The current status of sessile benthic organisms on the Great Barrier Reef

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Introduction

Sustaining a healthy environment requires an understanding of the processes and extent of temporal change in sessile benthic assemblages. Case histories of reef degradation have clearly indicated the need for a systematic approach to understanding change (Hughes 1994; Maragos et al. 1985). For an area as large as the Great Barrier Reef (GBR) predictive and hypothesis generating models are the only option for such a systematic approach. However obtaining data of sufficient scope and detail is a difficult task. The area encompassed by the Great Barrier Reef World Heritage Area contains a large number of reefal and coastal marine communities. In order to assess status, information on distribution is required over a broad area so as to identify ecological communities that can form the basis for management plans. Most spatial studies have focussed either on a limited number of localities (e.g. van Woesik 1992) or the changes in community composition from inshore to offshore habitats (Done 1982; Oliver et al. 1995; Wilkinson and Cheshire 1988; Dinesen 1982). These studies demonstrated that the strength of the physical and biological gradients from inshore to offshore means that reefs that are widely separated in latitude, but are in equivalent positions on the continental shelf are more similar to each other than reefs in other cross-shelf positions at the same latitude.

In this document we present existing spatial information in a context which emphasises the relationship between physical and biological variables. This has been a successful strategy in the reef environment (Massel and Done 1993; Van der Laan 1994). We describe the distributional patterns of major components of the benthos at the same spatial scale as functionally connected hydrodynamic patterns. As the hydrodynamic regime is stable over decades, describing spatial patterns on this scale provides a stable framework in which to assess the response of benthic communities to changes in the biological, physical or anthropogenic pressures. Existing temporal information is discussed, but insufficient data are available at present to allow a meaningful analysis of temporal trends at the large spatial scales relevant to managing and conserving World Heritage values. More work is also needed to be confident of understanding how population dynamics manifest in small scale experimental and monitoring studies relate to larger spatial scales.

The data presented here were collected as part of the Australian Institute of Marine Science's (AIMS) Long Term Monitoring Program (LTMP). For the purposes of the LTMP the GBR is subdivided into 11 sectors, six of which contain reefs that are surveyed (Fig. 1). Sites on the north east flank of 52 reefs at 6-9 m depth are visited on an annual basis. Therefore, comparisons of benthic communities in this document refer only to a small subset of the habitats that may be encountered at any one reef. The advantage of this sampling regime is that a large spatial area is surveyed each year and relevant comparisons between reefs in different locations can be made. At each reef data are collected on water quality, reef fish and sessile benthos. A broadscale survey using the manta tow method (English et al. 1994) of the entire reef perimeter is also conducted at each reef, and the number of crown-of-thorns starfish (COTS) and an estimate of hard coral cover are recorded. A SONY hi-8 underwater video is used to film benthic cover on each transect. The resulting footage is a belt transect from which percent cover can be calculated.

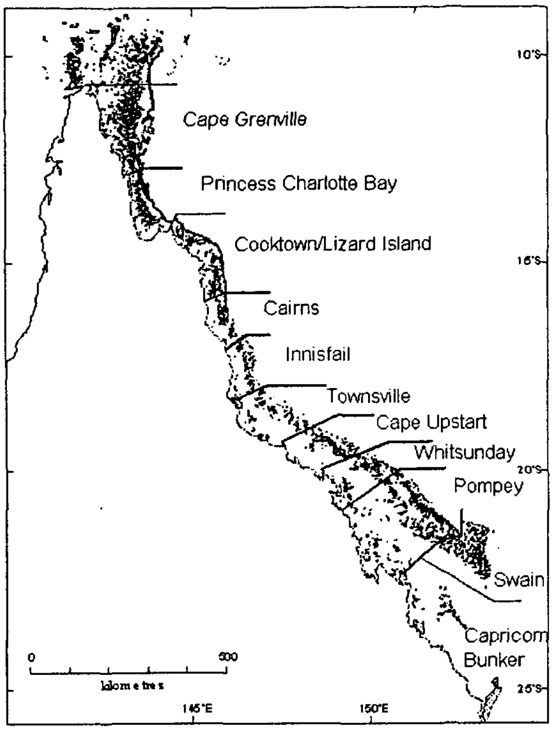


Figure 1. Location of AIMS LTMP monitoring sectors in relation to the Queensland coast. Benthic surveys are conducted on inner, mid and outer shelf reefs in the following sectors; Cooktown-Lizard, Cairns, Townsville, Whitsundays, and the Swains. Outer reefs only in the Capricorn Bunkers.

