GREAT BARRIER REEF
MARINE PARK AUTHORITY

RESEARCH PUBLICATION No. 60

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

ISSN 1037-1508
ISBN 0 642 23081 1

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National Library of Australia Cataloguing-in-Publication data:

Mapstone, Bruce D. (Bruce David).
A visual survey of demersal biota in the Cairns section of the Great Barrier Reef Marine Park.

Bibliography.
ISBN 0 642 23081 1

1. Coral reef ecology - Queensland - Great Barrier Reef. 2. Marine biological diversity conservation - Queensland - Great Barrier Reef Marine Park - Management - Evaluation. 3. Marine parks and reserves - Queensland - Great Barrier Reef Marine Park - Management - Evaluation. 4. Environmentally sensitive areas - Queensland - Great Barrier Reef Marine Park. 5. Sublittoral ecology - Queensland - Great Barrier Reef Marine Park. I. Choat, J. H. II. Ayling, Tony, 1947- . III. Great Barrier Reef Marine Park Authority (Australia). IV. Title. (Series : Research publication (Great Barrier Reef Marine Park Authority (Australia)) ; no. 60).

577.78909943

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SUMMARY

Closure of areas to destructive or extractive uses has gained increasing favour recently as a strategy to achieve the conservation goals for marine environments. In most cases, however, there has been neither the prior data nor the subsequent monitoring of area closures, and comparable non-closed areas, to allow empirical evaluations of the area-closure management strategy. In 1975, the Great Barrier Reef Marine Park Act provided for the declaration of the Great Barrier Reef Marine Park and its management for conservation and multiple use. During the following 12 years, strategies of zoning areas of the Great Barrier Reef for different levels of use were implemented over the entire Marine Park. For none of the management sections of the Marine Park were systematic, purposeful surveys of reefs with different zoning status done at or prior to the implementation of the first term of zoning. The second zoning plan for the Cairns Section of the Marine Park came into effect in 1992. In this project we sought to gather comprehensive survey data on the status of reefs prior to the implementation of this as amended zoning plan in order to facilitate future assessments of its effectiveness.

We surveyed 50 reefs over the entire Cairns Section, including reefs with a history of closure to extractive uses such as fishing, reefs that had always been open to most uses, and reefs that were to have their zoning status changed under the as amended zoning plan. In so doing, we were also in a position to compare the status, in 1990–91, of reefs with different zoning histories, albeit in the absence of structured baseline data from before the then effective zoning period (1983–91). We surveyed six locations around the perimeter of each reef by well-established and tested underwater visual survey methods.

The results we present here do not indicate a clear, unequivocal set of patterns in abundances of several organisms related to zoning history or notional tourist use. For many taxa, no effects of either past zoning or tourist use were evident. For other taxa, the zoning-related patterns frequently depended on either where across the continental shelf we looked, on the habitat considered, or on the notional history of consistent tourist use. Patterns in abundances related to frequency of tourist use also varied with habitat, zoning status, or shelf position.

We found no clear evidence of large numbers of crown-of-thorns starfish (COTS, *Acanthaster planci*) on any reef, indicating that there was no evidence of a re-emerging outbreak of COTS in 1991. The emergence of boom populations of *A. planci* since 1994 suggests either that those individuals present in the boom populations were not present in 1991, or that they were small and sufficiently cryptic that non-destructive visual surveys would not have detected them.

Apart from any logical considerations, our data suggest that there is only limited potential to infer effects of management strategies from simple one-off 'before and after' estimates of abundance or community structure. Considerable inter-annual variation in counts also suggest that simple paired surveys will be likely to produce large differences unrelated to effects of management strategy. Unequivocal inferences about the effectiveness of zoning strategies as management tools will require repeated measurements over extended periods at both managed and used reefs. Such a strategy specifically targeted at management strategy evaluation does not currently exist on the Great Barrier Reef. In the absence of such an explicit assessment and refinement approach, or formal and regular monitoring strategies targeted specifically at management strategy evaluation, interpretations of 'status' surveys of the type we have completed will be impaired by inadequate information and there will continue to be little empirical evidence from which to justify or refine existing management strategies.

ACKNOWLEDGMENTS

This work was facilitated by funding from the Great Barrier Reef Marine Park Authority, the Australian Research Council and James Cook University. Our thanks to the many people who helped with the field work and processing the data, including Linda Axe, Ian Butler, Stuart Cairns, Brian Cohen, Jim Higgs, James Larkum, Ian Roderick and Rachael Web. Comments from two anonymous reviewers improved the final product, as did extensive editorial attention by Dave Wachenfeld and Kim Davis at the Great Barrier Reef Marine Park Authority. Thanks especially to Gina Mercer and Lucy Mercer Mapstone for their support and patience during the writing of this report.

INTRODUCTION

The management of marine systems, or human use of them, has generally been seen in the context of management of fisheries, usually with an emphasis on maximising yield to the fishery without causing collapses of fished stocks (Russ 1991; Hilborn and Walters 1992). In recent decades, however, there has been increasing emphasis on conservation of the diversity of marine resources, and the protection of whole marine assemblages or ecological systems from ill-effects of harvesting some parts of them or ill-effects of non-harvest human impacts. Closures of areas to destructive or extractive uses has gained increasing favour as a strategy to achieve the conservation goals of marine environmental management (Alcala 1988; Alcala and Russ 1990; Bohnsack 1994; Hendee et al. 1990; Kelleher and Kenchington 1991; Kenchington 1990; McNeill 1994; Russ 1984, 1989; Russ and Alcala 1989). With relatively few exceptions, however, the enthusiasm for area-closure strategies has been based more on theory and arguments that area closures were precautionary management instruments, than on empirical evidence that such closures were effective either locally or generally. In most cases, there has been neither the prior data nor the subsequent monitoring of area closures, and comparable non-closed areas, to allow the evaluation of the area-closure management strategies (McNeill 1994; but see Russ 1989, 1991; Russ and Alcala 1989).

In 1975, the Great Barrier Reef Marine Park Act provided for the declaration of the Great Barrier Reef Marine Park (GBRMP) and its management for conservation and multiple use. Explicit in the Act was the requirement to manage the Marine Park explicitly for conservation of the biological characteristics of the Great Barrier Reef (GBR) in the context of ongoing recreational use and commercial development (*Great Barrier Reef Marine Park Act 1975*; Kenchington 1990). During the following 12 years, strategies of zoning areas of the GBR for different levels of use were implemented over the entire Marine Park. Provisions for use ranged from several forms of recreational and commercial fishing and collecting, including trawling (General Use Zones), to non-extractive uses such as recreational diving and snorkelling (Marine National Park Zones), to, in a few areas, no access at all (Preservation Zones). Though not explicit in most of the zoning plans (GBRMPA 1983, 1985, 1987, 1988), the clear intent of the zoning strategies was to protect areas of the GBR from the most obvious or likely impacts of human use on the assumption that those protected areas would come to represent near-pristine examples of the area. Presumably, it was also expected that the protected areas would act as refugia from which the offspring of abundant stocks of most organisms could re-populate areas where harvesting had reduced abundances (Bohnsack 1994; Plan Development Team 1990; Russ 1991).

In order to assess the utility of these (or other) management strategies for conservation, it is necessary that the effects on reef biota of zoning reefs for different use be thoroughly documented. This information is most efficiently provided by carefully planned quantitative descriptive studies from which the biotic status of reefs with different zoning and use histories can be compared, i.e. via a sound monitoring program. To establish whether restriction of human use of selected reefs leads to changes in the biota of those reefs, irrespective of the proximate cause of such changes, requires at its simplest the following two fundamental comparisons:

1. Comparison of the status of the reefs following closure with their status prior to closure;
2. Comparison, both before and after closure, of closed reefs with reefs having no restrictions on use.

Ideally, the comparisons should be based on relatively long-term data of the status and dynamics of closed and unrestricted reefs from before, during, and after the implementation of a zoning strategy. Clearly other data will also contribute to this evaluation, e.g. documentation of the effects of removing restrictions on reef use. In many respects, the requirements of rigorous management strategy evaluation parallel the requirements of environmental impact assessment (Fairweather 1991; Faith et al. 1995; Green 1979, 1989; Humphrey et al. 1995; Keough and Mapstone 1995; Schmitt and Osenberg 1995; Stewart-Oaten 1995; Stewart-Oaten et al. 1986;

Underwood 1991, 1993, 1995; Warwick 1993), except that the effects of management would be expected to be 'positive' compared to the background conditions (of use) whereas in impact assessment the impacts of specific actions are expected to be 'negative' compared to background conditions.

Such data, however, are not available currently for the GBR. For none of the management sections of the GBRMP were systematic, purposeful surveys of reefs with different zoning status done at, or prior to, the implementation of the first term of zoning. Any assessments of the effectiveness of management strategies to date rests entirely on the contrived use of disparate data collected for other purposes. Such data include surveys by Sea Research (Ayling 1983a, b; Ayling and Ayling 1984a, b, 1985, 1986a, b, 1991, 1992a), data from the Australian Institute of Marine Science COTS surveys and the still young Long-term Monitoring Program (Oliver et al. 1995), recruitment surveys by P. J. Doherty, D. McB. Williams and P. F. Sale (Doherty 1987, 1991; Sale et al. 1984, 1986; Williams et al. 1986), the 'Boult Reef experiment' (Beinssen 1988, 1989), and more recently tag-release-recapture studies by Davies (Davies 1995a, b), and work by Mapstone et al. (1998a, b). Although these studies have generated ample data, none provide temporal series of data specifically collected to assess the effectiveness of Marine Park zoning strategies. Only in recent years have there arisen specific attempts to test hypotheses about the effectiveness of specific management actions in the Great Barrier Reef Marine Park (Ayling and Ayling 1992b, 1993, 1994, 1995; Brown et al. 1993, 1996; Mapstone, Campbell and Smith 1996; Mapstone et al. 1996a, b).

In April 1992 the as amended zoning plan for the Cairns Section of the GBRMP became operational (GBRMPA 1992), signalling the beginning of the second iteration of management strategies for the GBR. We were asked by the Great Barrier Reef Marine Park Authority (GBRMPA) in this project to survey some elements of the macro-fauna on reefs in the Cairns Section prior to the beginning of the next period of zoning. In particular, it was considered important to survey those reefs which had been previously closed to fishing and which were to have that restriction removed in the as amended zoning plan. In so doing, we were also in a position to compare the status, in 1990–91, of reefs with different zoning histories, albeit in the absence of structured baseline data from before the then effective zoning period (1983–91).

Preliminary analyses of recent work by the authors suggested that these comparisons would have good power to detect only fairly gross differences, even with an unconventionally liberal test criterion (liberal Type I error rate, $\alpha_{crit} = 0.1$). For example, for coral trout, if we specified Type I and Type II error rates of 0.1 (i.e. power = 0.9) the *a posteriori* comparisons between zoning history categories would have been expected to detect differences in density of only 50% of existing densities on general use reefs in the north of the Cairns Section, and 100% of existing densities on general use reefs off Cairns. Our data indicated that this was a 'worst case' scenario, the results being likely to be better for other, more abundant, organisms. Clearly, in view of these preliminary results, the primary value of this project must be seen to be the provision of baseline information for the future assessment of the second zoning plan (1991 onwards).

