Department of Environment and Conservation

Disturbance and recovery of coral communities in Bill's Bay, Ningaloo Marine Park: Field survey 16-23 October 2006

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Main photograph: A DEC marine scientist monitors coral health in Bill's Bay, October 2006.

Small photographs, left to right: A north west snapper (*Lethrinus nebulosus*) in Bill's Bay.
Underwater landscape of disturbed coral reef, Bill's Bay, October 2006.
Blue staghorn coral (*Acropora* sp).
Aerial view of coral communities in Bill's Bay, April 2007.

Images — Department of Environment and Conservation

Main photograph: A DEC marine scientist monitors coral cover along a transect in Bill's Bay.

Small photographs, left to right: Blue staghorn coral (*Acropora* sp.) in the lagoon of Ningaloo Marine Park; the underwater landscape of a disturbed coral reef in Bill's Bay; an aerial view of Bill's Bay; north-west snapper (*Lethrinus nebulosus*) in the Point Maud Sanctuary Zone of Ningaloo Marine Park. All photographs – DEC.

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1 Summary

The 2006 survey of Bill's Bay has contributed to a comprehensive dataset describing coral community structure in this heavily visited area of Ningaloo Marine Park, including patterns of recovery since a natural mass mortality event in 1989. Comprised of information collected over 17 years by the Department of Environment and Conservation (DEC, previously CALM) and the Australian Institute of Marine Science (AIMS), this dataset is being compiled and analysed to produce a detailed quantitative description of the responses of these coral communities to disturbance over time. Such a long-term dataset is rare for coral reef environments, and it will become an increasingly valuable resource both for management of Ningaloo Reef, and also for international research programs investigating coral reef resilience and recovery.

1.1 Scientific Findings

Stability

In stark contrast to most Indian Ocean reefs, those in the outer zone of Bill's Bay appear to have been remarkably stable over time in terms of coral cover, high-level coral community composition, and rates and taxonomic composition of sexual recruitment. If these back reef habitats continue to be relatively unimpacted by and resilient to environmental disturbances and human activities, these stable outer zone reefs at Ningaloo, and others like them in Western Australia, may be able to serve a critical function as coral reef refugia and reference sites of local, regional and potentially international significance.

Recovery

Reefs in inner Bill's Bay were completely killed by the 1989 dystrophic crisis. Recovery of pre-disturbance levels of coral cover from this zero baseline occurred within 10 years, and recovery of pre-disturbance type acroporid-dominated coral communities was achieved at one site within 17 years (although most recovering inner zone reefs had not yet reached this successional stage at the time of the latest survey). If these reefs are not disturbed, continuing patterns of ecological succession are likely to result in recovery of mature coral communities in the inner zone of Bill's Bay. The implication is that areas of Ningaloo Reef may be capable of recovering from acute small-scale disturbances, although full recovery may require more than 20 years.

Vulnerability

Although recovery processes appear to be underway at some reefs in the middle zone of Bill's Bay, the apparent lack of recovery observed at some sites in recent surveys (2000, 2006) leads to concerns that these reefs may be vulnerable to degradation of resilience. The likely cause of this potential loss of resilience is the increased frequency and/or intensity of disturbance in this zone. Chronic disturbance of coral reefs elsewhere has been linked to loss of resilience and sudden shifts from coral- to algal-dominated communities, with concomitant dramatic reductions in biodiversity and productivity (in terms of ecosystem goods and services). Careful, informed management will be required to minimise disturbance and foster resilience of these vulnerable reefs in Bill's Bay.

1.2 RECOMMENDATIONS FOR MANAGEMENT

- Recognition of the potential for small-scale but repeated disturbances to seriously impact on reef resilience. Acknowledgement that loss of resilience may be cryptic. Increased awareness of the need for especially cautious management of reefs identified as vulnerable.
- Minimisation of human-derived disturbances to coral reef communities in Bill's Bay and elsewhere at Ningaloo Reef. Consultation with the regional Marine Ecologist and/or the Marine Science Program of DEC before licensing/permitting activities that could affect coral reef ecological processes, even on a very localised scale.
- Surveys of coral communities in Bill's Bay to continue to be held at least every six years, and preferably at higher frequency, with the aim of continuing to develop a detailed understanding of reef disturbance and recovery patterns.
- Construction and future maintenance of a detailed disturbance history of Bill's Bay (including both natural and anthropogenic events), which is essential for interpretation of observed reef recovery patterns.
- Annual scientific monitoring and reporting of coral spawning events in Bill's Bay, and documentation and reporting of the extent and severity of spawning-related dystrophic crises when they occur.
- Increasing levels of protection for the resilient reef at site 1 (the closest site to shore and town; Figure 1) by installation of an informative public snorkeling trail. In addition to increasing visitors' understanding and appreciation of the natural environment in Coral Bay, this will minimise human impacts on this reef by containing most visitors to the vicinity of the trail, educating them about safe snorkeling practices, and preventing boat access to the area.
- Scientific investigation of the apparently increasing size of the sand spit at Coral Bay, to determine whether human activities are contributing to this process. Changes in sand and water circulation patterns are likely to impact on coral communities in the vicinity and may have long-term ramifications for the health of local coral reefs.
- Reporting of observations of unusual biological or ecological phenomena in Bill's Bay or elsewhere at Ningaloo Reef to the regional Marine Ecologist and/or the Marine Science Program of DEC.

2 Contents

3 Introduction

3.1 BACKGROUND

Coral reefs are highly dynamic systems in which the frequency and intensity of disturbance is an important determinant of community structure (Connell 1978; Pickett & White 1986; Connell *et al.* 1997). Resilience and the ability to recover after disturbance is characteristic of coral reef communities, especially when the disturbance is acute (Connell 1997; Halford *et al.* 2003; Bellwood *et al.* 2006). However, increasing pressures on these ecosystems may transform discrete acute disturbances into conditions of chronic stress (Loya 1976; Nystrom *et al.* 2000), which can precipitate phase shifts to less biodiverse and less productive ecologies.

Some ecological mechanisms operate at temporal and spatial scales that differ from the patterns in community structure that they produce: relatively short-lived environmental or biological events may have significant long-term effects (Connell *et al.* 1997). For example, major impacts on reef community structure may be evident long after an acute disturbance event (Connell *et al.* 1997), even after conventional metrices indicate full recovery (Bellwood *et al.* 2006; Berumen & Pratchett 2006). Some reefs are resilient to some disturbances, while others are not. Understanding of the conditions that promote recovery and resilience is essential for future effective management of the world's coral reefs, and this understanding requires comparison of long-term studies of reef responses to disturbance. Despite considerable current interest and obvious management applications, surprisingly few studies documenting the long-term responses of coral reefs to disturbance have been published in the scientific literature (Connell *et al.* 1997; Brown *et al.* 2002; Halford *et al.* 2003; Berumen & Pratchett).

3.2 STUDY LOCATION

Ningaloo Reef extends for about 300 km along the coast of Western Australia, and Bill's Bay is an embayment of its shallow coastal lagoon (Figure 1). The lagoon is 2 – 2.5 km wide at this point and has an average depth of about 3 m. Water flow is controlled by wave, wind and tidal forcing; under very low swell conditions, tidal flushing is in the order of 24 h at spring tides, and potentially twice as long at neaps (Hearn & Parker 1988). Depending on wind speed and direction, wind forcing may also facilitate flushing of nearshore waters (Hearn & Parker 1988).

In 1989, Simpson et al. (1993) documented a novel form of disturbance in coral reef habitats: unusually calm wind and sea conditions coincident with mass coral spawning caused a dystrophic crisis (*sensu* (Adjeroud *et al.* 2001)) in Bill's Bay, as the respiratory demand of the spawn slick followed by its *in situ* decomposition apparently depleted available oxygen in the water column and sediments. Studies in other coral reef environments have demonstrated extreme rates of sedimentary oxygen consumption (2.5x pre-spawning values) even during normal coral mass spawning events with fairly low levels of spawn sedimentation (Wild *et al.* 2004). Up to 100% of corals, fishes and reef invertebrates died at some sites during this event in Bill's Bay, including colonies up to 50 years old, indicating that a mass mortality of this magnitude had not occurred for at least four to five decades (Simpson *et al.* 1993). Anecdotal reports of less severe anoxic events at Bill's Bay coincident with coral spawning on several occasions since 1989 indicate that such events may not be uncommon in this location.

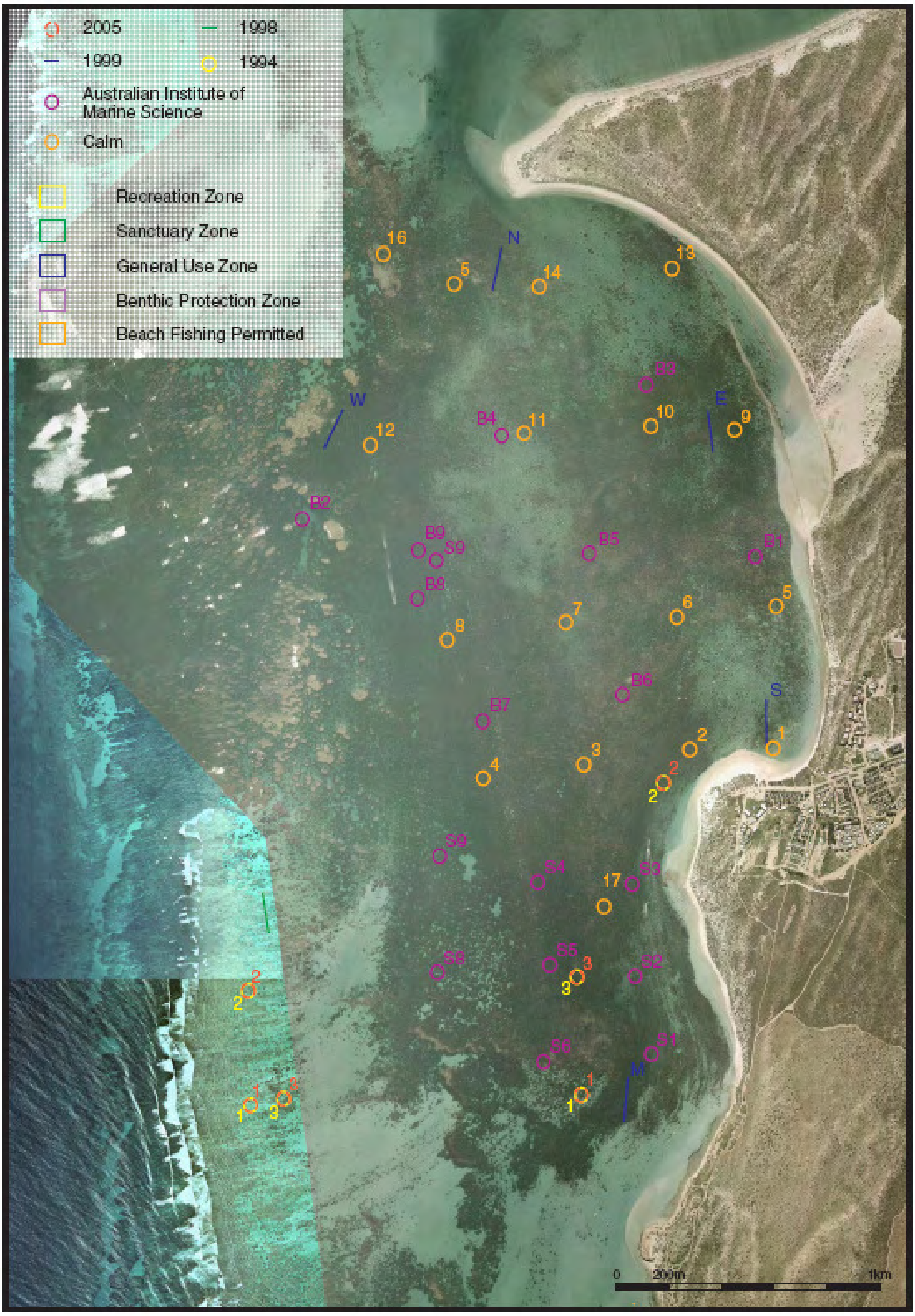


Figure 1. Orthorectified aerial photo of Bill's Bay, Ningaloo Marine Park, Western Australia. Locations of the 17 DEC and 18 AIMS survey sites are shown in orange and purple respectively. In 2006 the 17 DEC sites only were resurveyed.

Since establishment of the baseline in 1989, the coral reef communities of Bill's Bay have been resurveyed in 1994 (Simpson & Field 1995), 1995/96 (AIMS, unpubl.), 2000 (Grubba & Cary 2000), 2001 (AIMS, unpubl.) and 2004 (AIMS, unpubl.; see Figure 1). The 17 CALM sites were resurveyed from 16-23 October 2006. The combined results will not only inform management of this very popular and heavily visited area of the Ningaloo Marine Park, but will provide timely scientific insights into the long-term capacity of central Ningaloo Marine Park coral reef communities to recover from disturbance.

3.3 OBJECTIVES AND OUTCOMES

1. To quantify benthic community structure at the 17 CALM sites in Bill's Bay.
   Outcome: Benthic community structure was quantified through analysis of video transects filmed at the 17 CALM sites in Bill's Bay.

2. To measure size and frequency of juvenile coral colonies at selected sites (representing inner, middle and outer zones of Bill's Bay) and to identify to taxonomic family where possible.
   Outcome: Juvenile coral colonies were measured and identified to taxonomic family (where possible) at each of the 17 CALM sites in Bill's Bay.

4 Methods

4.1 QUANTIFYING BENTHIC COMMUNITY STRUCTURE

The methods of Grubba & Cary (2000) were used with the following exceptions. At the GPS coordinate for each site, a marker buoy was deployed. Three 50 m transect tapes were laid out in parallel in an east-west orientation, ~20 m apart, with the eastern end of the centre transect at the marker buoy. The coordinates of the start and finish of each transect were recorded using handheld GPS in decimal degrees and the datum WGS84.

Figure 2. Shannon Armstrong using the zoom to compensate for depth on a snorkel transect, site 7.

Each transect was filmed in normal definition rather than high definition format, to avoid potential hardware/software problems during the analysis stage. With the zoom set at maximum wide-angle, the camera was held approximately 50 cm above the substrate and positioned such that the transect tape was in view along the left side of the frame. On some snorkel transects the zoom function of the lens was used to compensate for the increased distance of the camera above the transect tape (Figure 2), such that the thickness of the tape proportional to the full width of the screen remained similar to that observed with maximum wide-angle when the camera was held 50 cm above the tape. Analysis of the tapes was performed according to Page et al. (2001).

4.2 CORAL RECRUITMENT

At all sites the size and family (where possible) of coral colonies less than 10 cm diameter was recorded. Colonies smaller than 10 cm diameter which appeared to have resulted from fragmentation or partial death of a larger colony were not recorded. In combination with coral settlement data collected previously in Bill's Bay by AIMS (unpubl.) and Harriot and Simpson (1997), these data will enable comparisons of rates of recruitment to the adult coral population between families and sites, and may provide some insights into factors constraining or promoting recovery at some sites.

An adaptation of the AIMS method as reported by Dr Luke Smith (pers. comm.) was used, to enable comparison of results with AIMS data collected in previous years. Corals <5 cm in diameter (where diameter = the longest horizontal axis) were measured and identified to family (Acroporidae, Poritidae, Pocilloporidae, Faviidae (including *Cyphastrea microphthalma*), Other/Unknown; see Appendices 1 and 2) within a 25 cm wide and 25 m long belt transect. Corals between 5 and 10 cm in diameter were measured and identified within a 1 m wide and 25 m long belt transect. In practice, the first 25 m of the 50 m transects laid out for the video recording of benthic community structure was also used for the coral recruitment survey.

Figure 3. Acroporid recruit (~6 cm dia) growing on unconsolidated turf-covered rubble, site 1.

4.3 COORDINATES OF SURVEY SITES

The GPS coordinates for the 17 CALM survey sites defined by Grubba & Cary (2000) are shown in Table 1.

Table 1. Standardised site coordinates in decimal degrees (datum WGS84) and in northing/easting (AMG zone 49) for non-permanent transect sites established in Bill's Bay in 1989, as specified by Grubba & Cary (2000). See Figure 1.

Site No.	Longitude (º E) dec deg WGS84	Latitude (º S) dec deg WGS84	Easting (mE) AMG 49 WGS84	Northing (mN) AMG 49 WGS84
1	113.76963	-23.14141	783,616.84	7,438,121.61
2	113.76654	-23.1415	783,300.42	7,438,117.82
3	113.76262	-23.14209	782,898.08	7,438,059.91
4	113.75889	-23.14263	782,514.18	7,438,007.71
5	113.76964	-23.13652	783,628.48	7,438,663.79
6	113.76597	-23.13697	783,252.03	7,438,621.16
7	113.76185	-23.13721	782,829.18	7,438,601.97
8	113.75747	-23.1379	782,378.50	7,438,534.41
9	113.76797	-23.13049	783,470.12	7,439,334.93
10	113.76487	-23.13042	783,152.34	7,439,348.87
11	113.76017	-23.13074	782,670.33	7,439,322.39
12	113.75448	-23.13125	782,086.21	7,439,276.58
13	113.76554	-23.12498	783,232.99	7,439,949.78
14	113.76063	-23.12569	782,728.10	7,439,881.46
15	113.75747	-23.12565	782,404.48	7,439,891.74
16	113.75483	-23.12467	782,135.82	7,440,005.58
17	113.76347	-23.14696	782,974.04	7,437,519.33

5 Data management and reporting

5.1 RAW DATA

Raw data are stored on the Marine Science Program server along with the electronic copy of the data report.

Video

Video tapes have been duplicated onto DVD and both versions are stored by the Marine Science Program on site at Kensington.

Still images

Still images are stored as high resolution jpegs in the Marine Science Program image library (on T drive).

5.2 PUBLICATIONS

A manuscript combining data from all previous quantitative surveys of benthic communities in Bill's Bay by both CALM and AIMS, as well as other published sources (eg, Harriot & Simpson 1997), is already in preparation. The addition of the 2006 survey data will enable a detailed quantitative picture of changes in reef community structure over the past 17 years to be developed. The resulting manuscript will be submitted for publication in an international peer-reviewed journal.

5.3 REPORT DISTRIBUTION

This data report will be distributed to the Manager of the DEC Exmouth District Office, the Northwest Research Association field station at Coral Bay, the DEC library at Kensington and the Batty Library. It will also be stored electronically on the Marine Science Program server (T drive) at Kensington.

6 Results

6.1 GPS COORDINATES OF TRANSECTS

The GPS coordinates of the start and finish of each transect recorded in the field were downloaded directly to computer (Table 2). The transects are presented overlaid on an aerial photo of Bill's Bay in Figure 4.

6.2 VIDEO TAPE ANALYSIS AND RESULTS

Point sampling analysis

Previous CALM surveys of coral communities in Bill's Bay used line intercept methods to estimate percent cover on two (1989, 1994) or three (2000) replicate transects. However, point sampling methods have been widely adopted for coral reef monitoring programs (Hill & Wilkinson 2004) as they can provide accurate estimates of percent coral cover, species richness and diversity more quickly and with less effort than conventional line intercept methods (Beenaerts & Vanden Berghe 2005). As a recent study found that results obtained using line intercept and point sampling methods of coral reef video transect analysis were virtually indistinguishable (Beenaerts & Vanden Berghe 2005), the transect videos from the 2006 Bill's Bay survey were analysed by consultant Cathie Page using the following point sampling method.

The software AVTAS was used to pause the tape at fixed time intervals during each 50 m transect. At each paused frame, the organism or substrate occurring underneath each of five points on the frame was classified into the categories described in Page et al. (2001). The complete list of benthic categories identified in Bill's Bay in 2006 is shown in Table 3. Two hundred points were sampled for each 50 m transect. These data were then converted to percentage cover per category for each transect.

A hard copy of the data resulting from point sampling analysis of the transect videos is given in Appendix 5. The database produced from this video tape analysis method is available in MS Access format in the same location as the electronic copy of this data report (on the Marine Science Program server at Kensington).

Comparability of point sampling and line intercept analysis methods

An important first step towards assimilation of these data was to explore the comparability of results obtained using PS and LI analysis methods. One possible difference between the two methods involves the estimated percent cover of branching (=arborescent) corals. The decision rules of the LI method used in 2000 (and in previous years) meant that a large live branching coral colony covered the complete intersection length under the transect tape, from where the first branch to be encountered crossed the tape, to the last.

Table 2. Actual GPS coordinates (decimal degrees, datum WGS 84) of the start (east) and finish (west) of each of the three transects (north, mid and south) surveyed at the 17 sites in Bill's Bay in 2006. These coordinates are mapped in Fig. 4. Transects at site 16b ran east from the central site 16 GPS coordinate, over a deeper more lagoonal environment relative to 16a, for which the transects ran west from the central site 16 GPS coordinate, and which was shallower.

Site	*Transect*	*Transect start (east)*		*Transect finish (west)*	
		LATITUDE	LONGITUDE	LATITUDE	LONGITUDE
1	(N)orth	S23.14090	E113.76967	S23.14099	E113.76919
	(M)id	S23.14106	E113.76970	S23.14111	E113.76924
	(S)outh	S23.14125	E113.76967	S23.14133	E113.76920
2	(N)orth	S23.14132	E113.76648	S23.14120	E113.76602
	(M)id	S23.14147	E113.76663	S23.14137	E113.76613
	(S)outh	S23.14162	E113.76668	S23.14148	E113.76627
3	(N)orth	S23.14177	E113.76264	S23.14163	E113.76222
	(M)id	S23.14205	E113.76259	S23.14192	E113.76216
	(S)outh	S23.14228	E113.76251	S23.14217	E113.76213
4	(N)orth	S23.14231	E113.75875	S23.14228	E113.75837
	(M)id	S23.14248	E113.75875	S23.14243	E113.75830
	(S)outh	S23.14279	E113.75864	S23.14274	E113.75824
5	(N)orth	S23.13635	E113.76959	S23.13627	E113.76914
	(M)id	S23.13651	E113.76956	S23.13661	E113.76911
	(S)outh	S23.13658	E113.76951	S23.13675	E113.76916
6	(N)orth	S23.13672	E113.76595	S23.13666	E113.76550
	(M)id	S23.13695	E113.76594	S23.13699	E113.76548
	(S)outh	S23.13718	E113.76599	S23.13719	E113.76559
7	(N)orth	S23.13685	E113.76189	S23.13681	E113.76138
	(M)id	S23.13713	E113.76188	S23.13700	E113.76140
	(S)outh	S23.13731	E113.76182	S23.13726	E113.76138
8	(N)orth	S23.13773	E113.75749	S23.13769	E113.75702
	(M)id	S23.13790	E113.75740	S23.13789	E113.75695
	(S)outh	S23.13810	E113.75739	S23.13812	E113.75697
9	(N)orth	S23.13032	E113.76800	S23.13040	E113.76755
	(M)id	S23.13051	E113.76802	S23.13054	E113.76761
	(S)outh	S23.13066	E113.76810	S23.13068	E113.76762
10	(N)orth	S23.13030	E113.76478	S23.13030	E113.76432
	(M)id	S23.13046	E113.76485	S23.13048	E113.76438
	(S)outh	S23.13060	E113.76492	S23.13063	E113.76443
11	(N)orth	S23.13048	E113.76017	S23.13048	E113.75968
	(M)id	S23.13072	E113.76019	S23.13076	E113.75970
	(S)outh	S23.13096	E113.76027	S23.13095	E113.75977
12	(N)orth	S23.13086	E113.75438	S23.13077	E113.75392
	(M)id	S23.13090	E113.75432	S23.13083	E113.75386
	(S)outh	S23.13115	E113.75430	S23.13117	E113.75384
13	(N)orth	S23.12461	E113.76568	S23.12465	E113.76519
	(M)id	S23.12489	E113.76566	S23.12483	E113.76520
	(S)outh	S23.12514	E113.76564	S23.12515	E113.76516
14	(N)orth	S23.12540	E113.76063	S23.12526	E113.76017
	(M)id	S23.12564	E113.76060	S23.12554	E113.76011
	(S)outh	S23.12589	E113.76054	S23.12577	E113.76014
15	(N)orth	S23.12538	E113.75751	S23.12531	E113.75705
	(M)id	S23.12560	E113.75742	S23.12559	E113.75696
	(S)outh	S23.12576	E113.75740	S23.12567	E113.75696
16a	(N)orth	S23.12441	E113.75494	S23.12447	E113.75447
(shallow)	(M)id	S23.12462	E113.75476	S23.12470	E113.75424
	(S)outh	S23.12482	E113.75467	S23.12486	E113.75425
16b	(N)orth	S23.12441	E113.75537	S23.12441	E113.75494
(deep)	(M)id	S23.12467	E113.75523	S23.12462	E113.75476
	(S)outh	S23.12477	E113.75515	S23.12482	E113.75467
17	(N)orth	S23.14665	E113.76349	S23.14648	E113.76310
	(M)id	S23.14685	E113.76349	S23.14683	E113.76302
	(S)outh	S23.14715	E113.76353	S23.14703	E113.76303

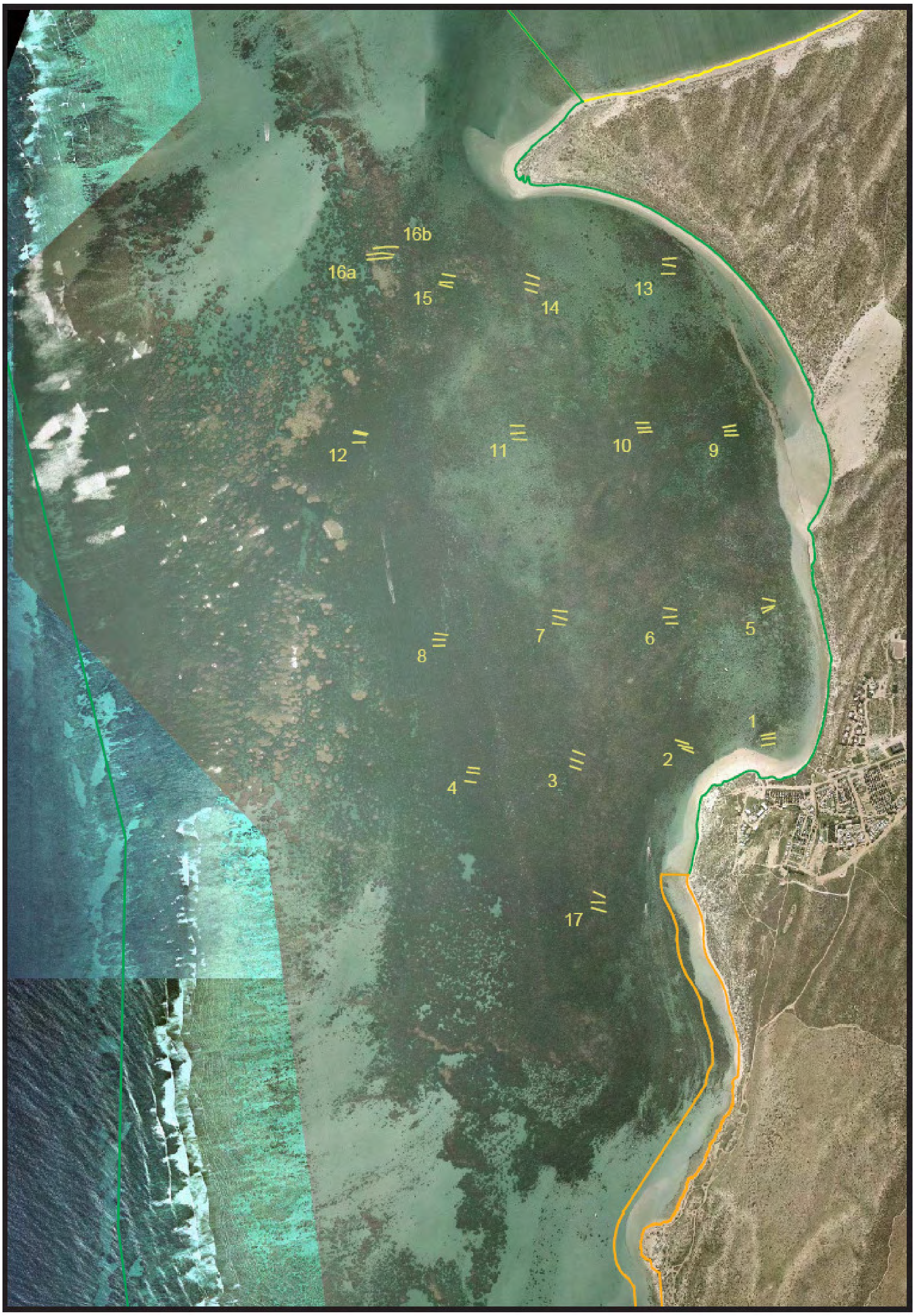


Figure 4. Actual transects (north, middle, south) surveyed at each of the 17 sites in Bill's Bay in 2006.

