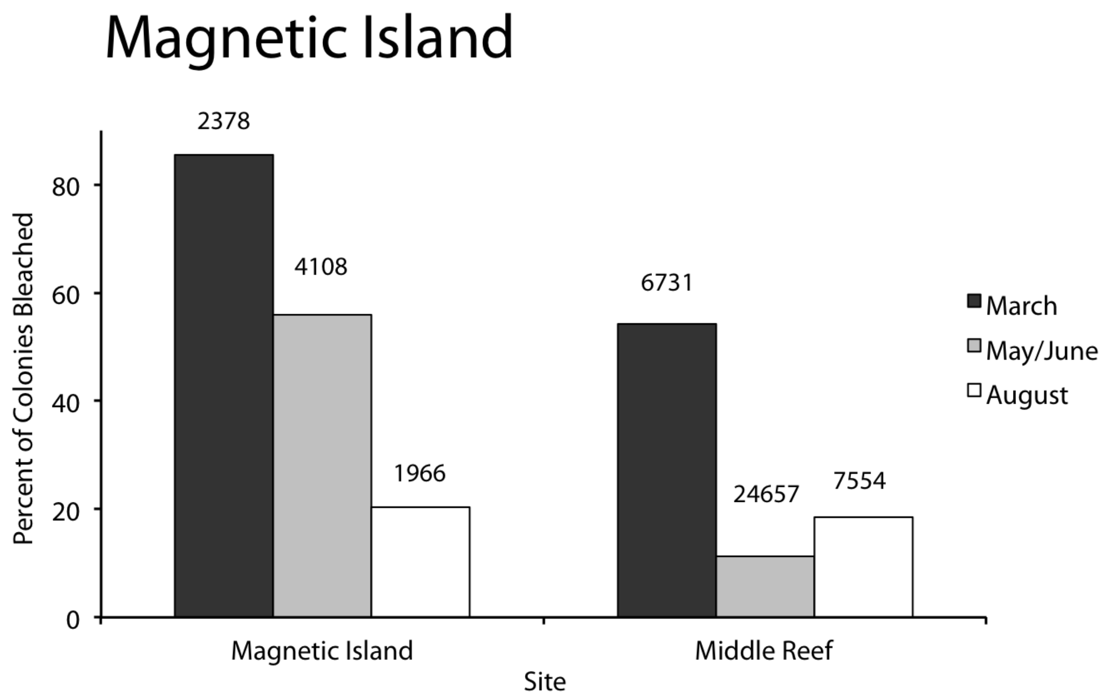


Fig. 4.5.1: Overall per cent of corals that were patchy bleached, pale bleached and white bleached on reefs during the summer of 2009 in the central sector of the Great Barrier Reef, i.e. on: a) inner-shelf reefs during March 2009, and b) mid- and outer-shelf reefs in January 2009. Sample sizes shown above bars.



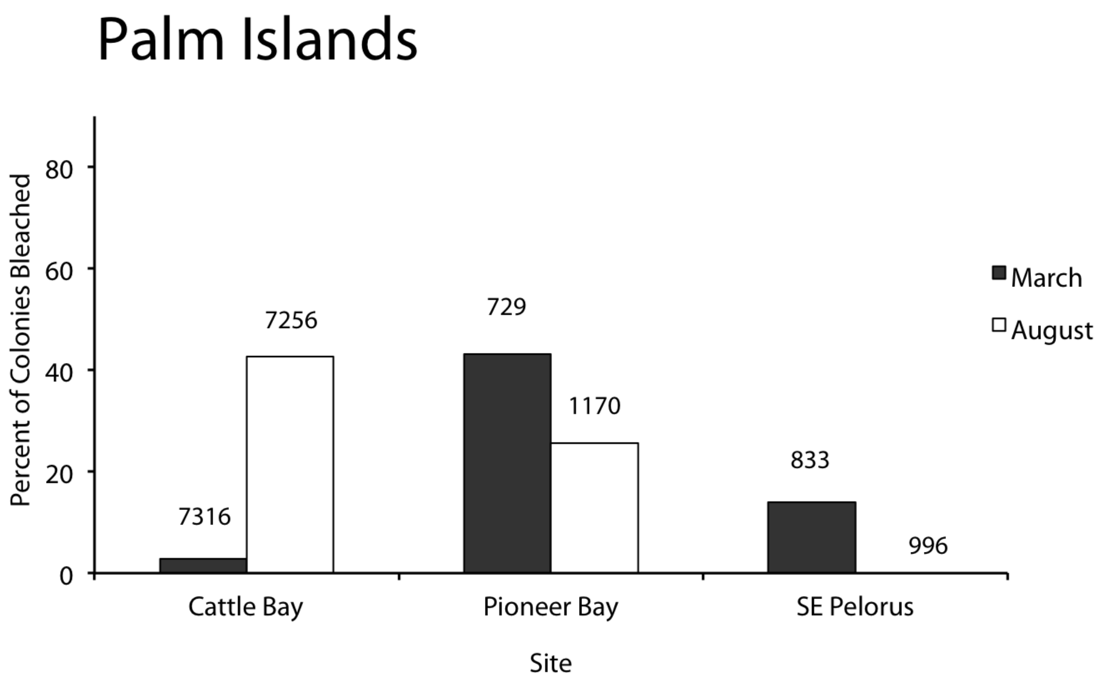


Fig. 4.5.2: Overall per cent of corals with signs of bleaching on reefs in the central sector of the Great Barrier Reef in 2009, i.e. on: a) Magnetic Island reefs in March, May/June and August, and b) reefs in the Palm Island Group in March and August. Sample sizes shown above bars.