The percentage cover data can be examined at various levels: broad groups, lifeforms, families, genera or species. Group level data summarise the components of the community into the following categories: abiotic, hard corals, soft corals, macro-algae, sponges and other. Lifeform data are concerned with hard coral growth forms. Generic and species level data group each hard coral according to its taxonomic affiliation. At generic level the results described here are confined to 30 of the most abundant hard coral genera found on the GBR. Genera were excluded from discussion if they were present on less than 50% of reefs within any one shelf position. In general the methods used in this study are biased against organisms with cryptic habitat association. This applies to some coral genera and also macro-algae and sponges. Detailed descriptions of the project design and relevant sampling protocols of the LTMP can be found in Oliver et al. (1995) and Christie et al. (1996).

Spatial trends in sessile reef benthos

Cross-shelf patterns

Most monitoring sites have a cover of living benthos approaching 100%, being composed predominantly of hard coral, soft coral and turf algae. The less abundant lifeforms, sponges and macro-algae, average 1.2 ± 0.3% and 2.6 ± 0.8% respectively. Shelf position (inner, mid or outer) refers to the location of a reef on the continental shelf and its relative proximity to the coast. Cross-shelf variation in the benthic community is well documented for the GBR (Done 1982; Oliver et al. 1995). The physical and biological gradients that characterise the cross-shelf environment create benthic communities with fundamentally different values for factors relevant to temporal change, such as disturbance regimes, recruitment, and growth and survival of hard coral. Cross-shelf patterns in the benthos are clearly related to exposure and water quality and are temporally consistent. At the levels of group, lifeform and genus, cross-shelf

trends account for 30-50% of the variation in the benthos (Oliver et al. 1995). Although most genera have broad cross-shelf distributions only a few account for most of the hard coral cover. *Acropora* is the most abundant genus in all shelf positions and increases from a mean of 21 ± 3% on inner shelf reefs to 35 ± 3% of the hard coral community on the outer shelf. *Porites* is the second most abundant genus, comprising on average 10% of the hard coral community in all shelf positions (Fig. 2).

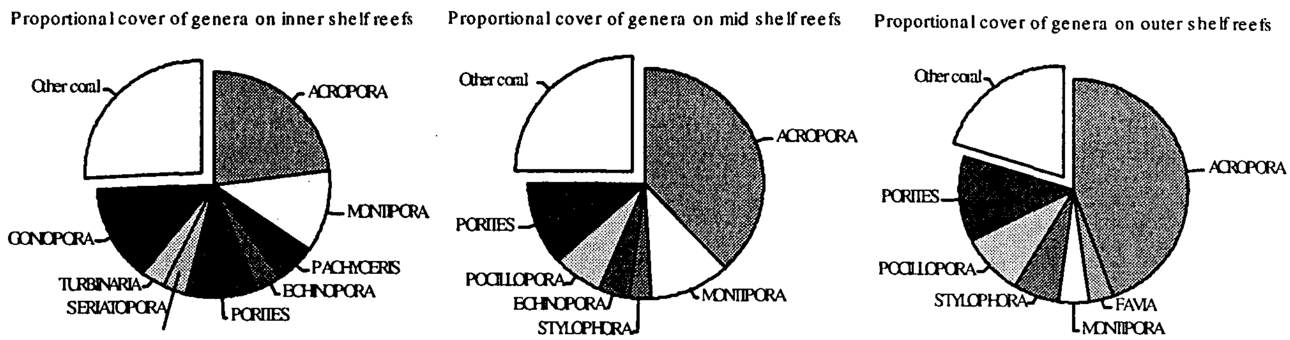
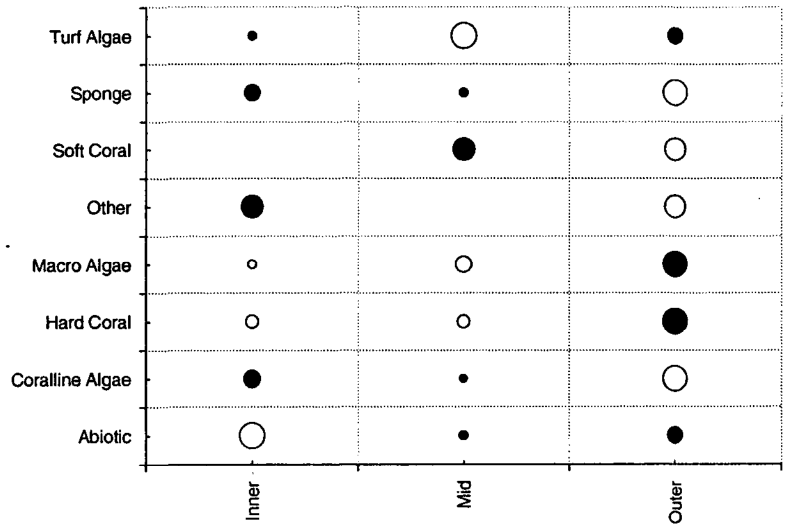