Table 3. Complete list of benthic categories identified in video transects from Bill's Bay in 2006.

Benthic category	Detailed description
Arb & Enc Soft Coral	*Sinularia* spp.
Branching *Acropora*	*Acropora* spp.
Branching non-*Acropora*	*Echinopora* spp.
Branching non-*Acropora*	*Hydnophora rigida*
Branching non-*Acropora*	*Seriatopora* spp.
Coralline algae	Coralline algae
Corymbose *Acropora*	*Acropora* spp.
Dead coral (recent)	Dead standing coral (white)
Digitate *Acropora*	*Acropora* spp.
Encrusting non-*Acropora*	*Echinopora* spp.
Encrusting non-*Acropora*	*Favites* spp.
Encrusting non-*Acropora*	*Galaxea fascicularis*
Encrusting non-*Acropora*	*Galaxea* spp.
Encrusting non-*Acropora*	*Merulina ampliata*
Encrusting non-*Acropora*	*Montipora* spp.
Encrusting non-*Acropora*	Non-*Acropora* coral
Encrusting non-*Acropora*	*Platygyra* spp.
Foliose non-*Acropora*	*Echinopora* spp.
Foliose non-*Acropora*	*Merulina* spp.
Foliose non-*Acropora*	*Montipora* spp.
Foliose non-*Acropora*	*Turbinaria reniformis*
Macroalgae	Fleshy Macro Algae
Macroalgae	*Padina australis*
Massive non-*Acropora*	*Diploastrea heliopora*
Massive non-*Acropora*	*Favia* spp.
Massive non-*Acropora*	*Favites pentagona*
Massive non-*Acropora*	*Goniastrea* spp.
Massive non-*Acropora*	*Goniopora* spp.
Massive non-*Acropora*	*Lobophyllia* spp.
Massive non-*Acropora*	Non-*Acropora* coral
Massive non-*Acropora*	*Platygyra* spp.
Massive non-*Acropora*	*Porites* spp.
Massive Soft Coral	*Pachyclavularia* spp.
Mushroom coral	*Fungia* spp.
Other organisms	Other organisms
Other organisms	*Tridacna* spp.
Reefal substrate	Reefal substrate
Sand	Sand
Sponge	Sponge spp.
Submassive non-*Acropora*	*Hydnophora exesa*
Submassive non-*Acropora*	*Montipora* spp.
Submassive non-*Acropora*	Non-*Acropora* coral[1]
Submassive non-*Acropora*	*Pocillopora damicornis*
Tabulate *Acropora*	*Acropora* spp.
Turf algae	Filamentous algae
Water	Water

[1] This very common non-acroporid submassive coral species has yet to be identified from the video tapes.

By contrast, the PS method used in 2006 could provide a relative underestimate of branching coral cover, as the substrate under sample points falling within a large live colony might often actually be sand (visible between branches) or algae (growing on lower, older branch sections). This possible incongruity between PS and LI methods was first raised by Carleton and Done (1995), who then showed that resultant differences in percent cover estimation of both branching corals and total live coral were insignificant at their study site on the Great Barrier Reef. To assess the significance of this potential problem for assimilation of the long-term monitoring data from Bill's Bay, PS and LI estimations of percent coral cover were compared at three sites.

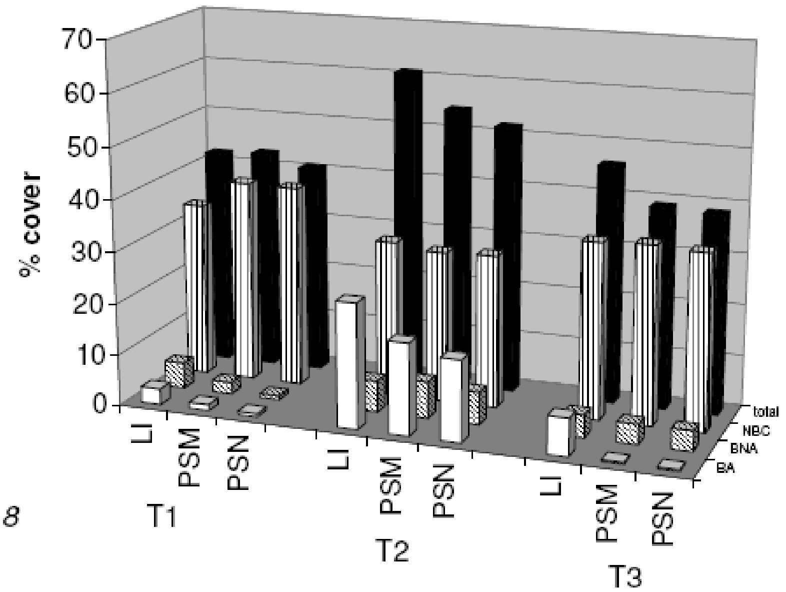
The three sites (site 8, 12 and 17) are all in similar sheltered backreef environments in Bill's Bay. At each site, three 50 m transect tapes were laid out in parallel in an east-west orientation, ~20 m apart. A diver swam slowly (~10 m min^{-1}) along each transect, filming at maximum wide angle and with the camera positioned ~50 cm above the substrate, such that the transect tape was in view along the left side of the image frame. For the purposes of this study the following highly simplified series of benthic categories was employed during analyses: branching acroporids (=arborescent acroporids), branching non-acroporids, non-branching corals, not live corals (this final category included all other substrates).

PS analyses involved the sampling of twenty fixed points from fifty frames taken from regular intervals during the recording of each 50 m transect. The substrate occurring underneath each of the twenty points on each frame was classified into one of the four benthic categories. Two decision rules were tested during PS analyses: the conventional method described in Page et al. (2001) in which points falling between branches were classified as non-branching corals (termed PS-normal or PSN), and a modified method in which points falling between branches were classified as branching corals (termed PS-modified or PSM). A total of one thousand points was sampled for each 50 m transect. These data were then converted to percentage cover per category for each transect.

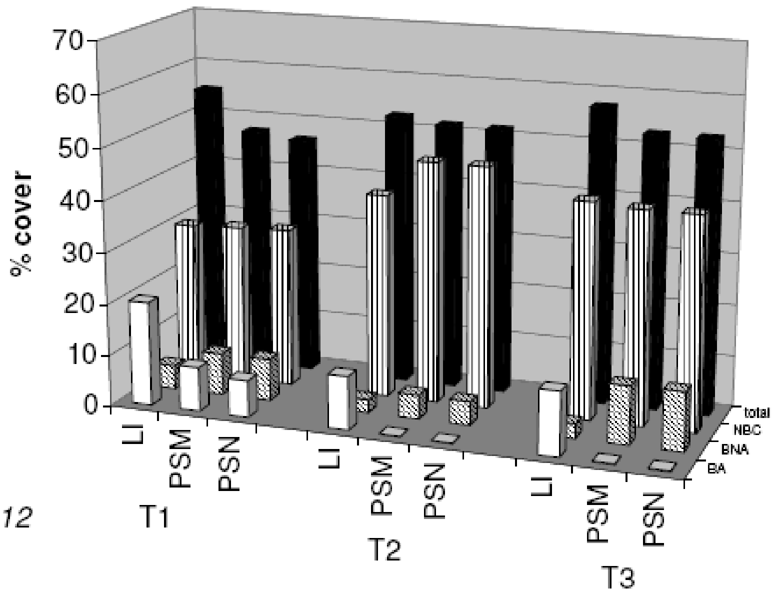
For LI analyses, the video was replayed at half normal speed on a wide-screen television, to facilitate best possible classification of the substrate under the transect tape. The length of transect tape occupied by each benthic category was recorded to the nearest centimetre. The decision rules employed by previous LI analyses of coral cover in Bill's Bay were used: specifically, when large branching colony morphologies were encountered, the intersection length of the entire colony was measured as one observation, and any substrates or organisms visible underneath or between the branches were ignored. The percent cover of each benthic category was then calculated for each transect.

Following square root transformation, the estimated percent cover of each benthic category along each transect was compared both between methods and across sites using univariate ANOVAs in which site and method were fixed factors, transect was a random factor, and transect was nested within site. Once method-related differences were detected, a post-hoc test (LSD) was used to investigate the significance of differences in mean estimations via pairwise comparisons. The relationship between PSN and LI estimates of branching acroporid cover for each transect was investigated using linear regression.

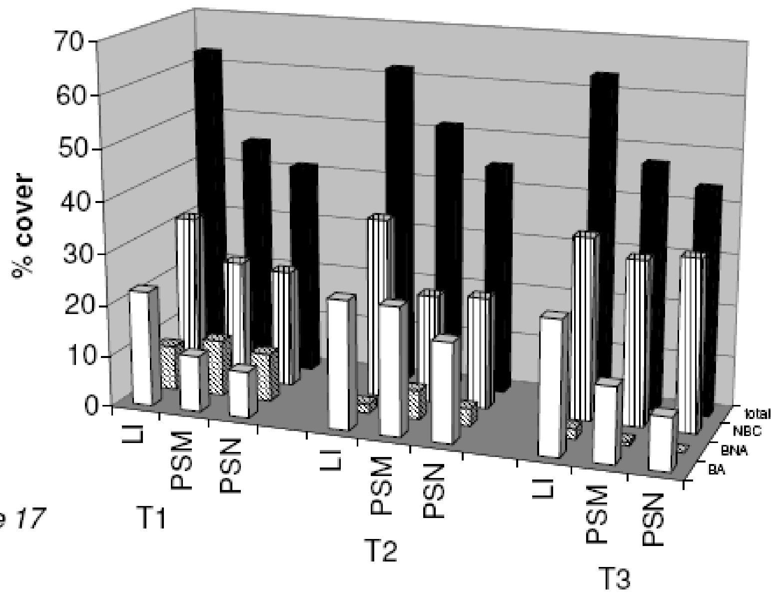
PS estimations of benthic cover of branching acroporids, branching non-acroporids, non-branching corals and total coral cover were frequently considerably different to the LI estimations along each transect, and this was the case across all three sites (Figure 5).



a. Site 8



b. Site 12



c. Site 17

Figure 5 (previous page). Comparison between line intercept (LI), normal point sampling (PSN) and modified point sampling (PSM) cover estimation methods for three transects (T1, T2, T3) at each of three sites (site 8, site 12, site 17; a, b, c respectively) in Bill's Bay in 2006. BA = branching acroporids; BNA = branching non-acroporids; NBC = non-branching coral; total = total coral cover.

Analysis of variance across all sites showed that these method-related differences in cover estimations were significant in the case of branching corals ($p<0.001$) and total coral cover ($p<0.001$). No significant method-related differences were found in estimations of branching non-acroporids or non-branching corals. Post-hoc pairwise comparisons across all sites showed that the LI method significantly overestimated both mean branching acroporid cover (LI/PSM $p=0.045$, LI/PSN $p=0.026$) and mean total coral cover (LI/PSM $p=0.014$, LI/PSN $p=0.003$) relative to both PS methods.

By contrast, no significant differences were found between estimations of percent coral cover made using PS (Aronson et al. 1994) and LI (Hughes 1994) at a site in Discovery Bay in Jamaica in 1992. However, this site had just ~3% live coral cover. Carleton and Done (1995) compared diverse methods of cover estimation at a site on the Great Barrier Reef with ~23% live coral cover including ~4.3% branching coral cover (estimated by PS methods). While their estimates of percent cover of branching corals derived from in-field LI methods were consistently higher than estimates derived from video PS, the difference between the two methods was not significant, and no significant differences were observed in estimations of total coral cover. This lack of significance could be due to the relatively high levels of variation between transects at their site (Table 6 in Carleton and Done (1995)).

As expected, PS-normal tended to underestimate cover of branching corals in Bill's Bay relative to PS-modified (Figure 5), but post-hoc tests found that the mean differences between methods were not sufficient to be significant. Although generally greater than PS-normal estimations, PS-modified estimations of branching coral cover, especially branching acroporid cover, were generally not equivalent to LI estimations (Figure 5). In fact the differences between mean estimations of LI and PS-modified methods remained statistically significant for branching acroporids ($p=0.045$) and total coral cover ($p=0.014$). Modification of the PS decision rules thus did not fully account for the observed differences in estimations between LI and PS-normal methods, even for branching acroporids. While the LI method always overestimated branching acroporid cover, cover of the other broad categories was sometimes underestimated and sometimes overestimated relative to PS methods. This indicates that additional factors, potentially unrelated to coral colony morphology, may be influencing LI estimation.

Are PS and LI methods comparable? Per-transect comparisons revealed a strong relationship ($R^2=0.755$; $p=0.002$) between PSN and LI estimations of branching acroporid cover (Figure 6). This indicates that conversion between the two methods may be feasible, and provides an equation that may be appropriate for sites in Bill's Bay with branching acroporid cover within this range ($y=0.7366x - 5.3966$; Figure 6). No relationship was detected between PSN and LI estimations of total coral cover, probably because of the inconsistencies observed in estimation of the other major components of total coral cover, branching non-acroporids and non-branching corals (Figure 5). While the basis of these inconsistencies remains unclear, this analysis will enable more informed comparison of results generated using the two methods.

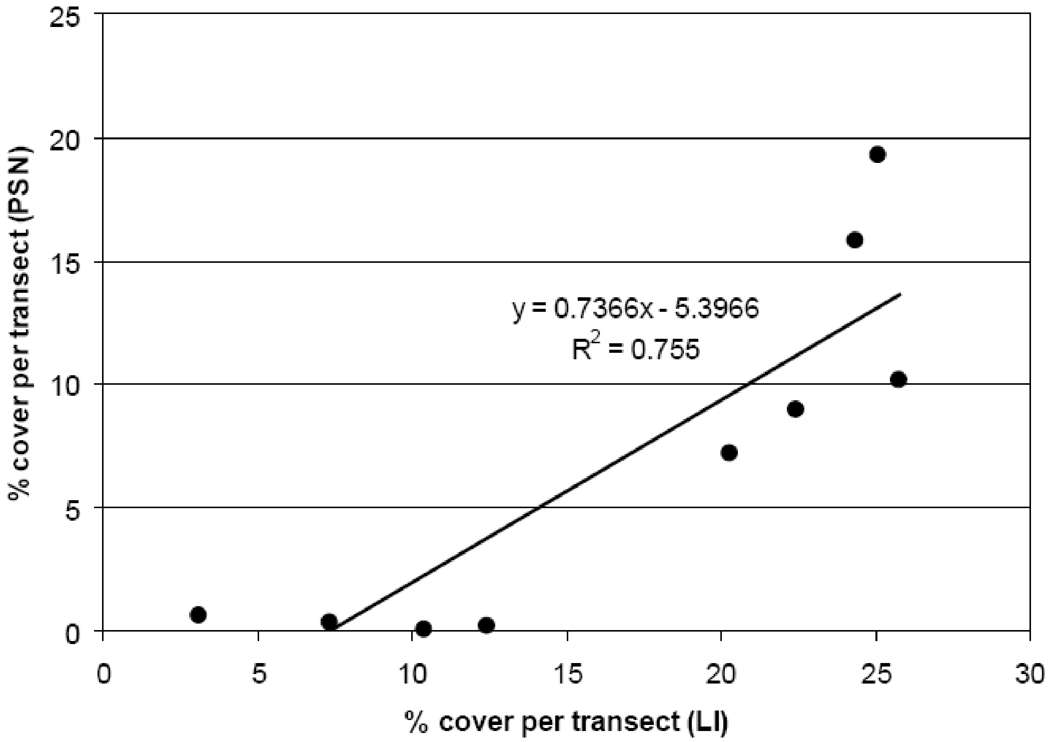


Figure 6. Relationship between point sampling (PSN) and line intercept (LI) methods of cover estimation for branching acroporids along each transect at three sites in Bill's Bay.

6.3 CORAL COMMUNITIES IN BILL'S BAY

Live coral cover over time

Sites in the inner zone of Bill's Bay (1, 5, 9, 13) display strikingly similar patterns of steady recovery in live coral cover since 1989 (Figure 7a). In 2006 each of these sites had live coral cover equal to or greater than that which existed prior to the mass mortality event in 1989. Of particular interest are sites 9 and 13, which contained no live coral even before the mass mortality in 1989, and yet had greater than 40% coral cover in 2006. Qualitative observations during the survey and subsequent data analyses suggest that the increase in live coral cover at sites 5, 9 and 13 has been driven chiefly by local proliferation of a faviid of the genus *Echinopora,* probably *E. ashmorensis* (some large colonies are visible in the foreground in Figure 2). No information is available on the reproductive mode of *E. ashmorensis*, but it is intriguing to speculate that like its congener *E. lamellosa* its reproductive traits may be somewhat plastic and environmentally regulated (Fan & Dai 1999), a feature which could have contributed to its current competitive dominance at these sites.

No similarity in recovery pattern is apparent amongst sites in the middle zone of Bill's Bay (Figure 7a). This lack of similarity may be due to the varying degrees of mortality suffered by these sites in 1989 (close to 100% at sites 10, 14 and 6, compared to substantially better survivorship at sites 2, 7, and 15), as well as differences in subsequent disturbance history (for example, coral spawning-related mortality events that affected relatively small areas of Bill's Bay in 2002 and 2005 (van Schoubroeck & Long 2007)).

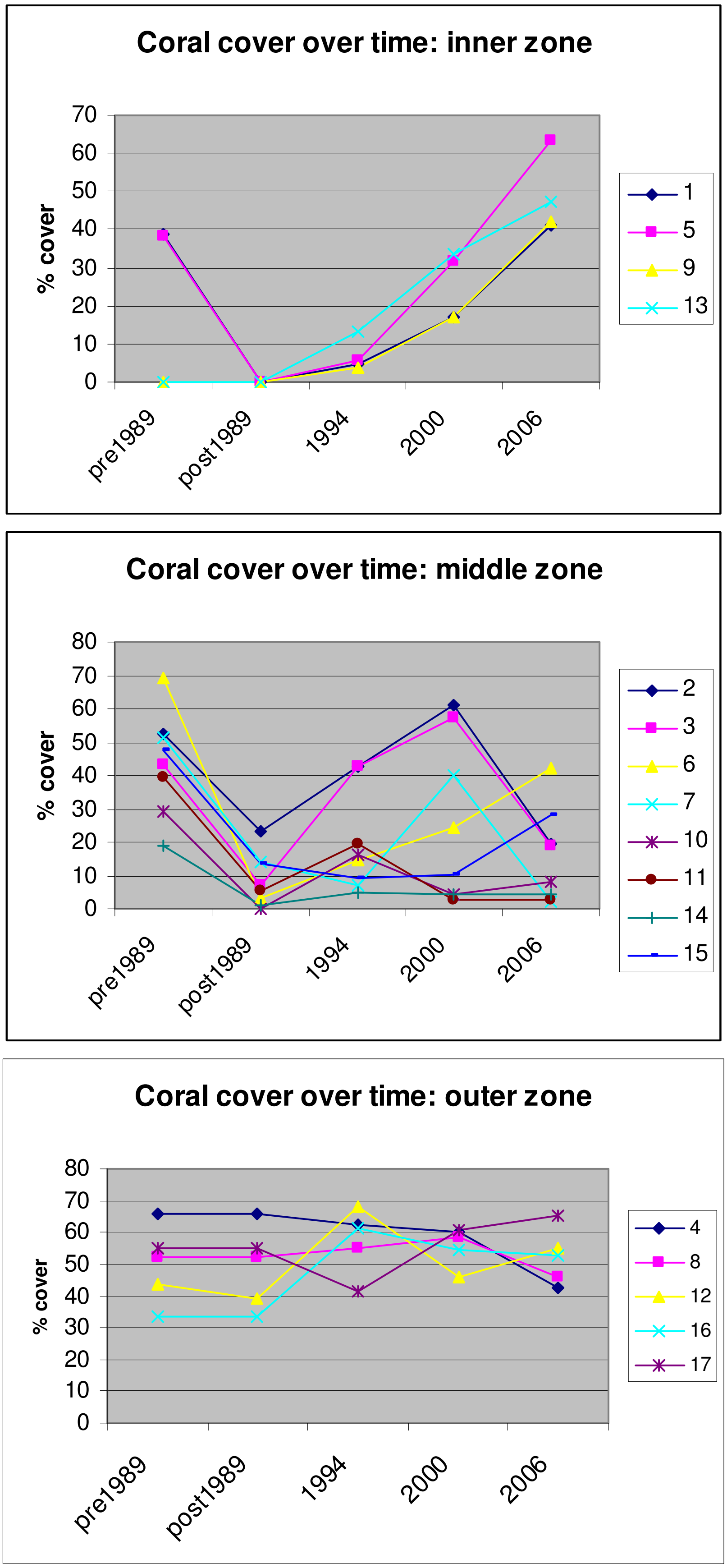


Figure 7a. Mean live coral cover over time for each site in each zone in Bill's Bay. Values for 2006 are PS-derived except in the case of the outer zone, where values from LI analysis are shown (for ease of comparability over time in these areas with high branching acroporid cover; see section 6.2).

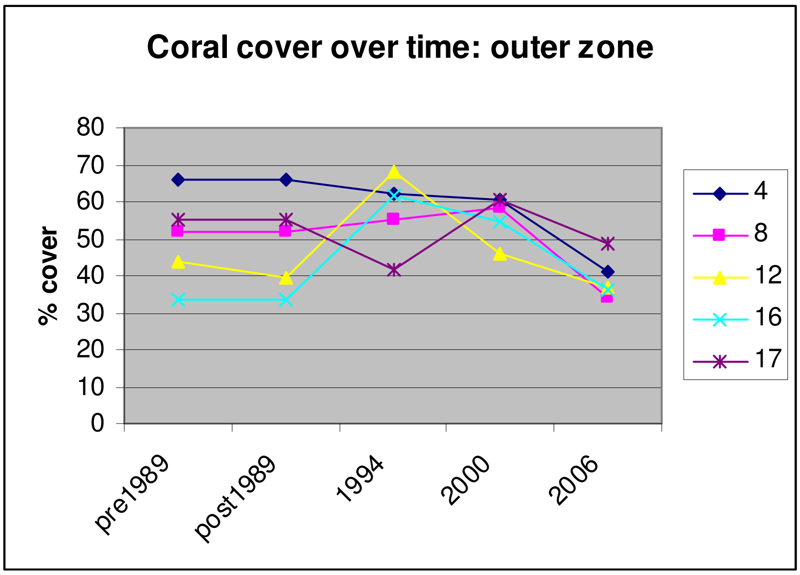


Figure 7b. Mean live coral cover over time for each outer zone site. Values for 2006 are derived from PS rather than LI analysis, illustrating the artefactual reduction in live coral cover attributable to a change in analysis methodology (see section 6.2).

Of particular note is the apparently persistent recovery failure at sites 11, 14 and 10. Closer examination of the physical and biological characteristics of these sites, as well as their recent disturbance history, may provide insights into the local constraints preventing reef recovery.

Corals in the outer zone of Bill's Bay (sites 4, 8, 12, 16 and 17) were unimpacted by the mass mortality in 1989 and, in the absence of other major disturbances, could be expected to show consistently high levels of coral cover over time. This is more or less the case (Figure 7a). Reductions at sites 4 and 8 in 2006 are probably attributable to the coral spawning-related mass mortality anecdotally recorded in the area in 2005 (van Schoubroeck & Long 2007). Figure 7b illustrates the artefactual reduction in live coral cover in the outer zone that occurred when transects from these branching acroporid-dominated sites were analysed using PS rather than LI (section 6.2).

A very small amount of bleaching (0.06% total coral cover) was observed on one transect at site 16 during the survey in October 2006, possibly related to the winter bleaching event that affected much of Ningaloo Reef in the winter of 2006; see Armstrong (2007) for more information.

Coral community structure over time

Changes in reef disturbance regimes are likely to produce concomitant shifts in coral community structure (Brown *et al.* 2002). Even at the gross taxonomic level of family, substantial changes in coral community structure can be detected over time in Bill's Bay. Prior to the mass mortality in 1989, acroporids dominated coral communities in all three zones of Bill's Bay (Figure 8a). Total live coral cover was lowest in inner Bill's Bay and highest in outer Bill's Bay. The dystrophic crisis caused the death of virtually all corals in inner Bill's Bay, and most of the acroporids were killed in the middle zone (Figure 8b). The outer zone was unimpacted by the 1989 dystrophic crisis. Six years after the mass mortality, acroporid cover was substantially decreased even from post-mass mortality levels in the middle and outer zones, while some faviid-led recovery had commenced in inner Bill's Bay (Figure 8c).