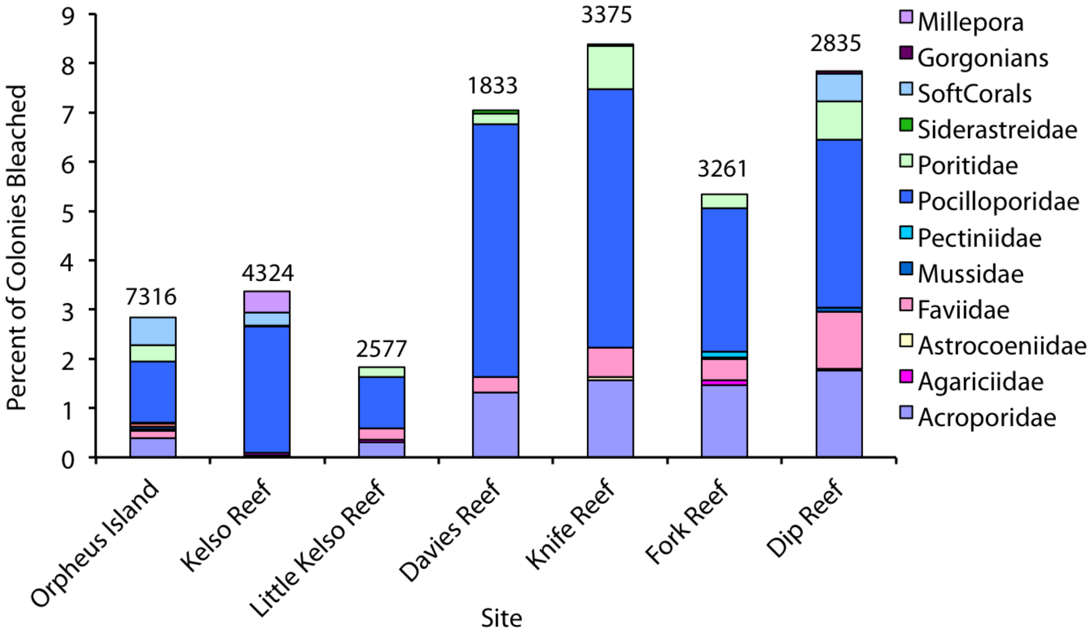
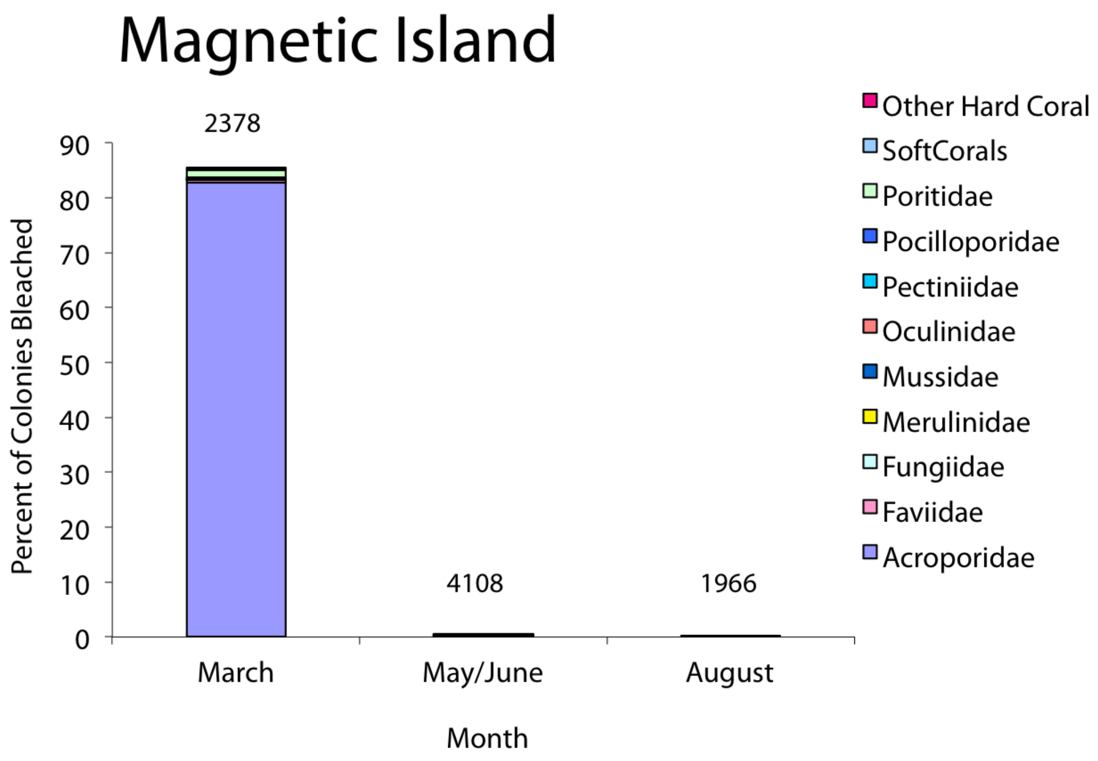


Fig. 4.5.3: Overall per cent of corals showing signs of bleaching in January 2009 by family from inner-, mid- and outer-shelf reefs in the central sector of the Great Barrier Reef. Sample sizes shown above bars.