Figure 2. Proportional abundance of hard coral genera by shelf position

The outer reef environment is characterised by exposure to swell and water bodies dominated by oceanic conditions. Latitudinal changes in the effectiveness of the barrier formed by outer reefs lead to variable exposure regimes as well as geomorphology and productivity potentials in the mid-shelf environment. The benthic community is also more variable in response to the variety of habitats available in this shelf position. Inner reef communities are less affected by latitudinal changes in circulation than mid- and outer reefs and vary more in response to local variation in habitat availability and runoff. The inner shelf environment is characterised by low exposure to swell and water quality influenced by terrigenous factors. Suspended solids are consistently higher than on mid and outer shelf reefs which show similar values (Oliver et al. 1995). Some water quality parameters associated with runoff (e.g. salinity, nitrates, phosphates) are also very variable, with inner reefs experiencing extreme values during high rainfall events. Historically, inner reefs have been more influenced by sea level change resulting in variation in structure which influences benthic habitat availability.

Inner reefs typically have non-contiguous reef structure which means that a higher percentage cover of silt, sand and rubble (abiotic) is found in these sites than on reefs in other shelf positions (Fig. 3). Rubble and consolidated substrate are colonised by turf algae, soft corals and hard corals. Large stands of coral (e.g. *Goniopora, Turbinaria* and *Pachyceris*) are found at some sites resulting in high overall percentage cover of hard coral.

Outer reefs have a greater proportion of coralline algae (Fig. 3). Foliose corals are more abundant on the inner shelf. Branching coral and bottlebrush growth forms of *Acropora* are more common on inner reefs while digitate, encrusting and submassive growth forms are more common on outer reefs (Fig. 3). The latter two growth forms are mainly represented by two species: *Acropora palifera* and *A. cuneata*. Corymbose *Acropora* spp. are relatively abundant on both mid- and outer shelf reefs. Tabulate *Acropora* are more abundant on mid-shelf reefs (Fig. 3). In general the more abundant hard coral growth forms are correlated with substrate type: those most abundant in environments with high sedimentation and low energy have smaller areas of basal attachment; those from high energy environments with consolidated substrates have lower profiles and larger basal attachments.



Abbreviation	Hard coral lifeform
CS	Coral submassive
CMR	Solitary corals
CM	Coral massive
CF	Coral foliose
CE	Coral encrusting
CB	Coral branching
ACX	A. bottlebrush
ACO	A. corymbose
ACT	A. tabulate
ACS	A. submassive
ACE	A. encrusting
ACD	A. digitate
ACB	Acropora branching