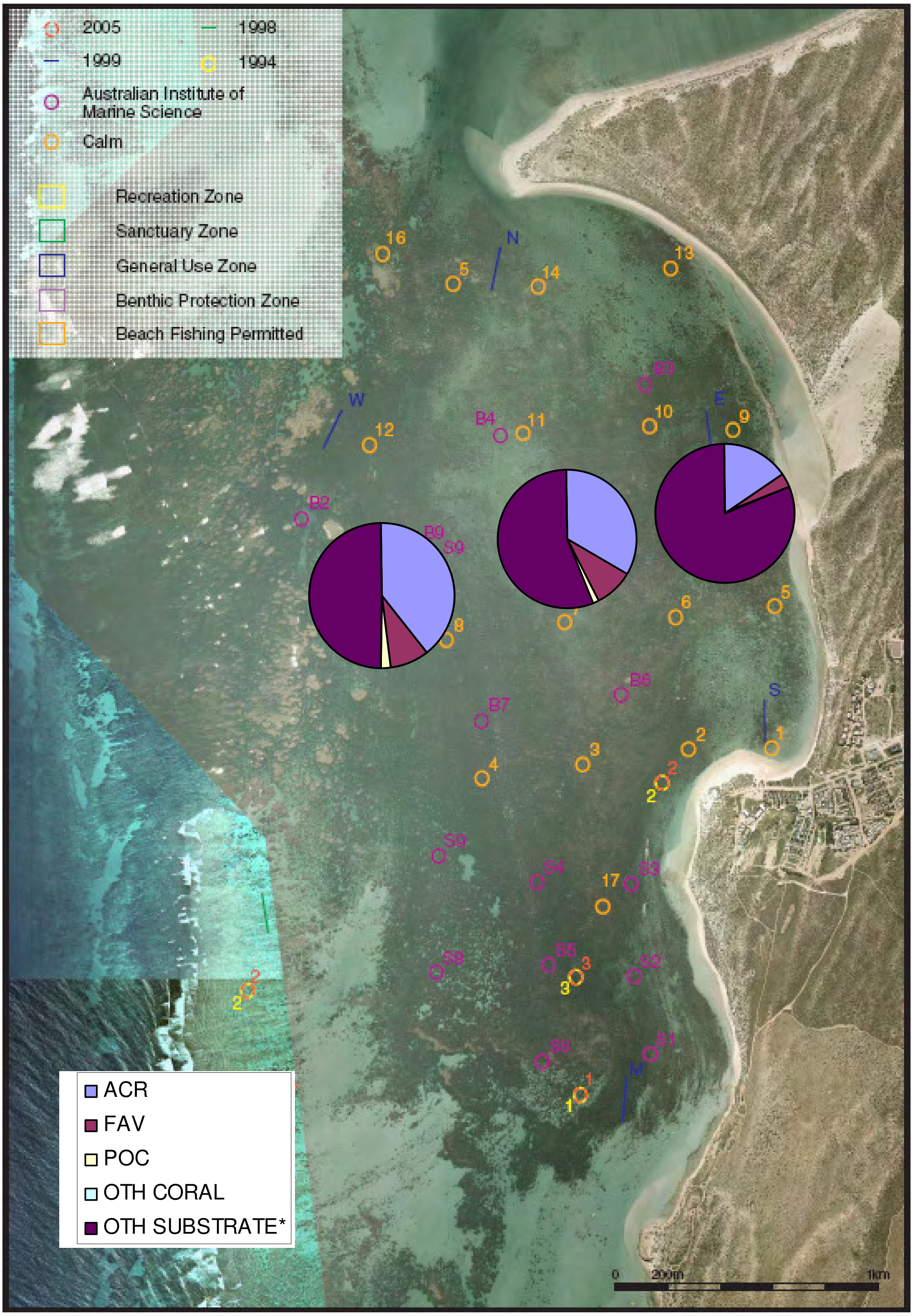


Figure 8a. Coral community structure in the inner, mid and outer zones of Bill's Bay in 1989 before the mass mortality caused by the dystrophic crisis. Acroporids dominated (in terms of percent cover) in all three zones.

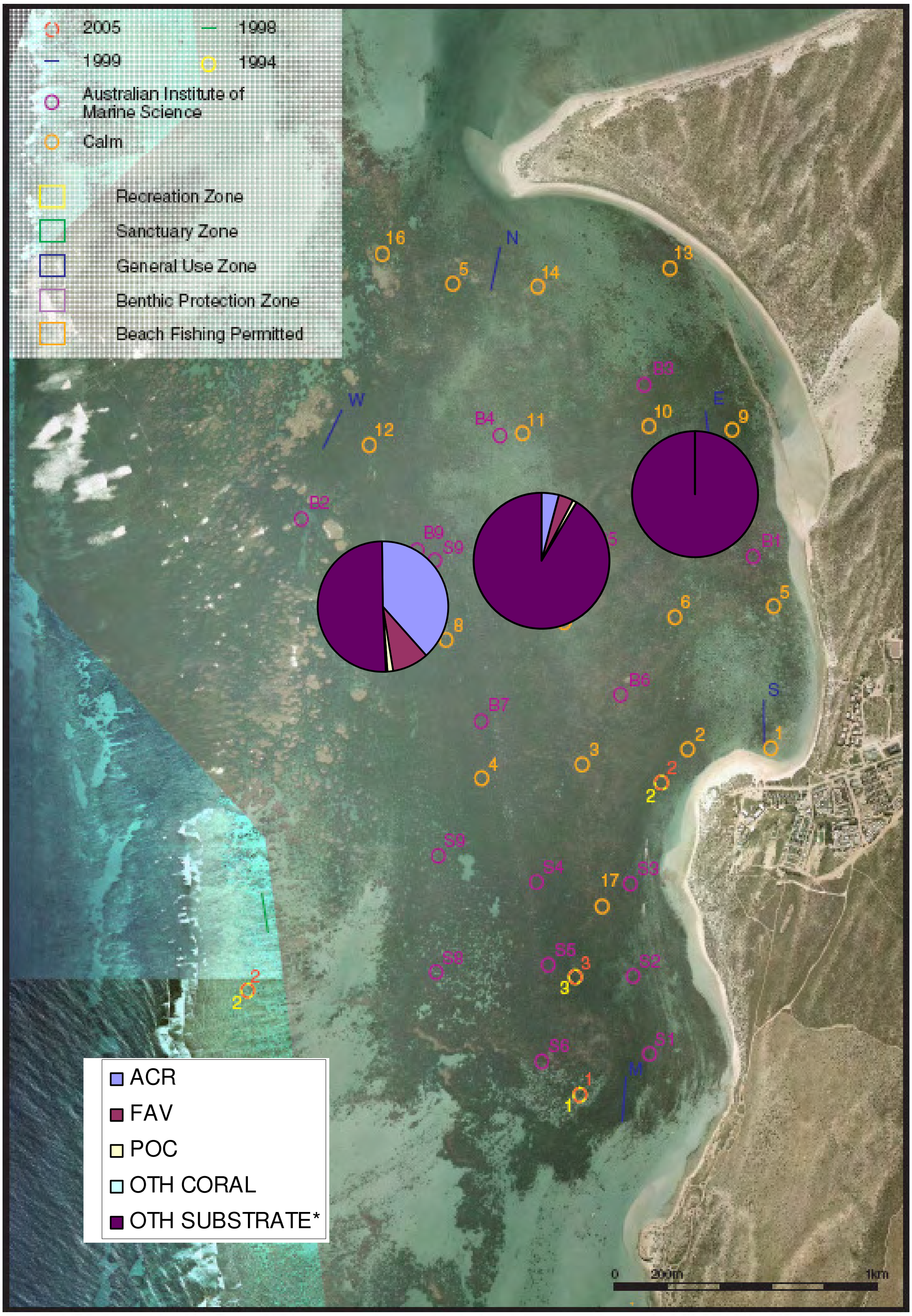


Figure 8b. Coral community structure in the inner, middle and outer zones of Bill's Bay in 1989 after the mass mortality caused by the dystrophic crisis. Virtually no live coral cover remained in inner Bill's Bay.

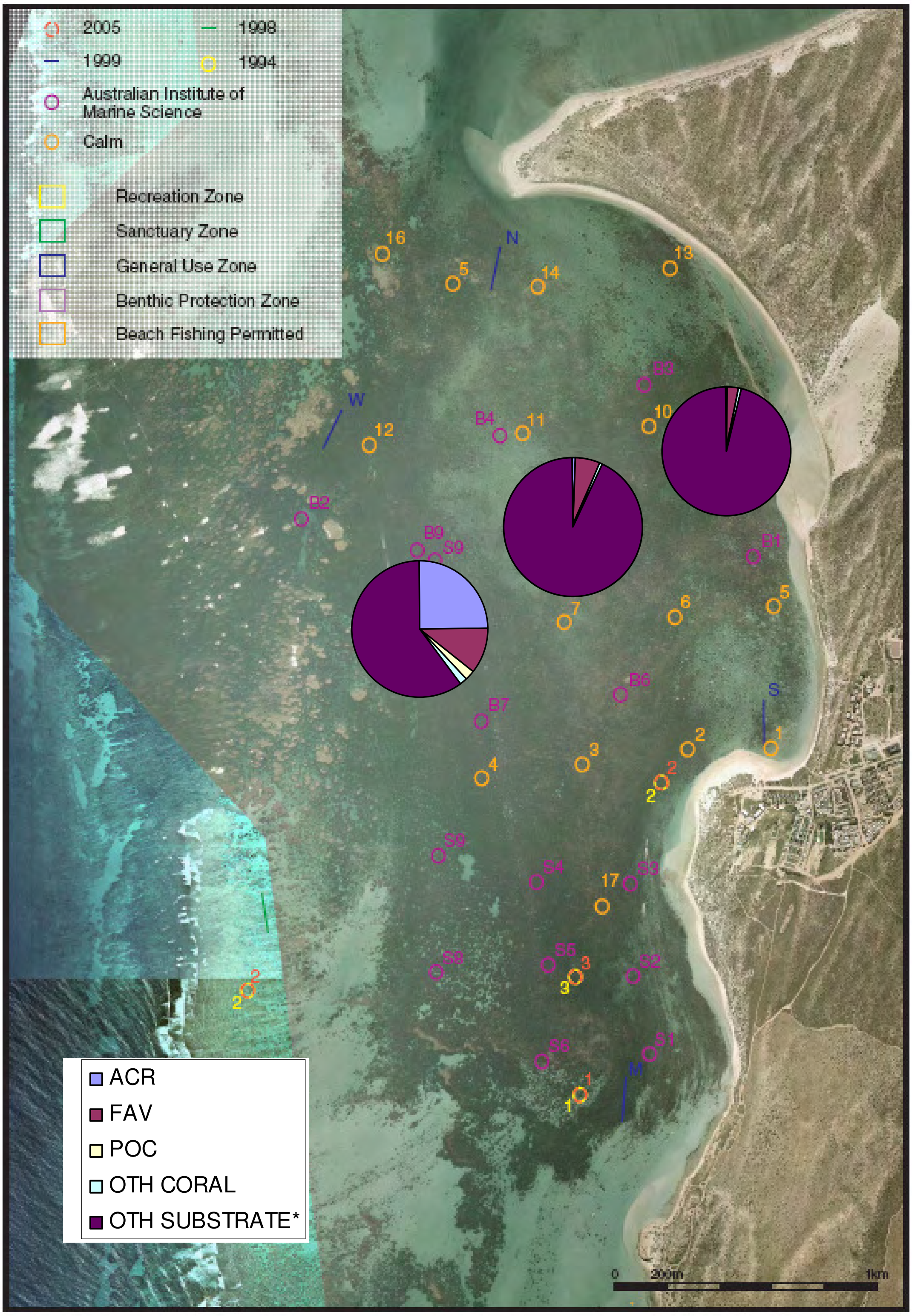


Figure 8c. Coral community structure in the inner, middle and outer zones of Bill's Bay in 1995/96 (based on unpublished AIMS data that was analysed using PS methods). Faviids were recovering in the inner and middle zones of Bill's Bay (predominantly *Cyphastrea microphthalma;* Luke Smith pers.comm.) but acroporids were not yet evident in terms of percent live coral cover. The apparent decrease in acroporid cover in the outer zone relative to 1989 is probably artefactual.

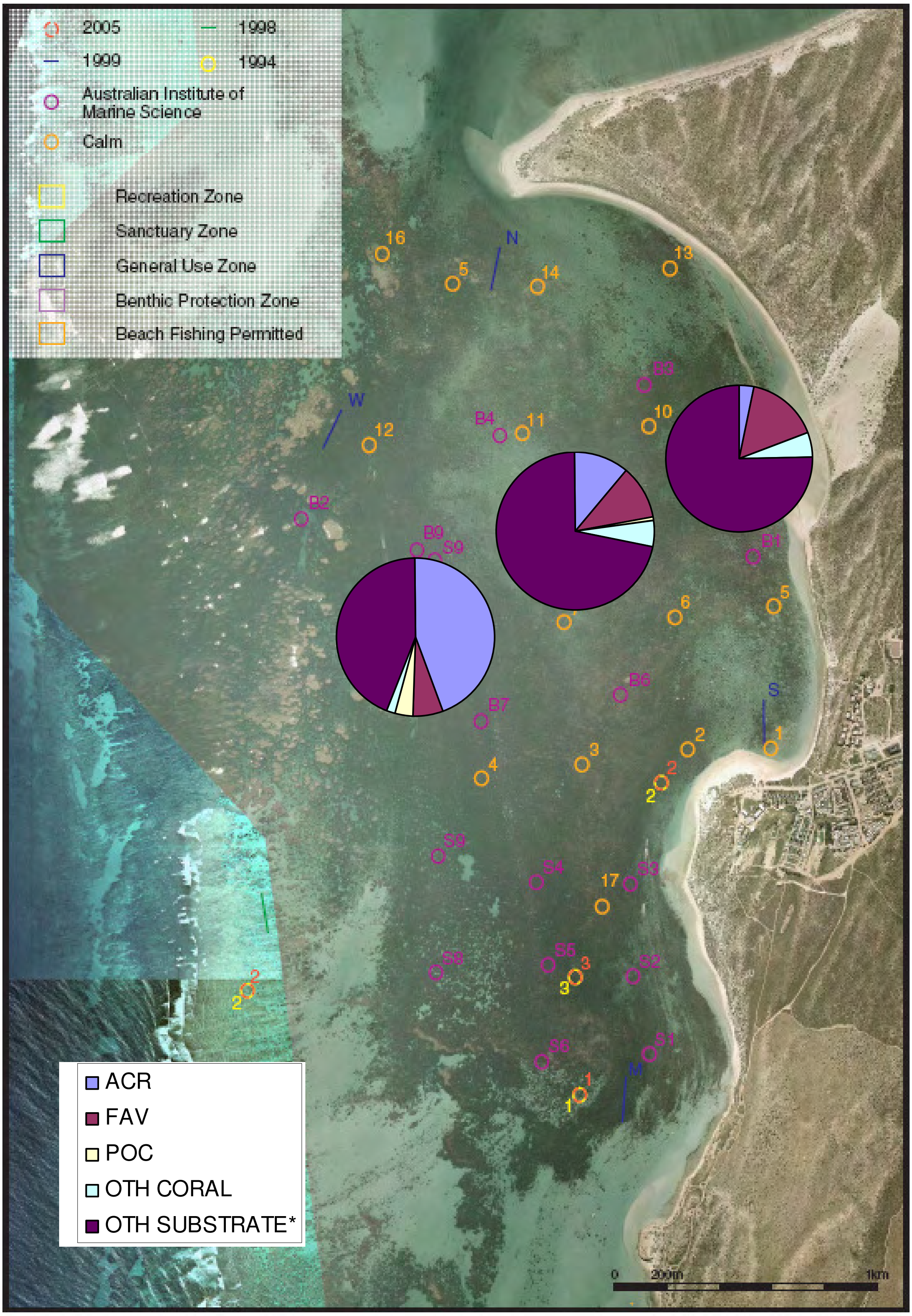


Figure 8d. Coral community structure in the inner, middle and outer zones of Bill's Bay in 2000. Although faviids still dominated in the inner and middle zones, percent cover of acroporids was increasing.

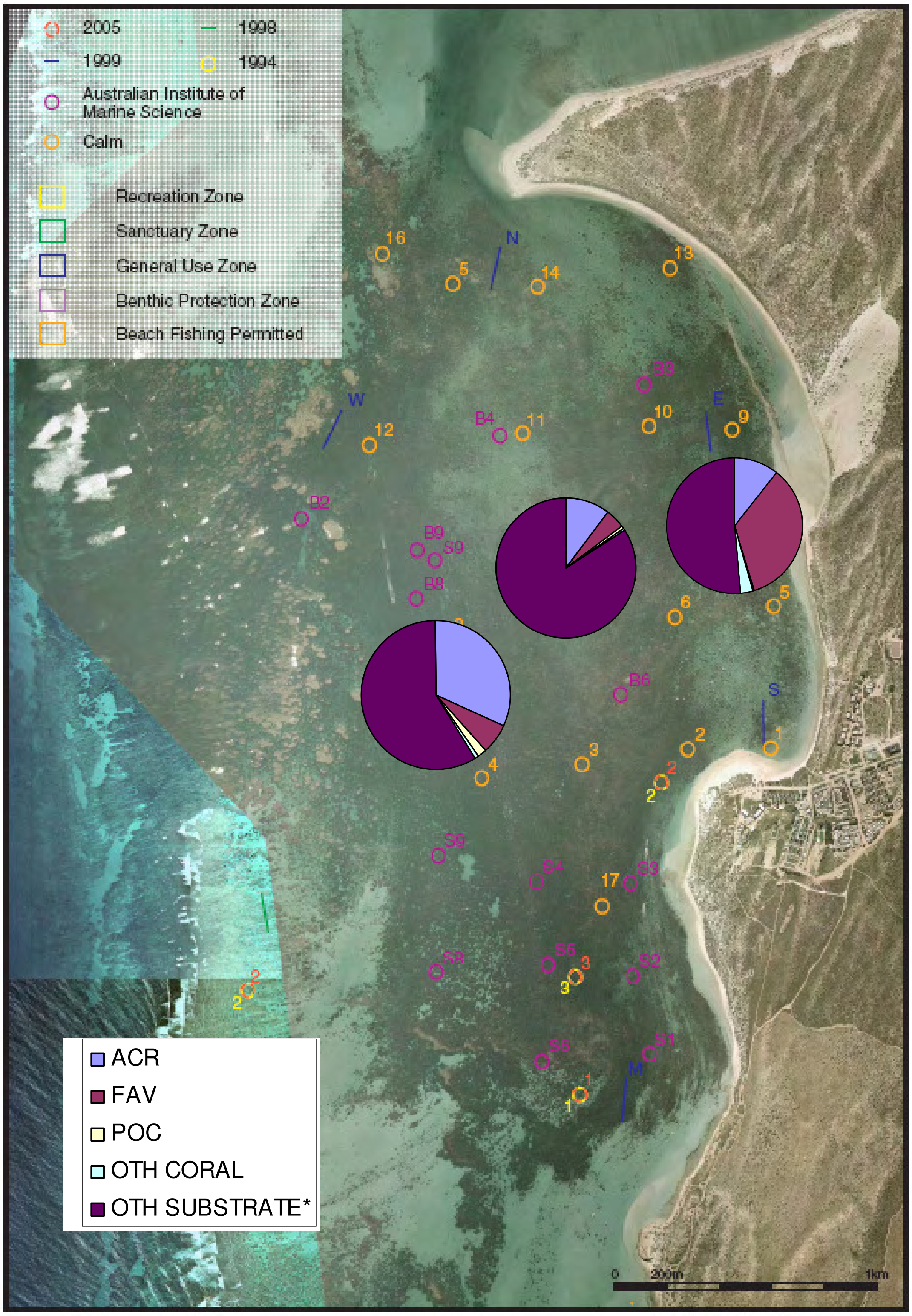


Figure 8e. Coral community structure in the inner, middle and outer zones of Bill's Bay in 2006. Faviids dominated in inner Bill's Bay although acroporid cover had also increased since 2000. Acroporid cover has decreased on average in the middle and outer zones, though this is probably a point sampling analysis artefact.

By 2000, more diverse coral communities including acroporids were becoming established in the inner zone of Bill's Bay, and the acroporid:faviid:pocilloporid ratio in the middle zone was approaching that which had existed in this area prior to the 1989 dystrophic crisis (Figure 8d). In 2006, the inner and middle zones of Bill's Bay were similar in terms of percent acroporid cover, but faviids clearly dominated inner Bill's Bay (Figure 8e). There were apparent reductions in acroporid cover in the middle and outer zones between 2000 and 2006, but at least in the outer zone this may be due to changes in data analysis methods (see section 6.2).

6.4 RECRUITMENT TO CORAL COMMUNITIES IN BILL'S BAY

The raw small coral colony data are given in hard copy in Appendix 6, and are available in electronic format as an MS Excel spreadsheet in the same location as the electronic copy of this data report (on the Marine Science Program T drive). The raw data were converted to numbers of small corals per 50 x 1 m belt transect for the purposes of comparison between size classes, taxonomic groups and sites. These 2006 data are comparable with those obtained during AIMS surveys of Bill's Bay in 1995.

The faviid counts used in the following analyses exclude the encruster *Cyphastrea microphthalma,* which occurred so densely at some sites (generally those in the inner zone of Bill's Bay) that it was impossible to determine whether small colonies were juveniles or fragments. Because so few juvenile poritids were identified (see raw data in Appendix 6), these were included in the Other category during analyses.

Size frequency distribution of juvenile corals

Juvenile coral colonies (<10 cm diameter) were observed at all 17 sites in Bill's Bay, although there was strong inter-site variation in both numbers of juvenile corals and their taxonomic composition. The lowest number of total recruits observed was at site 12 (0.64 m^{-2}), and the highest was at site 10 (6.9 m^{-2}; Figures 9 and 10). Averaged across zones, juvenile coral densities ranged from 1.4 m^{-2} (outer zone) to 3.9 m^{-2} (middle zone) to 1.7 m^{-2} (inner zone).

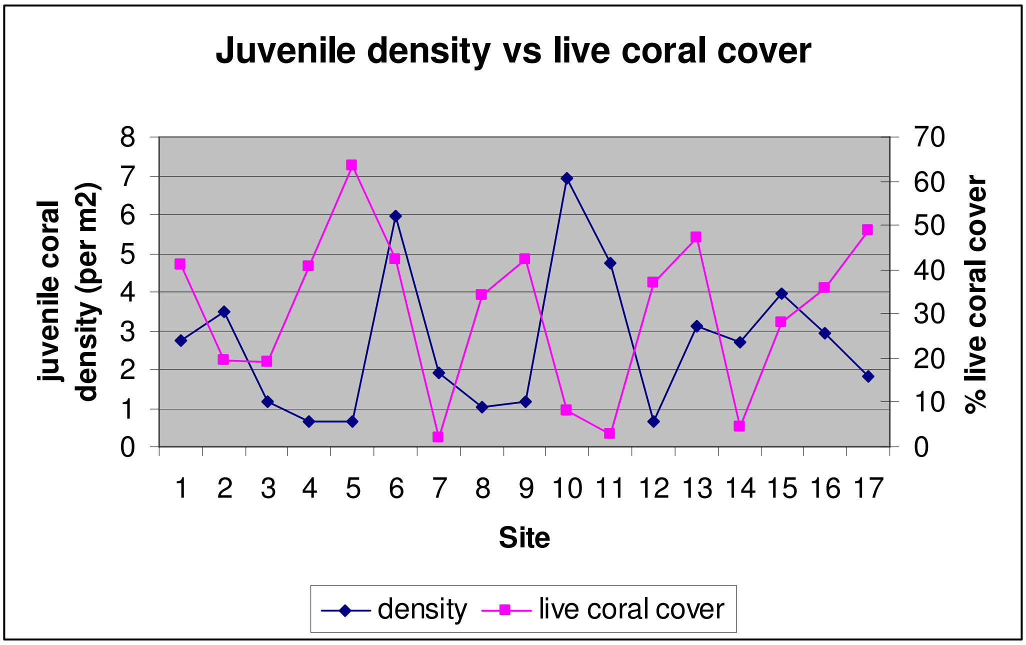


Figure 9. Density of juvenile corals observed in Bill's Bay in 2006, with percent live coral cover at each site provided for comparison.

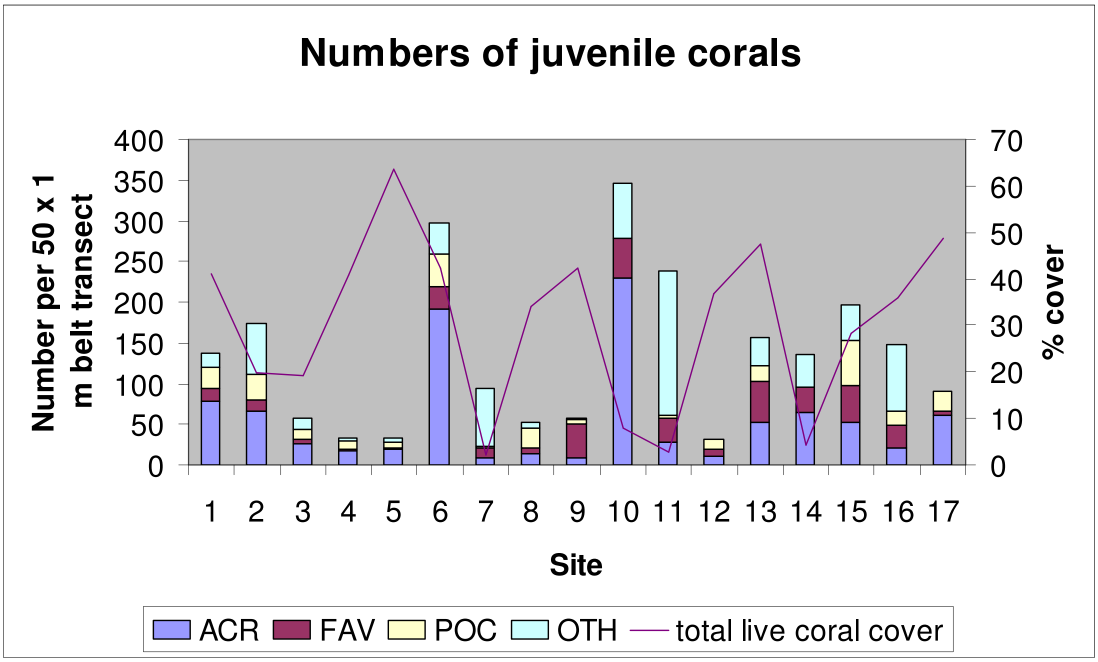


Figure 10. Number of juvenile corals (10 cm or less in diameter) per 50 x 1 m belt transect, by taxonomic group and site. Number shown is the mean of three transects. Small colonies of the encrusting faviid *Cyphastrea microphthalma* were excluded from this analysis. Also shown is mean percent cover of live coral per site (including *C. microphthalma)*. ACR = acroporid; FAV = faviid; POC = pocilloporid; OTH = poritid/other.

While estimates of juvenile coral density on coral reefs worldwide vary enormously (Edmunds 2000; Glassom & Chadwick 2006), these values from Bill's Bay certainly appear to be at the low end of the global spectrum. The relatively low density observed in the outer zone of Bill's Bay could reflect the relatively high coral cover in these areas and the relatively restricted space available for larval settlement. Conversely, the relatively high densities observed in the middle zone (particularly site 10) may reflect relative availability of appropriate substrate (such as coralline algae-covered coral skeletons resulting from mass mortalities of adult corals in previous years). Interestingly, a coral recruitment study in 1994 found that ten times more larvae settled on plates positioned near site 17 (outer zone) than in inner Bill's Bay, between sites 5 and 9 (Harriott & Simpson 1997), probably due to local oceanographic processes. Other studies have also repeatedly found low levels of coral settlement on tiles positioned in inner and middle Bill's Bay (Heyward *et al.* 2002). While fewer larvae may be arriving in inner Bill's Bay, the densities of juveniles observed there in 2006 were comparable with those observed in outer Bill's Bay.