The Authority specified a number of objectives, to which this project was principally tailored. Those objectives were:

1. To provide detailed 'baseline'[1] data on the status of selected macro-fauna (see below) on open (Marine Park Recreation/General Use) and closed (Marine National Park/Preservation Zone) reefs for comparison with data collected in the future to assess the effects of the new reef zoning strategies on the reef-associated biota;
2. To compare the status of the same suite of organisms on reefs which had a history of near continuous (~daily) use by commercial tourist operators with that on reefs with similar zoning history but without the history of consistent human use;

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[1] The term baseline here refers only to future assessments of the new zoning plan. Clearly, data collected in 1991 cannot be seen as baseline date for the existing zoning plan, which was implemented in 1983.

3. To compare densities of these organisms between reefs which had been zoned over the past seven years Marine Park B, Research, or Preservation Zone (i.e. no extractive use), and others zoned either General Use A or B, or Marine Park A (extractive uses allowed);
4. To do baseline surveys of all reefs in the Cairns Section designated for use in the proposed GBRMPA Effects of Fishing Program.[2]
5. To re-survey reefs which were surveyed by Sea Research in 1983–84, as a first step toward gathering long-term data on abundances;
6. To assess the status of *Acanthaster planci* on all reefs surveyed, providing, in the event of a repeated boom in COTS populations, data to test the prediction that COTS outbreaks have their genesis in the northern Cairns Section and cascade southward with successive generations.

In addition, we sought to provide estimates, by re-survey of some of the reefs surveyed in 1989–90, of inter-annual variation in population densities and assess the utility of proposed long-term monitoring programs designed to monitor temporal changes in abundances of these organisms.

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[2] Note, however, that changes in design of the Effects of Fishing experiment in 1994 meant that the reefs originally considered for such an experiment (Walters and Sainsbury 1990) were no longer relevant to the experiment. Two of six other reefs that were relevant to the revised experimental design (Mapstone, Campbell and Smith 1996) were surveyed.

METHODS

Fieldwork was done from the research vessel RV *Sunbird* during four cruises between 4 January and 28 May 1991. The order in which reefs were surveyed was determined substantially by prevailing weather conditions, with fronts of reefs in a local area being surveyed before back-reefs whilst good weather persisted. This introduced the potential for confounding of weather-related bias with habitat effects in survey results, but was unavoidable to ensure that all front-reefs were surveyed. All underwater surveys were done on SCUBA, and restricted to depths of less than 12 m.

Organisms and Survey Methods

The following organisms were counted by underwater visual survey using line-intercept or belt transect methods: coral trout (*Plectropomus* spp.), all chaetodontids (by species), selected acanthurids, all lethrinid and lutjanid species, *Acanthaster planci*, *Linckia laevigata*, *Tridacna gigas* and *T. derasa* (50 m x 5 m belt transects); selected pomacentrids and *Thalassoma lunare* (20 m x 2.5 m belt transects); total live hard coral, soft coral, and sponges (20 m line transects); and numbers of corals suspected of being eaten by *Drupella* spp. and unaffected corals (30 m x 1 m belt transects). These methods have been found to be cost effective in previous work by the authors (Mapstone and Ayling 1998).

Data were collected as follows. Three divers worked together on each transect. One diver layed out a 50 m fibreglass measuring tape parallel to the reef edge at constant depth (2–10 m). The principal observer (Ayling) swam abreast of the tape layer counting coral trout, chaetodontids, lethrinids, lutjanids and the selected acanthurids within a 5 m band immediately ahead of him on the deeper side of the tape. A second observer followed, counting asteroids (*L. laevigata*, *Acanthaster planci* [in three size classes]) and clams (*Tridacna gigas, T. derasa*—each in two size classes) over the same 5 m width of substratum. A five-metre line was layed perpendicular to the direction of swim at the beginning of each transect to serve as a reference from which the observers projected the 5 m transect width. At the end of each transect, the principal and secondary observers each indicated what they estimated to be five metres from the tape layer, and those distances were then measured as a record of the accuracy of the observers' distance estimation. The principal observer then returned along the tape counting the number of corals suspected of *Drupella* infestation and those unaffected within 0.5 m either side of the first 30 m of the tape. He then counted the smaller fishes over 1.25 m either side of the remaining 20 m of the tape, and left a marker an estimated 1.25 m from the end of the central tape to which the tape layer measured after re-winding the tape. The second observer also returned along the tape, summing the lengths of tape lying over four categories of live hard coral (plating and other acroporids, poritids, other hard corals) for the first 20 m and the lengths of tape covering live soft coral and sponges for the second 20 m of the return swim. The tape layer rewound the tape whilst summing the lengths of tape lying over dead standing coral for the first 20 m of tape rewound. A fourth diver acted as boat-person.

Survey Design

Within each reef, five 50 m x 5 m transects were surveyed at each of three well-dispersed locations on each of the front reef (windward) and back reef (leeward) reef slopes. One of each of the smaller belt transects and two line transects were sampled within each larger belt transect, as described above. This allocation of effort was determined on the basis of estimates of scale-related variations in population densities of the above organisms collected in 1989–90 by the authors (Mapstone et al. 1998b), and allowed each reef to be surveyed in one day by a team of four workers.

Several reefs fitted the criteria for more than one objective. For example, the relatively little used reefs with which tourist destination reefs were to be compared were also considered in terms of their zoning history. Table 1 provides a full list of reefs designated, during discussion with GBRMPA staff, as desirable for survey under one or more of the above objectives. Table 2 summarises the status of the survey reefs in terms of their shelf position, prior zoning status, future zoning status, and use by tourism operations. An additional constraint on the choice of reefs was that GBRMPA wanted all reefs surveyed that were changing zoning status substantially (e.g. from Marine National Park B (MNPB) in 1983–91 to General Use (GU) in 1992–97).

Table 1. The reefs nominated by GBRMPA staff and the authors for survey in order to fulfil the above objectives. **Abbreviations:** **OS**—Outer Shelf, **MS**—Mid Shelf, **IS**—Inner Shelf; **GU**—reefs designated General Use A or B or Marine Park A in 1983–91 or General Use or Marine Park Recreation Zone in 1992–97; **NPZ**—Marine Park B, Preservation, or Scientific Research Zones in 1983–91 or Marine National Park or Preservation Zones in 1992–97, **NPZ/2**—reefs with 'split' zoning—part NPZ and part GU; **TS**—continuous use by commercial tourist operations, **TS/-**—use unknown, but expected to be relatively slight.

	~LAT.	SHELF	ZONE -		PRIOR -	
REEF	(°:'S)	POS^n	83–91 →	92–97	USE	SURVEYS
Hilder	14:26	OS	GU	NPZ	-	-
No Name	14:39	OS	GU	NPZ	-	-
Ribbon No. 7	15:11	OS	GU	NPZ	-	-
Ribbon No. 2	15:33	OS	GU	NPZ	-	90
Opal	16:13	OS	GU	NPZ/2	-	83, 90
Norman	16:26	OS	GU	NPZ	TS	-
Milln	16:47	OS	GU	NPZ	-	83
Nymph Island	14:39	MS	GU	NPZ	-	-
Eyrie	14:43	MS	GU	NPZ	-	83, 90
Endeavour	15:46	MS	GU	NPZ	-	90
Mackay	16:03	MS	GU	NPZ	-	-
Hastings	16:31	MS	GU	NPZ/2	TS	83, 90
Moore	16:53	MS	GU	NPZ/2	TS	-
Farquharson	17:48	MS	GU	NPZ	-	-
Normanby Isl.	17:12	IS	GU	NPZ	-	83
Nth Barnard Isl.	17:41	IS	GU	NPZ	TS	83
Sth Barnard	17:45	IS	GU	NPZ	TS	83
Hicks	14:27	OS	GU	GU	-	83, 90
Agincourt 4	15:57	OS	GU	GU	TS	90
Agincourt 2	16:03	OS	GU	GU	TS	90
St Crispin	16:06	OS	GU	GU	TS/-	83, 90
Saxon	16:28	OS	GU	GU	TS	-
Flynn	16:44	OS	GU	GU	-	83
Gilbey	17:35	OS	GU	GU	-	83
Martin	14:45	MS	GU	GU	-	83, 90
Undine	16:07	MS	GU	GU	-	-
Chinaman	16:13	MS	GU	GU	-	-
Upolu Cay	16:41	MS	GU	GU	-	83
Arlington	16:42	MS	GU	GU	-	83, 90
Potter	17:42	MS	GU	GU	-	-
Eddy	17:46	MS	GU	GU	-	-
Taylor	17:50	MS	GU	GU	-	-
Carter	14:33	OS	NPZ	NPZ	-	83, 90
Ribbon No. 6	15:16	OS	NPZ	NPZ	-	83
Escape/092	15:52	OS	NPZ	NPZ	-	-
Agincourt 3	15:59	OS	NPZ	NPZ	TS	90
Euston	16:41	OS	NPZ	NPZ	-	-
Nth West	16:52	OS	NPZ	NPZ	-	83

Table 1 (continued)

REEF	~LAT. (°:'S)	SHELF POS^n	ZONE – 83–91	→ 92–97	PRIOR – USE	SURVEYS
MacGillivray	14:39	MS	NPZ	NPZ	-	83, 90
Lizard Island	14:41	MS	NPZ/2	NPZ/2	TS	83, 90
Lark	15:18	MS	NPZ	NPZ	-	-
Williamson	15:22	MS	NPZ	NPZ	-	83
Michaelmas	16:35	MS	NPZ	NPZ	TS	83, 90
Green Island	16:45	MS	NPZ	NPZ	TS	83
Beaver	17:51	MS	NPZ	NPZ	TS	-
Low Islands	16:23	IS	NPZ	NPZ	TS	83
Ribbon No. 4	15:26	OS	NPZ	GU	-	83, 90
Channel	16:57	OS	NPZ	GU	-	83
Wardle	17:27	OS	NPZ	GU	-	83
Nor Easter	17:47	OS	NPZ	GU	-	-

Table 2. Numbers of reefs in each category of past and future zoning status, shelf position, and tourist use. The four inner-shelf reefs are not included in this table: three were formerly general use, three were tourist destinations, and all were to be zoned MNP in the as amended zoning plan. **Abbreviations**: **OS**—outer-shelf, **MS**—mid-shelf; **GU**—reefs designated General Use A or B or Marine Park A in 1983–91 or General Use or Marine Park Recreation Zone in 1992–97; **NPZ**—Marine Park B, Preservation, or Scientific Research Zones in 1983–91 or Marine National Park or Preservation Zones in 1992–97.

ZONING	History:	NPZ				GU			
	Future:	NPZ		GU		NPZ		GU	
	Shelf Position	OS	MS	OS	MS	OS	MS	OS	MS
USE	Tourist	1	4	0	0	1	2	4	0
	Non-Tourist	5	3	4	0	6	5	3	8
	TOTAL:	6	7	4	0	7	7	7	8

Data Processing and Statistical Analyses

Data Entry and Checking

During field trips one person remained on the survey vessel and entered data collected on the previous day into a dBase III$^+$ database. This allowed immediate resolution of any ambiguities on data sheets encountered during data entry. Subsequently, at James Cook University, all data were entered independently again into an identical database. The duplicate sets of data were then compared by custom software and any non-matching records were copied to a third database of apparent errors. These mis-matches were checked against the original data sheets and corrected in the duplicate databases. The compare-check-correct cycle was repeated until no further mis-matches were found. A random sample of 100 records was then taken from the databases and manually cross-checked by two people. In addition, several logical checks were conducted prior to analysis to ensure that no systematic errors had been duplicated in both databases. All data are archived at James Cook University and at another site by one of the authors (Mapstone).