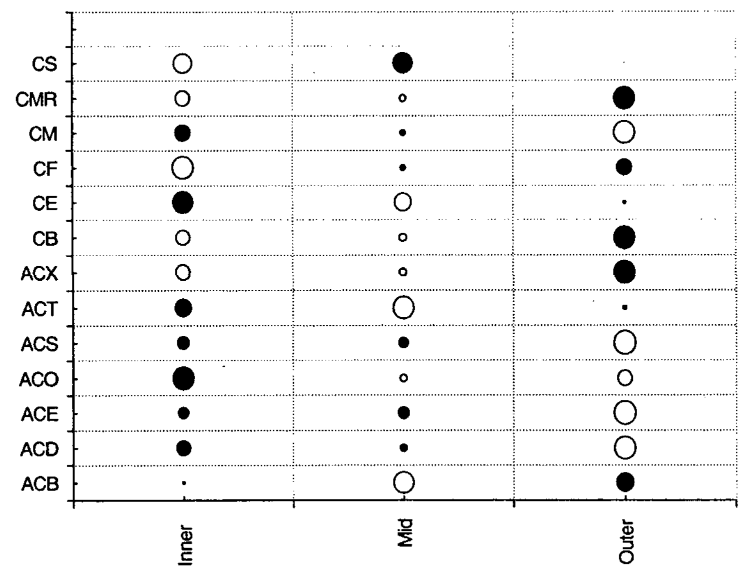


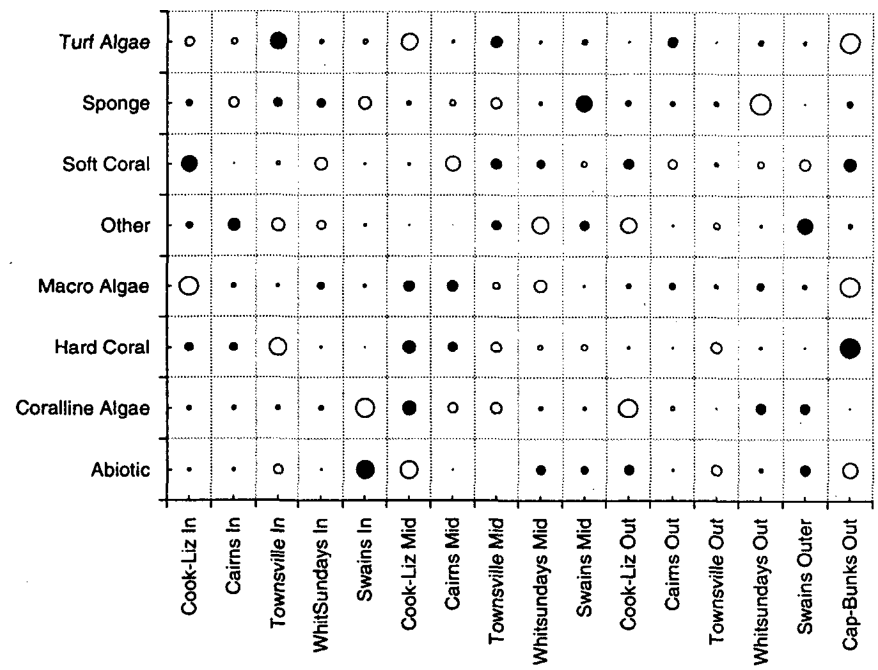
Figure 3. Relative abundance of benthos across the continental shelf of the GBR. Inner reefs are closest to the coast. The size of each dot indicates abundance relative to the overall reef mean. Clear dots indicate values above the mean and black dots indicate values below the mean. Blanks mean the value is equal to the reef mean. Values for lifeform are proportional to total coral cover.

Variations with latitude

Although small in comparison to cross-shelf gradients, regional patterns (Fig. 4) of benthic communities also provide a meaningful basis for management and assessment of status.

In the Cooktown-Lizard sector the shelf drops steeply into deep water. This has been favourable for reef growth and there are reefs situated on the shelf edge that have steep slopes and form a continuous barrier. They are structurally similar and have a high component of coralline algae, *Millepora* spp. and digitate Acroporid corals (Fig. 4). Corals of the genera *Pocillopora* and *Stylophora* are relatively more abundant than in other regions. The continuous outer barrier and small tidal variation means wave energy is low on mid-shelf reefs and

circulation is restricted. In the context of the GBR, mid-shelf reefs in the Cooktown - Lizard region form a distinct group, being more like inner reefs than mid-shelf reefs in other regions. They have higher relative abundance of sand and turf algae. In the coral community, massive corals and the genera *Porites*, *Diploastrea*, *Lobophyllia*, *Echinopora* and *Goniastrea* are relatively abundant. Solitary corals are also more common than on other mid-shelf reefs.