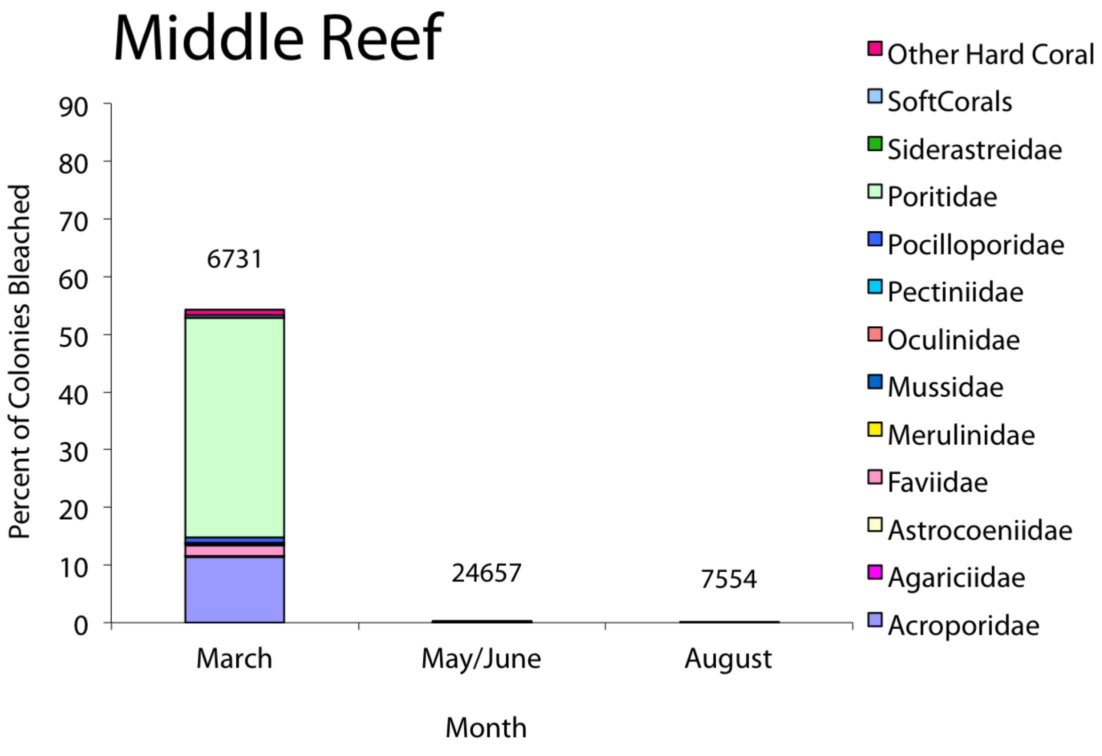


Fig. 4.5.4: Overall per cent of corals appearing bleached in March, May/June and August of 2009 by coral family on inshore fringing reefs in the central sector of the Great Barrier Reef, i.e.on a) Magnetic Island reefs, and b) Middle Reef. Sample sizes shown above bars.

4.6. Disease prevalence in the central sector

The total per cent of colonies affected by disease on mid-shelf reefs in January was low, ranging from three to approximately six per cent (Fig. 4.6.1). The dominant diseases were skeletal eroding band and other cyanobacterial infections, followed by lesions suspected to be caused by white syndromes, which accounted for between five and 20 per cent of diseased colonies detected (Fig. 4.6.1).

Closer to the mainland, suspected white syndrome lesions and atramentous necrosis were the dominant categories recorded at Magnetic Island and Middle Reef, respectively, accounting for greater than 80 per cent of diseased colonies in March at these sites (Fig. 4.6.2). Overall, the total per cent of diseased colonies did not exceed eight per cent and declined to less than one per cent by August at both locations (Fig. 4.6.2).

Very little disease was observed on Palm Island reefs between March and August, with less than one per cent of colonies affected by either skeletal eroding band or suspected white syndrome lesions in Cattle Bay and Pioneer Bay (Fig. 4.6.3). No diseases were observed in Pioneer Bay following the low salinity event in March (Fig. 4.6.3), but diseases were observed in August, when salinities were within expected ranges.