Univariate analyses reveal the following patterns in the juvenile coral colony size frequency data (Figures 11-13). Juveniles in the 2.5-4.9 cm diameter size class dominated at all sites across the three zones of Bill's Bay (Figure 11). This could reflect practical difficulties in consistently observing juveniles less than 2.4 cm in diameter in the field, or alternatively it may represent a pulse of successful juvenile coral settlement 2-3 years before present. Post-settlement mortality processes probably cause the observed gradual decline in frequency with increasing size class.

More juvenile acroporids were recorded in each zone than any other coral group surveyed (faviids, pocilloporids, poritids/other/unknown). Figure 10 compares the size frequency distribution of juveniles of each coral group across zones. Relatively high numbers of juvenile acroporids were observed at sites 6 and 10, both in the middle zone of Bill's Bay, while relatively low numbers were observed at sites 7, 9, 12 and 8. While acroporid numbers and sizes showed similar patterns in the inner and outer zones, markedly higher numbers of smaller size class acroporid juveniles were recorded in the middle zone (Figure 12). These higher numbers for smaller size class juvenile acroporids in the middle zone principally result from observations at sites 6 and 10, and may indicate that recruitment-led recovery of the acroporid community is underway in these areas.

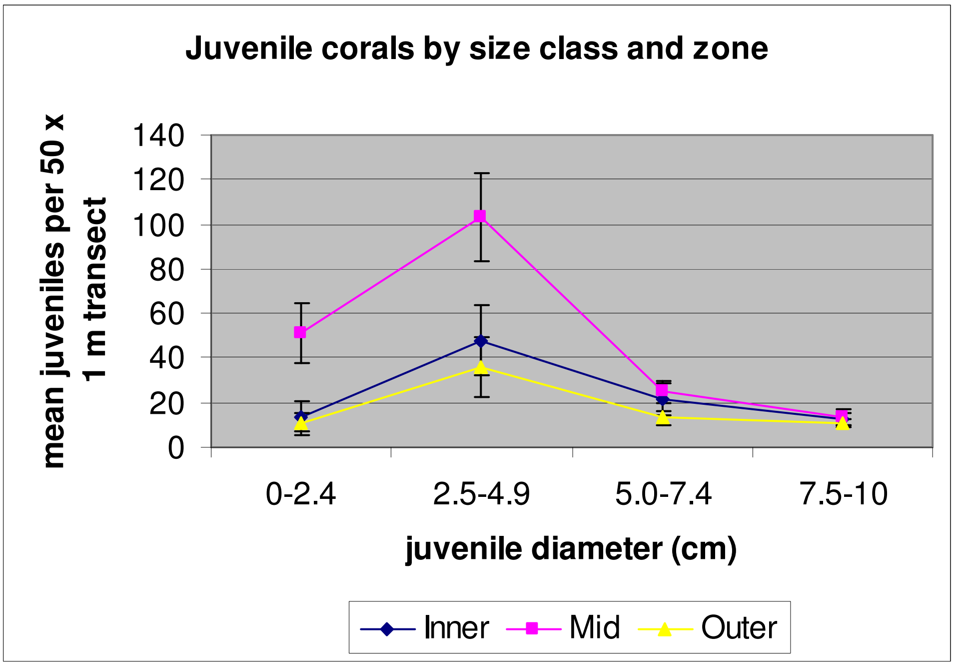


Figure 11. Mean numbers of juvenile corals per 50 x 1 m belt transect in the inner, middle and outer zones of Bill's Bay in 2006, by size class. Error bars are standard error. The greatest numbers of juveniles were found in the middle zone of Bill's Bay.

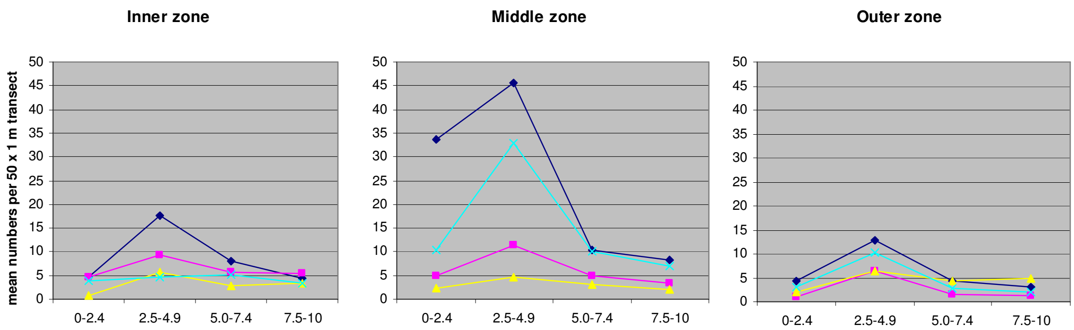
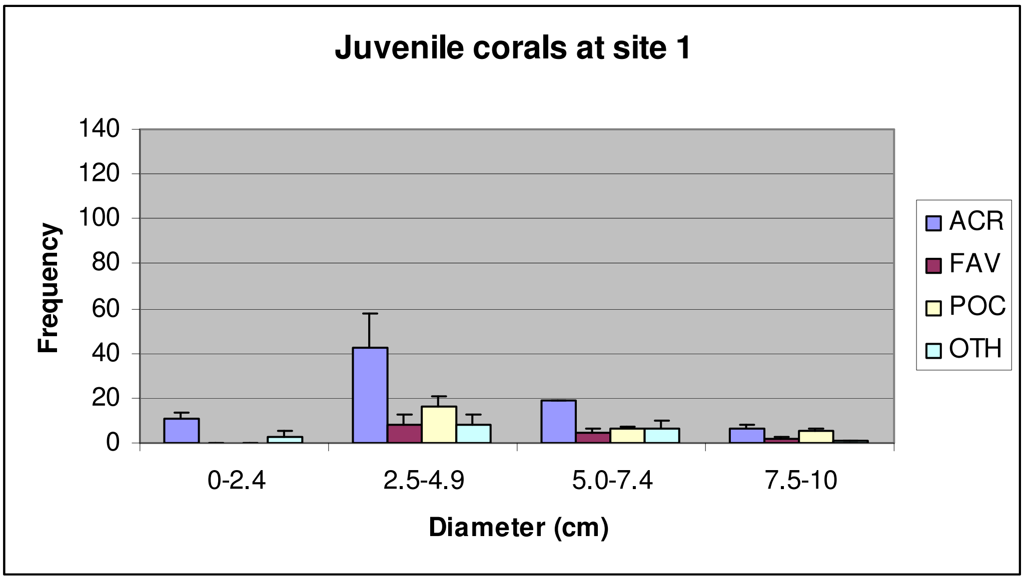
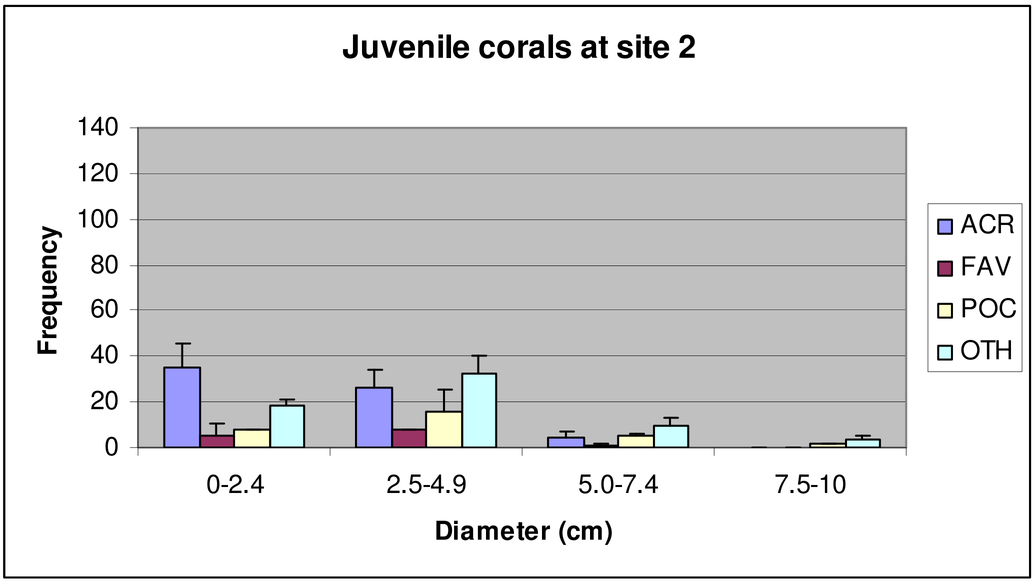
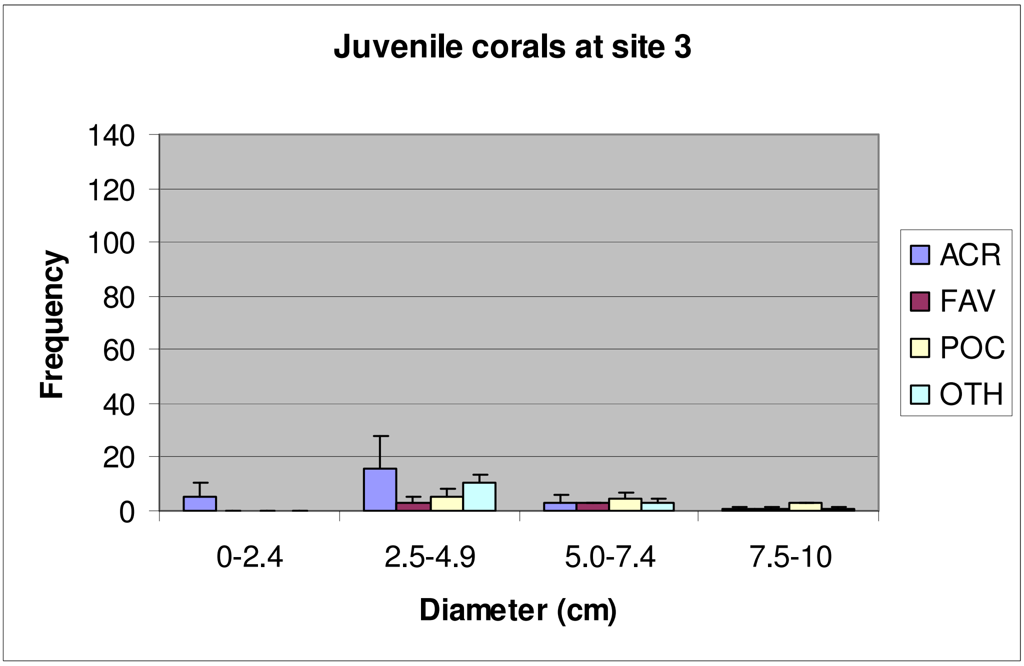


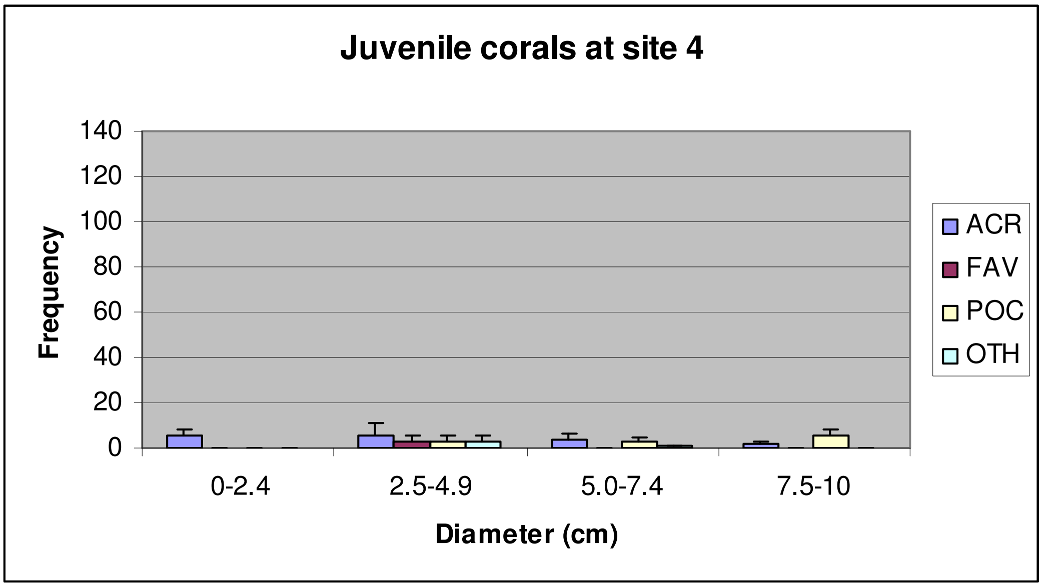
Figure 12. Size frequency distribution (frequency expressed as mean number per 50 x 1 m transect in each zone) of juvenile corals by taxonomic group (blue diamonds = acroporids; pink squares = faviids; yellow triangles = pocilloporids; blue crosses = poritids/other/unknown).

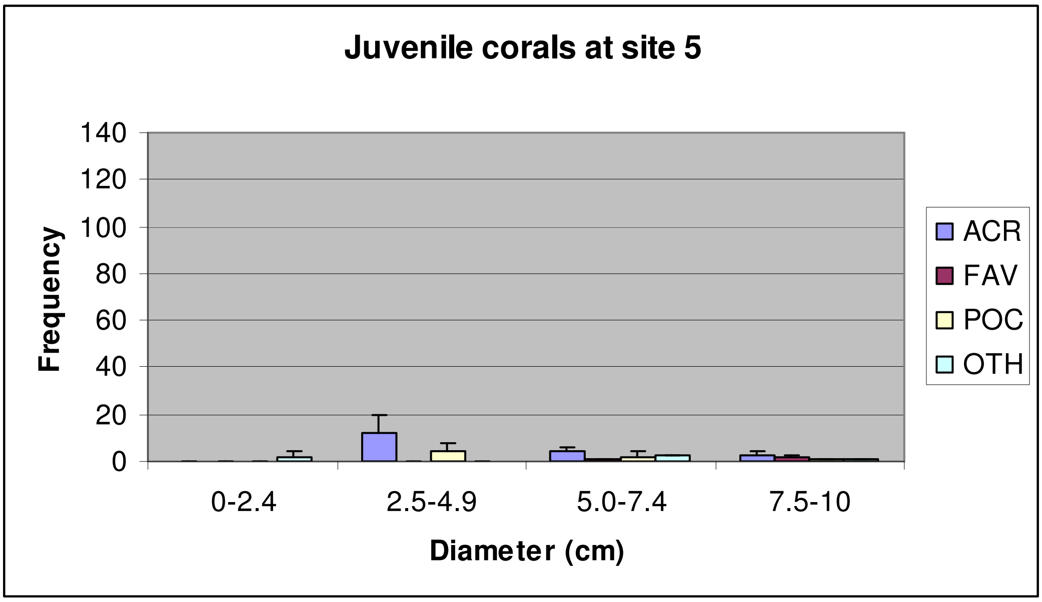
Figure 13 (following pages). Size frequency histograms of juvenile corals of four taxonomic groups (Acroporidae, Faviidae, Pocilloporidae, Other/Unknown/Poritid) at the 17 sites in Bill's Bay, October 2006. Frequency is expressed as the number of colonies per 50 m x 1 m belt transect (mean of three transects per site), and the error bars are standard errors. Note that the scale of the y-axis is different for site 10, to accommodate the greater numbers of smaller acroporids observed at this site.

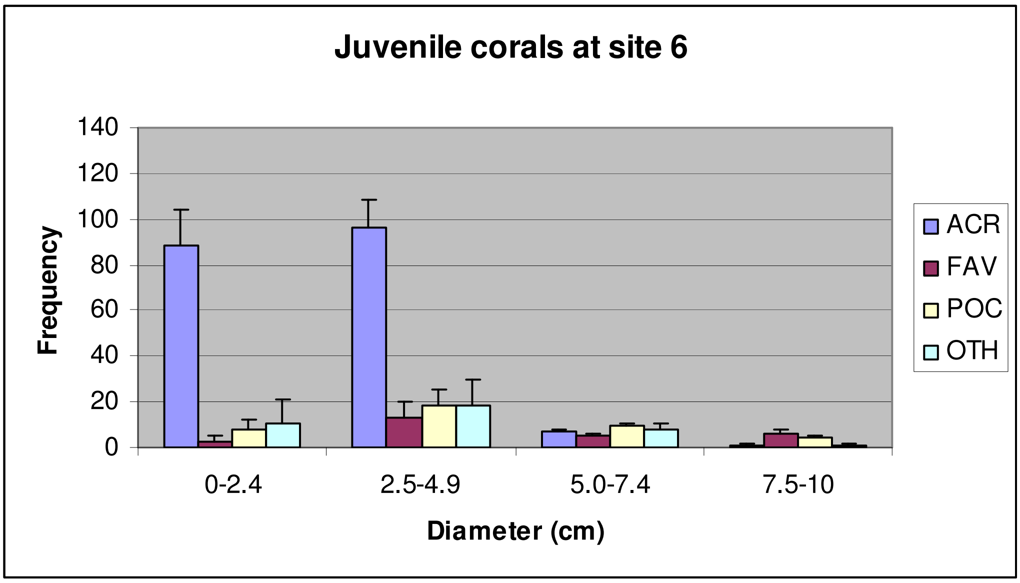

Juvenile corals at site 1
140
120
100
80
60
40
20
0
Frequency
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

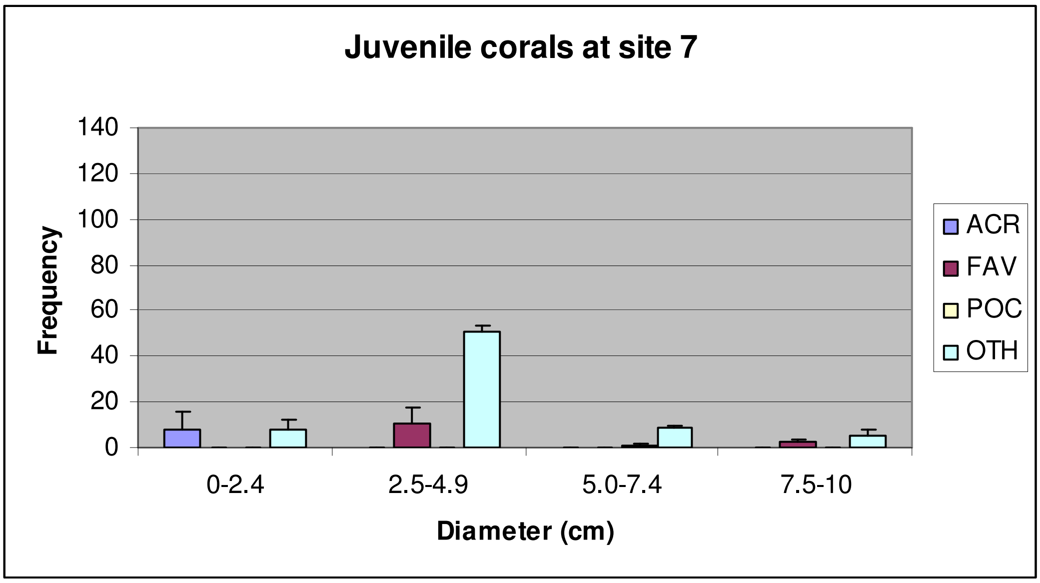

Juvenile corals at site 2
140
120
100
80
60
40
20
0
Frequency
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

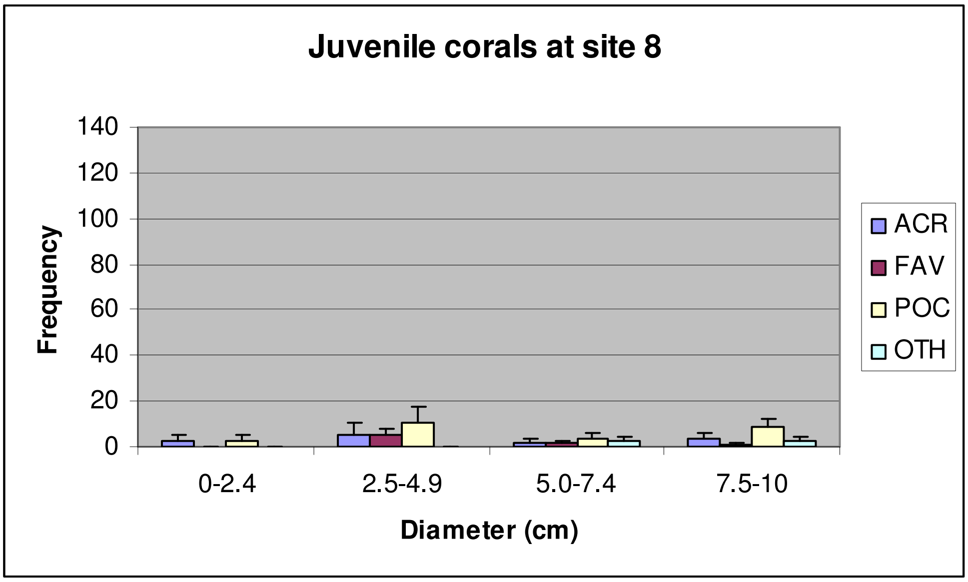

Juvenile corals at site 3
140
120
100
80
60
40
20
0
Frequency
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

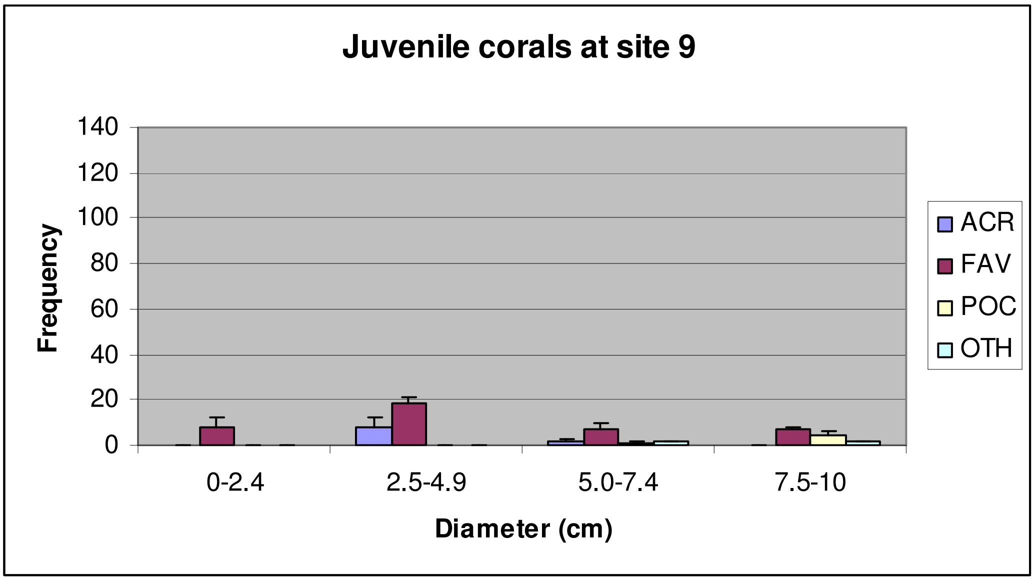

Juvenile corals at site 4
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

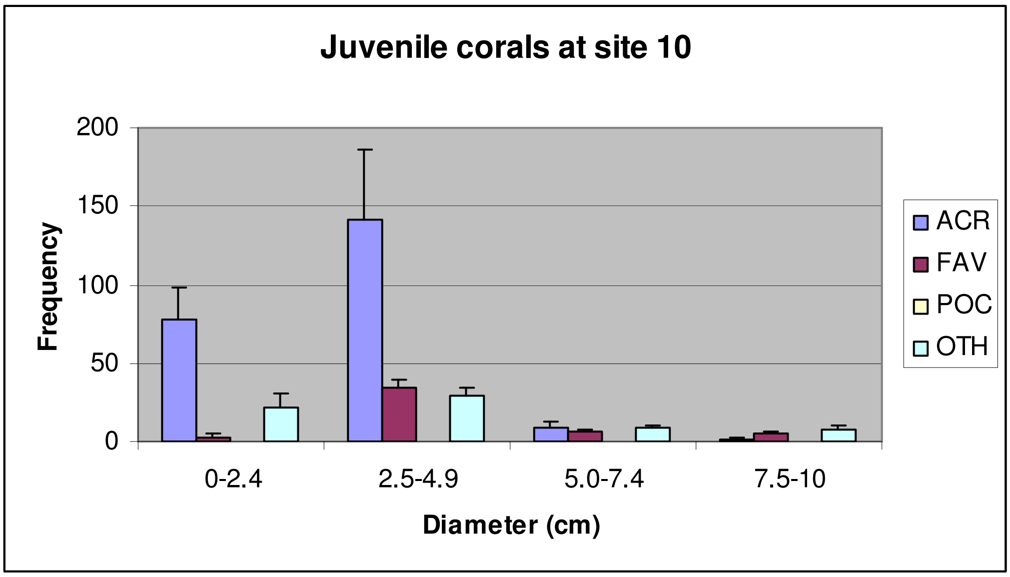

Juvenile corals at site 5
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

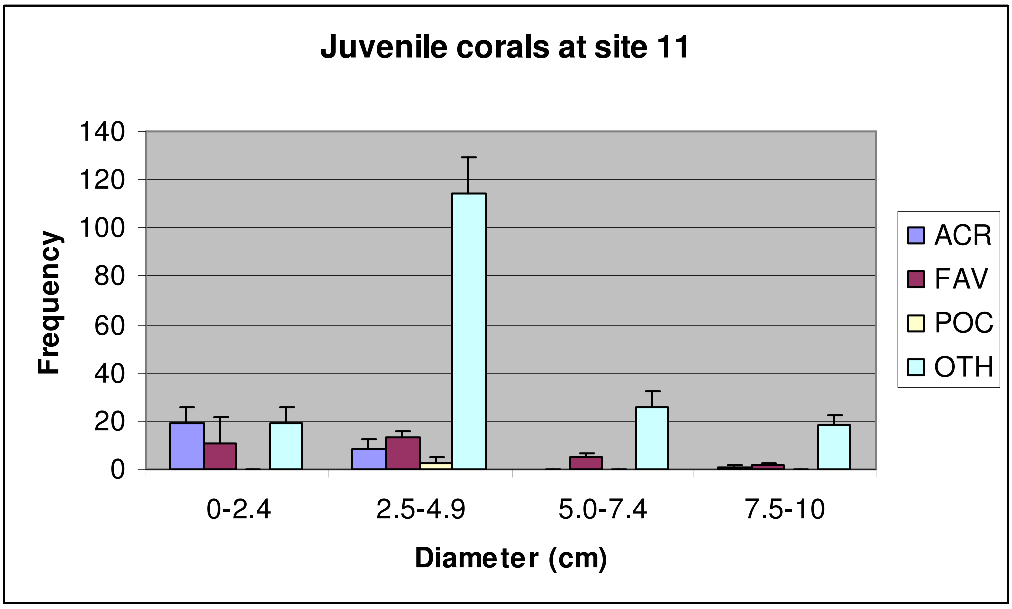

Juvenile corals at site 6
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

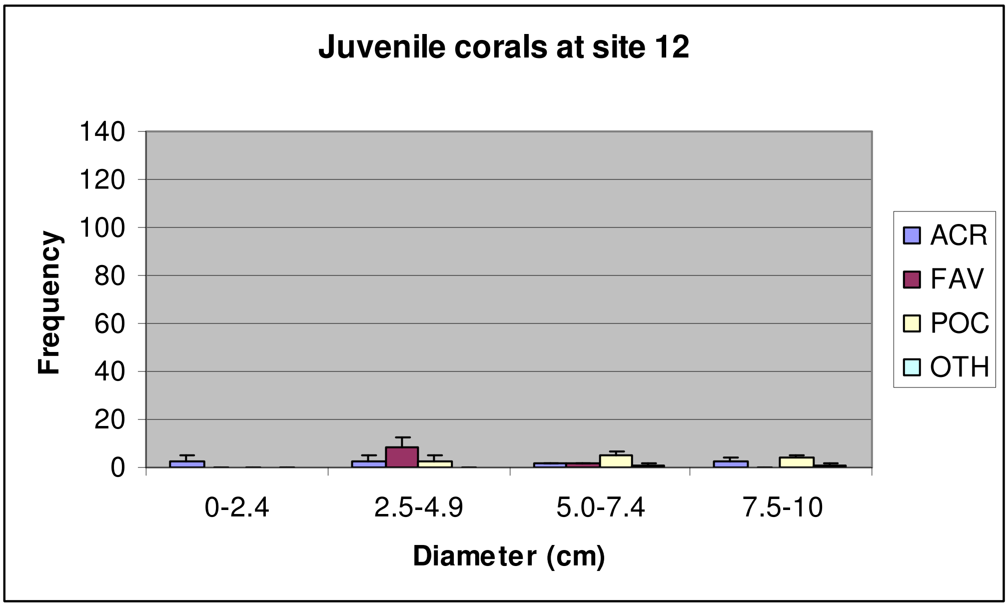

Juvenile corals at site 7
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH

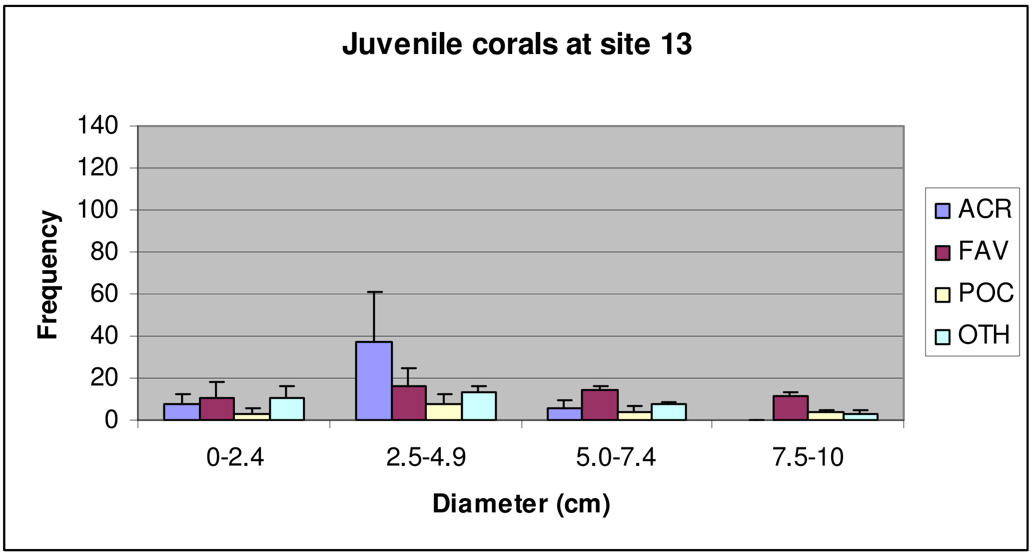

Juvenile corals at site 8
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH


Juvenile corals at site 9
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH


Juvenile corals at site 10
Frequency
200
150
100
50
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH