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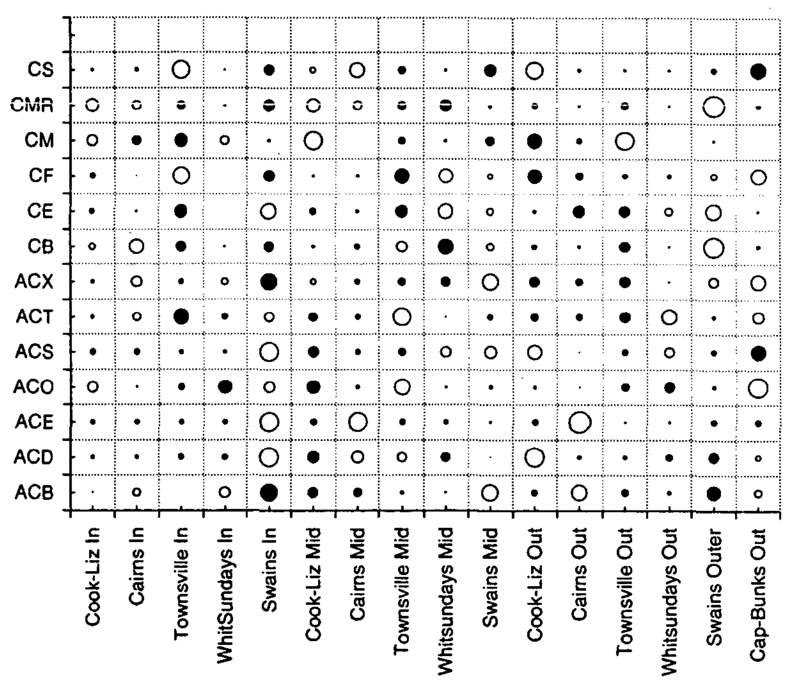

Figure 4. Relative abundance of benthos by sector and shelf position. Sectors are shown in latitudinal order from north to south. The size of each dot indicates abundance relative to the within shelf mean. Clear dots indicate values above the mean and black dots indicate values below the mean. Blanks mean the value is equal to the within shelf mean. Values for hard coral lifeforms are proportional to total coral cover.

To the south the continental shelf gets wider and the outer slope is more gradual. In the Cairns sector both outer and mid-shelf reefs are exposed to oceanic swells and circulation. In both Cairns and Townsville sectors, reef development is sparse in comparison with the Whitsundays and Swains regions which experience high tidal and current regimes as well as exposure to ocean swells. In the Cairns and Townsville sectors, reefs are scattered across the exposed outer slope and are variable in their structure, slope and aspect and have variable benthic communities. Mid-shelf reefs in the Cairns sector have a high incidence of digitate and submassive *Acropora* (Fig. 4). Mid- and outer reefs in the Cairns sector are similar to outer reefs in the Swains and Whitsundays in having relatively high abundance of soft corals (Fig. 4). High abundance of soft corals is correlated with low angle of the reef slope on exposed reefs. Sponges are also more abundant on outer reefs in the Whitsundays and Swains regions than in other regions.

The Swains region is unique in terms of the cross-shelf distribution of benthic communities. Inner-shelf reefs are unlike those in other regions, firstly because they have minimal influence from terrestrial factors due to the distance from the mainland and secondly because the broad inner channel allows more fetch and makes them more exposed than the midshelf reefs nearby, sheltered as these are behind the relatively dense outer reefs. In the low exposure mid-shelf communities, a contiguous reef slope commonly grades into a sediment-based slope with high coral cover and a diversity of coral growth forms and species. The benthic community on inner Swains reefs is similar to that on outer reefs in other regions.