Statistical Analyses

Multivariate Analyses of Variance (MANOVA) were used to compare the status of reefs in each of several 'treatments' (Zoning, Tourist Use, Habitat, Shelf Position) in terms of the many taxa that were sampled along the same transects. Analyses were done on the mean abundances at each of the three locations on the fronts and backs of reefs, the transect-level data being averaged to reduce heteroscedasticity and increase normality in the analysed data. Tourist Use, Zoning, Habitat, and Shelf Position were considered fixed effects, whilst reefs were considered random variables. In all MANOVA, four test statistics were considered: Pillai's Trace, Wilkes' Lambda, Roy's Greatest Root, and the Hotelling-Lawley Trace, each with different performance characteristics depending on the 'shape' of the multivariate distribution of effects (B. McArdle pers. com.). We accepted as significant any effects that would be considered significant by at least two of the test statistics, and usually cite the result for Pillai's Trace unless it was not consistent with the other statistics.

Where effects were considered statistically significant ($\alpha \leq 0.1$) in the MANOVA, univariate ANOVA of analogous models were done to resolve which taxa precipitated the effect in the MANOVA. Significant effects of Tourist Use or Zoning (or their interactions with other factors) from the univariate analyses were plotted as bar graphs to illustrate the effects. Since cross-shelf and habitat effects on abundances of the organisms we surveyed have been discussed previously for the Cairns Section (Mapstone et al. 1998a) and because the focus of this project was on the status of fauna with respect to zoning and tourist use, we did not examine in any detail effects of Habitat or Shelf Position. These factors were included in analyses only because they had been shown previously to account for considerable variation in abundances and we sought to partition out that variation before testing for the effects of use or zoning. The potential for Type II error for non-significant results was calculated based on the critical significance criterion of $\alpha = 0.1$ and an effect size corresponding to a difference in abundance (between treatments) of 50% of those observed in treatments expected to be 'most impacted' by human use (i.e. GU and tourist reefs). All analyses and plots were done using SAS™ software.

Given surveys described above, the following analyses were done:[3]

1. Comparison of reefs with different zoning histories. The analyses provided comparisons between reefs with histories of protection or general use. Comparisons were made separately for sets of tourist and non-tourist reefs. Shelf Position was also factored into the analyses, with the number of shelf positions considered for each taxon (ANOVA) or group of taxa (MANOVA) being determined by their distribution.
2. Comparison of reefs with a history of tourism with reefs with the same zoning status but having had low-frequency use. These comparisons took into account the zoning history of the reefs, but separate analyses were done for mid-shelf and outer-shelf reefs.
3. Estimation, following re-survey of some of the reefs surveyed in 1989–90 (7 MS, 7 OS), of inter-annual variation in population densities on reefs.

Clearly, in most of the above analyses the numbers of experimental units (reefs) per 'treatment' combination were not equal (table 2), though the sub-sampling regime within reefs was consistent among all reefs. This analytical inconvenience arose because of the history of the zoning procedures and the user demands which constrained the allocation of reefs to zones.

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[3] It was also intended that COTS densities (if non-zero) would be compared among four regions: 1) north of 15°S [5 mid-shelf reefs, 4 outer-shelf reefs]; 2) between 15°S and the lower end of the ribbon reefs [6 MS, 8 OS]; 3) below the ribbon reefs to 17°S [7 MS, 8 OS]; 4) south of 17°S [4 MS, 4 OS]. However, too few COTS were observed for this comparison.

We assessed inter-annual variation in estimates for selected reefs by calculating the signed relative change in density between surveys in 1990 and 1991. Relative change ($\delta_{i,90-91}$) was calculated per habitat stratum per reef as:

$$\delta_{i,90-91} = \frac{\bar{y}_{i,90} - \bar{y}_{i,91}}{\bar{Y}_{i,.}}$$

where $\bar{y}_{i,year}$ was the mean density from all transects at all locations on a front reef slope or back reef slope of reef *i* in *year*, and $\bar{Y}_{i,.}$ was the mean abundance over both years in that habitat at reef *i*.

Seven mid-shelf and seven outer-shelf reefs were surveyed in both 1990 and 1991 and thus provided data from which this difference could be estimated. Difference values were compared among habitats and shelf positions first by MANOVA and then, when effects were significant in the MANOVA, by univariate ANOVA. Both Habitat and Shelf Position were considered fixed effects in these analyses.

RESULTS

The survey was completed as planned, without omission of any locations at any reefs. The resulting data have been collated and checked and are now archived as a reference set for future monitoring of the same reefs in the Cairns Section of the GBRMP. Thus, objectives 1, 4[4] and 5 were met.

Crown-of-thorns starfish (COTS, *Acanthaster planci*) were not sufficiently abundant for any statistical analysis, and there was no evidence of large populations of COTS on any reef. Counts of *A. planci* are given in table 3, together with the latitude and shelf position of the reefs on which they were seen. More of the COTS seen were of medium size (20–50 cm diameter) than other sizes, with the greatest numbers being seen on Endeavour Reef (table 3).

Table 3. Details of reefs on which at least one *Acanthaster planci* was seen during the 1991 visual surveys of 50 reefs in the Cairns Section of the Great Barrier Reef Marine Park. **Abbreviations**: OS—outer-shelf, MS—mid-shelf.

REEF	SHELF POS^n	LATITUDE	HABITAT	*A. PLANCI*		
				<20 cm	**20–50 cm**	**>50 cm**
MacGillivray	MS	14:39	Back	-	-	1
			Front	-	2	-
Lizard	MS	14:41	Back	-	2	1
			Front	-	1	-
Eyrie	MS	14:43	Back	-	2	-
Williamson	MS	15:22	Back	-	1	-
Endeavour	MS	15:46	Back	2	5	-
			Front	-	1	-
Chinaman	MS	16:13	Front	1	1	-
Opal	OS	16:13	Back	-	-	1
Arlington	MS	16:42	Back	-	-	1
Moore	MS	16:53	Back	1	1	-

The taxa counted and their relative distributions across shelf positions and habitats are given in appendix 1. The distributions of taxa dictated their inclusion in different analyses. Taxa were included in an analysis if the taxon was present in a given habitat on over 50% of the reefs in all shelf positions included in an analysis (table 4). Thus, for example, *Chrysiptera rollandi* would have been included in any analyses of mid-shelf reefs and the back-reef habitats of outer-shelf reefs, but would not have been included in analyses involving inner-shelf reefs or the fronts of outer-shelf reefs. By contrast, the summed counts of all *Plectropomus* species could have been included in all analyses. The linear models for the analyses done and the taxa considered in each are given in tables 5 and 6.

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[4] Note, however, that changes in design of the Effects of Fishing experiment in 1994 meant that the reefs originally considered for such an experiment (Walters and Sainsbury 1990) were no longer relevant to the experiment. Two of six other reefs that were relevant to the revised experimental design (Mapstone, Campbell and Smith 1996) were surveyed.

Table 4. Taxa counted sufficiently frequently for inclusion in at least one analysis. Tabulated numbers are percentages of reefs at each shelf position where each taxon occurred in the nominated habitat. Four inner-shelf, 22 mid-shelf and 24 outer-shelf reefs were surveyed.

A. Benthic Organisms

TAXON ⇓ // HABITAT⇒	SHELF POSITION					
	Inner-Shelf		Mid-Shelf		Outer-Shelf	
	Back	Front	Back	Front	Back	Front
BENTHOS						
Poritids	100	100	100	100	100	96
Other Hard Coral	100	100	100	100	100	100
Dead Corals	100	75	100	100	100	96
Soft Corals	100	75	100	100	100	100
Sponges	100	75	100	95	96	96
Acroporids – Other	75	75	100	100	100	100
***Drupella* Infestation**	75	75	100	100	100	100
Acroporids – Plate	50	0	95	86	92	83
Tridacna gigas	75	50	86	86	79	17
Linckia laevigata	25	50	91	64	50	4
Tridacna derasa	25	0	73	77	92	4

B. Small Fish and Acanthurids

TAXON ⇓ // HABITAT⇒	SHELF POSITION					
	Inner-Shelf		Mid-Shelf		Outer-Shelf	
	Back	Front	Back	Front	Back	Front
DAMSELFISH						
Pomacentrus moluccensis	100	75	100	100	96	17
Thalassoma lunare	100	50	100	100	67	8
Amblyglyphidodon curacao	50	50	100	100	96	17
Chrysiptera rollandi	25	25	95	68	88	0
Chromis atripectoralis	25	25	95	68	79	25
P. lacrymatus	0	25	86	86	100	92
Pomacentrus philippinus	0	0	23	27	92	92
SURGEONFISH						
Total Acanthurids	100	100	92	96	100	100
Other Acanthurids[5]	100	100	92	96	100	100
Zebrasoma scopas	0	100	72	76	100	100

C. Large Fish and Chaetodons

TAXON ⇓ // HABITAT⇒	SHELF POSITION					
	Inner-Shelf		Mid-Shelf		Outer-Shelf	
	Back	Front	Back	Front	Back	Front
CORAL TROUT						
All *Plectropomus* spp.	100	100	100	100	100	88
P. leopardus	25	50	100	100	100	54
P. laevis	0	0	27	23	67	79
SNAPPERS						
All Lutjanids	100	75	100	100	100	100
Lutjanus carponotatus	100	75	95	100	13	8
Other Lutjanids[5]	50	50	95	86	75	79
L. fulviflamma	50	25	55	73	33	54
L. bohar	0	0	77	95	96	100
L. gibbus	0	25	73	86	83	92
Macolor niger	0	0	14	5	83	83

Table 4 (continued)

EMPERORS						
Total Lethrinids	50	0	91	95	100	92
Other Lethrinids[5]	50	0	86	91	96	75
Lethrinus atkinsoni	25	0	73	82	96	79
L. obsoletus	25	0	64	55	79	4
Monotaxis grandoculis	0	0	100	91	100	100
BUTTERFLYFISH						
All Chaetodons	100	100	100	100	100	100
Chaetodon vagabundus	100	75	91	95	88	71
Other Chaetodons[5]	100	100	86	86	58	88
C. aureofasciatus	100	100	82	77	0	0
C. trifascialis	50	50	100	100	100	96
C. rainfordi	50	50	100	82	17	8
C. baronessa	50	25	95	100	96	75
C. auriga	50	25	95	86	92	46
C. melannotus	50	50	82	64	88	88
C. ephippium	25	0	41	59	71	67
C. plebeius	0	50	95	95	100	92
C. trifasciatus	0	25	73	68	88	83
C. citrinellus	0	0	68	45	96	88
C. kleinii	0	0	64	45	67	63
C. ulietensis	0	0	45	23	92	71
C. unimaculatus	0	0	23	27	50	54
C. pelewensis	0	0	5	5	83	79
Forcipiger flavissimus	0	0	0	0	67	67
C. ornatissimus	0	0	0	14	54	83

Table 5. Analytical framework by which we tested for effects of Zoning History on reefs, given potential effects of Shelf Position and Habitat[6]. A prefix of ^{3} indicates that counts of that taxon from tourist reefs in all shelf positions were analysed. For those and all other taxa from non-tourist reefs, only counts from mid-shelf and outer-shelf reefs were analysed.