Juvenile corals at site 11
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH


Juvenile corals at site 12
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
OTH


Juvenile corals at site 13
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
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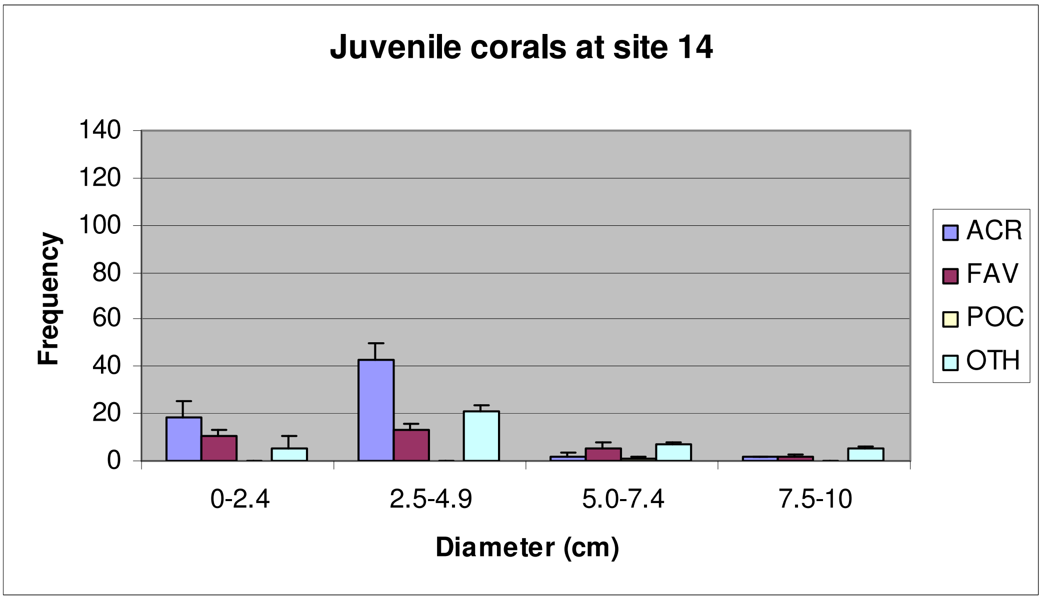
Juvenile corals at site 14
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
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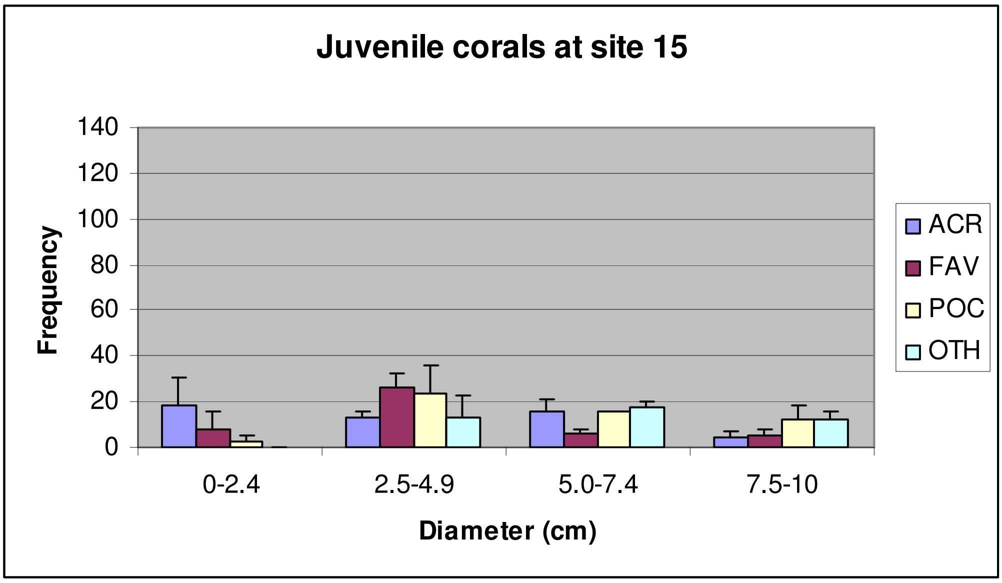
Juvenile corals at site 15
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
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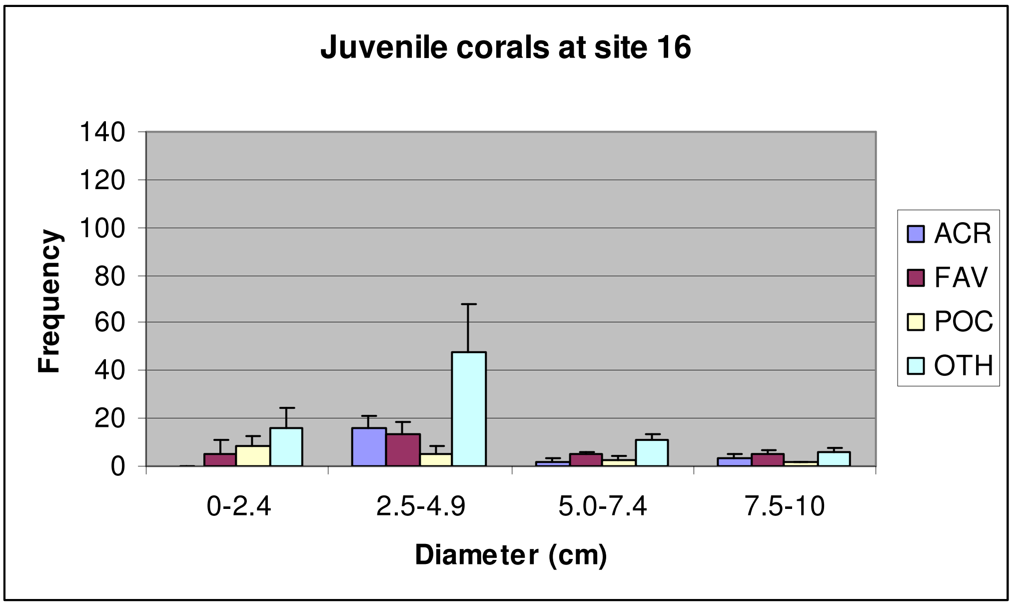
Juvenile corals at site 16
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
ACR
FAV
POC
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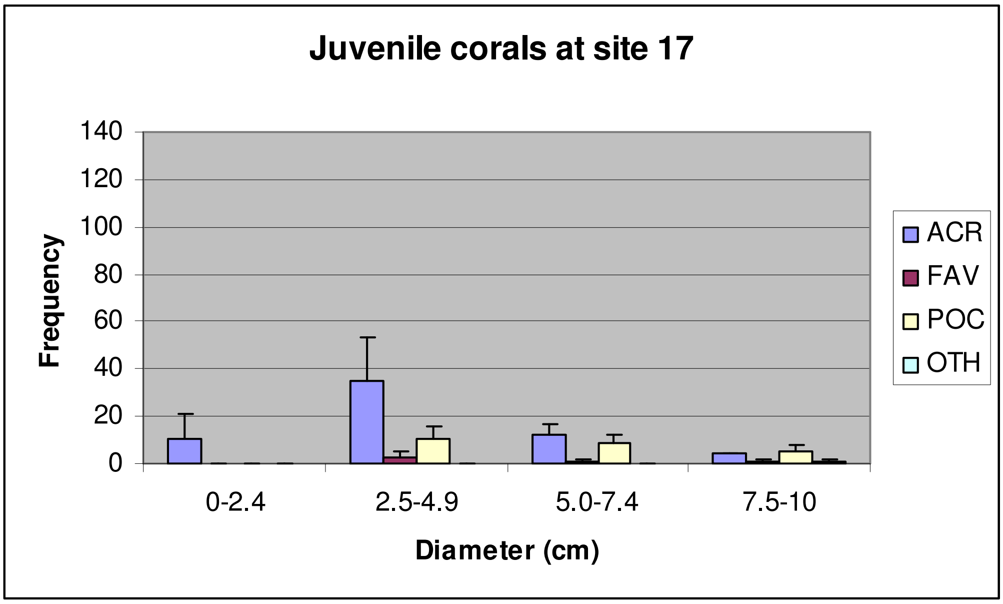
Juvenile corals at site 17
Frequency
140
120
100
80
60
40
20
0
0-2.4
2.5-4.9
5.0-7.4
7.5-10
Diameter (cm)
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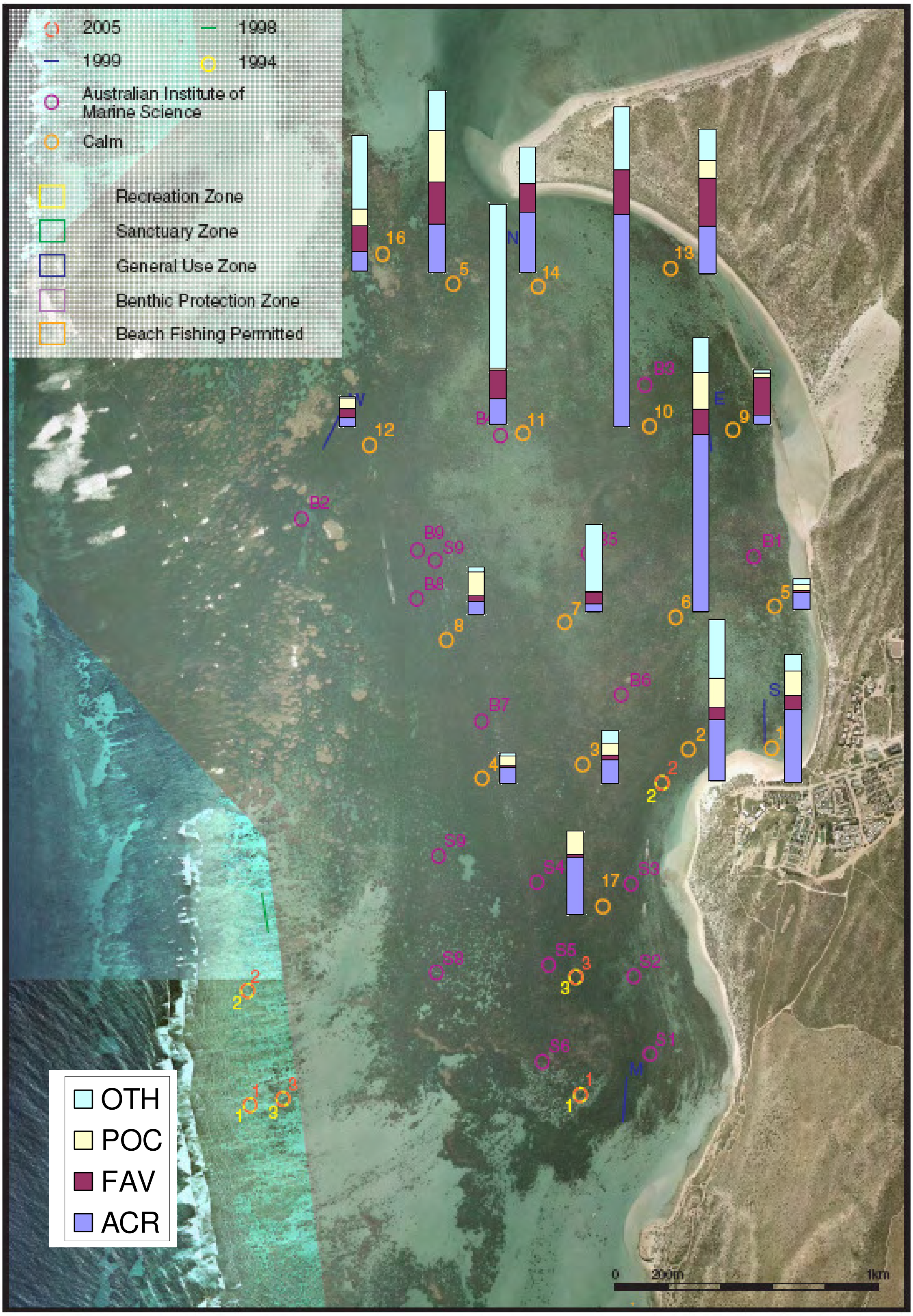


Figure 14. Juvenile coral numbers and taxonomic structure by site in Bill's Bay, October 2006.

7 Brief discussion

Although coral reefs have been considered highly dynamic communities characterised by resilience (=rapid return to previous equilibrium state following acute disturbance), evidence is growing worldwide that chronic disturbance significantly degrades reef resilience. Similarities and differences between the recovery patterns of different sites within Bill's Bay will provide insights into the suite of factors promoting or degrading reef resilience, and potentially into ways in which conserved coral reefs may be managed for resilience.

7.1 RECOVERY AND RESILIENCE OF CORAL COMMUNITIES IN BILL'S BAY

Seventeen years is unlikely to be enough time for full recovery of coral communities from a mass mortality even under ideal conditions, and some sites in Bill's Bay have suffered additional disturbances in the interim. Differing susceptibilities of coral taxa to disturbance means that acroporids tend to be under-represented and faviids over-represented on disturbed relative to undisturbed reefs (Bellwood & Hughes 2001; Sheppard 2006), and this pattern is clear in Bill's Bay.

In this context it is unsurprising that few sites currently display coral community structures broadly similar to those observed before the dystrophic crisis in 1989 (Figure 15a). However, it should be noted that these baseline 1989 observations may not have represented climax, equilibrium communities that were resilient to disturbance. Some sites – for example 9 and 13, which had zero live coral cover prior to the mass mortality of 1989 – are likely to have been observed at varying stages of ecological succession following disturbance. Of the sites that were impacted by the dystrophic crisis in 1989 (ie those in the inner and middle zones of Bill's Bay), only site 1 could be said to have recovered a broadly similar coral community structure and percent live coral cover by 2006 (Figure 15a).

Outer zone

Sites in the outer zone of Bill's Bay (4, 8, 12, 16 and 17) were unimpacted by the dystrophic crisis in 1989 (Simpson et al. 1993), and consequently could be expected to have similar coral community structures in 2006. However, coral reefs are highly dynamic systems, and over long periods of time small changes in community structure are likely. In terms of both live coral cover and coral community composition, sites in the outer zone of Bill's Bay could be described as broadly similar to those which were surveyed in 1989 (Figure 15a). Most of these outer sites had very low densities of juvenile corals relative to sites in other zones of Bill's Bay (Figure 10), which might indicate that substrate availability for larval settlement is limiting in the outer zone.

Middle and inner zones

Sites in the inner and middle zones of Bill's Bay were impacted to varying degrees by the 1989 dystrophic crisis (Simpson et al. 1993), and Figure 15b gives an indication of progress to date towards recovery. Total live coral cover has increased at all sites in the inner and middle zones since the mass mortality in 1989, except site 2 where there has been a small decrease (potentially artefactual). However, few sites resemble their pre-1989 selves; see for example sites 7 and 9 (Figures 16 and 17). Some sites appear to have been disturbed by dystrophic crises on several occasions since 1989 (for example, site 7), while others appear to have made steady progress towards increasing coral cover and community diversity (for example, site 1).

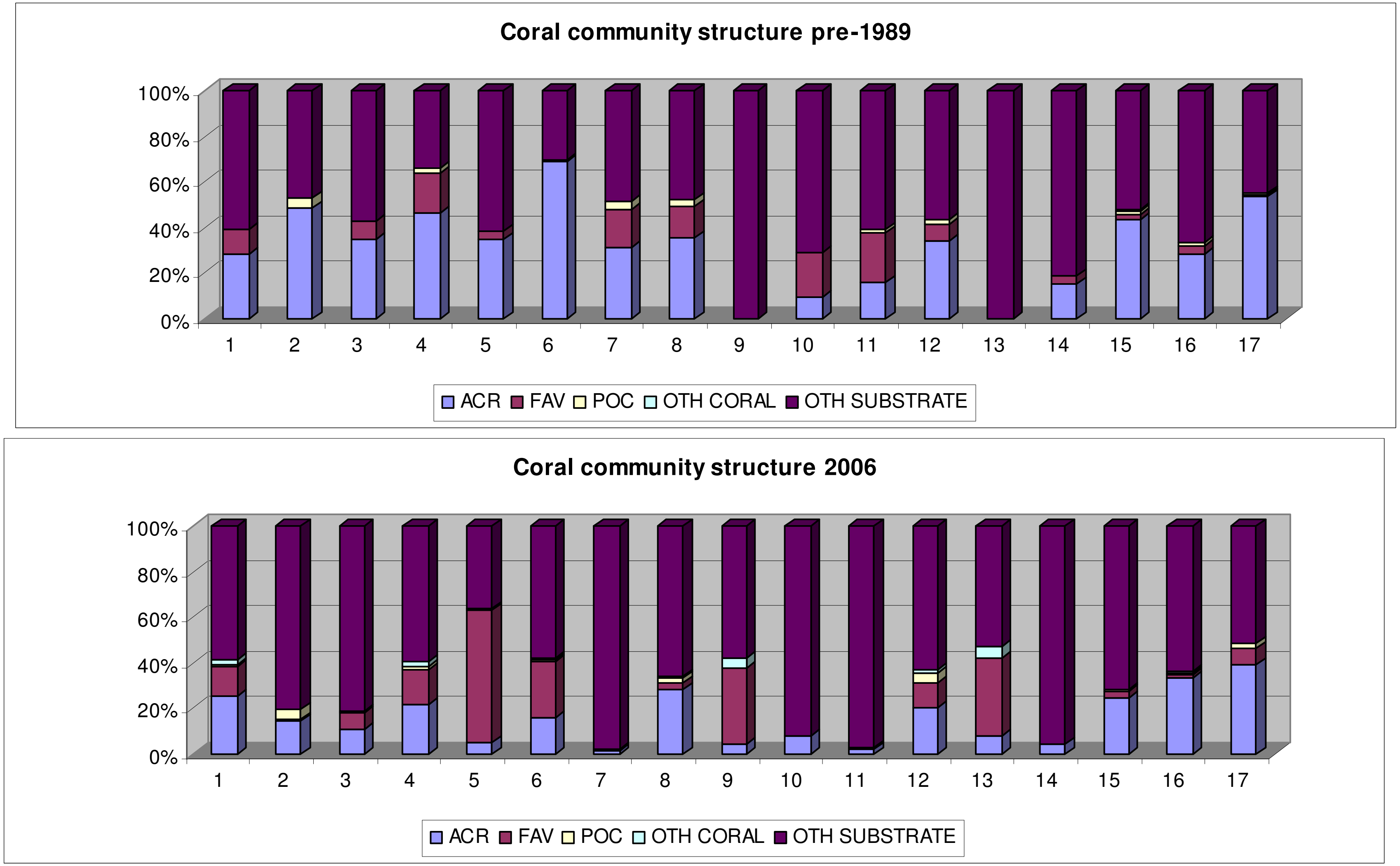
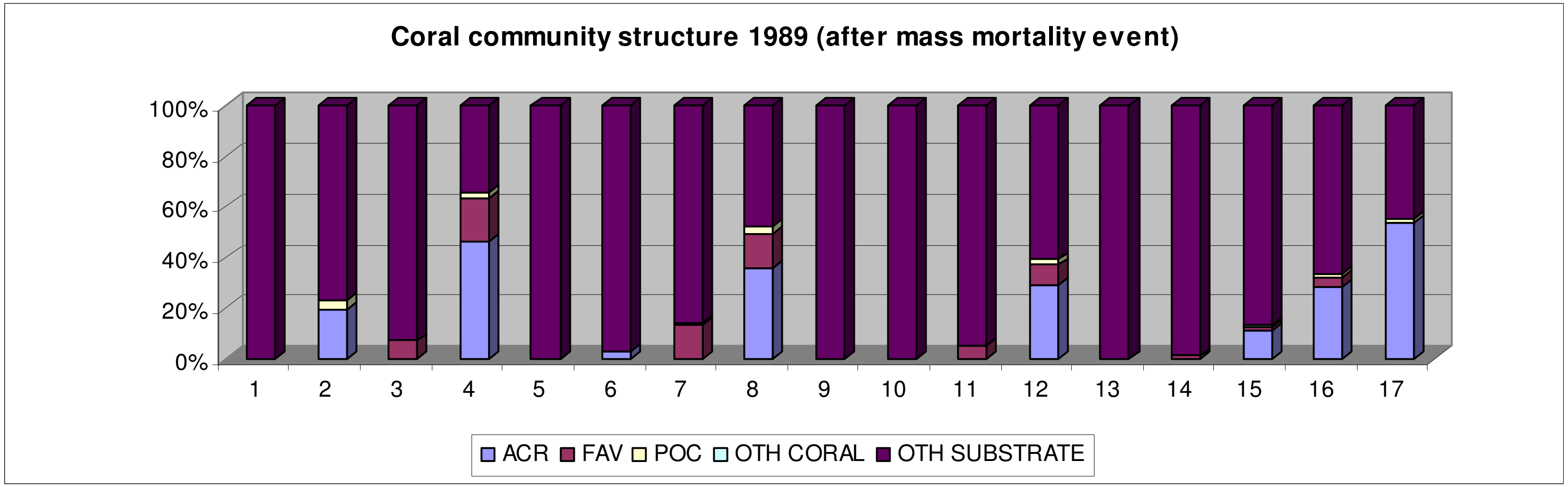


Figure 15a. Comparison of coral community structure in terms of mean percent cover of acroporids, faviids, pocilloporids and other corals (including poritids) at 17 sites within Bill's Bay, between early 1989 (before the dystrophic crisis; mean of two 25 m transects; Simpson et al. 1993) and present (2006; mean of three 50 m transects). Values for "Other substrate" were calculated by subtracting the total live coral cover from 100.



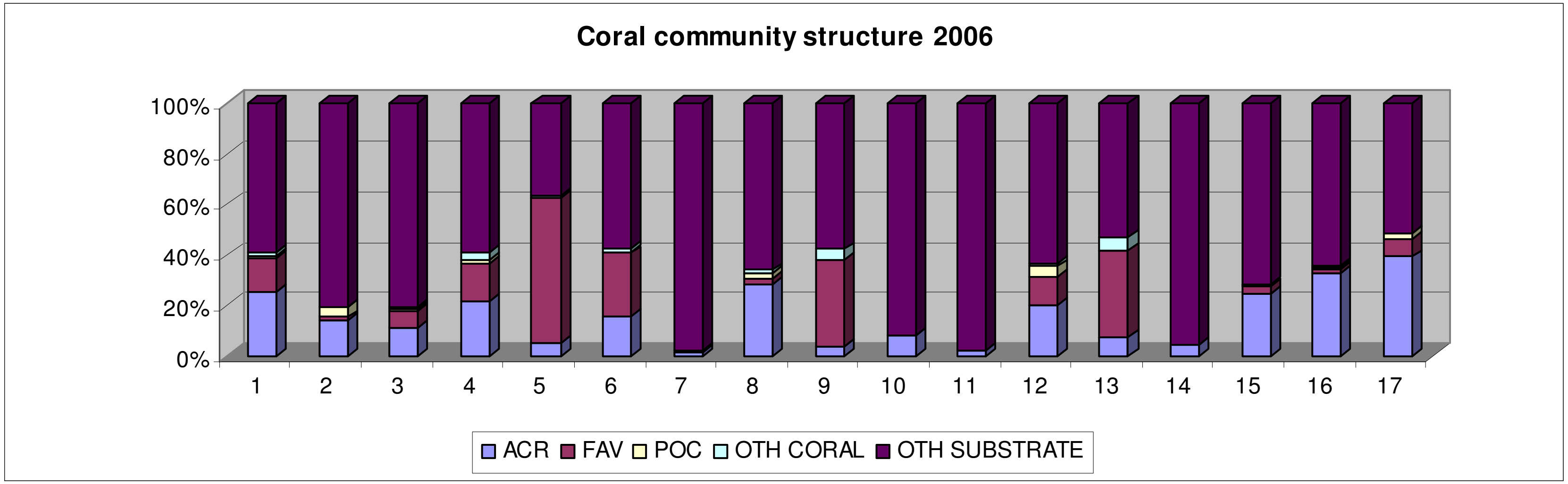


Figure 15b. Comparison of coral community structure in terms of mean percent cover of acroporids, faviids, pocilloporids and other corals (including poritids) at 17 sites within Bill's Bay, between 1989 (after the dystrophic crisis; mean of two 25 m transects; Simpson et al. 1993) and present (2006; mean of three 50 m transects). Values for "Other substrate" were calculated by subtracting the total live coral cover from 100.