Reefs in the Capricorn-Bunker region are isolated and influenced by a regime of current and water masses that is different from reefs in other sectors. They experience exposed conditions and typically have shallow reef slopes. Reefs in the Capricorn-Bunkers have a high component of turf algae (mean 65% $\pm$ 6.9 compared to a mean for all reefs of 38% $\pm$ 2). Corymbose *Acropora* corals and massive favid corals are relatively abundant.

The role of disturbance

The relative stability of the spatial pattern of benthic communities created by hydrodynamic and structural constraints is overlaid by processes such as disturbance and recruitment variability operating at shorter time scales. Results of monitoring suggest that disturbance is a formative factor for many of the benthic communities of the GBR. The incidence of disturbance is unpredictable within a management time frame. Understanding the temporal response of communities is therefore crucial and long term temporal data are required to assess the present status and likelihood of persistence of benthic communities. In some cases historical information and monitoring data are available which support the findings of the benthic component of the LTMP. Factors that have caused large shifts in community structure on mid and outer shelf reefs are cyclones and COTS predation.

Communities dominated by *Acropora* appear to be characteristic of reefs with high disturbance regimes. Monitoring studies in the Capricorn-Bunkers region prior to 1990 indicated the benthic community was dominated by tabulate *Acropora.* Coral cover in 1987-88 was 40-50% (Bass et al. 1989) but dropped to 20-30% after 1990. No cyclonic storms were recorded and the disturbance event that produced the present algal-dominated community is unknown. Where recruitment and growth have occurred following the depletion of hard coral in 1989, the benthic community is once again dominated by tabulate *Acropora* (100% of regrowth was due to an increase in the percentage cover of *Acropora* at One Tree Island). Outer reefs in the Cooktown-Lizard and, to a lesser extent, the Cairns region are also presently recovering from damage to the reef slope community by cyclone 'Ivor' (van Woesik et al. 1991). The greater change in coral cover in Cairns and Cooktown-Lizard sectors (Fig. 5) compared to other outer reefs is primarily a result of *Acropora* recruitment and growth. In the Cooktown-Lizard sector,

59% of regrowth on outer reefs was due to an increase in the percentage cover of *Acropora*. The scale of patchiness both between reefs and within reefs as a result of disturbance and recovery varies in both the Cooktown-Lizard region and in the Capricorn-Bunkers (Doherty et al. in press). In both sectors however, there is evidence that a significant recruitment of *Acropora* occurred within a few years of disturbance and that pre- and post-disturbance coral communities were dominated by *Acropora* spp. There is also evidence for the persistence of *Acropora*-dominated communities following COTS outbreaks. Coral cover on mid-shelf reefs in the Townsville sector was greatly reduced by COTS activity in the 1980s but has been increasing rapidly over the last three years. In 1994-95 average coral cover was 44.8 ± 10.6% compared to a mean for all reefs of 22.2 ± 2.3% in the same period. This high value is a reflection of the dominance of tabulate and corymbose *Acropora*. As was the case in the Capricorn-Bunkers this community was also dominant prior to the most recent disturbance (Williams pers. comm.).

Biological disturbance events in the form of predation of coral communities by COTS have affected many of the survey reefs. Coral cover at Gannet Cay in the Swains sector decreased between 1993-94 and 1994-95 as a result of predation on coral within the monitoring sites. In these years the Swains was the only sector between Cooktown-Lizard and the Capricorn-Bunkers to have COTS outbreaks. So far COTS outbreaks have affected few reefs in the southern sectors (Whitsundays to Capricorn-Bunkers) compared to the north.

