INTRODUCTION

Recent decades have been characterised by increasing concern for conservation of the global environment, socially, economically and politically (Hendee *et al.* 1990). In particular, the past 30 years has seen a dramatic shift in approach to management of marine resources. Whereas historically access to marine resources was generally assumed, now restrictions on their access and use are commonplace. The development of numerous Marine Environment Protected Areas (MEPAs) encapsulates this recent shift in emphasis (Kelleher & Kenchington 1991).

The motivation for MEPAs typically includes conservation of marine environments and principles of multiple use (Kelleher & Kenchington 1991, Kenchington 1990). In practice, however, the establishment of MEPAs has been somewhat *ad hoc*, with the objectives of their declaration and management couched in generalities, and rarely consistent (McNeill, 1994). In many cases, the features to be conserved are not specified in detail. This is almost certainly reasonable in many (perhaps most) cases initially, because understanding of the function of the target ecological systems is rudimentary at best. We rarely understand completely, for example, the multitude of interactions that are essential for the maintenance of a particular habitat type.

Whatever the overriding objective(s) of a protected area, the extent and nature of features to be conserved must be established at some stage, usually meaning either the use of prior information (such as a resource inventory) or dedicated surveys or monitoring programmes. It is important also to establish a framework of regular, systematic, and carefully designed studies for monitoring the environmental status of the protected area(s) as a means of assessing the degree to which management strategies are ensuring the conservation of those resources.

The declaration of the Great Barrier Reef Marine Park in 1975 (GBR Marine Park Act 1975) arose out of concern about perceived threats to the Great Barrier Reef (GBR) from extractive activities, particularly mining, petroleum exploration and extraction, and fishing (Kenchington 1990). The rationale for the declaration of the Great Barrier Reef Marine Park, then, was firstly the conservation of the Great Barrier Reef as an ecologically valuable resource. Recognising the existing uses of the GBR, and potential benefits from continued use, however, a secondary motivation was to provide for ongoing human use and enjoyment of the GBR, consistent with the conservation of its environmental characteristics. The Act called for the GBR to be zoned for multiple use on a regional basis, but offered no guidance to the demarcation of regions.

Management of the GBR for conservation (as well as multiple use) should include efforts to conserve the full range of bio-geographical characteristics of reef assemblages. Adequate judgement of management strategies with respect to conservation of the GBR environment, therefore, requires sound empirical knowledge of spatial and temporal patterns in the distribution and abundance of organisms on the GBR under 'normal' conditions. The Great Barrier Reef Marine Park Authority (GBRMPA) sought to use existing knowledge of the hydrodynamics and geomorphology of the GBR to define several sections of the GBR Marine Park, which were eventually amalgamated into four major sections for the purposes of zoning and management (GBRMPA 1983, 1985, 1987, 1988, 1992). The GBRMPA adopted a strategy in each section of zoning different areas for different levels of human use, on the premise that ensuring minimum human impact on at least some areas would ensure conservation of the GBR's key features. The choice of particular areas for each zone, however, arose more out of patterns of contemporary human use than from knowledge of key bio-physical features of the ecosystem.

The GBRMPA recently has initiated planning for the protection of a system of 'representative areas' to ensure that samples of major features of the GBR are conserved. This approach necessarily draws more than the zoning approach on knowledge of the distribution and abundance of bio-physical features. Flexibility in allocation of resources to different management regimes should be greatest within relatively homogeneous bio-physical strata of the GBR, and least flexible across such strata. For this to happen, and for 'representative areas' to be chosen sensibly, some knowledge of the systematic patterns in distribution and abundances of reef biota is necessary.