Figure 16. Faviid-dominated underwater landscape of Site 9 (inner Bill's Bay) in 2006. Almost spherical faviid colonies were growing atop columns of dead coral (probably dating from the mass mortality of 1989) with *Echinopora* spp. colonies proliferating over most other substrates. Few juvenile corals were observed here in 2006 relative to other sites in Bill's Bay, and the vast majority of those were faviids.

Figure 17. Unusual underwater landscape of site 7, Bill's Bay, October 2006. The tall columns of dead *Galaxea fascicularis* (?) probably date from the mass mortality event in 1989. The tabulate *Acropora* in the foreground must have recruited to the dead *Galaxea* skeleton sometime after 1989, and grew for several years before dying, possibly in another natural mass mortality event in 2002. Some live *Pocillopora damicornis* colonies currently occupy the tops of the columns. This is a weedy, fast-growing species that may have recruited since 2002.

A noteworthy feature of site 11 in 2006 was the presence of large live tabulate acroporid colonies atop dead coral substrates (the latter possibly dating from the mass mortality in 1989). Table 4 records the dimensions of four of these colonies in the vicinity of the western end of the northern transect at site 11. (Underwater video of these colonies can be viewed on the tapes/DVDs immediately following the site 11 transects.) Using conservative tabulate acroporid growth rates of ~15 cm (diameter)/year (Simpson pers. comm.), these colonies may be <10 years old. Their presence indicates that a disturbance sufficient to cause death of tabulate acroporid colonies has not occurred at this site since ~1998; despite this, coral cover did not increase appreciably at this site between 2000 and 2006 (Figure 7a).

Table 4. Dimensions of four large live tabulate acroporid colonies growing on dead coral substrates at site 11.

Colony	Maximum diameter (cm)	Minimum diameter (cm)
1	129	108
2	134	108
3	122	96
4	118	95

This is in contrast to the situation at site 7, where a similar pattern of recruitment of tabulate acroporids to dead coral substrates and subsequent growth was interrupted by another mass mortality event, possibly in 2002 (Figure 17; see also Figure 7a; van Schoubroeck & Long 2007). The dimensions of these dead tabulate acroporids at site 7 were not measured but are estimated to have been at maximum ~80 cm diameter.

The shift from acroporid- to faviid-dominated reefs that has been observed elsewhere in the Indian Ocean following severe disturbances has in at least some cases been accompanied by a similar shift in juvenile coral communities (Sheppard 2006). By contrast, the juvenile coral community at most sites in the middle and inner zones of Bill’s Bay in 2006 appeared to be dominated by small (<5 cm) acroporids, rather than faviids. Taxonomic diversity within the juvenile coral community is likely to be a sign of reef resilience. Surveys of the juvenile coral community can thus serve as useful indicators of reef recovery and resilience processes as well as future reef health.

The relatively high densities of juvenile corals observed in the middle zone of Bill’s Bay, particularly at sites 6 and 10 (Figure 14), may indicate that processes of recruitment-led recovery are occurring in this area. Although larval supply to the middle and inner zones of Bill’s Bay appears to be very low relative to the outer zone, and indeed other reefs worldwide (Harriott & Simpson 1997), there is probably relatively high availability of appropriate substrate for settlement in these zones. However, these may also be risky environments for juvenile corals. In addition to the possibility of periodic coral spawning-associated dystrophic crises, other factors potentially reducing juvenile survivorship in these zones include decaying coral skeleton substrates and movement of unconsolidated rubble. Coral skeletons, particularly those with branching or columnar morphologies, generally break down within 2-3 years of death (Sheppard 2006). The apparent longevity of coral skeletons in Bill’s Bay – with many large dead colonies still standing after seventeen years (eg Figures 16 & 17) - may reflect the sheltered nature of the embayment, or alternatively limited recruitment of bioeroders to this area since the major mass mortality of 1989 (Luke Smith pers. comm.).

Has reef resilience been degraded?

Recovery processes - increases in coral cover and diversity over time, and recruitment of juveniles - have occurred to varying degrees at all sites in Bill's Bay since the dystrophic crisis of 1989. Mass mortalities associated with coral spawning events probably occurred at low frequency in Bill's Bay in the past, and may even have been important community structuring events for shallow reefs in the region (Simpson *et al.* 1993). However, based on the past 17 years of observations, some sites in Bill's Bay appear to be increasingly prone to dystrophic crises that result in partial or total mortality of coral communities. Increased frequency of disturbance can lead to degradation of resilience, and subsequent inability of the reef to recover towards its previous undisturbed state. In addition, loss of resilience is often cryptic and detected only when a rapid phase shift occurs (Bellwood *et al.* 2006). Although recovery processes remain limited at some sites in Bill's Bay, no sites have yet undergone a phase shift towards macroalgal-dominated or barren communities. However, sites with little or no acroporid cover, low numbers of juvenile corals and/or which have suffered multiple mass mortalities in the recent past – for example, site 7 - should be considered vulnerable to degradation of resilience and managed accordingly.

7.2 IMPLICATIONS FOR MANAGEMENT

While these dystrophic events and consequent mass mortalities of coral do not appear to be caused by human activities, informed management of Bill's Bay will help to promote local reef recovery and resilience.

Managing for resilience in Bill's Bay

Degraded reefs have sprung ecological surprises on managers in the recent past, by undergoing rapid phase shifts towards macroalgal-dominated systems or barren landscapes in response to seemingly minor disturbances (Bellwood *et al.* 2004; Gunderson 2006). While natural disturbances are obviously beyond the control of managers, a clear objective for any manager of a vulnerable reef should be to minimize human-generated disturbance. Such disturbances could include changes in water or sediment transport patterns due to coastal construction or installation of permanent structures (such as jetties or sea walls), or leaching of nutrients (or other organic pollutants) into Bill's Bay from the settlement. Any impacts that could favour proliferation of macroalgae rather than corals should be avoided.

Maintenance of biodiversity (functional redundancy within ecosystems), and in particular maintenance of healthy populations of herbivores, can also help to promote resilience (eg, Bellwood *et al.* 2006), thereby mitigating the risk of ecological surprise. Bill's Bay is currently a sanctuary zone of Ningaloo Marine Park, in which no fishing or other extractive activities are permitted. This is probably helping to promote ecosystem resilience and should be continued. In addition, scientific opinion should be sought before licensing any activities in Bill's Bay that could cause even apparently minor changes in local ecosystem function.

Specific recommendations and future studies

- It is important to build on the solid foundation provided by the past 17 years of work in Bill's Bay. Surveys of coral communities in Bill's Bay should continue to be held at least every six years, and preferably at higher frequency, with the aim of developing a detailed understanding of reef disturbance and recovery patterns. This dataset is already unusually long-term (by global coral reef research standards) and will only become more valuable and useful over time. Lack of information about reef recovery patterns is a major impediment for coral reef management worldwide (Gunderson 2006), and the Bill's Bay study has the potential to contribute substantially to both local management information needs and broader scientific discussion.

- Surveys to date have shown that different sites in Bill's Bay have responded in different ways since the dystrophic crisis of 1989. Although this results in a complex story of shifting patterns of disturbance and community structure over time, it also presents an opportunity to investigate topical issues associated with the concept of coral reef resilience. What features are shared by sites that have not recovered, and what features are shared by sites that have recovered? Can we determine the level of disturbance at which acute becomes chronic and resilience is degraded? The results of such a study would be invaluable for informed management of the entire Ningaloo Marine Park, and of interest for reef managers worldwide. All that prevents this analysis from the current dataset is the absence of a reasonably reliable history of recent disturbances in Bill's Bay. Acquisition of this disturbance history is well within the capabilities of the Department, and should be a priority given the vulnerable status of some reefs within Bill's Bay. The survey form in Appendix 4 gives an indication of the information required.
- Development of a reliable, ongoing disturbance history is also crucial to addressing the important question of whether the frequency of coral spawning-related dystrophic events in Bill's Bay is increasing over time. Research will be required into causative factors (eg, might climate change-induced shifts in weather patterns be a contributing factor?), as well as management options, if the disturbance frequency is found to be increasing.
- Site 1 is the only middle or inner zone site in Bill's Bay (so far) that has recovered to approximately pre-1989 condition, and which therefore could be described as resilient to disturbance. Interestingly, it is also located just off the closest beach site to the township of Coral Bay (Figure 1), and as a consequence is likely to experience high visitation rates. This combination of factors means that the site warrants special attention. Evidence of boat strikes on coral colonies at site 1 was observed during the 2006 survey. This is obviously deleterious to reef recovery, and it is recommended that the area be officially closed to boating. While site 1 is in the vicinity of the area where boats are currently launched across the beach, it is too shallow for safe boating and is also adjacent to an area that is reserved for swimmers.
- Given its location, probably the most productive way to minimise human impacts on the resilient reef at site 1 would be to educate and inform visitors about snorkelling safely, via installation of a snorkel trail. Visitors could access the snorkel trail directly from the beach, and follow an informative and educational series of plaques describing coral reef features of interest, all while safe from boats and within ~100 m of the shore. Care would have to be taken to position the trail away from the immediate vicinity of the long-term monitoring sites in the area (ie, site 1 and a Ningaloo Marine Park long-term monitoring transect; see Figure 1). The first plaque, closest to shore, would describe safe snorkelling practices aimed at minimising impact on the reef. Studies monitoring the impact of snorkellers on the reef along the trail should be performed, as well as social studies of the educational and informative

value of the trail for visitors. A well-managed, easy-access snorkel trail in this area could become an asset for Coral Bay, whilst simultaneously minimising visitor impacts on the resilient reef of site 1.

- Concerns have been raised by both residents and DEC staff at Coral Bay regarding the apparently increasing size of the sand spit between sites 1 and 2. While sand movements naturally ebb and flow over long periods of time, there are several large faviid bommies, decades to centuries old, which in 2006 appear to be being smothered by encroaching sands (Figure 18). Changes in sediment transport and water movement patterns could affect resilience of reefs in the area. However, before any intervention is attempted, it is recommended that scientific opinion be sought regarding the likelihood of human contribution to this sand movement pattern in Bill's Bay.

Figure 18. Decades-old massive faviid coral colony being smothered by encroaching sand, between site 1 and site 2 in Bill's Bay, October 2006.

- While coral cover in inner Bill's Bay now equals or surpasses pre-1989 levels, at most sites the current coral communities differ profoundly from their predecessors. The domination of site 5 by what appears to be a single *Echinopora* species (possibly *Echinopora ashmorensis*) in 2006 may represent a stage in ecological succession towards more structured coral communities, or it may signal cryptic loss of resilience. Almost nothing is known of this species – life history, reproductive mode, or the mechanism by which it has so rapidly and comprehensively dominated the community. It is known to be an extremely fecund broadcast spawner – individual polyps may produce up to 180 eggs during each spawning event (Smith 1993) – and a time series of egg development has been collected and preserved by Fiona Webster (awaiting analysis; pers. comm.). Frequency of disturbance can dramatically alter the contribution of asexual reproduction to recruitment in corals (Foster *et al.* 2007), and the decreased local genetic diversity that would result from increased rates of asexual reproduction could degrade the reef's capacity to respond to environmental changes (Van Oppen & Gates 2006). This species and site should be incorporated into any future studies assessing genetic diversity or reproductive mode of corals at Ningaloo Marine Park.

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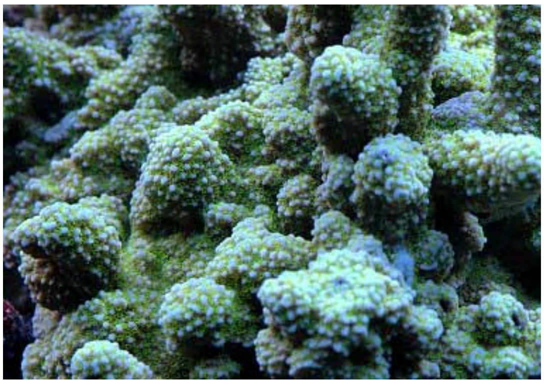
9 Appendix 1: Coral taxon identification

The following images were used to train observers to identify juvenile coral colonies to family: Acroporidae, Pocilloporidae, Poritidae, and Faviidae. Colonies not clearly identifiable as belonging to one of these families were recorded as unknown/other. These images are **not for distribution** as DEC has no rights to their use.

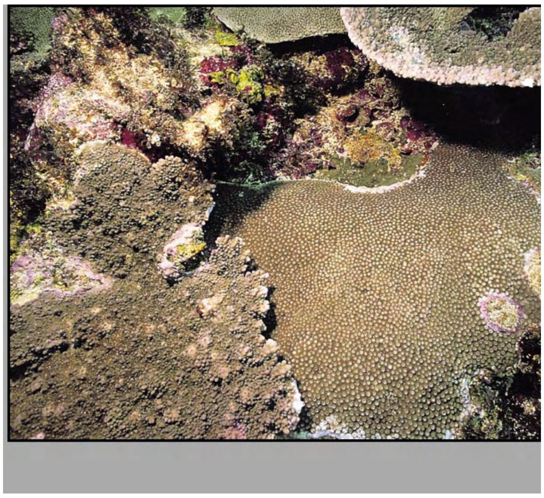
Acroporidae

Acropora

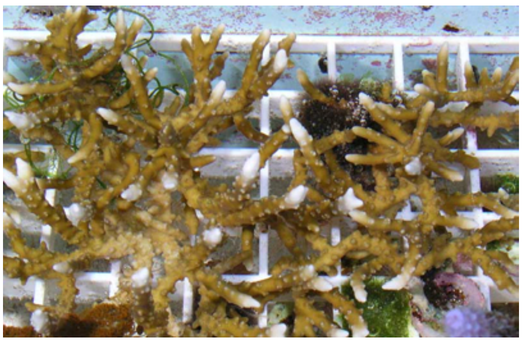


Montipora

Montipora



Astreopora



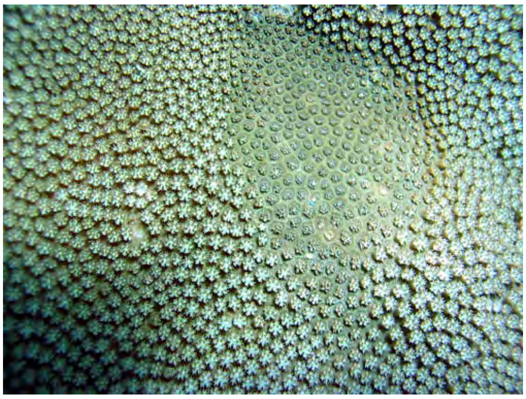
Anacropora

Poritidae

Porites lobata

Porites rus

Porites cylindrica

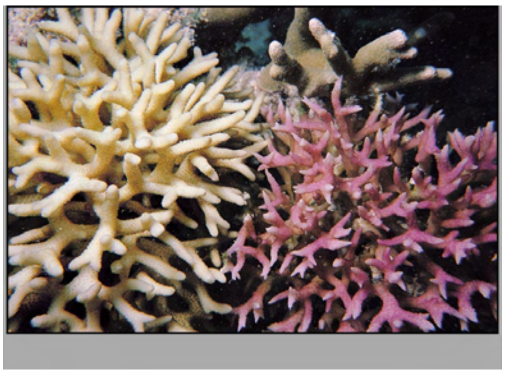


Goniopora

Pocilloporidae

Pocillopora damicornis

Stylophora pistillata

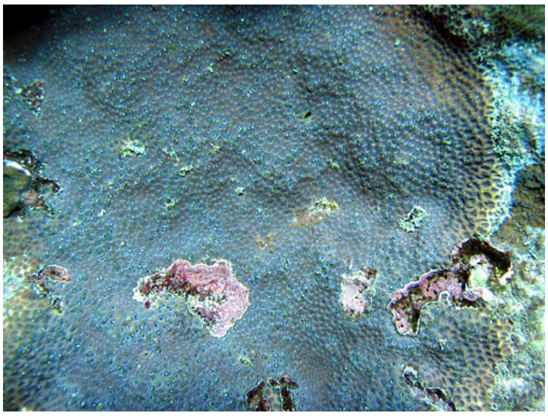


Seriatopora spp.

Faviidae

Goniastrea favulus

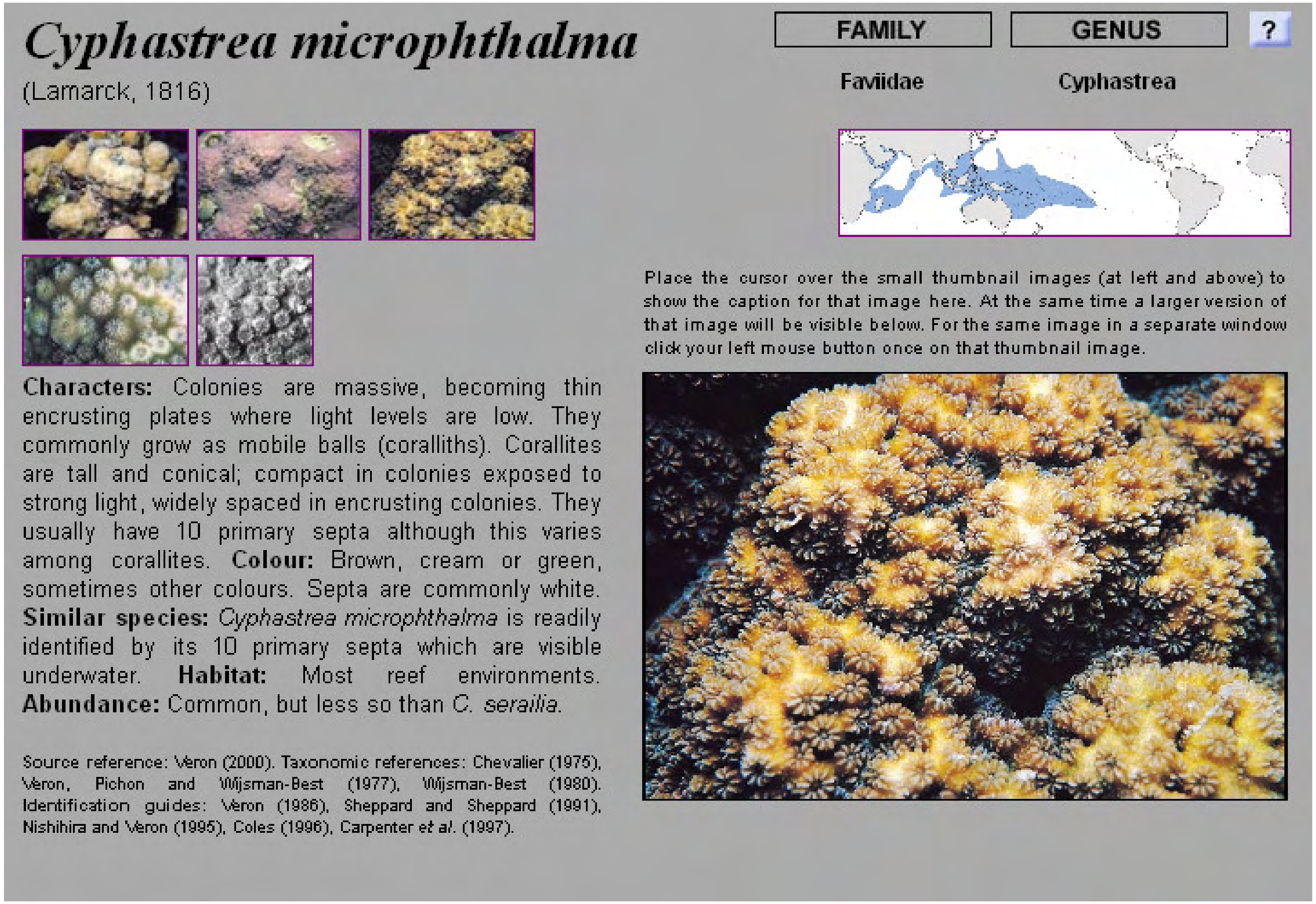
Platygyra



Leptastraea

Favites abdita

10 Appendix 2: *Cyphastrea microphthalma*



Cyphastrea microphthalma

(Lamarck, 1816)

FAMILY GENUS ?

Faviidae Cyphastrea

Place the cursor over the small thumbnail images (at left and above) to show the caption for that image here. At the same time a larger version of that image will be visible below. For the same image in a separate window click your left mouse button once on that thumbnail image.

Characters: Colonies are massive, becoming thin encrusting plates where light levels are low. They commonly grow as mobile balls (coralliths). Corallites are tall and conical; compact in colonies exposed to strong light, widely spaced in encrusting colonies. They usually have 10 primary septa although this varies among corallites. **Colour:** Brown, cream or green, sometimes other colours. Septa are commonly white. **Similar species:** *Cyphastrea microphthalma* is readily identified by its 10 primary septa which are visible underwater. **Habitat:** Most reef environments. **Abundance:** Common, but less so than *C. serailia*.

Source reference: Veron (2000). Taxonomic references: Chevalier (1975), Veron, Pichon and Wijsman-Best (1977), Wijsman-Best (1980). Identification guides: Veron (1986), Sheppard and Sheppard (1991), Nishihira and Veron (1995), Coles (1996), Carpenter *et al.* (1997).

The encrusting brooding faviid *Cyphastrea microphthalma* was the only coral species to survive the 1989 dystrophic event, and anecdotal reports indicate that it has continued to dominate the live coral cover in the inner zone of Bill's Bay, either in the form of new recruits or by fragmentation or partial mortality of adult colonies. As this species is relatively uncontroversial to identify in the field, observers will be able to record the size and derivation (juvenile/ fragment) of each <10 cm diameter *C. microphthalma* encountered in the belt transects. The information at left will be used to train observers to identify the species (available online at http://whelk.aims.gov.au/coralsearch/html/101200/Species%20pages/130.htm).

11 Appendix 3: Draft media statement

DRAFT MEDIA STATEMENT
MINISTER FOR THE ENVIRONMENT

Ningaloo reef survey to guide management

A team of Department of Environment and Conservation marine scientists is heading for Coral Bay next week to undertake a two-week survey of the coral reef communities in nearby Bill's Bay, which is part of the Ningaloo Marine Park.

The survey is part of a DEC marine science program that will help increase the knowledge and understanding of the reef, how it responds to natural disturbances and how it may respond in the face of climate change.

Environment Minister Mark McGowan today said the results of the survey would build on a rapidly expanding information base and understanding of the coral reef ecosystems of Ningaloo Marine Park resulting from the Government's $5M Ningaloo Research Program as part of the WA Marine Science Institution.

"Over the past decade, DEC, the Australian Institute of Marine Science and universities have also undertaken significant research to help build up a 'picture' of the structure of the reef and how it functions. A key question is how the reef responds to disturbances," he said.

"For example, in 1989 a combination of unusually calm wind and sea conditions and a mass coral spawning caused an extensive die-off of reef animals in Bill's Bay.

"Up to 100 per cent of corals, fish and other reef-dwelling animals died at some sites during this event, suggesting that a mass death event of this size had not occurred for at least 50 years.

"A 1989 survey of this event provided a valuable base to monitor the recovery of the reef communities, a process often measured in decades rather than years.

"Subsequent surveys have indicated that the reef is recovering and next week's survey will provide further information on the extent of this recovery."

Mr McGowan said the results of the surveys will be incorporated into future management response in Bill's Bay and other parts of the reef as human usage of this popular marine park increases.

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12 Appendix 4: Coral health survey

SURVEY: Coral health in Coral Bay since 1989

The Department of Environment and Conservation (in cooperation with the Australian Institute of Marine Science and WA universities) has been conducting a long-term research program monitoring coral health in Bill's Bay, at Coral Bay, Ningaloo Marine Park.

We have put together a list of events that may have affected coral health in the area since 1989.

Date	Event
Apr/May 1989	Coral spawn-associated natural anoxic event: death of almost all corals and fish in inner Bill's Bay
Early 1990s	*Drupella* outbreak: large proportion of live acroporids and pocilloporids in Bill's Bay consumed by predatory snails
4-7 April 2002	Coral spawn-associated natural anoxic event: death of up to 80% of acroporids in inner Bill's Bay
4-7 March 2005	Coral spawn-associated natural anoxic event: death of large numbers of fish and invertebrates; no records of coral death
June 2006	Winter bleaching: non-lethal low temperature-induced bleaching, principally affecting shallow corymbose and tabular acroporids

Do you know of any other major events that affected coral health in this area?

Examples could include cyclones, runoff or floods, coral spawning-associated deaths in other years, or spills (eg oil, petrol). We would value your input into this list. All contributions will be formally acknowledged in the scientific report that will be published in 2007.

To contribute to this scientific study, please contact:

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SURVEY: Events affecting coral health in Coral Bay

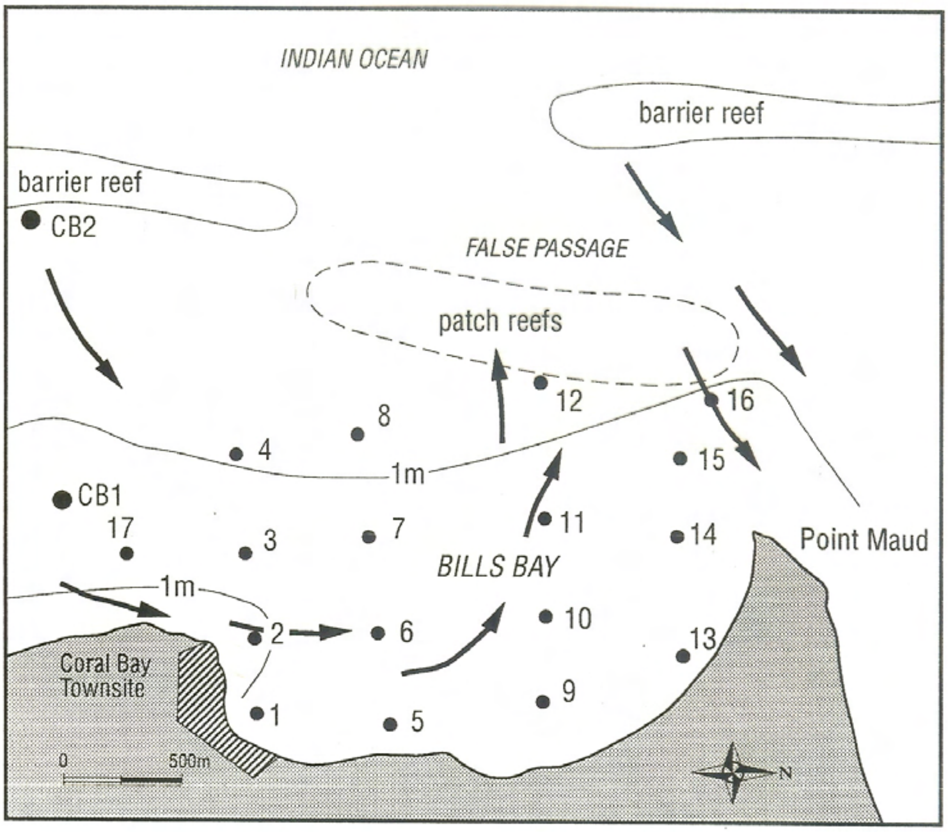
Name:

Contact details:
(phone, address, email)

Date of event:
(year, month, date where possible)

Detailed description of event:

Area affected:
Please indicate approximate area of Bill's Bay where dead or bleached corals were observed associated with the event.