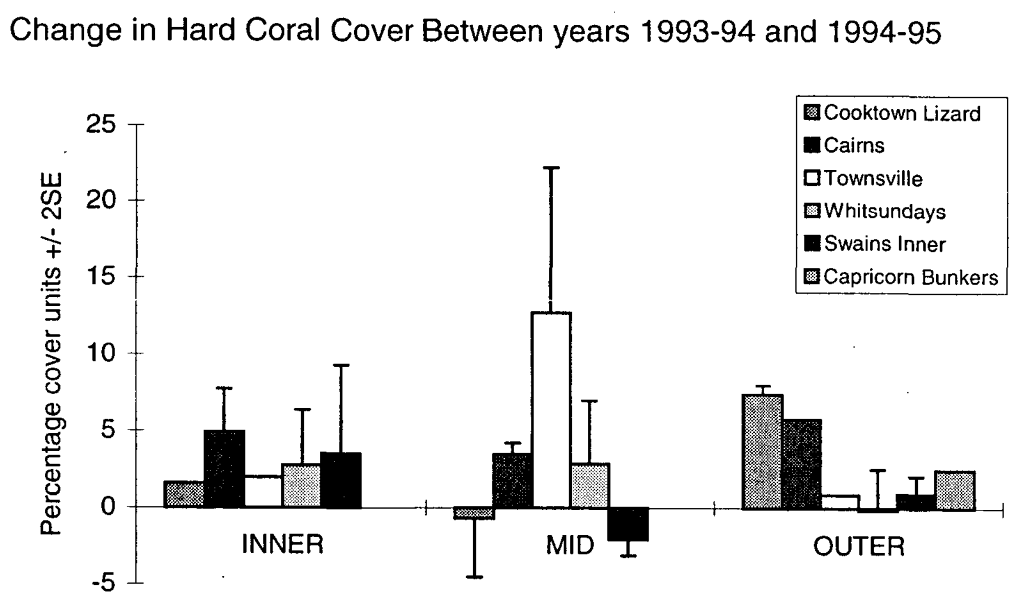

Figure 5. Percentage change hard coral ± 2 standard error by sector and shelf position. Percentage units are absolute.

In the Townsville, Cairns and Cooktown-Lizard sectors 17 of 25 reefs where benthic surveys are conducted annually have outbreak histories (Fernandes 1991). The benthic communities in these regions are clearly influenced by impact of and recovery from COTS predation. Recovery of reefs in Cooktown-Lizard and Cairns sectors differs from that observed on mid-shelf reefs in the Townsville region. In 1994-95 hard coral cover was lower on inner and mid-shelf reefs in Cairns and Cooktown-Lizard than the southern sectors (ANOVA $p<.01$) (Fig. 6). The Cooktown-Lizard region is presently experiencing COTS outbreaks on three of twenty two reefs surveyed during 1995-96 and has an average decrease in coral cover on mid-shelf reefs (Fig. 5). Cairns sector reefs on the other hand are increasing in coral cover at a proportional rate of 35% which is above the overall mean of 14.6% ± 3.2 for all survey reefs. This suggests that recovery is now under way in the Cairns sector.

Further investigation is required to determine if inner and mid-shelf reefs in Cooktown-Lizard and Cairns sectors should be considered to have a higher risk of degradation than other sectors, as recovery has been slower. The probability of coral mortality due to flood plumes is higher due to the narrow width of the continental shelf compared with more southern regions. The Cairns area also has extensive human use of the hinterland, high rainfall and high human usage of reefs. Reduced mixing and circulation may affect recruitment and growth potential for coral in the Cooktown-Lizard region. There is increasing evidence for the location of a centre of recruitment for COTS in the northern region. Available evidence suggests that the occurrence of large numbers of starfish at a reef is predictable at large spatial scales as the manifestation of high recruitment south of areas with already large adult populations (Moran et al. 1992). Numbers of COTS are presently increasing on the northern GBR (Engelhardt et al. this volume) so further decreases in coral cover are expected in the future. Reefs from the Whitsundays south may experience a different dynamic of COTS dispersal and population dynamics. Continued research on this issue is important to determine management strategies for reef benthos on the GBR. In summary, the type, frequency and intensity of disturbance and probable recovery rate and trajectory that any reef experiences are also related to hydrodynamic and structural factors (see Burrage et al. this volume). Developing models to adequately integrate physical and biological variables is necessary to manage an appropriate response to the changing status of reef communities.