Model: $y_{ijklm} = \mathbf{Z}_{i....} + \mathbf{S}_{.j...} + \mathbf{H}_{..k..} + \mathbf{ZS}_{ij...} + \mathbf{ZH}_{i.k..} + \mathbf{SH}_{.jk..} + \mathbf{ZSH}_{ijk..} + \mathbf{r(ZS)}_{l(ij)..} + \mathbf{Hr(ZS)}_{kl(ij).} + \varepsilon_{ijklm}$
Scope: Inner-, mid-, and outer-shelf reefs (3), or mid- and outer-shelf reefs only (remainder)

Benthos	Large Fish	Other Fish
^{3}Acroporids – Plate	*P. leopardus*	*Z. scopas*
^{3}Acroporids – Other	^{3}All *Plectropomus* spp.	^{3}Other Acanthurids
^{3}Poritids		*P. lacrymatus*
^{3}Other Hard Coral	*L. atkinsoni*	*C. auriga*
^{3}Dead Corals	*M. grandoculis*	*C. baronessa*
^{3}*Drupella* Infestation	Other Lethrinids	*C. citrinellus*
^{3}Soft Corals		*C. kleinii*
^{3}Sponges	*L. bohar*	^{3}*C. melannotus*
	L. gibbus	*C. plebeius*
	Other Lutjanids	^{3}*C. trifascialis*
	^{3}All Lutjanids	*C. trifasciatus*
		^{3}*C. vagabundus*
		^{3}Other Chaetodons

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[5] The 'Other' categories here include all those species within a family that were counted but too uncommon to be analysed. They differ, therefore, from the 'Other' categories in appendix 1.

[6] Upper-case symbols in ANOVA models / tables indicate fixed effects; lower-case indicates random variables.

Table 6. Analytical framework by which we tested for effects of Tourist Use and Zoning History on reefs, given potential Habitat effects. A ^{M} prefix indicates taxa that were analysed on only mid-shelf reefs, whilst a prefix of ^{O} indicates those taxa that were considered only from outer-shelf reefs. All other taxa were included in analyses for both shelf positions.

Model: $y_{ijklm} = \mathbf{Z}_{i....} + \mathbf{U}_{.j...} + \mathbf{H}_{..k..} + \mathbf{ZU}_{ij...} + \mathbf{ZH}_{i.k..} + \mathbf{UH}_{.jk..} + \mathbf{ZUH}_{ijk..} + \mathbf{r(ZU)}_{l(ij)..} + \mathbf{Hr(ZU)}_{kl(ij).} + \varepsilon_{ijklm}$

Scope: Tourist and non-tourist reefs, mid-shelf and outer-shelf reefs separate

Benthos	Large Fish	Other Fish
Acroporids – Plate Acroporids – Other Poritids Other Hard Coral Dead Corals *Drupella* Infestation Soft Corals Sponges ^{M}*Tridacna gigas* ^{M}*Linckia laevigata* ^{M}*Tridacna derasa*	*P. leopardus* ^{O}*P. laevis* *L. atkinsoni* *M. grandoculis* Other Lethrinids *L. bohar* ^{M}*L. carponotatus* ^{M}*L. fulviflamma*♦ *L. gibbus* ^{O}*M. niger* Other Lutjanids	*Z. scopas* Other Acanthurids *C. auriga* ^{M}*C. aureofasciatus* *C. baronessa* ^{O}*C. citrinellus* ^{O}*C. ephippium* ^{O}*C. kleinii* *C. melannotus* ^{O}*C. ornatissimus* ^{O}*C. pelewensis* *C. plebeius*
	^{M}*A. curacao* ^{M}*C. atripectoralis* ^{M}*C. rollandi* *P. lacrymatus* ^{O}*P. philippinus* ^{M}*P. moluccensis* ^{M}*T. Lunare*	^{M}*C. rainfordi* *C. trifascialis* *C. trifasciatus* ^{O}*C. ulietensis* ^{O}*C. unimaculatus* *C. vagabundus* ^{O}*F. flavissimus* Other Chaetodons

♦This was the only analysis in which *L. fulviflamma* was treated separately because this was the only analysis in which mid-shelf reefs were treated alone. In all other analyses, counts of *L. fulviflamma* were pooled with 'Other Lutjanids'.

Effects of Zoning History and Tourist Use on Abundances

MANOVA indicated that zoning history apparently significantly affected[7] assemblages of benthos and fish on both non-tourist reefs (table 7) and tourist reefs (tables 8 and 9), though in some cases the effects of zoning interacted with shelf position, habitat, or degree of use by tourists.

Uncomplicated main effects of zoning were apparent in assemblages of benthos on non-tourist reefs (table 7) and some butterflyfish (chaetodons) on mid-shelf and outer-shelf tourist reefs (table 9). Interactions between zoning and shelf position were statistically significant ($\alpha_{>F} \leq 0.1$) for fish assemblages on non-tourist reefs (table 7) and benthos on tourist reefs (table 8), whilst interactions between zoning and habitat were significant for fish assemblages on tourist reefs averaged over all shelf positions (table 8).

When both tourist and non-tourist reefs were considered together, clear main effects of zoning were apparent only for benthic assemblages on mid-shelf reefs (table 10). Interactions between effects of zoning and use were significant for assemblages of small fish (pomacentrids, chaetodons, acanthurids) on both mid-shelf reefs (table 10) and outer-shelf reefs (table 11), though on mid-shelf reefs both zoning and use effects interacted with effects of habitat (table 10). Main effects of tourist use were interpretable without consideration of other effects only for benthic assemblages on mid-shelf reefs (table 10).

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[7] We refer here to 'effects' of zoning, but inferences should be regarded with caution. More correctly, they should be considered as 'correlations' between zoning history and patterns in abundances, because we have no prior data that would allow separation of effects of zoning from pre-existing differences among reefs confounded with zoning or that had influenced the choice of reefs to be included in different zones.

Table 7. Results of multivariate analyses of variance to test for the effects of reef zoning history (MNP vs GU), in the presence of potential effects of shelf position, habitat and reef, on abundances of eight benthic and 20 fish taxa on 34 mid- or outer-shelf reefs where no consistent tourist sites had been established. The test statistic was Pillai's Trace unless otherwise indicated. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Tabled numbers in bold indicate statistically significant effects ($\alpha_{obs} \leq 0.1$).

	BENTHOS			FISH		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$
Zone	2.565	8, 23	**0.037**	1.374	20, 11	0.299
Shelf Position	4.616	8, 23	**0.002**	7.485	20, 11	**0.001**
Zone*Shelf	1.337	8, 23	0.275	2.362	20, 11	**0.072**
Habitat	1.298	8, 23	0.293	1.286	20, 11	0.342
Zone*Habitat	0.336	8, 23	0.943	1.624	20, 11	0.205
Shelf*Habitat	4.917	8, 23	**0.001**	2.776	20, 11	**0.043**
Zone*Shelf*Habitat	1.448	8, 23	0.230	0.851	20, 11	0.638
reef(Zone*Shelf)	2.744	240, 960	**<0.001**	2.179	600, 2400	**<0.001**
Hab*reef(Zone*Shelf)	2.147	240, 960	**<0.001**	1.612	600, 2400	**<0.001**

Table 8. Results of multivariate analyses of variance to test for the effects of reef zoning history (MNP vs GU), in the presence of effects related to shelf position, habitat and reef, on abundances of eight benthic and seven fish taxa on 15 inner-, mid- or outer-shelf reefs with a history of consistent tourist visitation. The test statistic was Pillai's Trace unless otherwise indicated. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Tabled numbers in bold indicate statistically significant effects ($\alpha_{obs} \leq 0.1$).

	BENTHOS			FISH		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$
Zone	13.791	8, 2	**0.069**	16.848	7, 3	**0.020**
Shelf Position	7.455[8]	16, 4	**0.033**	8.318[7]	14, 6	**0.008**
Zone*Shelf	8.274[6]	16, 4	**0.027**	2.307	14, 8	0.118
Habitat	1.630	8, 2	0.435	3.707	7, 3	0.155
Zone*Habitat	0.729	8, 2	0.692	5.274	7, 3	**0.100**
Shelf*Habitat	1.728	16, 6	0.258	4.607	14, 8	**0.018**
Zone*Shelf*Habitat	2.308	16, 6	0.154	1.754	14, 8	0.214
reef(Zone*Shelf)	1.874	72, 432	**0.001**	2.042	63, 378	**<0.001**
Hab*reef(Zone*Shelf)	1.360	72, 432	**0.035**	1.608	63, 378	**0.004**

Main Effects of Zoning and Tourist Use

Main effects of zoning history on abundances were apparent for several taxa (figure 1), from both reefs frequented by tourists and reefs not consistently visited. Differences between General Use (GU) and Marine National Park (MNP) reefs were generally small, however, (< 20% of mean abundance), and varied with taxon.

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[8] Result for Wilkes' Lambda statistic, which was consistent with Roy's Greatest Root and the Hotelling-Lawley Trace

Table 9. Results of multivariate analyses of variance to test for the effects of reef zoning history (MNP vs GU), in the presence of effects related to shelf position, habitat and reef, on abundances of 16 fish taxa on 12 mid- or outer-shelf reefs with a history of consistent tourist visitation (table 1). The taxa were analysed in two groups of eight to enable sufficient df for tests of the main effects of interest. The test statistic was Pillai's Trace unless otherwise indicated. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Tabled numbers in bold indicate statistically significant effects ($\alpha_{obs} \leq 0.1$).

SOURCE OF VARIATION	**Chaetodons, *P. lacrymatus***			**Acanthurids, Lethrinids, Lutjanids, *P. leopardus***		
	F	**df**	$\alpha_{>F}$	**F**	**df**	$\alpha_{>F}$
Zone	71.007	8, 1	**0.092**	1.508	8, 1	0.561
Shelf Position	17.865	8, 1	0.181	6.355	8, 1	0.298
Zone*Shelf	9.177	8, 1	0.250	4.975	8, 1	0.334
Habitat	107.436	8, 1	**0.075**	23.119	8, 1	0.160
Zone*Habitat	0.413	8, 1	0.842	0.603	8, 1	0.766
Shelf*Habitat	19.224	8, 1	0.175	15.361	8, 1	0.195
Zone*Shelf*Habitat	18.473	8, 1	0.178	0.307	8, 1	0.891
reef(Zone*Shelf)	2.171	64, 368	**<0.001**	1.864	64, 368	**<0.001**
Hab*reef(Zone*Shelf)	1.905	64, 368	**<0.001**	1.587	64, 368	**0.005**

Abundances of live acroporid and poritid corals were greater on MNP reefs than on GU reefs, but the reverse was so for dead corals and *Drupella* affected corals. The only fish taxa for which main effects of zone were significant were found in greater abundances on GU reefs than on MNP reefs (figure 1). Similar results occurred when main effects of zoning were considered across both tourist and non-tourist reefs within single shelf positions (figure 2), although in these cases differences between GU and MNP reefs were larger.

Main effects of tourist use of reefs were few. Dead corals and one chaetodon *(C. vagabundus)* were approximately 80% and 40% (respectively) more common on tourist reefs than non-tourist reefs, but the reverse was true for the miscellaneous ('Other') acroporid corals (figure 2).