13 Appendix 5: Raw data for benthic cover 2006

Site	Transect	Benthic category	Detailed description	Sum of percent cover
1	1	Branching Acropora	Acropora spp.	0.5
1	1	Branching non-Acropora	Echinopora spp.	6
1	1	Branching non-Acropora	Seriatopora spp.	0.5
1	1	Corymbose Acropora	Acropora spp.	0.5
1	1	Encrusting non-Acropora	Montipora spp.	11
1	1	Encrusting non-Acropora	Non-Acropora coral	1.5
1	1	Foliose non-Acropora	Echinopora spp.	1
1	1	Massive non-Acropora	Favia spp.	2
1	1	Mushroom coral	Fungia spp.	0.5
1	1	Sand	Sand	19
1	1	Submassive non-Acropora	Non-Acropora coral	2
1	1	Turf algae	Filamentous algae	55.5
1	2	Branching non-Acropora	Echinopora spp.	5
1	2	Dead coral (recent)	Dead standing coral (white)	0.5
1	2	Encrusting non-Acropora	Echinopora spp.	0.5
1	2	Encrusting non-Acropora	Montipora spp.	14
1	2	Foliose non-Acropora	Echinopora spp.	4
1	2	Foliose non-Acropora	Montipora spp.	20.5
1	2	Massive non-Acropora	Favia spp.	1.5
1	2	Massive non-Acropora	Favid spp.	0.5
1	2	Massive non-Acropora	Goniastrea spp.	0.5
1	2	Sand	Sand	3.5
1	2	Submassive non-Acropora	Non-Acropora coral	0.5
1	2	Submassive non-Acropora	Pocillopora damicornis	1
1	2	Turf algae	Filamentous algae	48
1	3	Branching Acropora	Acropora spp.	17.5
1	3	Branching non-Acropora	Echinopora spp.	15
1	3	Encrusting non-Acropora	Galaxea spp.	1.5
1	3	Encrusting non-Acropora	Montipora spp.	12
1	3	Encrusting non-Acropora	Non-Acropora coral	1
1	3	Foliose non-Acropora	Echinopora spp.	2.5
1	3	Foliose non-Acropora	Merulina spp.	0.5
1	3	Foliose non-Acropora	Montipora spp.	0.5
1	3	Massive non-Acropora	Favia spp.	1
1	3	Mushroom coral	Fungia spp.	2.5
1	3	Sand	Sand	7.5
1	3	Submassive non-Acropora	Non-Acropora coral	3
1	3	Submassive non-Acropora	Pocillopora damicornis	0.5
1	3	Turf algae	Filamentous algae	35
2	1	Branching non-Acropora	Seriatopora spp.	1.5
2	1	Coralline algae	Coralline algae	2.5
2	1	Corymbose Acropora	Acropora spp.	0.5
2	1	Encrusting non-Acropora	Montipora spp.	3.5
2	1	Foliose non-Acropora	Montipora spp.	9
2	1	Reefal substrate	Reefal substrate	0.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
2	1	Sand	Sand	3
2	1	Turf algae	Filamentous algae	79.5
2	2	Branching non-Acropora	Seriatopora spp.	6.5
2	2	Coralline algae	Coralline algae	4.5
2	2	Encrusting non-Acropora	Echinopora spp.	2.5
2	2	Encrusting non-Acropora	Montipora spp.	6.5
2	2	Foliose non-Acropora	Montipora spp.	7
2	2	Macroalgae	Fleshy Macro Algae	0.5
2	2	Massive non-Acropora	Favia spp.	0.5
2	2	Sand	Sand	3
2	2	Submassive non-Acropora	Non-Acropora coral	0.5
2	2	Turf algae	Filamentous algae	68.5
2	3	Branching non-Acropora	Seriatopora spp.	4.5
2	3	Coralline algae	Coralline algae	2
2	3	Dead coral (recent)	Dead standing coral (white)	1
2	3	Encrusting non-Acropora	Montipora spp.	7
2	3	Foliose non-Acropora	Montipora spp.	9.5
2	3	Massive non-Acropora	Lobophyllia spp.	0.5
2	3	Sand	Sand	1.5
2	3	Submassive non-Acropora	Non-Acropora coral	0.5
2	3	Turf algae	Filamentous algae	73.5
3	1	Branching Acropora	Acropora spp.	7.5
3	1	Branching non-Acropora	Echinopora spp.	5
3	1	Branching non-Acropora	Seriatopora spp.	2
3	1	Coralline algae	Coralline algae	3.5
3	1	Encrusting non-Acropora	Echinopora spp.	1
3	1	Encrusting non-Acropora	Montipora spp.	3
3	1	Foliose non-Acropora	Echinopora spp.	2.5
3	1	Foliose non-Acropora	Montipora spp.	0.5
3	1	Macroalgae	Fleshy Macro Algae	5.5
3	1	Submassive non-Acropora	Non-Acropora coral	2
3	1	Tabulate Acropora	Acropora spp.	1.5
3	1	Turf algae	Filamentous algae	66
3	2	Branching Acropora	Acropora spp.	3
3	2	Branching non-Acropora	Seriatopora spp.	1
3	2	Coralline algae	Coralline algae	5.5
3	2	Digitate Acropora	Acropora spp.	0.5
3	2	Encrusting non-Acropora	Echinopora spp.	5
3	2	Encrusting non-Acropora	Montipora spp.	3
3	2	Foliose non-Acropora	Echinopora spp.	1
3	2	Foliose non-Acropora	Merulina spp.	0.5
3	2	Foliose non-Acropora	Montipora spp.	3.5
3	2	Massive non-Acropora	Favites pentagona	0.5
3	2	Massive non-Acropora	Platygyra spp.	0.5
3	2	Submassive non-Acropora	Non-Acropora coral	6
3	2	Turf algae	Filamentous algae	70
3	3	Branching Acropora	Acropora spp.	7
3	3	Branching non-Acropora	Echinopora spp.	2.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
3	3	Coralline algae	Coralline algae	16.5
3	3	Encrusting non-Acropora	Echinopora spp.	3
3	3	Encrusting non-Acropora	Montipora spp.	3.5
3	3	Macroalgae	Fleshy Macro Algae	3
3	3	Massive non-Acropora	Porites spp.	0.5
3	3	Submassive non-Acropora	Non-Acropora coral	1.5
3	3	Turf algae	Filamentous algae	62.5
4	1	Branching Acropora	Acropora spp.	0.5
4	1	Branching non-Acropora	Echinopora spp.	4.5
4	1	Branching non-Acropora	Hydnophora rigida	5
4	1	Branching non-Acropora	Seriatopora spp.	1.5
4	1	Corymbose Acropora	Acropora spp.	4
4	1	Encrusting non-Acropora	Echinopora spp.	8.5
4	1	Encrusting non-Acropora	Montipora spp.	8
4	1	Foliose non-Acropora	Echinopora spp.	5
4	1	Foliose non-Acropora	Montipora spp.	12
4	1	Foliose non-Acropora	Turbinaria reniformis	0.5
4	1	Massive non-Acropora	Porites spp.	0.5
4	1	Sand	Sand	2.5
4	1	Submassive non-Acropora	Non-Acropora coral	4.5
4	1	Tabulate Acropora	Acropora spp.	0.5
4	1	Turf algae	Filamentous algae	42.5
4	2	Branching Acropora	Acropora spp.	2.5
4	2	Branching non-Acropora	Echinopora spp.	5.5
4	2	Branching non-Acropora	Seriatopora spp.	2
4	2	Corymbose Acropora	Acropora spp.	0.5
4	2	Dead coral (recent)	Dead standing coral (white)	1
4	2	Encrusting non-Acropora	Echinopora spp.	3.5
4	2	Encrusting non-Acropora	Montipora spp.	2
4	2	Foliose non-Acropora	Echinopora spp.	6
4	2	Foliose non-Acropora	Montipora spp.	16
4	2	Macroalgae	Fleshy Macro Algae	2.5
4	2	Massive non-Acropora	Favia spp.	0.5
4	2	Sand	Sand	2
4	2	Submassive non-Acropora	Non-Acropora coral	4.5
4	2	Tabulate Acropora	Acropora spp.	2
4	2	Turf algae	Filamentous algae	49.5
4	3	Branching Acropora	Acropora spp.	3
4	3	Branching non-Acropora	Echinopora spp.	4.5
4	3	Branching non-Acropora	Seriatopora spp.	1.5
4	3	Dead coral (recent)	Dead standing coral (white)	1
4	3	Encrusting non-Acropora	Echinopora spp.	4.5
4	3	Encrusting non-Acropora	Montipora spp.	5
4	3	Encrusting non-Acropora	Non-Acropora coral	0.5
4	3	Foliose non-Acropora	Echinopora spp.	2
4	3	Foliose non-Acropora	Montipora spp.	9.5
4	3	Macroalgae	Fleshy Macro Algae	1.5
4	3	Massive non-Acropora	Lobophyllia spp.	1.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
4	3	Sand	Sand	1
4	3	Submassive non-Acropora	Non-Acropora coral	1.5
4	3	Turf algae	Filamentous algae	63
5	1	Branching non-Acropora	Echinopora spp.	44
5	1	Corymbose Acropora	Acropora spp.	0.5
5	1	Digitate Acropora	Acropora spp.	0.5
5	1	Encrusting non-Acropora	Echinopora spp.	1
5	1	Encrusting non-Acropora	Montipora spp.	5
5	1	Encrusting non-Acropora	Non-Acropora coral	1.5
5	1	Foliose non-Acropora	Echinopora spp.	5
5	1	Massive non-Acropora	Diploastrea heliopora	0.5
5	1	Massive non-Acropora	Favia spp.	2.5
5	1	Massive non-Acropora	Goniastrea spp.	0.5
5	1	Sand	Sand	17.5
5	1	Submassive non-Acropora	Non-Acropora coral	4.5
5	1	Turf algae	Filamentous algae	17
5	2	Branching non-Acropora	Echinopora spp.	45.83
5	2	Encrusting non-Acropora	Favites spp.	0.83
5	2	Encrusting non-Acropora	Galaxea spp.	1.67
5	2	Encrusting non-Acropora	Montipora spp.	6.67
5	2	Foliose non-Acropora	Echinopora spp.	3.33
5	2	Foliose non-Acropora	Montipora spp.	0.83
5	2	Massive non-Acropora	Favia spp.	0.83
5	2	Mushroom coral	Fungia spp.	0.83
5	2	Sand	Sand	1.67
5	2	Submassive non-Acropora	Non-Acropora coral	2.5
5	2	Turf algae	Filamentous algae	35
5	3	Branching non-Acropora	Echinopora spp.	60
5	3	Encrusting non-Acropora	Non-Acropora coral	1.25
5	3	Foliose non-Acropora	Echinopora spp.	3.75
5	3	Massive non-Acropora	Favia spp.	1.25
5	3	Mushroom coral	Fungia spp.	1.25
5	3	Sand	Sand	3.75
5	3	Submassive non-Acropora	Non-Acropora coral	3.75
5	3	Turf algae	Filamentous algae	25
5	4	Branching non-Acropora	Echinopora spp.	49
5	4	Encrusting non-Acropora	Montipora spp.	3.5
5	4	Encrusting non-Acropora	Non-Acropora coral	1
5	4	Foliose non-Acropora	Echinopora spp.	13.5
5	4	Foliose non-Acropora	Montipora spp.	1
5	4	Macroalgae	Fleshy Macro Algae	0.5
5	4	Massive non-Acropora	Non-Acropora coral	0.5
5	4	Massive non-Acropora	Platygyra spp.	1
5	4	Sand	Sand	1.5
5	4	Submassive non-Acropora	Non-Acropora coral	2.5
5	4	Turf algae	Filamentous algae	26
6	1	Branching non-Acropora	Echinopora spp.	22.5
6	1	Encrusting non-Acropora	Echinopora spp.	2.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
6	1	Encrusting non-Acropora	Montipora spp.	4
6	1	Encrusting non-Acropora	Non-Acropora coral	1.5
6	1	Foliose non-Acropora	Echinopora spp.	10
6	1	Foliose non-Acropora	Merulina spp.	2
6	1	Foliose non-Acropora	Montipora spp.	9
6	1	Macroalgae	Fleshy Macro Algae	2
6	1	Massive non-Acropora	Favia spp.	0.5
6	1	Massive non-Acropora	Lobophyllia spp.	0.5
6	1	Massive non-Acropora	Platygyra spp.	2
6	1	Massive non-Acropora	Porites spp.	0.5
6	1	Sand	Sand	1
6	1	Submassive non-Acropora	Montipora spp.	0.5
6	1	Submassive non-Acropora	Non-Acropora coral	7.5
6	1	Turf algae	Filamentous algae	34
6	2	Branching non-Acropora	Echinopora spp.	16.5
6	2	Encrusting non-Acropora	Echinopora spp.	4
6	2	Encrusting non-Acropora	Montipora spp.	4
6	2	Encrusting non-Acropora	Non-Acropora coral	3
6	2	Foliose non-Acropora	Echinopora spp.	9.5
6	2	Foliose non-Acropora	Merulina spp.	1
6	2	Foliose non-Acropora	Montipora spp.	8.5
6	2	Macroalgae	Fleshy Macro Algae	2.5
6	2	Massive non-Acropora	Favia spp.	1.5
6	2	Massive non-Acropora	Goniastrea spp.	0.5
6	2	Sand	Sand	2
6	2	Submassive non-Acropora	Non-Acropora coral	2.5
6	2	Turf algae	Filamentous algae	44.5
6	3	Branching Acropora	Acropora spp.	0.5
6	3	Branching non-Acropora	Echinopora spp.	2
6	3	Branching non-Acropora	Seriatopora spp.	1
6	3	Coralline algae	Coralline algae	3
6	3	Corymbose Acropora	Acropora spp.	12
6	3	Encrusting non-Acropora	Echinopora spp.	0.5
6	3	Encrusting non-Acropora	Montipora spp.	7
6	3	Encrusting non-Acropora	Platygyra spp.	1
6	3	Foliose non-Acropora	Montipora spp.	2
6	3	Macroalgae	Fleshy Macro Algae	3
6	3	Massive non-Acropora	Favia spp.	1
6	3	Massive non-Acropora	Platygyra spp.	0.5
6	3	Sand	Sand	8
6	3	Turf algae	Filamentous algae	58.5
7	S	Coralline algae	Coralline algae	6
7	S	Encrusting non-Acropora	Montipora spp.	2
7	S	Encrusting non-Acropora	Non-Acropora coral	0.5
7	S	Foliose non-Acropora	Echinopora spp.	0.5
7	S	Macroalgae	Fleshy Macro Algae	9.5
7	S	Sand	Sand	3
7	S	Submassive non-Acropora	Non-Acropora coral	0.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
7	S	Turf algae	Filamentous algae	78
7	M	Coralline algae	Coralline algae	12.5
7	M	Encrusting non-Acropora	Montipora spp.	1
7	M	Macroalgae	Fleshy Macro Algae	9.5
7	M	Sand	Sand	5
7	M	Submassive non-Acropora	Non-Acropora coral	0.5
7	M	Turf algae	Filamentous algae	71.5
7	N	Coralline algae	Coralline algae	8.5
7	N	Encrusting non-Acropora	Echinopora spp.	2
7	N	Encrusting non-Acropora	Montipora spp.	1
7	N	Macroalgae	Fleshy Macro Algae	8
7	N	Sand	Sand	2
7	N	Turf algae	Filamentous algae	78.5
8	1	Branching non-Acropora	Echinopora spp.	1
8	1	Branching non-Acropora	Hydnophora rigida	1
8	1	Branching non-Acropora	Seriatopora spp.	3.5
8	1	Corymbose Acropora	Acropora spp.	4.5
8	1	Encrusting non-Acropora	Montipora spp.	10
8	1	Foliose non-Acropora	Montipora spp.	3.5
8	1	Macroalgae	Padina australis	1.5
8	1	Massive Soft Coral	Pachyclavularia spp.	0.5
8	1	Sand	Sand	0.5
8	1	Submassive non-Acropora	Montipora spp.	7
8	1	Submassive non-Acropora	Non-Acropora coral	2
8	1	Turf algae	Filamentous algae	65
8	2	Branching non-Acropora	Echinopora spp.	0.5
8	2	Branching non-Acropora	Seriatopora spp.	3
8	2	Corymbose Acropora	Acropora spp.	8.5
8	2	Encrusting non-Acropora	Montipora spp.	10
8	2	Foliose non-Acropora	Echinopora spp.	1.5
8	2	Foliose non-Acropora	Montipora spp.	4
8	2	Macroalgae	Fleshy Macro Algae	1
8	2	Massive non-Acropora	Lobophyllia spp.	0.5
8	2	Sand	Sand	0.5
8	2	Submassive non-Acropora	Montipora spp.	1.5
8	2	Submassive non-Acropora	Non-Acropora coral	4
8	2	Turf algae	Filamentous algae	65
8	3	Branching Acropora	Acropora spp.	13.5
8	3	Branching non-Acropora	Echinopora spp.	1
8	3	Branching non-Acropora	Seriatopora spp.	0.5
8	3	Corymbose Acropora	Acropora spp.	4.5
8	3	Encrusting non-Acropora	Montipora spp.	12.5
8	3	Foliose non-Acropora	Echinopora spp.	3
8	3	Foliose non-Acropora	Montipora spp.	3.5
8	3	Macroalgae	Fleshy Macro Algae	1.5
8	3	Massive non-Acropora	Favia spp.	0.5
8	3	Massive non-Acropora	Lobophyllia spp.	0.5
8	3	Sand	Sand	6

Site	Transect	Benthic category	Detailed description	Sum of percent cover
8	3	Submassive non-Acropora	Montipora spp.	2
8	3	Submassive non-Acropora	Non-Acropora coral	4.5
8	3	Turf algae	Filamentous algae	46.5
9	1	Branching non-Acropora	Echinopora spp.	19
9	1	Encrusting non-Acropora	Echinopora spp.	2
9	1	Encrusting non-Acropora	Montipora spp.	3
9	1	Encrusting non-Acropora	Non-Acropora coral	1.5
9	1	Foliose non-Acropora	Echinopora spp.	11.5
9	1	Foliose non-Acropora	Merulina spp.	3.5
9	1	Foliose non-Acropora	Montipora spp.	2.5
9	1	Macroalgae	Fleshy Macro Algae	1
9	1	Massive non-Acropora	Favia spp.	2.5
9	1	Massive non-Acropora	Favid spp.	0.5
9	1	Massive non-Acropora	Lobophyllia spp.	0.5
9	1	Sand	Sand	6.5
9	1	Submassive non-Acropora	Non-Acropora coral	3
9	1	Turf algae	Filamentous algae	43
9	2	Branching non-Acropora	Echinopora spp.	21.5
9	2	Branching non-Acropora	Hydnophora rigida	3.5
9	2	Encrusting non-Acropora	Montipora spp.	5
9	2	Encrusting non-Acropora	Non-Acropora coral	1
9	2	Foliose non-Acropora	Echinopora spp.	9.5
9	2	Foliose non-Acropora	Merulina spp.	3.5
9	2	Foliose non-Acropora	Montipora spp.	0.5
9	2	Macroalgae	Fleshy Macro Algae	0.5
9	2	Massive non-Acropora	Favia spp.	4
9	2	Sand	Sand	8
9	2	Submassive non-Acropora	Non-Acropora coral	3
9	2	Turf algae	Filamentous algae	40
9	3	Branching non-Acropora	Echinopora spp.	14
9	3	Encrusting non-Acropora	Galaxea fascicularis	0.5
9	3	Encrusting non-Acropora	Montipora spp.	1
9	3	Foliose non-Acropora	Echinopora spp.	13
9	3	Foliose non-Acropora	Merulina spp.	0.5
9	3	Macroalgae	Fleshy Macro Algae	0.5
9	3	Massive non-Acropora	Favia spp.	4.5
9	3	Massive non-Acropora	Non-Acropora coral	0.5
9	3	Massive non-Acropora	Porites spp.	0.5
9	3	Sand	Sand	4
9	3	Submassive non-Acropora	Non-Acropora coral	5
9	3	Turf algae	Filamentous algae	56
10	1	Coralline algae	Coralline algae	1.5
10	1	Encrusting non-Acropora	Montipora spp.	5.5
10	1	Foliose non-Acropora	Montipora spp.	5.5
10	1	Macroalgae	Fleshy Macro Algae	1.5
10	1	Sand	Sand	6
10	1	Turf algae	Filamentous algae	80
10	2	Encrusting non-Acropora	Montipora spp.	1

Site	Transect	Benthic category	Detailed description	Sum of percent cover
10	2	Foliose non-Acropora	Montipora spp.	3
10	2	Macroalgae	Fleshy Macro Algae	2.5
10	2	Sand	Sand	1
10	2	Turf algae	Filamentous algae	92.5
10	3	Encrusting non-Acropora	Montipora spp.	1
10	3	Foliose non-Acropora	Montipora spp.	5
10	3	Macroalgae	Fleshy Macro Algae	1.5
10	3	Sand	Sand	1
10	3	Submassive non-Acropora	Montipora spp.	3
10	3	Turf algae	Filamentous algae	88.5
11	1	Coralline algae	Coralline algae	0.5
11	1	Encrusting non-Acropora	Montipora spp.	1
11	1	Macroalgae	Fleshy Macro Algae	2.5
11	1	Massive non-Acropora	Platygyra spp.	1
11	1	Sand	Sand	14
11	1	Submassive non-Acropora	Montipora spp.	3
11	1	Turf algae	Filamentous algae	78
11	2	Coralline algae	Coralline algae	2.5
11	2	Macroalgae	Fleshy Macro Algae	7.5
11	2	Sand	Sand	5
11	2	Submassive non-Acropora	Non-Acropora coral	0.5
11	2	Turf algae	Filamentous algae	84.5
11	3	Coralline algae	Coralline algae	2
11	3	Corymbose Acropora	Acropora spp.	0.5
11	3	Encrusting non-Acropora	Montipora spp.	1
11	3	Macroalgae	Fleshy Macro Algae	4.5
11	3	Sand	Sand	11
11	3	Submassive non-Acropora	Non-Acropora coral	1
11	3	Submassive non-Acropora	Pocillopora damicornis	0.5
11	3	Tabulate Acropora	Acropora spp.	1
11	3	Turf algae	Filamentous algae	78.5
12	1	Branching Acropora	Acropora spp.	4.5
12	1	Branching non-Acropora	Echinopora spp.	3.5
12	1	Branching non-Acropora	Seriatopora spp.	3.5
12	1	Coralline algae	Coralline algae	0.5
12	1	Corymbose Acropora	Acropora spp.	3.5
12	1	Dead coral (recent)	Dead standing coral (white)	0.5
12	1	Encrusting non-Acropora	Montipora spp.	5
12	1	Foliose non-Acropora	Echinopora spp.	6.5
12	1	Foliose non-Acropora	Montipora spp.	4
12	1	Massive non-Acropora	Favia spp.	1
12	1	Massive non-Acropora	Lobophyllia spp.	0.5
12	1	Other organisms	Other organisms	0.5
12	1	Sand	Sand	5.5
12	1	Sponge	Sponge spp.	0.5
12	1	Submassive non-Acropora	Non-Acropora coral	3.5
12	1	Turf algae	Filamentous algae	57
12	2	Branching non-Acropora	Echinopora spp.	2.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
12	2	Branching non-Acropora	Seriatopora spp.	4
12	2	Corymbose Acropora	Acropora spp.	3.5
12	2	Encrusting non-Acropora	Montipora spp.	3.5
12	2	Foliose non-Acropora	Echinopora spp.	4.5
12	2	Foliose non-Acropora	Montipora spp.	19
12	2	Macroalgae	Fleshy Macro Algae	2.5
12	2	Massive non-Acropora	Non-Acropora coral	0.5
12	2	Massive non-Acropora	Platygyra spp.	0.5
12	2	Sand	Sand	1.5
12	2	Submassive non-Acropora	Non-Acropora coral	8.5
12	2	Turf algae	Filamentous algae	49.5
12	3	Branching non-Acropora	Echinopora spp.	3.5
12	3	Branching non-Acropora	Hydnophora rigida	0.5
12	3	Branching non-Acropora	Seriatopora spp.	5
12	3	Coralline algae	Coralline algae	2.5
12	3	Corymbose Acropora	Acropora spp.	6.5
12	3	Encrusting non-Acropora	Montipora spp.	3.5
12	3	Encrusting non-Acropora	Non-Acropora coral	1
12	3	Foliose non-Acropora	Echinopora spp.	9
12	3	Foliose non-Acropora	Merulina spp.	2
12	3	Foliose non-Acropora	Montipora spp.	2.5
12	3	Macroalgae	Fleshy Macro Algae	2.5
12	3	Massive non-Acropora	Favia spp.	1.5
12	3	Massive non-Acropora	Favid spp.	0.5
12	3	Massive non-Acropora	Platygyra spp.	0.5
12	3	Mushroom coral	Fungia spp.	0.5
12	3	Submassive non-Acropora	Hydnophora exesa	0.5
12	3	Submassive non-Acropora	Non-Acropora coral	6
12	3	Tabulate Acropora	Acropora spp.	5
12	3	Turf algae	Filamentous algae	43.5
12	3	Water	Water	3.5
13	S	Arb & Enc Soft Coral	Sinularia spp.	0.5
13	S	Branching Acropora	Acropora spp.	0.5
13	S	Branching non-Acropora	Echinopora spp.	27
13	S	Coralline algae	Coralline algae	0.5
13	S	Encrusting non-Acropora	Echinopora spp.	3
13	S	Encrusting non-Acropora	Merulina ampliata	1
13	S	Encrusting non-Acropora	Montipora spp.	3.5
13	S	Encrusting non-Acropora	Non-Acropora coral	1.5
13	S	Foliose non-Acropora	Echinopora spp.	3.5
13	S	Foliose non-Acropora	Montipora spp.	1.5
13	S	Massive non-Acropora	Favia spp.	4.5
13	S	Massive non-Acropora	Porites spp.	0.5
13	S	Sand	Sand	22
13	S	Submassive non-Acropora	Non-Acropora coral	2.5
13	S	Turf algae	Filamentous algae	28
13	M	Branching non-Acropora	Echinopora spp.	22
13	M	Coralline algae	Coralline algae	0.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
13	M	Encrusting non-Acropora	Echinopora spp.	2
13	M	Encrusting non-Acropora	Merulina ampliata	2.5
13	M	Encrusting non-Acropora	Montipora spp.	7.5
13	M	Encrusting non-Acropora	Non-Acropora coral	0.5
13	M	Foliose non-Acropora	Echinopora spp.	10.5
13	M	Foliose non-Acropora	Montipora spp.	3.5
13	M	Macroalgae	Fleshy Macro Algae	1
13	M	Massive non-Acropora	Favia spp.	7
13	M	Massive non-Acropora	Goniastrea spp.	0.5
13	M	Massive non-Acropora	Goniopora spp.	1
13	M	Massive non-Acropora	Porites spp.	4
13	M	Sand	Sand	3.5
13	M	Submassive non-Acropora	Non-Acropora coral	7
13	M	Turf algae	Filamentous algae	27
13	N	Branching Acropora	Acropora spp.	2
13	N	Branching non-Acropora	Echinopora spp.	11.5
13	N	Encrusting non-Acropora	Echinopora spp.	2
13	N	Encrusting non-Acropora	Merulina ampliata	0.5
13	N	Encrusting non-Acropora	Montipora spp.	0.5
13	N	Encrusting non-Acropora	Non-Acropora coral	0.5
13	N	Foliose non-Acropora	Echinopora spp.	6
13	N	Foliose non-Acropora	Merulina spp.	3.5
13	N	Foliose non-Acropora	Montipora spp.	1
13	N	Macroalgae	Fleshy Macro Algae	0.5
13	N	Massive non-Acropora	Favia spp.	2
13	N	Massive non-Acropora	Favid spp.	1.5
13	N	Massive non-Acropora	Porites spp.	3
13	N	Sand	Sand	12.5
13	N	Submassive non-Acropora	Non-Acropora coral	6
13	N	Tabulate Acropora	Acropora spp.	3
13	N	Turf algae	Filamentous algae	44
14	1	Coralline algae	Coralline algae	12
14	1	Macroalgae	Fleshy Macro Algae	0.5
14	1	Sand	Sand	5.5
14	1	Tabulate Acropora	Acropora spp.	2.5
14	1	Turf algae	Filamentous algae	79.5
14	2	Branching Acropora	Acropora spp.	2.5
14	2	Coralline algae	Coralline algae	0.5
14	2	Corymbose Acropora	Acropora spp.	1.5
14	2	Encrusting non-Acropora	Montipora spp.	0.5
14	2	Sand	Sand	5.5
14	2	Tabulate Acropora	Acropora spp.	1.5
14	2	Turf algae	Filamentous algae	88
14	3	Coralline algae	Coralline algae	1.5
14	3	Digitate Acropora	Acropora spp.	0.5
14	3	Sand	Sand	8
14	3	Tabulate Acropora	Acropora spp.	4
14	3	Turf algae	Filamentous algae	86