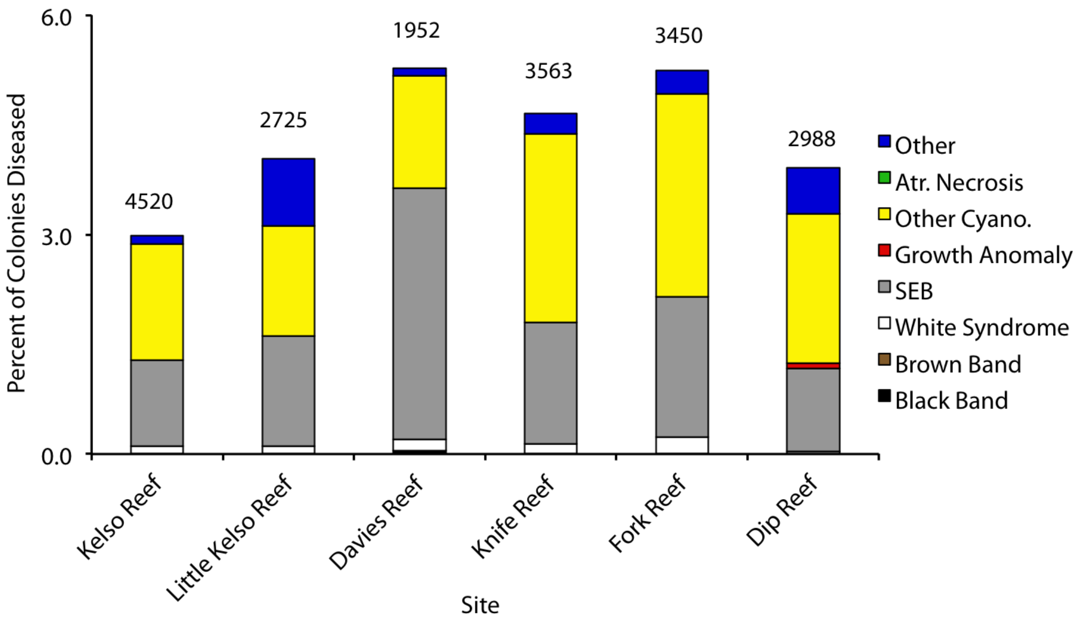
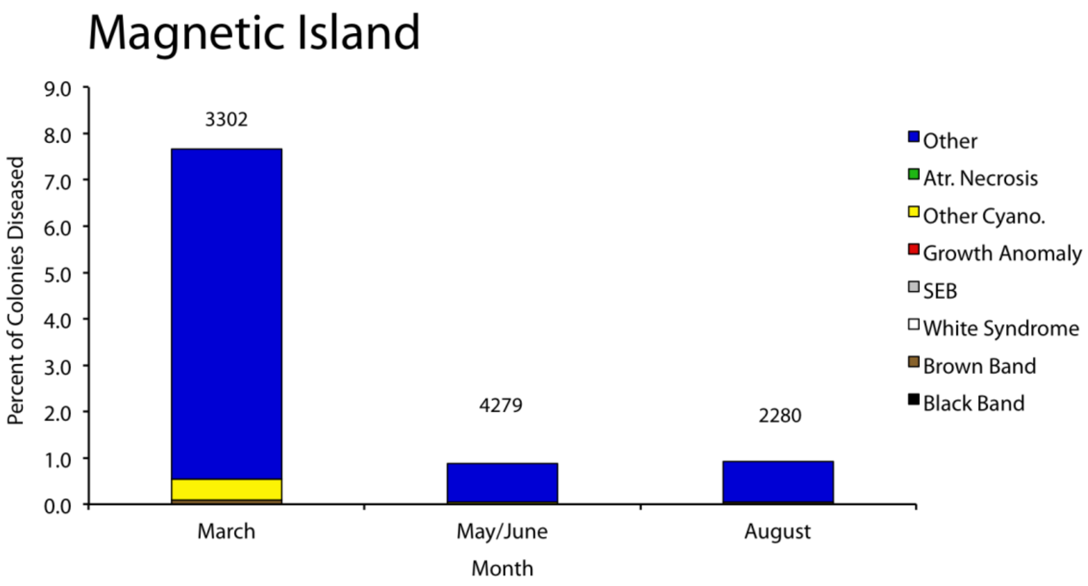


Fig. 4.6.1: Per cent of coral colonies affected by disease on mid- and outer-shelf reefs in the central sector of the Great Barrier Reef in January 2009. Sample sizes shown above bars.



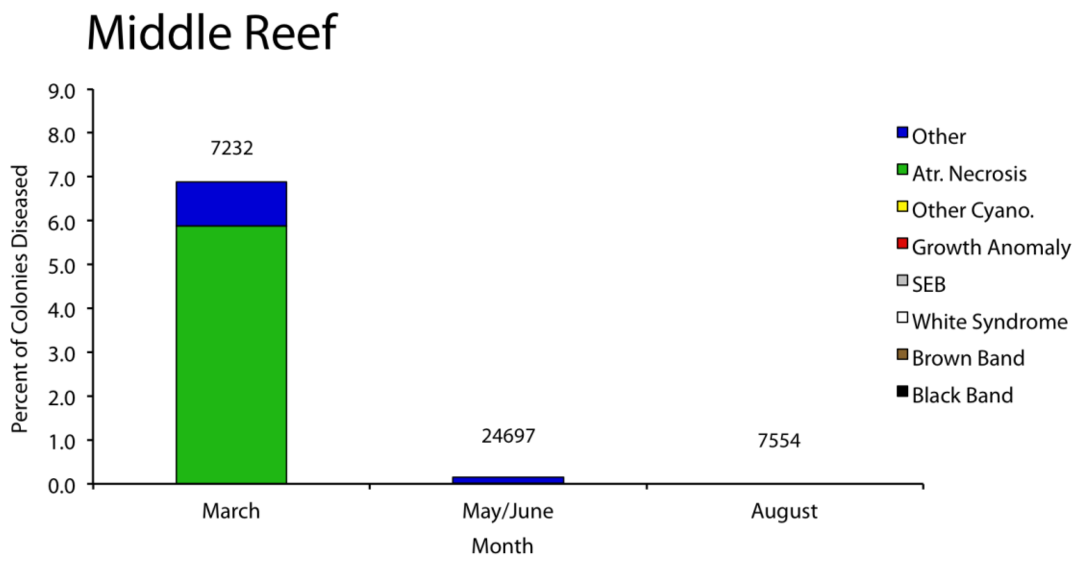


Fig. 4.6.2: Overall per cent of coral colonies affected by disease in March, May/June and August of 2009 on inshore reefs in the central sector of the Great Barrier Reef, i.e. on: a) Magnetic Island reefs, and b) Middle Reef. Sample sizes shown above bars.