For those taxa where effects of zoning history and/or use were not statistically significant[9], the probability of Type II error given the data we collected was mostly low ($\beta<0.2$, tables 12–14), although for several taxa in different analyses there was a high probability of Type II error.

In summary, significant main effects of both zoning and tourist use were relatively few and were not consistent in nature among taxa. For most taxa, the failure to detect significant effects of either factor were unlikely to be the result of Type II errors.

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[9] For a few taxa, effects of either zoning history or use were statistically significant in univariate analyses even though the MANOVA in which they were considered did not indicate a significant effect. We followed the MANOVA results in such cases when inferring significant effects (i.e. only interpreted significant univariate effects after a significant corresponding effect in the MANOVA). The 'significance' of *any* univariate effects, however, made a nonsense of estimating power for those effects, even if the MANOVA was not significant, so we have not presented estimates of Type II error for such cases.

Table 10. Results of MANOVA to test for the effects of tourist use and zoning history, in the presence of effects related to habitat and reef, on abundances of 11 benthic taxa and 27 fish taxa on 22 mid-shelf reefs. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Tabled numbers in bold indicate statistically significant effects ($\alpha_{obs} \le 0.1$).

	BENTHOS			SMALL FISH			LARGE FISH		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$
Use	10.100	11, 8	**0.002**	145.779	18, 1	**0.065**	1.300	9, 10	0.344
Zone	4.069	11, 8	**0.028**	104.559	18, 1	**0.077**	1.169	9, 10	0.403
Use*Zone	2.153	11, 8	0.143	2407.374	18, 1	**0.016**	1.069	9, 10	0.456
Habitat	1.433	11, 8	0.311	15.903	18, 1	0.195	1.901	9, 10	0.166
Use*Habitat	1.870	11, 8	0.192	158.971	18, 1	**0.062**	0.524	9, 10	0.828
Zone*Habitat	1.011	11, 8	0.507	231.306	18, 1	**0.052**	1.734	9, 10	0.202
Use*Zone*Habitat	0.635	11, 8	0.762	133.911	18, 1	**0.068**	0.917	9, 10	0.547
reef(Use*Zone)	2.534	198, 902	**<0.001**	1.986	324, 1476	**<0.001**	2.439	162, 738	**<0.001**
Hab*reef(Use*Zone)	1.901	198, 902	**<0.001**	1.400	324, 1476	**<0.001**	1.182[10]	162, 616.5	**0.083**

Table 11. Results of MANOVA to test for the effects of tourist use and zoning history, in the presence of effects related to habitat and reef, on abundances of eight benthic taxa and 29 fish taxa on 24 outer-shelf reefs. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Tabled numbers in bold indicate statistically significant effects ($\alpha_{obs} \le 0.1$).

	BENTHOS			SMALL FISH			LARGE FISH		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$
Use	1.951	8, 13	0.137	54.254	20, 1	0.107	0.678	9, 12	0.716
Zone	2.161	8, 13	0.105	76.523	20, 1	**0.090**	1.437	9, 12	0.274
Use*Zone	0.638	8, 13	0.734	62.339	20, 1	**0.100**	1.821	9, 12	0.165
Habitat	5.480	8, 13	**0.004**	4.416	20, 1	0.361	3.611	9, 12	**0.021**
Use*Habitat	1.467	8, 13	0.259	1.473	20, 1	0.580	0.916	9, 12	0.543
Zone*Habitat	0.984	8, 13	0.490	0.980	20, 1	0.676	0.627	9, 12	0.755
Use*Zone*Habitat	0.893	8, 13	0.549	1.275	20, 1	0.614	0.399	9, 12	0.913
reef(Use*Zone)	1.911	160, 672	**<0.001**	1.811	400, 1680	**<0.001**	1.471	180, 756	**0.003**
Hab*reef(Use*Zone)	2.046	160, 672	**<0.001**	1.630	400, 1680	**<0.001**	1.657	180, 756	**<0.001**

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[10] Result for Wilkes' Lambda statistic, which was consistent with Roy's Greatest Root and the Hotelling-Lawley Trace

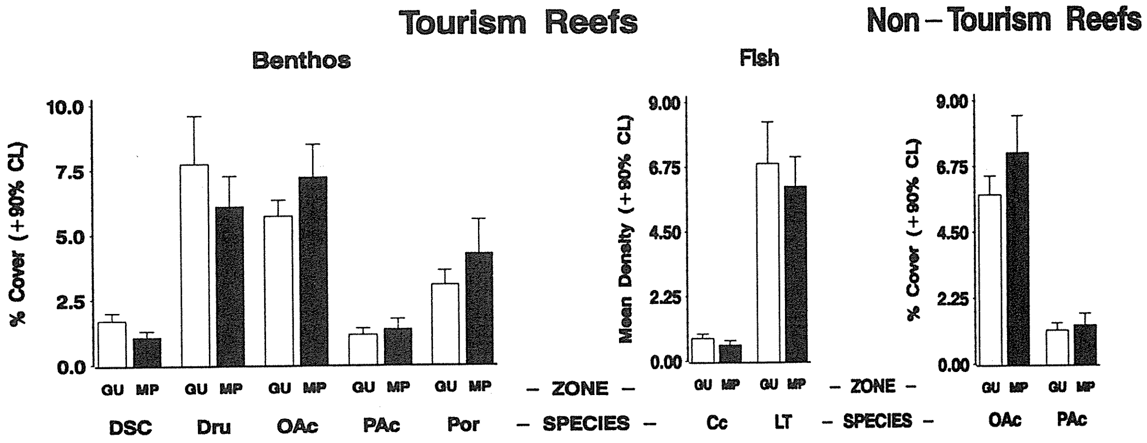

Figure 1. Bar charts of statistically significant main effects of zoning history on abundances of surveyed organisms. Bars represent the mean responses over both habitats in all shelf positions for Benthos and total counts of lutjanids on Tourism Reefs, but the mean of counts from only mid-shelf and outer-shelf reefs for *C. citrinellus* on tourism reefs and plating and other acroporids on Non-Tourism Reefs. **Abbreviations: GU**—General Use Zone; **MP**—Marine National Park B Zone; **DSC**—Dead Standing Coral; **Dru**—% *Drupella* affected corals; **PAc**—Plate Acroporids; **OAc**—Other Acroporids; **Por**—Poritids; **Cc**—*Chaetodon citrinellus*; **LT**—Total Lutjanids.

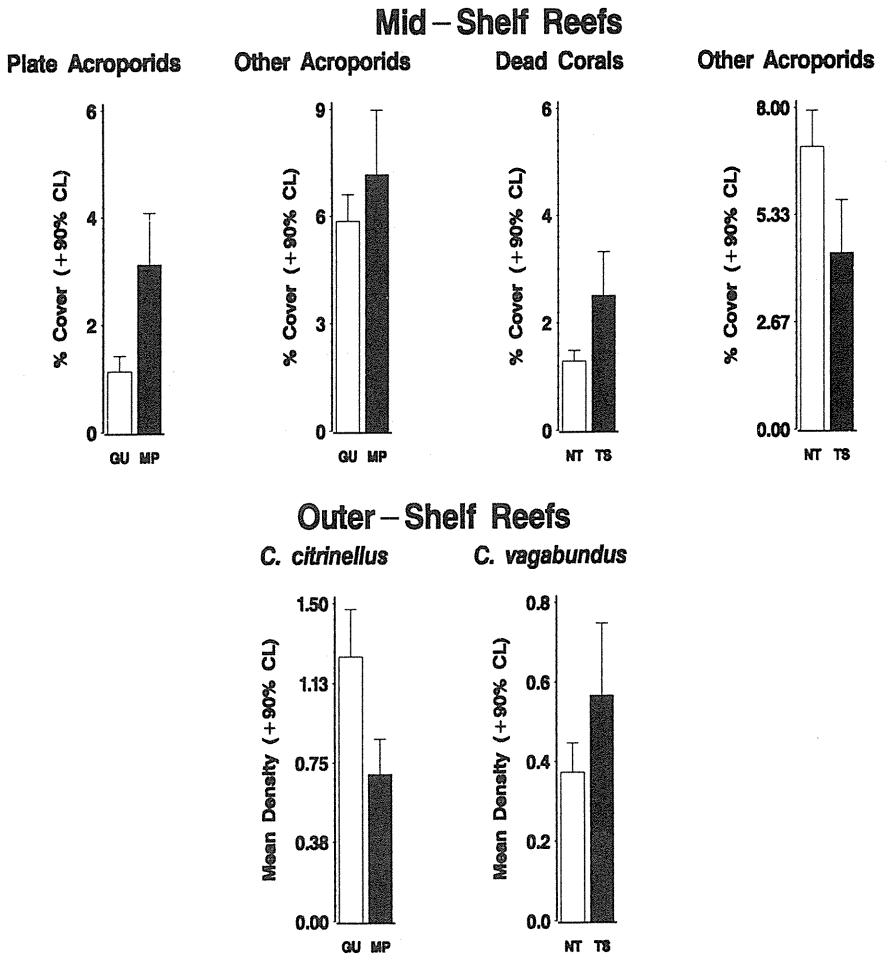

Figure 2. Bar charts of statistically significant main effects of zoning history on abundances of plate and other acroporids (mid-shelf) and *C. citrinellus* (outer-shelf), and of tourist use on abundances of dead corals and other acroporids (mid-shelf) and *C. vagabundus* (outer-shelf). Bars represent mean responses over all other effects at each shelf position. **Abbreviations**: **GU**—General Use Zone; **MP**—Marine National Park B Zone; **NT**—Non-Tourism Reefs; **TS**—Tourism Reefs.

Table 12. Probability of Type II error (β_{obs}) for each **taxon** for which the main effect of Zoning History was considered non-significant, and zoning history did not interact significantly with other factors. **Use** and **Shelf Pos**^{n} indicate the conditions on the reefs from which data were analysed, and α_{obs} is the probability of the observed data under the null hypothesis of no effect of zoning history. Type II error was calculated against a critical significance criterion of $\alpha_{crit}=0.1$, with an effect size equal to a difference between GU and MNP reefs of 50% of the mean abundances on GU reefs (**Mean**$_{GU}$). Taxa for which $\beta_{obs}>0.2$ (statistical power < 0.8) are shaded.