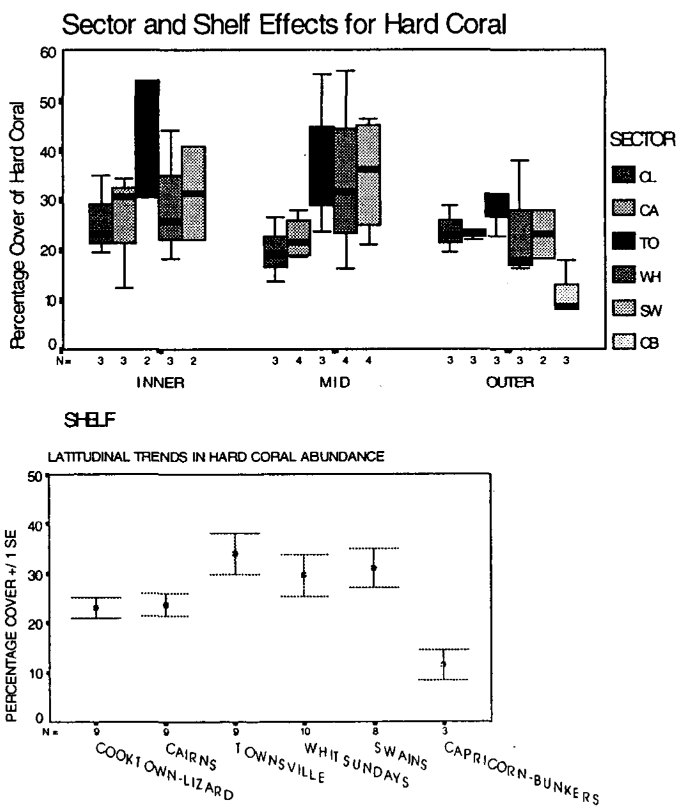

Figure 6. Boxplots of percent cover of hard coral in 1994-95 at each sector and shelf position and sector means (+/- 1 standard error).

The concept of assigning value for indices of reef health at a variety of spatial scales is used in conservation management and is relevant to management of the GBR World Heritage Area. For example, hard coral cover is commonly used by ASEAN countries as a measure of 'value'. While this has some relevance within defined boundaries it has little significance in comparing regions. In 1994-95 the mean percentage cover for hard coral was 27.2 $\pm$ 1.64% with 50% of

reefs having values for coral cover between 8 and 30%. A great range of values is found within each shelf position (Fig. 6). The average coral cover on the GBR is lower than on many other reef systems in the Indo-Pacific. No evidence exists to suggest this is a result of degradation. How value is assigned needs to be relevant to the scale at which management is implemented and the relative importance of the processes which structure benthic communities within this area.

For the GBR some natural management structures suggest themselves on the basis of historical evidence and current status. The uniqueness and conservation status of inshore reefs should be assessed in relation to regional land use and circulation patterns and runoff regimes in addition to coral species diversity which is high on some inshore reefs (Veron 1995). Impacts on coral due to elevated water temperatures are more likely in inshore areas as are phase changes to communities dominated by macro-algae (Done 1995). For mid and outer reefs three management regions are suggested. In the regional context the Capricorn-Bunkers are unique in that reefs are isolated from other reef communities on the GBR by physical distance and by periodic changes in the prevailing hydrodynamic conditions. Species compositions of fish and coral are also distinctly different from other regions in the GBR (Veron 1995; Sweatman et al. this volume). Veron (1995) postulates that the lower number of coral species in this region is due to a lack of habitat diversity with all reefs having limited topographical relief. A second region is formed by the Swains and Whitsundays where hydrodynamics and structural factors are a primary influence on the community, and a third from Townsville to Cooktown-Lizard where a history of high biological and physical disturbance is a primary factor.

Insufficient observations currently exist on disturbance and recovery rates of non-*Acropora* community types. Current monitoring methods need to be modified to ensure that communities with 'high value' as assessed by parameters of demography and productivity are adequately documented, as suggested by Done (1995). Both these tasks require additional information and compilation of existing data resources.

The contribution of monitoring data to managing the reef as a healthy and sustainable environment is two-fold. Risk assessment models such as those suggested by Done (1995) require large scale spatial information on the distribution of community types and process information of how each community functions. Exposure, water quality and circulation interact with disturbance by affecting recruitment supply, growth rates and by defining the kind of habitat that is available for colonisation. A meaningful assessment of status, however, does require a dedicated inter-disciplinary project. Compiling information on demographic population structure is the next priority for the benthic component of the LTMP to ensure that models for management and conservation can be successfully implemented.

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