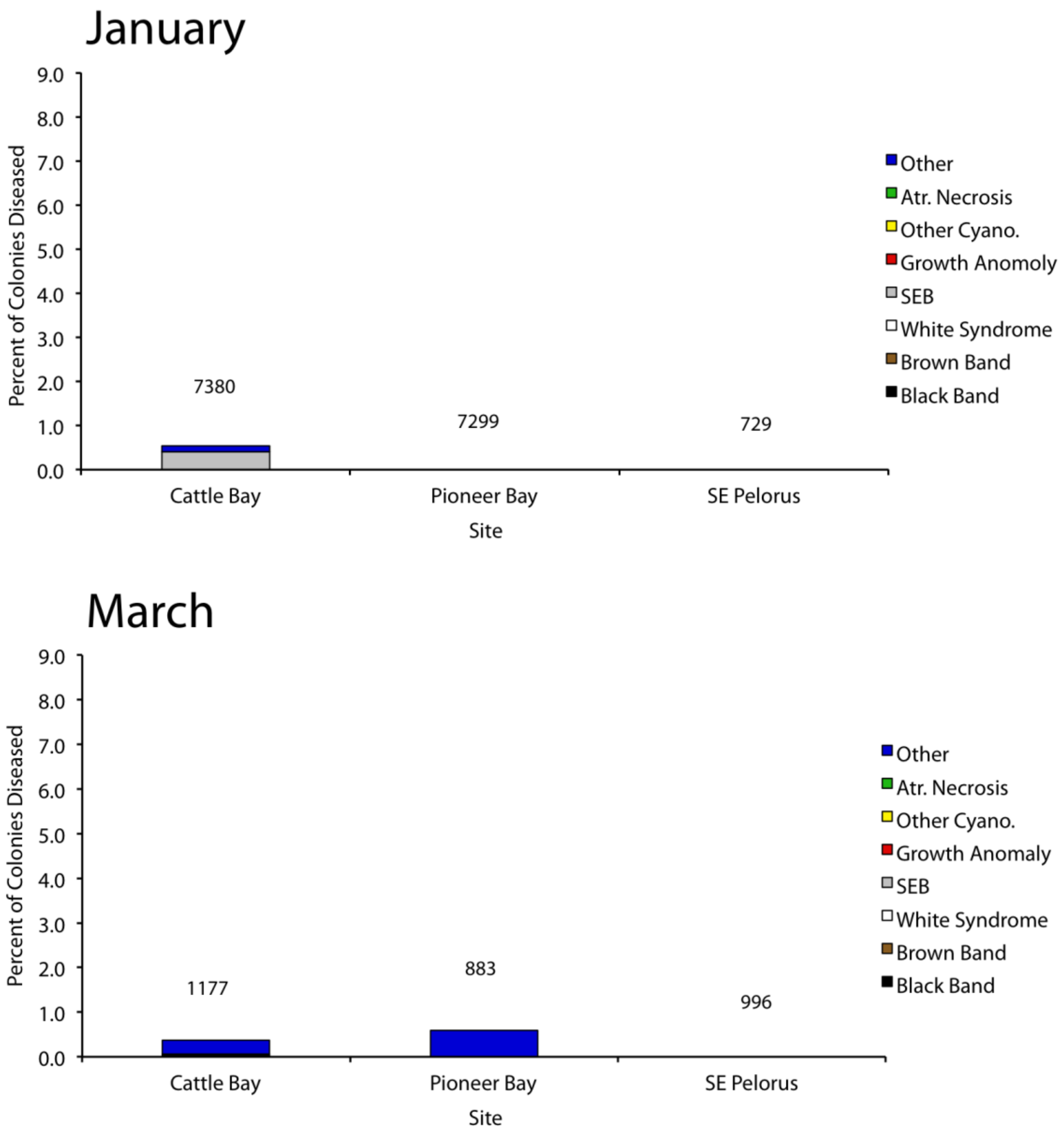


Fig. 4.6.3: Overall per cent of coral colonies affected by disease on inner-shelf, fringing reefs of the Palm Islands in the central sector of the Great Barrier Reef in: a) March, and b) August 2009. Sample sizes shown above bars.

4.7. Temporal variation in per cent hard coral cover in central sector

Following the low salinity event in late February 2009, no change in mean per cent coral cover was detected between March and August 2009 on inner-shelf, central sector reefs. Coral cover was highest in Cattle Bay and on Middle Reef, ranging between 30 and 42 per cent between March and August (Fig. 4.7.1). The inclusion of earlier data, however, indicates that a more than five-fold decline in mean per cent coral cover, from 71 per cent to 13 per cent, occurred at Magnetic Island between April 2008 and August 2009 (Fig. 4.7.2). A trend for declining coral cover was also observed at Middle Reef; mean per cent coral cover declined from 58 to 42 per cent between April 2008 and August 2009, reaching as low as 30 per cent in March 2009 (Fig. 4.7.3). The dominant coral family present at these sites was Acroporidae, the exceptions being Orpheus Island, where Poritidae represented 65 per cent of colonies surveyed, and Fork Reef, where these two families and the Faviidae were equally represented (Fig. 4.7.3).