				POTENTIAL ERRORS	
USE	**SHELF POS**^{N}	**TAXON**	**MEAN**$_{GU}$	α_{obs}	β_{obs}
Non-Tourist	**Mid, Outer**	***C. plebeius***	0.88	0.400	0.000
		P. leopardus	0.98	0.248	0.000
		Other Hard Coral	5.71	0.769	0.000
		C. baronessa	1.00	0.974	0.001
		Other Acanthurids	23.74	0.824	0.003
		C. trifasciatus	0.39	0.395	0.003
		Sponges	1.17	0.188	0.007
		C. auriga	0.44	0.167	0.013
		C. melannotus	0.42	0.192	0.038
		L. gibbus	1.55	0.219	0.151
		***Drupella* Infestation**	7.91	0.654	0.167
		L. bohar	0.63	0.296	0.234
		Other Chaetodons	0.51	0.942	0.489
		Other Lutjanids	2.29	0.289	0.508
		Other Lethrinids	0.71	0.752	0.534
Tourist	**Inner, Mid, Outer**	**Other Hard Coral**	7.52	0.860	0.000
		All Lutjanids	3.69	0.127	0.000
		Poritids	3.95	0.900	0.005
		Acroporids -- Other	5.68	0.248	0.009
		Other Acanthurids	20.88	0.200	0.039
		***Drupella* Infestation**	7.21	0.323	0.083
		C. melannotus	0.40	0.680	0.283
Tourist	**Mid, Outer**	***Zebrasoma scopas***	5.79	0.632	0.000
		C. plebeius	1.41	0.672	0.024
		Monotaxis grandoculis	1.88	0.674	0.047
		L. bohar	0.57	0.787	0.064
		L. gibbus	0.88	0.501	0.115
		C. trifasciatus	0.68	0.630	0.168
		C. baronessa	1.29	0.518	0.187
		Lethrinus atkinsoni	0.55	0.253	0.270
		C. auriga	0.24	0.404	0.377
		C. kleinii	0.39	0.248	0.464
		Other Lutjanids	0.74	0.326	0.780

Table 13: Type II error (β_{obs}) for each **taxon** for which the main effect of Zone was non-significant in analyses of Use and Zone, and Zone did not interact with other factors. **Shelf Pos^{n}**—the shelf position of the reefs analysed; α_{obs}—probability of the observed data under the null hypothesis of no zone effect. Type II error was calculated against $\alpha_{crit} = 0.1$. Effect size equalled a difference between GU and MNP reefs of 50% of mean abundances observed on GU reefs (**Mean**$_{GU}$). Taxa for which β_{obs}>0.2 are shaded.

			POTENTIAL ERRORS	
SHELF POS^{N}	**TAXON**	**MEAN$_{GU}$**	α_{obs}	β_{obs}
Mid-shelf	***C. plebeius***	0.92	0.419	0.000
	Other Hard Coral	5.39	0.492	0.000
	Soft Corals	8.38	0.183	0.000
	Poritids	2.65	0.761	0.015
	C. auriga	0.47	0.884	0.039
	A. curacao	2.53	0.767	0.080
	T. gigas	0.33	0.611	0.100
	L. carponotatus	1.51	0.244	0.126
	C. rollandi	1.61	0.503	0.131
	Other Chaetodons	0.35	0.752	0.212
	C. melannotus	0.36	0.432	0.218
	C. trifasciatus	0.26	0.411	0.257
	C. aureofasciatus	2.15	0.790	0.377
	***Drupella* Infestation**	9.52	0.730	0.431
	L. laevigata	2.24	0.609	0.522
	Other Lutjanids	1.37	0.713	0.547
	L. gibbus	0.92	0.483	0.599
	Other Lethrinids	0.82	0.808	0.721
	L. fulviflamma	1.42	0.702	0.784
Outer-shelf	***Z. scopas***	6.97	0.342	0.000
	C. plebeius	1.10	0.729	0.000
	Acroporids – Other	6.18	0.136	0.000
	Other Hard Coral	7.49	0.670	0.000
	Dead Corals	1.41	0.505	0.000
	***Drupella* Infestation**	6.39	0.126	0.000
	M. grandoculis	2.11	0.389	0.001
	P. leopardus	0.54	0.515	0.001
	C. vagabundus	0.43	0.519	0.003
	Sponges	1.36	0.466	0.003
	Poritids	4.04	0.386	0.012
	Other Lethrinids	0.37	0.730	0.020
	Acroporids - Plate	0.77	0.486	0.028
	C. pelewensis	1.31	0.159	0.033
	C. melannotus	0.50	0.414	0.037
	C. ornatissimus	0.37	0.821	0.037
	L. gibbus	1.90	0.197	0.094
	L. atkinsoni	0.45	0.693	0.113
	C. unimaculatus	0.16	0.929	0.144
	Other Lutjanids	0.95	0.541	0.151
	L. bohar	1.00	0.934	0.164
	M. niger	0.48	0.138	0.200
	C. auriga	0.30	0.383	0.237
	F. flavissimus	0.56	0.165	0.373
	C. kleinii	0.33	0.967	0.448
	Other Chaetodons	0.54	0.650	0.646

Table 14. Probability of Type II error (β_{obs}) for each **taxon** for which the main effect of Tourist Use was considered non-significant in analyses of Use and Zoning History, and use did not interact significantly with other factors. **Shelf Pos^n** indicates the shelf position of the reefs from which data were analysed, and α_{obs} is the probability of the observed data under the null hypothesis of no effect of different levels of Use by tourists. Type II error was calculated against a critical significance criterion of $\alpha_{crit}=0.1$, with an effect size equal to a difference between Non-tourist (NT) and Tourist (TS) reefs of 50% of the mean abundances observed on TS reefs (**Mean$_{TS}$**). Taxa for which $\beta_{obs}>0.2$ (statistical power < 0.8) are shaded.

			POTENTIAL ERRORS	
SHELF POS^N	**TAXON**	**MEAN$_{TS}$**	α_{obs}	β_{obs}
Mid-shelf	**Other Hard Coral**	5.59	0.447	0.000
	Soft Corals	8.43	0.200	0.001
	C. plebeius	0.81	0.157	0.003
	Poritids	3.16	0.828	0.003
	C. baronessa	1.54	0.803	0.012
	L. bohar	0.33	0.103	0.039
	A. curacao	2.89	0.556	0.043
	C. rollandi	1.97	0.683	0.053
	Acroporids – Plate	1.93	0.123	0.100
	Other Lutjanids	1.81	0.718	0.374
	Other Chaetodons	0.29	0.429	0.409
	C. melannotus	0.23	0.506	0.580
	L. laevigata	1.71	0.594	0.691
	Other Lethrinids	0.37	0.151	0.867
	L. fulviflamma	0.63	0.574	0.880
Outer-shelf	***Z. scopas***	7.21	0.172	0.000
	C. citrinellus	1.35	0.317	0.000
	M. grandoculis	2.22	0.124	0.002
	Dead Corals	1.00	0.300	0.003
	Poritids	5.08	0.119	0.004
	P. leopardus	0.51	0.613	0.009
	C. ornatissimus	0.44	0.875	0.026
	Other Lethrinids	0.39	0.776	0.041
	L. atkinsoni	0.60	0.470	0.043
	C. pelewensis	1.43	0.313	0.044
	C. melannotus	0.55	0.830	0.049
	P. laevis	0.13	0.853	0.173
	C. auriga	0.27	0.942	0.422
	C. unimaculatus	0.13	0.643	0.449
	Acroporids – Plate	0.45	0.230	0.451
	L. gibbus	1.13	0.345	0.563
	L. bohar	0.66	0.209	0.568
	C. kleinii	0.29	0.245	0.621
	M. niger	0.30	0.146	0.630
	Other Lutjanids	0.48	0.239	0.696
	F. flavissimus	0.38	0.256	0.698
	Other Chaetodons	0.30	0.279	0.840

Effects of Zoning Related to Habitat

Interactions between zoning history and habitat effects on abundances were significant only for four fish taxa (*P. lacrymatus, C. trifascialis, C. vagabundus*, and other chaetodons) (figure 3). In all cases, abundances were either significantly greater on MNP reefs than on GU reefs, or did not differ with zone. Protective zoning (MNP) apparently resulted in greater abundances more often on back reefs (three taxa) than on front reefs (one taxon). The size of effects were also generally greater in back reef habitat (MNP ~ 2–2.5 x GU) than in front reef habitats (MNP~GU or MNP ~ 1.4 x GU) (figure 3). The differential effects of zoning in back reef and front reef habitats meant that the relationship between habitats varied with zoning history for three of the four taxa (figure 3).

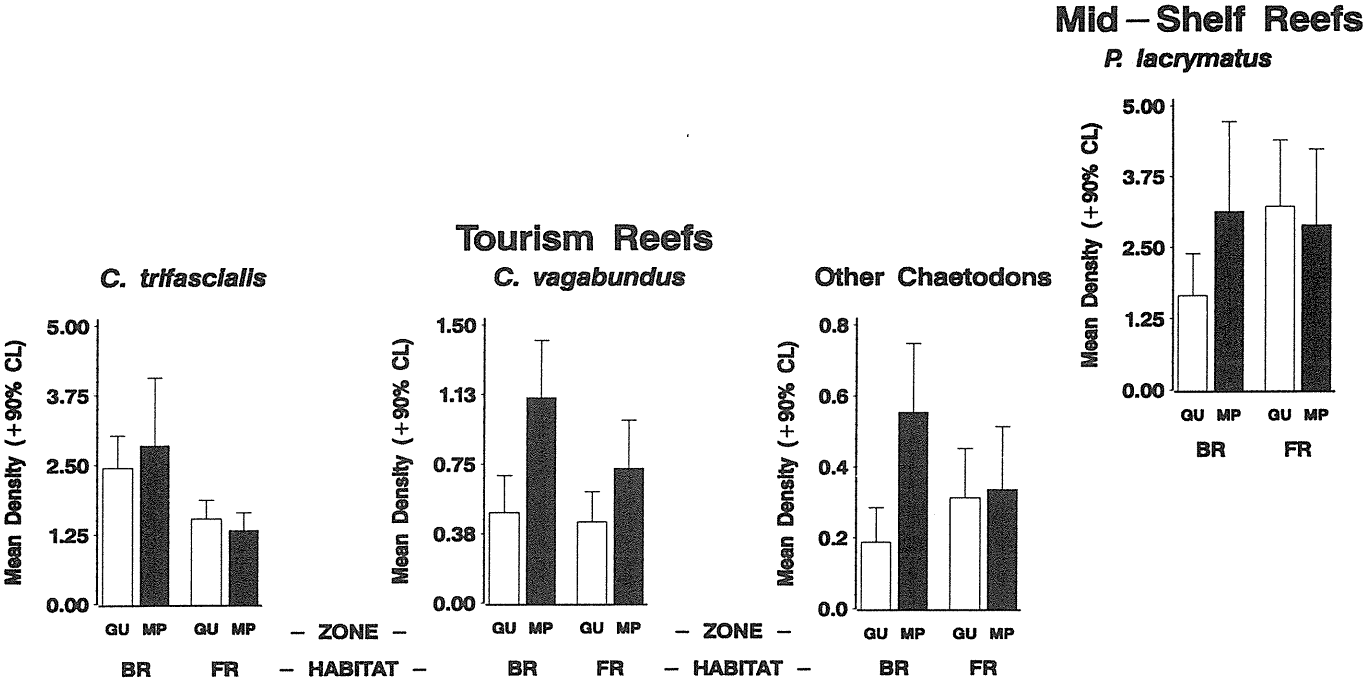

Figure 3. Bar charts of statistically significant interactions between zoning history and habitat. Effects were significant for only one taxon on mid-shelf non-tourism reefs, but for three taxa on tourism reefs, where they were consistent across all shelf positions (inner-, mid- and outer-). **Abbreviations**: **GU**—General Use Zone; **MP**—Marine National Park B Zone; **BR**—Back Reef; **FR**—Front Reef.

Effects of Zoning Related to Shelf Position

Abundances of three taxa varied significantly with zoning history in different ways at different shelf positions (figure 4), but these effects were apparent only on non-tourism reefs. *C. trifascialis*, *M. grandoculis* and *Z. scopas* were all recorded more on MNP reefs than on GU reefs on the mid-shelf, but on the outer-shelf were at either similar densities in both zones (*M. grandoculis*) or slightly more abundant on GU reefs (*C. trifascialis* and *Z. scopas*) (figure 4). The substantially greater abundances of *C. trifascialis* and *M. grandoculis* on mid-shelf MNP reefs (than on mid-shelf GU reefs) meant that the effects of shelf position on these species were not consistent across both zones (figure 4).