Site	Transect	Benthic category	Detailed description	Sum of percent cover
15	1	Branching Acropora	Acropora spp.	0.5
15	1	Branching non-Acropora	Echinopora spp.	1
15	1	Branching non-Acropora	Seriatopora spp.	0.5
15	1	Coralline algae	Coralline algae	2
15	1	Corymbose Acropora	Acropora spp.	2.5
15	1	Encrusting non-Acropora	Echinopora spp.	1
15	1	Encrusting non-Acropora	Montipora spp.	15
15	1	Foliose non-Acropora	Echinopora spp.	0.5
15	1	Macroalgae	Fleshy Macro Algae	1
15	1	Macroalgae	Padina australis	1.5
15	1	Massive non-Acropora	Favia spp.	0.5
15	1	Massive non-Acropora	Platygyra spp.	0.5
15	1	Massive Soft Coral	Pachyclavularia spp.	0.5
15	1	Sand	Sand	5.5
15	1	Submassive non-Acropora	Non-Acropora coral	1
15	1	Tabulate Acropora	Acropora spp.	11.5
15	1	Turf algae	Filamentous algae	55
15	2	Branching non-Acropora	Seriatopora spp.	1
15	2	Coralline algae	Coralline algae	1.5
15	2	Corymbose Acropora	Acropora spp.	1.5
15	2	Encrusting non-Acropora	Montipora spp.	7
15	2	Foliose non-Acropora	Echinopora spp.	0.5
15	2	Macroalgae	Fleshy Macro Algae	4.5
15	2	Macroalgae	Padina australis	1
15	2	Massive non-Acropora	Favia spp.	2.5
15	2	Massive non-Acropora	Platygyra spp.	0.5
15	2	Sand	Sand	2.5
15	2	Submassive non-Acropora	Non-Acropora coral	1
15	2	Tabulate Acropora	Acropora spp.	9
15	2	Turf algae	Filamentous algae	67.5
15	3	Branching Acropora	Acropora spp.	0.5
15	3	Branching non-Acropora	Seriatopora spp.	0.5
15	3	Coralline algae	Coralline algae	2.5
15	3	Corymbose Acropora	Acropora spp.	1
15	3	Encrusting non-Acropora	Montipora spp.	2
15	3	Foliose non-Acropora	Montipora spp.	3.5
15	3	Macroalgae	Fleshy Macro Algae	0.5
15	3	Massive non-Acropora	Favia spp.	0.5
15	3	Massive non-Acropora	Goniastrea spp.	0.5
15	3	Sand	Sand	8.5
15	3	Submassive non-Acropora	Montipora spp.	1.5
15	3	Submassive non-Acropora	Non-Acropora coral	0.5
15	3	Tabulate Acropora	Acropora spp.	18.5
15	3	Turf algae	Filamentous algae	59.5
16	1	Branching Acropora	Acropora spp.	4
16	1	Branching non-Acropora	Echinopora spp.	0.5
16	1	Branching non-Acropora	Seriatopora spp.	0.5
16	1	Coralline algae	Coralline algae	10.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
16	1	Corymbose Acropora	Acropora spp.	21.5
16	1	Dead coral (recent)	Dead standing coral (white)	0.5
16	1	Encrusting non-Acropora	Montipora spp.	2
16	1	Foliose non-Acropora	Montipora spp.	4.5
16	1	Macroalgae	Fleshy Macro Algae	1.5
16	1	Massive non-Acropora	Favia spp.	0.5
16	1	Massive non-Acropora	Favid spp.	0.5
16	1	Sand	Sand	1.5
16	1	Submassive non-Acropora	Non-Acropora coral	0.5
16	1	Tabulate Acropora	Acropora spp.	15.5
16	1	Turf algae	Filamentous algae	36
16	2	Branching non-Acropora	Seriatopora spp.	1.5
16	2	Coralline algae	Coralline algae	11.5
16	2	Corymbose Acropora	Acropora spp.	8
16	2	Encrusting non-Acropora	Montipora spp.	5
16	2	Encrusting non-Acropora	Non-Acropora coral	0.5
16	2	Macroalgae	Fleshy Macro Algae	0.5
16	2	Massive non-Acropora	Favia spp.	0.5
16	2	Massive non-Acropora	Porites spp.	0.5
16	2	Other organisms	Tridacna spp.	0.5
16	2	Sand	Sand	5
16	2	Submassive non-Acropora	Montipora spp.	0.5
16	2	Tabulate Acropora	Acropora spp.	18.5
16	2	Turf algae	Filamentous algae	47.5
16	3	Branching Acropora	Acropora spp.	1
16	3	Coralline algae	Coralline algae	7.5
16	3	Corymbose Acropora	Acropora spp.	10
16	3	Encrusting non-Acropora	Montipora spp.	1
16	3	Foliose non-Acropora	Montipora spp.	4
16	3	Macroalgae	Fleshy Macro Algae	2
16	3	Massive non-Acropora	Favia spp.	0.5
16	3	Massive non-Acropora	Favid spp.	1.5
16	3	Massive non-Acropora	Goniastrea spp.	0.5
16	3	Massive non-Acropora	Platygyra spp.	0.5
16	3	Sand	Sand	21
16	3	Submassive non-Acropora	Montipora spp.	0.5
16	3	Tabulate Acropora	Acropora spp.	3
16	3	Turf algae	Filamentous algae	47
16b	1	Branching non-Acropora	Seriatopora spp.	2
16b	1	Coralline algae	Coralline algae	0.5
16b	1	Corymbose Acropora	Acropora spp.	19.5
16b	1	Encrusting non-Acropora	Montipora spp.	1
16b	1	Foliose non-Acropora	Montipora spp.	3
16b	1	Macroalgae	Fleshy Macro Algae	2.5
16b	1	Massive non-Acropora	Favid spp.	1
16b	1	Massive non-Acropora	Platygyra spp.	0.5
16b	1	Sand	Sand	1
16b	1	Submassive non-Acropora	Non-Acropora coral	0.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
16b	1	Tabulate Acropora	Acropora spp.	23.5
16b	1	Turf algae	Filamentous algae	45
16b	2	Branching Acropora	Acropora spp.	2
16b	2	Coralline algae	Coralline algae	3
16b	2	Corymbose Acropora	Acropora spp.	10.5
16b	2	Dead coral (recent)	Dead standing coral (white)	0.5
16b	2	Digitate Acropora	Acropora spp.	1
16b	2	Encrusting non-Acropora	Montipora spp.	1
16b	2	Foliose non-Acropora	Echinopora spp.	0.5
16b	2	Foliose non-Acropora	Montipora spp.	11.5
16b	2	Macroalgae	Fleshy Macro Algae	0.5
16b	2	Massive non-Acropora	Goniastrea spp.	0.5
16b	2	Other organisms	Tridacna spp.	0.5
16b	2	Sand	Sand	1.5
16b	2	Submassive non-Acropora	Montipora spp.	3.5
16b	2	Tabulate Acropora	Acropora spp.	13.5
16b	2	Turf algae	Filamentous algae	50
16b	3	Coralline algae	Coralline algae	0.5
16b	3	Corymbose Acropora	Acropora spp.	17
16b	3	Encrusting non-Acropora	Montipora spp.	1.5
16b	3	Macroalgae	Fleshy Macro Algae	3
16b	3	Sand	Sand	6.5
16b	3	Submassive non-Acropora	Montipora spp.	0.5
16b	3	Tabulate Acropora	Acropora spp.	38.5
16b	3	Turf algae	Filamentous algae	32.5
17	M	Branching Acropora	Acropora spp.	7.5
17	M	Branching non-Acropora	Echinopora spp.	4
17	M	Branching non-Acropora	Seriatopora spp.	2
17	M	Coralline algae	Coralline algae	1.5
17	M	Corymbose Acropora	Acropora spp.	1.5
17	M	Encrusting non-Acropora	Echinopora spp.	5
17	M	Encrusting non-Acropora	Montipora spp.	7
17	M	Foliose non-Acropora	Echinopora spp.	4
17	M	Foliose non-Acropora	Montipora spp.	9
17	M	Macroalgae	Fleshy Macro Algae	5
17	M	Massive non-Acropora	Favid spp.	0.5
17	M	Submassive non-Acropora	Non-Acropora coral	2.5
17	M	Submassive non-Acropora	Pocillopora damicornis	0.5
17	M	Turf algae	Filamentous algae	50
17	S	Branching Acropora	Acropora spp.	19
17	S	Branching non-Acropora	Echinopora spp.	1.5
17	S	Branching non-Acropora	Seriatopora spp.	2.5
17	S	Coralline algae	Coralline algae	2.5
17	S	Corymbose Acropora	Acropora spp.	6.5
17	S	Encrusting non-Acropora	Echinopora spp.	1
17	S	Encrusting non-Acropora	Montipora spp.	11.5
17	S	Foliose non-Acropora	Echinopora spp.	3.5
17	S	Foliose non-Acropora	Merulina spp.	1.5

Site	Transect	Benthic category	Detailed description	Sum of percent cover
17	S	Foliose non-Acropora	Montipora spp.	11.5
17	S	Macroalgae	Fleshy Macro Algae	0.5
17	S	Sand	Sand	0.5
17	S	Submassive non-Acropora	Montipora spp.	1.5
17	S	Turf algae	Filamentous algae	36.5
17	N	Branching Acropora	Acropora spp.	7.5
17	N	Branching non-Acropora	Seriatopora spp.	1
17	N	Coralline algae	Coralline algae	1.5
17	N	Encrusting non-Acropora	Montipora spp.	6
17	N	Foliose non-Acropora	Echinopora spp.	2
17	N	Foliose non-Acropora	Montipora spp.	25
17	N	Macroalgae	Fleshy Macro Algae	5
17	N	Tabulate Acropora	Acropora spp.	4
17	N	Turf algae	Filamentous algae	48

14 Appendix 6: Raw data for juvenile coral colonies 2006

SITE: 1 *RECORDER:* SLO *DATE:*

	Colony sizes (cm)		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	4, 8, 5, 5, 7, 10, 2, 3, 5, 7, 8, 6, 6, 4, 4, 6, 5	10, 9, 3, 4, 3, 7, 8, 5, 4, 8, 5, 4, 4, 3, 2, 7, 3, 3, 5, 5, 5, 8, 7, 5	10, 6, 4, 1.5, 5, 8, 7, 2, 6, 5, 7, 6, 5, 4, 6, 5, 3
POCILLOPORID	10, 4, 4, 10, 4, 6, 8, 5, 5	4, 4, 6, 9, 7, 10, 8	4, 9, 5, 6, 6, 6, 9
PORITID		6	3, 7, 3, 2
FAVIID	3, 4, 6, 6, 10, 7, 6, 10	4, 5, 6	8, 5
C. microphthalma	10, 5, 4, 5, 6, 6, 6	6, 7, 5, 6, 9, 8, 6, 8, 10, 6, 5	10, 5, 9, 5, 4, 2, 2, 5, 7, 5, 6
OTHER/UNKNOWN		4, 10, 5	6, 7, 6, 6, 7, 5

SITE: 2 *RECORDER:* SLO *DATE:*

	Colony sizes (cm)		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	1, 2, 2, 4, 4	5, 4, 6, 3, 1, 1, 2, 1, 4, 2, 7, 2, 3, 3, 1	2, 1, 5, 4, 6, 5, 5, 4, 3, 2
POCILLOPORID	5, 2, 3, 4, 5, 5, 4, 3	6, 2, 10, 5, 5	4, 4, 2, 5, 7, 10
PORITID		6, 5, 5	3, 2, 2
FAVIID	3, 5	3	2, 4, 1
C. microphthalma			4
OTHER/UNKNOWN	10, 3, 2, 4, 5, 6, 5, 2, 2, 3, 3, 6, 4, 6, 6, 10, 6, 5, 10	3, 10, 3, 4, 1, 2, 3, 5, 3, 5, 10	5, 4, 5

SITE: 3 *RECORDER:* SLO *DATE:*

	Colony sizes (cm)		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID		6, 4, 10	3, 7, 4, 3, 2, 5, 5, 5, 2, 4, 3
POCILLOPORID	10, 7, 8	5, 9, 4, 7, 6, 7	7, 8, 5, 3
PORITID			
FAVIID	6	8, 7	6, 5, 3
C. microphthalma			
OTHER/UNKNOWN	6, 4	3, 8	6, 5, 5, 4, 3

SITE: 4 *RECORDER:* SLO *DATE:*

	Colony sizes (cm)		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	2	7, 6, 6, 9	2, 5, 8, 4, 5, 4, 6, 10
POCILLOPORID	9, 8, 6	10	10, 10, 6, 10, 8, 10, 4, 6, 6
PORITID			

FAVIID	3		
C. microphthalma		6	5
OTHER/UNKNOWN	3		6

SITE: 5 *RECORDER:* SLO *DATE:*

	Colony sizes (cm)		
	(N)ORTH[1]	**(M)ID**	**(S)OUTH**
ACROPORID	-	4, 3, 7, 6, 6, 4, 6, 8, 6, 4, 4, 7	9, 8, 8, 5, 7, 4, 9
POCILLOPORID	-	7, 5, 5, 4, 7, 4	10
PORITID	-	8	9, 5, 6
FAVIID	-		8, 10, 9, 5
C. microphthalma	-	3, 4, 7, 5, 6	LOTS
OTHER/UNKNOWN	-	6, 5	2, 6

SITE: 6 *RECORDER:* SLO *DATE:*

	Colony sizes (cm)		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	2, 1, 4, 1, 3, 3, 2, 1, 2, 3, 3, 3, 5, 3, 3, 4, 3, 4, 2, 5, 2, 4, 4, 2	3, 5, 3, 3, 4, 2, 3, 3, 1, 2, 2, 1, 3, 5, 4, 5, 2, 3, 2, 2, 2, 5	8, 3, 1.5, 7, 4, 2, 2, 4, 5, 3, 3, 1, 2, 3, 1, 3, 5, 6, 3, 3, 4, 1, 2, 3, 2, 2, 2, 2, 4, 3, 2, 2, 4, 2
POCILLOPORID	6, 5, 7, 3, 10, 6, 8, 6, 4, 7	10, 7, 2, 5, 5, 8, 7, 9, 4	6, 7, 3, 3, 4, 3, 5, 10, 7, 2, 2
PORITID	3		
FAVIID	9, 2, 7, 8, 5, 5, 10, 8	7, 5, 10, 3, 10, 9, 8, 4, 4	10, 7, 3, 5, 7, 4
C. microphthalma	5, 5, 6, 4, 10, 9	6, 5	
OTHER/UNKNOWN	2, 2, 3, 2, 3, 2, 5, 6, 4, 5, 4, 6, 10	6, 3, 7	6, 3, 6, 7, 6, 5, 6

SITE: 7 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	2, 1		
POCILLOPORID	5		
PORITID			
FAVIID	8, 10, 3	8	9, 3, 4, 3
C. microphthalma	everywhere	everywhere	everywhere
OTHER/UNKNOWN	5, 4, 5, 4, 6, 6, 2, 3, 5, 8, 4, 3, 4, 4	3, 7, 7, 5, 3, 3, 4, 2, 1, 3, 3, 10, 10	4, 9, 10, 4, 3, 6, 4, 5, 5, 6, 3, 3, 10, 8, 6, 9

SITE: 8 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	8	7, 5, 2, 10, 10, 10, 8	4, 5, 4
POCILLOPORID	5, 5, 5, 2, 9, 9, 10, 7	8, 10, 10, 8, 8, 8, 4, 10, 6, 8	4, 3, 10, 10, 4
PORITID			

[1] Juvenile coral colony numbers were not recorded for the northern transect at site 5.

FAVIID	8, 6, 6	3	3
C. microphthalma	4, 5	6, 8	6, 5, 7, 9, 8
OTHER/UNKNOWN	6, 5	8, 6, 10, 7	10, 10

SITE: 9 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID		5, 5, 3, 3	4
POCILLOPORID	10	6, 10, 8, 8	10, 10, 10
PORITID			
FAVIID	3, 2, 2, 10, 10, 8, 6, 3, 6	5, 10, 4, 3, 2, 4, 6, 10, 10, 8	10, 8, 5, 6, 8, 10, 7, 4, 3, 6, 5, 5
C. microphthalma	8	5, 6, 6, 7, 8, 7, 9	5, 8, 10, 2, 6, 3
OTHER/UNKNOWN	5, 10	10	7

SITE: 10 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	2, 2, 3, 3, 3, 5, 2, 2, 2, 2, 10, 2, 3, 4, 4, 6, 3	3, 3, 2, 2, 1, 2, 3, 3, 2, 2, 5, 3, 6, 2, 2, 4, 4, 6, 2, 3, 4, 1, 2, 2, 3, 3, 3, 4, 2, 3, 3, 3, 1, 4, 2, 5, 3, 5, 3, 4	5, 5, 5, 4, 2, 4, 1, 4, 3, 3, 4, 3, 3, 3, 2, 2, 5, 3, 3, 4, 4, 3, 3, 6, 4, 3, 3, 4, 10, 4, 5, 4, 3, 3, 3, 2, 2, 2, 3, 5, 4
POCILLOPORID			
PORITID			
FAVIID	3, 10, 10, 5, 5, 8, 4, 2, 3	10, 3, 10, 5, 5, 3, 5, 10, 4, 5, 4, 3	6, 3, 9, 6, 3, 4, 5, 3, 3, 5
C. microphthalma	lots		everywhere
OTHER/UNKNOWN	1, 6, 6, 8, 2, 6, 10, 5, 3, 9, 3, 8, 10, 3	5, 3, 10, 10, 5, 5, 10, 3, 3, 8, 1, 5, 8	3, 3, 7, 4, 3, 1, 2, 1, 1, 5, 5, 6, 5, 6, 10, 2, 3, 8

SITE: 11 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	1, 1, 1, 2	2, 1, 4	2, 3, 3, 10
POCILLOPORID		3	
PORITID			4
FAVIID	5, 7, 5, 3, 6, 3	5, 10, 4, 10, 5	2, 1, 2, 6, 4, 2, 3, 5
C. microphthalma			
OTHER/UNKNOWN	4, 6, 3, 2, 6, 8, 4, 3, 4, 10, 8, 4, 4, 3, 2, 3, 4, 10, 5, 6, 6, 7, 6, 8, 1, 1, 5, 7, 8, 8, 10, 4, 3	6, 7, 10, 8, 6, 10, 4, 5, 5, 2, 3, 4, 5, 4, 3, 10, 3, 5, 6, 3, 3, 2, 3, 7, 3, 3, 5, 5, 3, 10, 6, 6, 6, 5, 6, 4, 5, 3, 4, 4, 5, 6, 4, 3, 10	3, 7, 8, 5, 9, 4, 5, 3, 4, 9, 3, 10, 9, 5, 4, 10, 10, 10, 8, 5, 5, 5, 3, 5, 2, 3, 3, 3, 5, 3, 3, 5, 6, 10, 8, 10, 8

SITE: 12 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	6, 5, 10, 7, 5, 3, 2	8, 9, 10, 6	6
POCILLOPORID	10, 5, 7, 4, 6, 10, 6	10, 9, 6, 10	10, 7, 7
PORITID			

FAVIID	4, 4	7	3, 6
C. microphthalma			6, 2, 3, 7
OTHER/UNKNOWN		5, 9	

SITE: 13 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	4, 2, 3, 3, 3, 1	6, 5, 5	4, 4, 5, 3, 6, 5, 5, 3, 4, 5, 3, 3, 3, 2, 3, 7, 4
POCILLOPORID	7, 8, 6, 8, 4, 7, 8, 6	2, 8, 9	6, 9, 3, 4, 5
PORITID	8, 5	5	5
FAVIID	10, 7, 5, 10, 5, 9, 10, 10, 8, 6, 9, 7	5, 5, 7, 3, 1, 2, 7, 8, 3, 10, 7, 8, 7, 6, 5, 10, 6, 1	4, 3, 10, 10, 5, 3, 6, 8, 10, 7, 10, 5, 5, 6, 5, 10, 2, 3
C. microphthalma	6, 3, 7	6, 4, 4	10
OTHER/UNKNOWN	1, 2, 10, 5, 10, 4, 6	5, 6, 8, 3, 4	2, 6, 5, 3, 6, 5, 3, 2

SITE: 14 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	2, 3, 4, 3, 10, 4, 3	2, 2, 4, 3, 6, 3, 3	3, 4, 2, 10, 3, 3, 4, 4, 5, 2, 2, 4, 5, 2
POCILLOPORID			5
PORITID			
FAVIID	4, 6, 2	6, 2, 3, 6, 4	10, 2, 1, 10, 4, 5, 5, 5, 5, 5, 3
C. microphthalma			lots
OTHER/UNKNOWN	10, 9, 8, 5, 5, 6, 7, 3, 3	5, 6, 4, 4, 5, 6, 3, 8, 10	3, 3, 7, 10, 3, 2, 10, 6, 10, 7, 2

SITE: 15 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	7, 4, 5, 6, 6, 5, 5, 5, 6, 6, 6, 6, 6, 7	7, 6, 9, 4, 3, 7, 6, 9, 1, 1, 2, 2, 7, 5, 2, 10, 6	8, 2, 10, 6, 10, 5, 4, 6, 3, 10, 1.5
POCILLOPORID	6, 6, 9, 3, 4, 2, 10, 6, 5, 6, 3, 6, 10, 4, 5, 3, 6	6, 4, 9, 6, 5, 10, 3, 4, 8, 10, 9, 6, 10, 8, 6, 9, 9, 7, 10, 6, 4, 10, 8, 6	10, 5, 9, 6, 7, 10, 5, 5, 9, 5, 6, 6
PORITID	7, 8, 4	7	
FAVIID	5, 5, 2, 10, 4, 1, 2, 3	8, 3, 7, 8, 9, 5, 9, 4, 5, 4, 7, 6, 8, 3	4, 10, 6, 3, 10, 3, 5, 2.5
C. microphthalma	6, 7	8, 9	
OTHER/UNKNOWN	3, 7, 10, 8, 7, 7, 9, 9, 3, 6, 9, 6, 6, 9, 5, 10, 9, 6, 4	5, 8, 10, 5, 3, 6, 7, 6, 8, 8, 5, 7, 6, 5, 9, 5, 10	8, 10, 9, 6, 6, 5, 9, 6, 5, 7

SITE: 16 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	10, 9, 3, 10, 3	10, 6, 3, 5	10, 3, 5, 3, 4
POCILLOPORID	7, 5, 4, 8, 6, 1, 2		3, 2, 5, 10
PORITID			
FAVIID	9, 5, 4, 5, 4, 7, 10, 3	5, 5, 7, 8, 4, 8, 10, 10,	5, 8, 4

		2, 2	
C. microphthalma			
OTHER/UNKNOWN	8, 6, 5, 5, 4, 3, 3, 4, 2, 4, 3, 4, 2, 5, 4, 7, 6, 3, 4, 7, 8, 9, 2, 2, 3	5, 8, 2, 5, 3, 7, 5, 5, 4, 5, 9, 4	10, 6, 4, 7, 10, 8, 4, 4, 2, 5, 10, 3

SITE: 17 *RECORDER:* SLO *DATE:*

	Colony sizes		
	(N)ORTH	**(M)ID**	**(S)OUTH**
ACROPORID	5, 8, 5, 6, 5, 8, 3, 3, 6, 5	4, 8, 5, 5, 10, 4	7, 4, 6, 4, 3, 4, 3, 5, 5, 6, 10, 5, 5, 5, 4, 3, 8, 2, 2, 3, 1, 1, 4, 5, 5
POCILLOPORID	8, 4, 4, 6	10, 8, 7, 9, 6, 8, 7, 10, 6, 5, 6, 5	7, 5, 6, 9, 10, 3, 3, 5, 5
PORITID			
FAVIID		10	3, 5
C. microphthalma	7, 6, 5, 5	5, 6, 5	7, 7, 7, 5, 10, 6, 8, 5, 3
OTHER/UNKNOWN	8		

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