Persistent Systematic Effects on Abundances

Done (1982), Williams (1982), Dinesen (1983), Williams & Hatcher (1983), and Russ (1984), suggested that strong gradients in abundances and/or occurrence of several species exist across the continental shelf of the GBR off Townsville, with inshore, mid-shelf, and shelf-break assemblages being distinct. Strong, predictable patterns in abundances have been observed also in conjunction with the major habitat-types within most reefs (Bradbury *et al.* 1987, Chave & Eckert 1974, Clarke 1977, Done 1983, Done & Potts 1992, Galzin 1987, Helfman 1978, Jones & Chase 1975), whilst latitudinal (regional) patterns in abundances have been observed for some species, but are generally perceived to be less dramatic than the cross-shelf or habitat related patterns (Doherty 1987, Sale *et al.* 1984, Williams *et al.* 1986).

In most cases, however, these systematic patterns have been thoroughly explored at only relatively few locations, and usually not together. It remains unclear how the cross shelf patterns suggested by previous workers relate to habitat-related patterns or regional patterns in abundances. Similarly, the consistency of habitat effects across the continental shelf or among regions is not well documented. Thus, the degree to which these patterns can be accepted as a general basis from which to implement conservation management plans remains uncertain.

Knowledge of systematic patterns in abundances is critical also in the design of monitoring programmes, impact assessment studies, and experimental field projects. This is so especially if systematic patterns across one effect (such as shelf position) are not consistent across other common effects (such as habitats). If important interactions between systematic effects occur, then it will be misleading to invoke general patterns on the basis of sampling within only selected (supposedly 'standardised') strata of any of those effects, as often has been the case. For example, Ayling (1983a,b) and Ayling & Ayling (1984a,b,c, 1985, 1986a,b) sampled reefs along the length of the GBR but sampled only one location on each reef (generally the northern end of the back-reef). The AIMS Long Term Monitoring Programme (AIMS 1992) now in progress (Oliver *et al.* 1995) adopts a sampling strategy similar to that reported by Sale *et al.* (1984) and Doherty (1987), which involved sampling three sites at only one location on the north-eastern margin of each reef. Williams (1982) attempted to standardise community surveys across the continental shelf off Townsville by sampling exposed reef slopes, but was forced by bad weather to confound exposure with reefs. It has been argued that such standardisation of the within-reef location of sampling should provide a satisfactory index of abundances on each reef for comparisons among reefs, regions, and assessment of cross-shelf patterns etc. This argument rests on the assumptions that: i) the relationship between the location sampled and other locations within the same habitat is consistent among reefs and across larger geographic (or temporal) strata; and ii) relationships among habitats are also consistent across reefs and larger-scale effects. The presence of interactions between Habitat and Region and/or Shelf Position would mean that regional or cross-shelf comparisons based on samples from only one Habitat would be prone to provide results that were habitat specific rather than applicable to entire reefs. The nature of interactions between cross-shelf effects, habitat effects, regional effects, and location effects on the GBR have been explored by Mapstone *et al.* (1995) with the data from this study to test the assumptions implicit in many prior sampling programmes.

Thus, a primary objective of this study was to investigate some aspects of spatial pattern in the abundances of a number of reef organisms over a large area of the GBR Marine Park. We were concerned principally with:

- *Acanthaster planci*, *Linckia laevigata*, and *Tridacna* spp.;
- Sessile benthic biota and non-living substrata, with particular emphasis on live corals;
- Fish with medium to great mobility over short periods, including *Plectropomus* spp., lutjanids, chaetodontids, and lethrinids;
- Fish with restricted home-ranges and relatively low mobility over short intervals, such as most of the pomacentrids and some labrids.

We chose to cover as many organisms as logistically possible because: 1) the choice of areas for explicit conservation should include consideration of as wide a variety of organisms as possible; 2) a monitoring programme (for assessing the status of managed areas) should take into account the status of several species; 3) the optimum sizes of sampling units proved to be the same for several organisms (Mapstone & Ayling 1993); 4) many of the organisms could be efficiently counted concurrently; and 5) much of the cost of such a study is incurred in getting to survey sites and support costs whilst in the field, and it was desirable to maximise the return from such costs.