Interactions Between Effects of Zoning and Use

Interactions between zoning history and level of tourist use were common signals, relative to other possible effects considered. Zoning-Use interactions were statistically significant for four fishes and two benthic taxa on mid-shelf reefs, and for three chaetodontid fishes on outer-shelf reefs (figure 5). The nature of the interactions varied among taxa. Abundances of *Chaetodon trifascialis*, *Chromis atripectoralis*, *Thalassoma lunare* and *Tridacna derasa* (on mid-shelf reefs) and *C. trifascialis* and *C. ulietensis* (on outer-shelf reefs) were consistently either greater on MNP reefs than on GU reefs (seven cases), or not significantly different between zones (five comparisons), on both tourist and non-tourist reefs (figure 5). In only three of the 18 comparisons (9 taxa*shelf positions x 2 Use levels) between MNP and GU zones were mean abundances on GU reefs significantly greater than those on MNP reefs (sponges and *P. lacrymatus* on tourist reefs and *C. ephippium* on non-tourist reefs, figure 5).

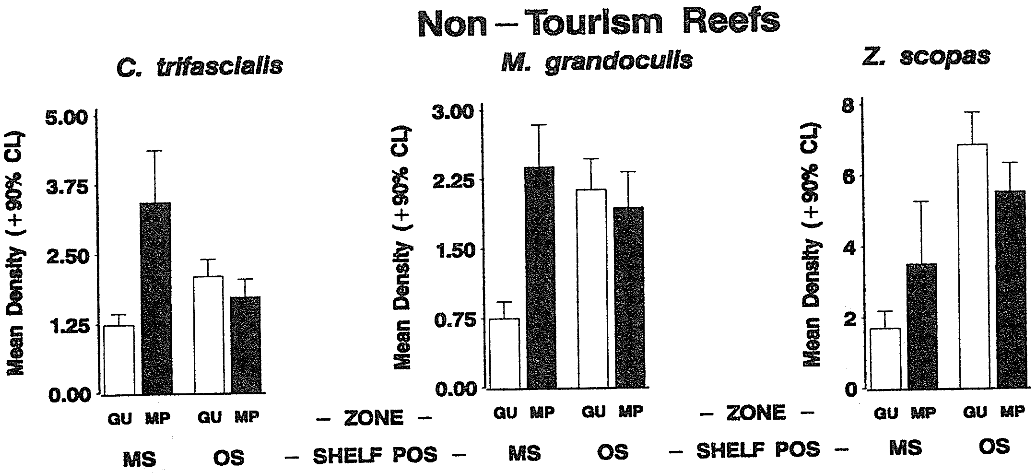

Figure 4. Bar charts of statistically significant interactions between zoning history and shelf position. Effects were significant for only three taxa on non-tourism reefs but were consistent across habitats. **Abbreviations**: **GU**—General Use Zone; **MP**—Marine National Park B Zone; **MS**—mid-shelf reefs; **OS**—outer-shelf reefs

Abundances of six taxa were lower on tourist reefs than on non-tourist reefs in either MNP zones (*C. trifascialis* on the mid-shelf, *T. derasa*, and *P. lacrymatus*) or GU zones (*C. atripectoralis*, *T. lunare* and *C. ephippium*) (figure 5). In four cases (the chaetodons on outer shelf reefs and *T. lunare* on the mid-shelf) abundances were significantly greater on tourist MNP reefs than on non-tourist MNP reefs, and a similar pattern was evident on GU reefs for another three taxa (sponges, *P. lacrymatus* and *C. trifascialis* on the outer-shelf) (figure 5). There was apparently no effect of intensity of tourist use in the remaining five comparisons (three on GU reefs and two on MNP reefs).

In summary, effects of protective zoning (MNP reefs) were most often either negligible or resulted in increased abundances. Effects of tourist use, however, were neither predominantly 'positive' (enhanced abundances) or 'negative', both effects occurring with approximately equal frequency.

Effects of Use Related to Habitat

Although abundances of three taxa varied in a habitat-dependent way with notional intensity of tourist visitation to reefs, the effects were not consistent among taxa (figure 6). Further, in both habitats all possibilities occurred: abundances on tourist reefs significantly greater than those on non-tourist reefs (*C. trifascialis* in back reefs, other acanthurids in front reefs); counts greater on non-tourist reefs than on tourist reefs (*P. lacrymatus* in back reefs, *C. trifascialis* in front reefs); and no significant difference between levels of use (Other acanthurids in back reefs, *P. lacrymatus* in front reefs) (figure 6).

Effects of Zoning Related to Use and Habitat

Abundances of *C. vagabundus* and *P. moluccensis* on mid-shelf reefs varied with zoning history, but the patterns related to zoning depended on both the habitat and degree of tourist use of reefs (figure 7). Results were similar for both species, however. Abundances in back reef habitats were greater on MNP reefs than on GU reefs only where tourist use was relatively higher (the 'tourist', TS reefs), but in front reef habitats abundances were greater on MNP reefs than on GU reefs only for non-tourist reefs (figure 7). On the backs of non-tourist reefs and the fronts of tourist reefs, abundances of neither species differed significantly with zoning history.

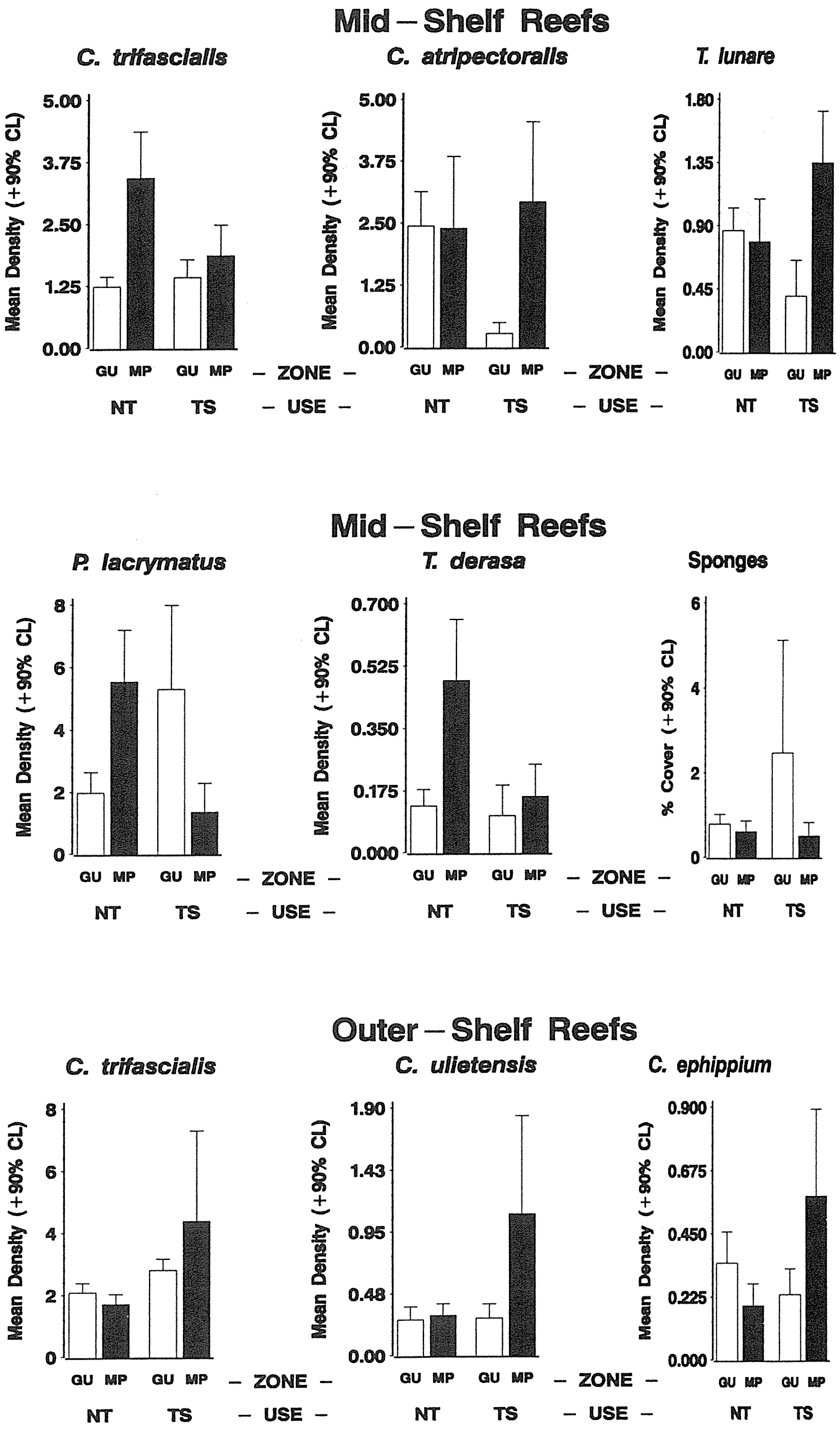

Figure 5. Bar charts of statistically significant interactions between zoning history and tourist use. **Abbreviations**: **GU**—General Use Zone; **MP**—Marine National Park B Zone; **NT**—Non-Tourism Reefs; **TS**—Tourism Reefs.

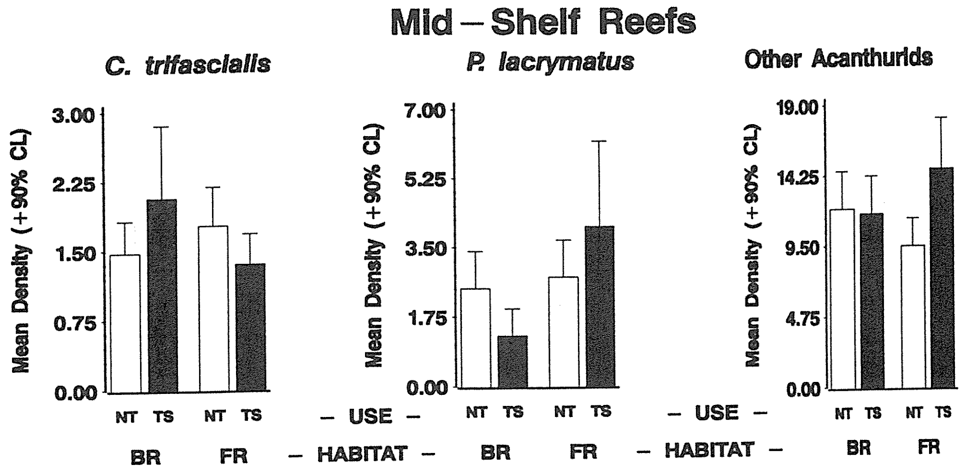

Figure 6. Bar charts of statistically significant interactions between tourism use and habitat. Effects were significant for only three taxa on mid-shelf reefs, but were consistent across zoning categories (GU, MNPB). **Abbreviations**: NT—Non-Tourism Reefs; TS—Tourism Reefs; BR—Back Reef; FR—Front Reef.