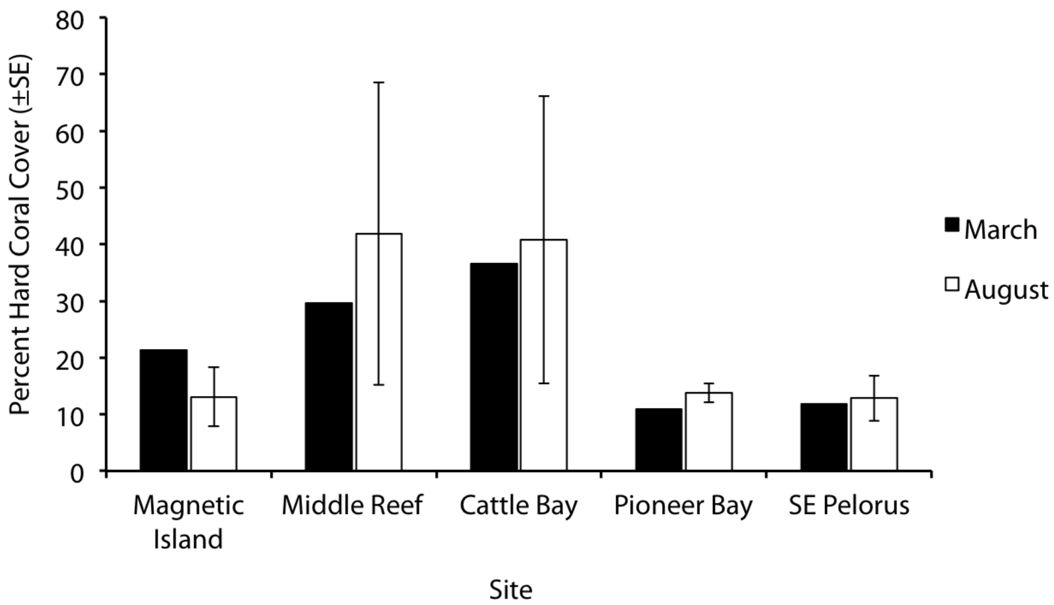


Fig. 4.7.1: Mean (±SE) per cent hard coral cover on inner-shelf, fringing reefs in the central sector of the Great Barrier Reef in March and August 2009.

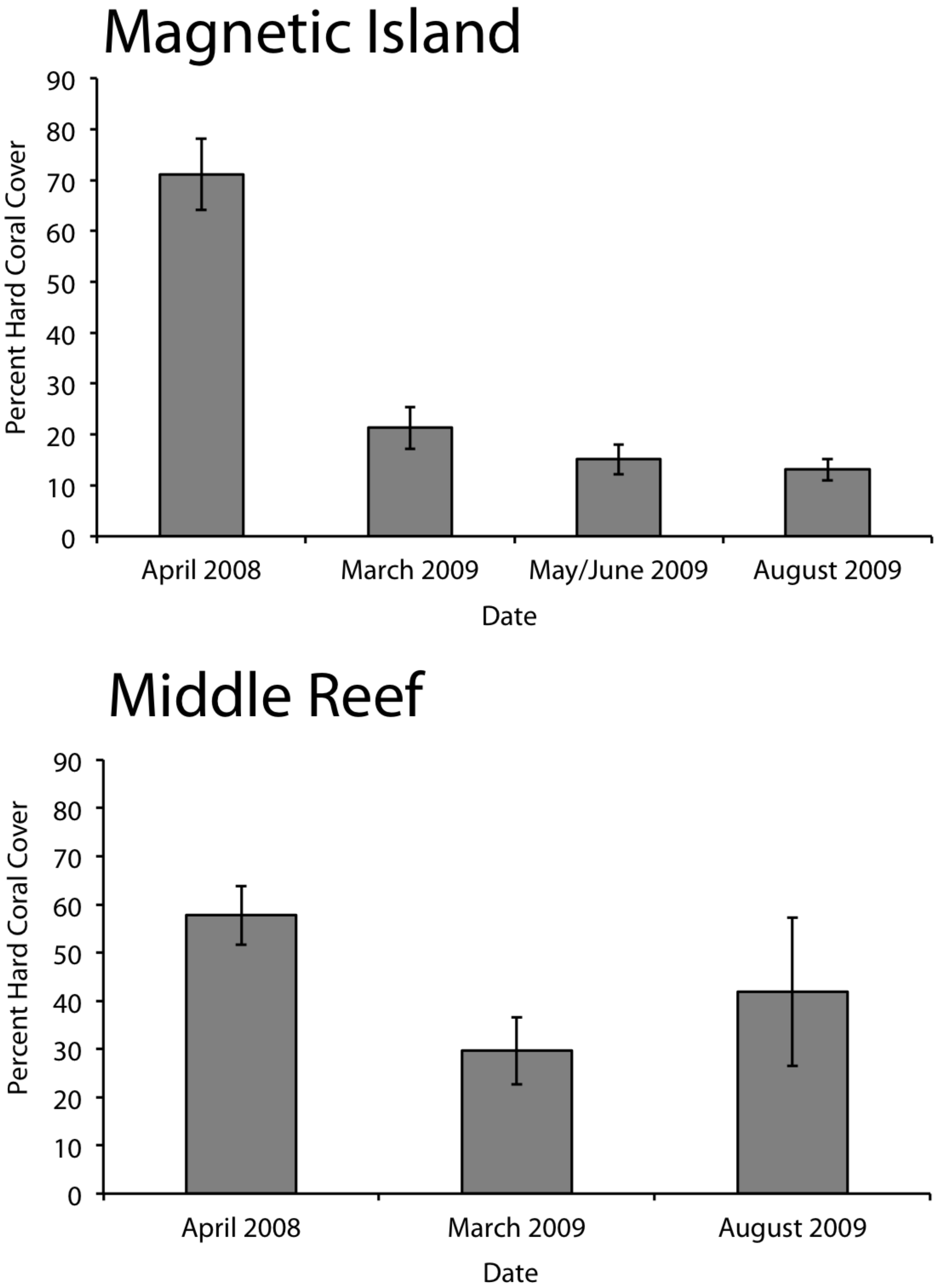


Fig. 4.7.2: Total per cent coral cover on inner-shelf, fringing reefs in the central sector of the Great Barrier Reef in April 2008, March 2009 and August 2009.