Survey of *Acanthaster planci*

Outbreaks of *Acanthaster planci* (crown of thorns, COTS) on the Great Barrier Reef have become the focus of considerable financial, personal, and institutional resources over the past decade (Bradbury *et al.* 1985, Brodie 1992, Endean & Cameron 1990, Moran *et al.* 1988). The economic, management, and potential ecological consequences of *A. planci* outbreaks is of great ongoing concern. It is still unclear whether the phenomenon of widespread explosions of populations of crown of thorns are entirely natural, episodic events or in part the result of anthropogenic perturbations to the reef and neighbouring environments (Brodie 1992). Irrespective of their cause, it is clearly in everyone's interests to describe in detail the dynamics of these events.

One model of the genesis and propagation of crown of thorns outbreaks is that periodically very successful recruitment leads to 'boom' populations on reefs inshore of the ribbon reefs north of Cape Tribulation/Cape Kimberley. These population explosions then generate a wave of recruitment that cascades southward with successive generations. This seems to have been the pattern of the two most recent series of outbreaks (Dight 1992, Moran *et al.* 1988, Moran & De'Ath 1992, but see James & Scandol 1992, Scandol 1994). The southern migration of strong cohorts of starfish has been attributed to the influence of the East Australia Current on dispersal of larvae, and the generally southerly flow of GBR lagoonal water south of the ribbon reef area. The reefs behind the ribbon reefs seem relatively unaffected by the East Australia current, probably because the emergent, near continuous ribbon reefs provide an effective barrier to Coral Sea circulation (Frith *et al.* 1986).

If the above model is true, any large populations of crown of thorns that might appear in the future would be expected to do so first on the reefs north of Cape Tribulation/Cape Kimberley. We have relatively little detailed information, however, about the dynamics of non-outbreak populations or the growth of populations to plague status. The provision of such information would greatly aid our understanding of outbreaks and increase the predictive power of models of their development.

Prior to 1995, when the GBRMPA commenced fine-scale SCUBA counts of *A. planci*, most information about crown of thorns abundance came from rapid manta-tow surveys of reef perimeters (Moran *et al.* 1988). Those methods allowed useful qualitative statements about whether a reef had an outbreak or not, but did not provide reliable or accurate estimates of abundances, particularly at intermediate levels (Fernandez 1990, Fernandez *et al.* 1990, but see De'Ath 1992). From a management perspective, the precise description of population dynamics prior to outbreak conditions would provide a vital ability for managers to predict where and when outbreaks were imminent. In the longer term, better understanding of consistent spatial patterns in *A. planci* outbreaks will provide a better basis for zoning decisions and regulating use of the GBR.

Accordingly, a secondary objective of the study was to document the status of *A. planci* in the mid-north regions of the Cains Section of the GBR Marine Park. We sought to obtain precise estimates of densities of *A. planci* on the reefs north of Cape Tribulation and on those reefs immediately south of Cape Kimberley, where the first 'flow-on' effects of increases in northern populations are likely to be seen under the above model. If sufficient numbers of COTS were observed, we sought to test the hypothesis that COTS outbreaks first arise on reefs behind the shelf-break ribbon reefs north of Cape Kimberley (Dight 1992, but see James & Scandol 1992, Scandol 1994). If few COTS were recorded, our data would provide useful baseline information for future surveys of *A. planci* that might indicate the genesis of further 'booms' in COTS populations. In either case,

these data will contribute to an empirical test of the predictions of the model in the event of future increases in numbers of crown of thorns.

The density data we obtained for *A. planci* also provided an important complement to the more qualitative data provided by manta tow surveys of the same areas by AIMS personnel. The two methods were used sequentially, through collaboration with Moran and his co-workers, to provide valuable data for comparison of the methods and validation of the generality of the conclusions drawn about manta tows by Fernandez (1990) and Fernandez *et al.* (1990). Concurrent with counting *A. planci*, we estimated percent coverage and some gross population parameters of hard corals. Given knowledge of the recent history of COTS outbreaks, these data allowed us to compare recovering assemblages with coral assemblages not recently affected by crown of thorns.