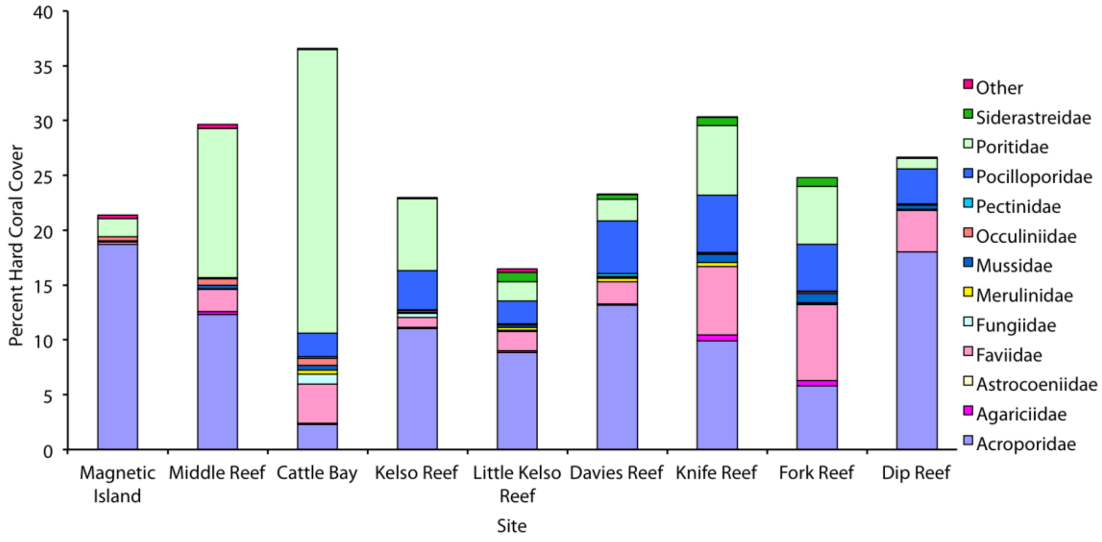


Fig. 4.7.3: Overall per cent hard coral cover by family on inner-shelf reefs in March 2009, and on mid- and outer-shelf reefs in January 2009 in the central sector of the Great Barrier Reef.

5.0. DISCUSSION

5.1. Thermal stress in the northern sector of the Reef

Extreme sea surface temperatures were recorded in a number of regions of the Reef during the 2008–2009 summer, including reefs in the northern sector surveyed in this study (ReefTemp). Although accumulated heat stress in December 2008 was comparable to accumulated stress preceding the mass coral bleaching events on the Reef in 1998 and 2002 (GBRMPA), the extent of thermal stress in the northern sector resulted in only minor and generally patchy thermal bleaching in this region. At the height of bleaching in the northern sector, only a small proportion of bleached colonies were white bleached (between five and 20 per cent) and, by August, less than 0.25 per cent of colonies showed any signs of bleaching at any sites surveyed. Coral disease prevalence remained low (between 0.5 and eight per cent) and comparable to estimates measured in this region in previous years (B. Willis unpubl. data). Coral cover remained similar for most sites (with the exception of No Name and Day Reefs, (Fig. 4.3.1)) indicating that overall, thermal bleaching in this region did not result in either a disease epizootic or substantial coral mortality following thermal stress from the 2008–2009 summer.

Although No Name Reef experienced a 22 per cent decline in hard coral cover between January and March, the greatest decline for any site surveyed, bleaching severity and coral disease prevalence remained low at this site. Similarly, thermal bleaching at Day Reef was moderate (18 per cent) when compared with other sites, but declines in hard coral cover recorded here between January and March were also high (13 per cent). The greatest prevalence of coral disease was recorded at Day Reef, where between seven and eight per cent of colonies were diseased between January and March. Significantly, a new tool for predicting the likelihood of white syndromes outbreaks (Maynard et al. 2011) identified this reef region as an area at ‘high risk’ of a white syndromes outbreak based on sea surface temperature data from the year leading up to the 2008–09 summer. The authors will further investigate this in an upcoming study aimed at assessing the validity of the model by surveying high and low risk areas for white syndromes and other coral disease outbreaks leading into and including the upcoming 2009–2010 summer.

The corals that exhibited the greatest signs of bleaching and the highest incidence of disease were the tabular, staghorn and corymbose corals in the genus *Acropora*, which dominate coral assemblages in this region. It should be noted, however, that bleaching was greatest for corymbose and tabular corals, whereas disease prevalence was highest among staghorn corals.

5.2. LOW SALINITY STRESS IN THE CENTRAL SECTOR OF THE REEF

Between Cairns and Townsville, rainfall up to 600 millimetres above the long-term, three month average was recorded in February 2009 (GBRMPA), resulting in high coastal run-off along the Queensland coast. Flood plumes in river catchments extended beyond mid-shelf reefs in some areas and resulted in reduced salinity, with standing layers of freshwater run-off in some inner-shelf reef areas (GBRMPA). At Magnetic Island sites in the central sector, low salinity stress resulted in increases of between five- and 10-fold in the prevalence of atramentous necrosis, and is believed to have resulted in declines in coral cover of up to 50 per cent at Nelly Bay and Geoffrey Bay sites between 2008 and 2009. Here, bleaching in response to low salinity stress was more severe than bleaching in response to the northern thermal stress event. Overall, between 55 and 85 per cent of colonies bleached on the inshore reefs surveyed in the central section. The majority of this bleaching was white bleaching (60 per cent), as opposed to patchy or pale bleaching; clearly indicating that freshwater run-off following severe coastal flooding has major impacts on reefs located close to shore. Because surveys conducted on mid- and outer-shelf reefs as part of a long-term monitoring program were completed earlier in the summer (i.e. before the rainfall event) than those from inner-shelf reefs, it is not possible to assess the impact of potential coastal freshwater inputs on these reefs.

At inner-shelf sites surveyed as part of a long-term monitoring program, disease prevalence in March 2009 was similar to that observed in the northern sector throughout this period (not exceeding eight per cent), although with notably less disease observed at some reef sites than others. Hard coral cover declined dramatically at the Picnic Bay site, from approximately 70 per cent in April 2008 to less than 20 per cent in August 2009. Long-term data indicates that coral cover declined significantly at nearby Middle Reef, from nearly 60 per cent in April 2008 to approximately 30 per cent in March 2009, immediately following the low salinity event. Although bleaching was severe and hard coral cover declined in these locations, coral disease prevalence remained fairly low at the majority of sites surveyed. Monthly re-surveying/sampling of Nelly Bay and Geoffrey Bay sites in a short-term monitoring program identified a clear link between low salinity stress and the abundance of atramentous necrosis at these sites. Decreases in salinity from 35 to 20 ppt corresponded to five- to 10-fold increases in the abundance of atramentous necrosis at these two sites. The peak in atramentous necrosis lasted for only a month, possibly explaining why disease prevalence data collected with less frequency from other near shore sites does not reveal the same clear patterns.

5.3. Conclusions

Thermal stress in the northern sector did not result in large-scale coral mortality or reef degradation in this region, although there is some evidence to suggest that declines in hard coral cover are the result of moderate bleaching and disease prevalence at some reef sites. Although major changes to coral community structure were not identified at the majority of sites within the timeframe of this study, regular monitoring of coral disease prevalence, hard coral cover and seasonal coral bleaching should continue at Day Reef and No Name Reef following declines in hard coral cover and higher than average occurrence of disease infections (at Day Reef) identified in this study.

Near shore floodwater run-off had severe impacts on salinity levels at inner-shelf reef sites, resulting in high prevalence of the disease atramentous necrosis at sites in Nelly and Geoffrey Bays (Magnetic Island). Salinity stress also resulted in severe bleaching and declines in hard coral cover at Picnic Bay (Magnetic Island) and Middle Reef sites. Because Picnic Bay and Middle Reef sites were surveyed only twice in the summer of 2009, it is likely that the peak in atramentous necrosis infections was not sampled at these two sites. Although evidence linking disease and coral mortality is less clear at these sites, the presence of diseases that were similar to those at the more frequently monitored Geoffrey and Nelly Bay sites suggests that atramentous necrosis is likely to have contributed to declines in coral cover at Picnic Bay and Middle Reef sites.

5.4. Implications for management

Reef monitoring typically occurs on an annual basis, largely because logistical and financial constraints preclude frequent resurveying. However, coral disease prevalence is often low and patchy on the Reef (Willis et al 2004; Brandt and McManus 2009) posing challenges to detection that are not well addressed by infrequent surveys at small spatial scales. Consequently, it is difficult to attribute changes in coral community structure to disease, especially when changes occur in relation to short-lived epizootics (Harvell et al. 2001). Thus, understanding the relationship between coral disease occurrence and environmental anomalies in coral communities is problematic without frequent and regular monitoring. The correlation between declining salinity and the prevalence of atramentous necrosis from Magnetic Island observed in this study is a good example of how potentially low the probability of detecting an epizootic outbreak is with only annual or even seasonal samples/surveys. In both cases, had February 2009 samples not been collected in a concurrent, more intense survey program (Haapkyla et al. 2011), estimates of salinity and prevalence of atramentous necrosis would not have given clear evidence of the linkage between declining coral cover and these two factors.

Given the difficulty of covering large reef areas frequently using intensive, quantitative surveys, any action plan designed to respond to environmental stress and disease outbreaks should include (1) a rapid response team of trained reef monitors who can quickly survey and assess reef sites that are recognised as being at high risk of coral mortality, as identified by (2) a team of reef reporters (made of dive company operators and other stakeholders with a vested interest in monitoring reef health) who regularly report on the state of frequently visited reef sites. Instrumental to this plan is the implementation of a simple, rapid coral disease assessment which allows for surveying large areas of reef quickly while accurately measuring the extent of an epizootic, including identification of common coral diseases and the coral taxa they infect. Frequent resurveying is required for reef sites where environmental climate has changed or coral bleaching and/or disease outbreaks have been identified in order to understand the long-term consequences and recovery dynamics.

6.0. Literature cited

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