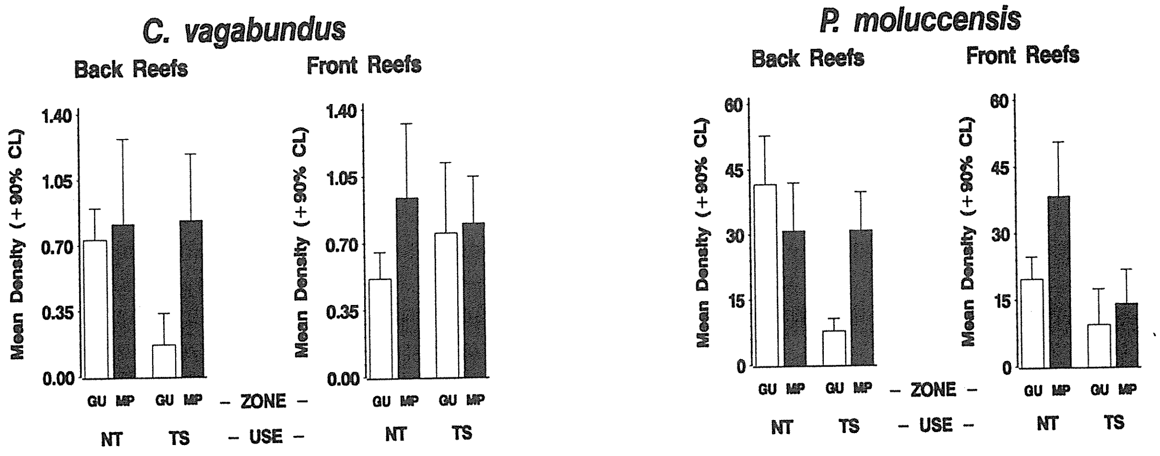

Figure 7. Bar charts of statistically significant interactions between zoning history, use and habitat. Effects were significant for only two taxa on mid-shelf reefs. **Abbreviations**: GU—General Use Zone; MP—Marine National Park B Zone; NT—Non-Tourism Reefs; TS—Tourism Reefs.

Patterns in abundances varied with tourist use in very irregular ways. Both species were more abundant on non-tourist than on tourist GU reefs in back reef habitat, but did not differ with use in the back reef habitats of MNP reefs (figure 7). In front reef habitats, abundances of *C. vagabundus* were greater on tourist GU reefs than on non-tourist GU reefs, but did not differ with use on MNP reefs. For *P. moluccensis*, however, abundances were greater on the fronts of non-tourist than on the fronts of tourist reefs for both GU and MNP zoning categories (figure 7).

Inter-annual Variations in Abundances

Relative differences (δ) in abundances of multiple taxa between 1990 and 1991 varied significantly with habitat (chaetodons) and both shelf position and habitat (benthos and major groupings of taxa) (table 15). Inter-annual variation in counts did not vary with habitat for those taxa found commonly on only mid-shelf reefs, however (table 16).

Table 15. Results of MANOVA to test whether inter-annual differences in mean abundances between 1990 and 1991 varied with gross habitat features (front reef and back reef) or shelf position (mid-shelf and outer-shelf). Mean abundances of seven benthic taxa and five chaetodon species (**A**), and five gross groupings of taxa (**B**: all hard coral, all chaetodons, all lutjanids, all acanthurids, and all *Plectropomus* spp.) were compared among seven mid-shelf and seven outer-shelf reefs sampled in the same way in both 1990 (Mapstone et al. 1998a, b) and 1991 (this report). Analysed data were the means of four (benthos in 1990) or five (all others) counts at each of three locations in each habitat of each reef. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Numbers in bold indicate significant effects.

A. Species and Genera

	BENTHOS			CHAETODONS		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$
Shelf Position	4.474	5, 20	**0.007**	1.431	5, 17	0.263
Habitat	8.350	5, 20	**<0.001**	2.927	5, 17	**0.044**
Shelf Pos^n*Habitat	2.506	5, 20	**0.064**	1.397	5, 17	0.275

B. Major Groups of Taxa

	MAJOR GROUPED TAXA		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$
Shelf Position	6.523	5, 20	**0.001**
Habitat	5.029	5, 20	**0.004**
Shelf Pos^n*Habitat	0.876	5, 20	0.515

Table 16. Results of MANOVA to test whether inter-annual differences in mean abundances between 1990 and 1991 varied with gross habitat features (front reef and back reef) on mid-shelf reefs. Mean abundances of five pomacentrid species and five miscellaneous other taxa (*Chaetodon aureofasciatus*, *Thalassoma lunare*, and *Lutjanus carponotatus, Tridacna* spp., *Linckia laevigata*) were compared between front and back reef habitats on seven mid-shelf reefs sampled in the same way in both 1990 (Mapstone et al. 1998a, b) and 1991 (this report). Analysed data were the means of four (pomacentrids in 1990) or five (all other cases) counts at each of three locations in each habitat at each reef. $\alpha_{>F}$: probability of the given **F**-ratio or greater, with indicated **df**, under the null hypothesis of no effect of the relevant **Source of Variation**. Numbers in bold indicate significant effects.

	POMACENTRIDS			MISCELLANEOUS TAXA		
SOURCE OF VARIATION	F	df	$\alpha_{>F}$	F	df	$\alpha_{>F}$
Habitat	0.992	5, 8	0.479	3.157	5, 5	0.116

Plots of taxon-specific differences in counts between years for taxa where no effects of shelf position or habitat were apparent are shown in figure 8. Inter-annual difference/mean ratios were generally about 0.5 or less, corresponding to a two-fold (or smaller) increase in the smaller of the values differenced. Differences were mostly highly variable among reefs, and our counts suggested that the net change between 1990 and 1991 would not be distinguishable from zero for all of the small fish, *L. laevigata*, tridacnid clams, and two of the chaetodons (*C. baronessa* and *C. vagabundus*). For most of the chaetodon taxa and both large fish species in this group (*L. carponotatus* and *Z. scopas*) our data suggested that abundances had increased significantly from 1990 to 1991, whilst abundances of poritid corals and *C. trifasciatus*[11] apparently decreased from 1990 to 1991 (figure 8).

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[11] *C. trifasciatus* is included here only for comparison with the other chaetodons. It was the only chaetodon for which a significant habitat effect was apparent (and then in interaction with shelf position), and the more detailed results are shown in figure 10.

Habitat effects on inter-annual differences were generally small, and usually did not affect the direction of apparent change (figure 9). Counts of most sessile benthic taxa were either greater in 1990 than in 1991 (relative difference, $\delta > 0$), or apparently did not change significantly between 1990 and 19091 (figure 9). For most large fish, however, counts were higher in 1991 than in 1990 ($\delta < 0$). Absolute values of differences in front reef habitats were most often greater than analogous estimates from back reefs for benthos, but there was no similarly consistent pattern for the large fishes (figure 9).

Interactions between shelf position and habitat significantly affected inter-annual variation in abundances of dead corals and the chaetodon *C. trifasciatus* (figure 10). For both taxa, inter-annual differences in abundance were similar in both habitats on mid-shelf reefs and the backs of outer-shelf reefs (1990 > 1991), but all three differed from the fronts of outer-shelf reefs (figure 10). Dead corals were considerably more abundant in 1991 than in 1990 on the fronts of outer-shelf reefs, whereas abundances of *C. trifasciatus* were greater in 1990 than in 1991 (as in the other three habitat x shelf position combinations), but the difference was less than elsewhere.

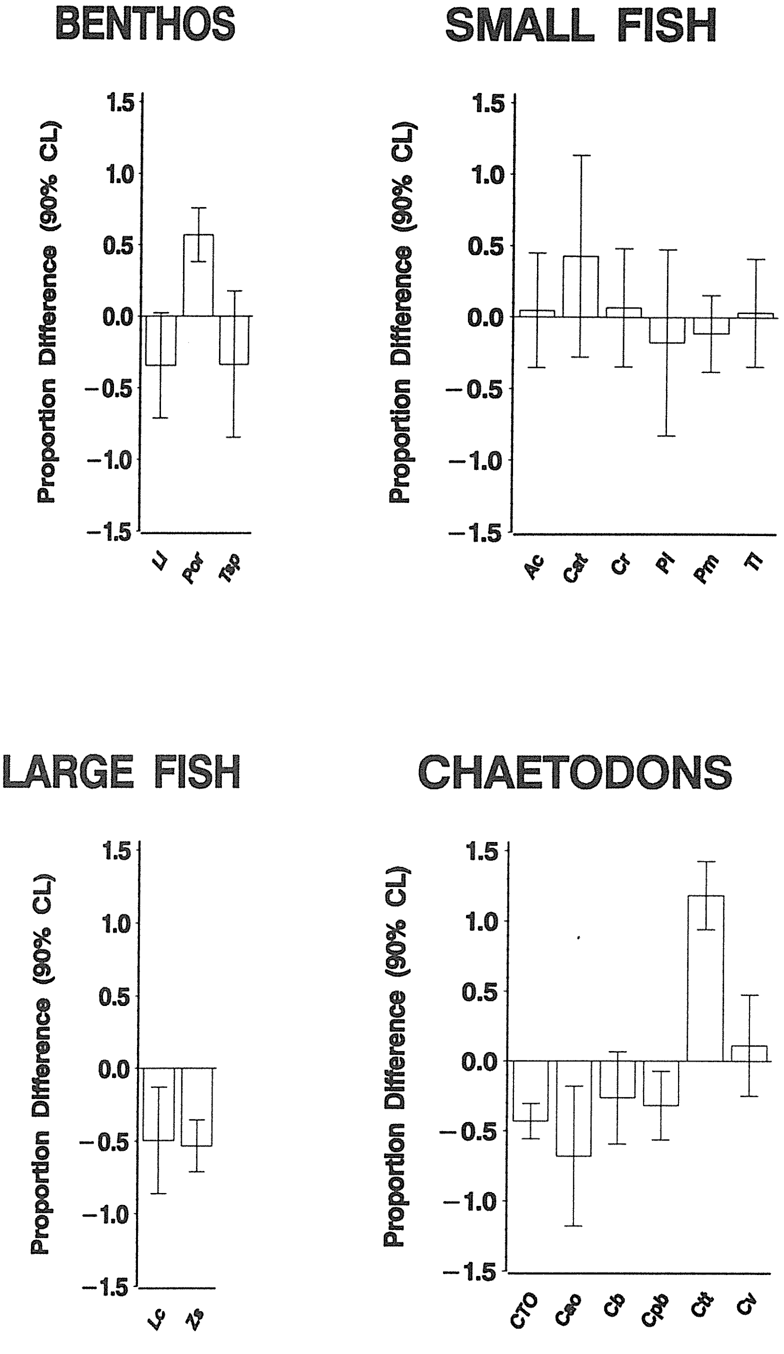

Figure 8. Bar charts of inter-annual variation in abundances of taxa sampled in 1990 and 1991 for which variation was similar across habitats and/or shelf positions. Data for small fish, *L. laevigata*, *Tridacna* spp., *L. carponotatus* and *C. aureofasciatus* were from seven mid-shelf reefs only, whilst data for the remaining taxa were from those reefs and seven outer-shelf reefs. Variation is expressed as the difference in counts between the years divided by their average. **Abbreviations**: ***Ll***—*Linckia laevigata*; ***Por***—Poritids; ***Tsp***—*Tridacna* spp. (clams); ***Ac***—*Amblyglyphidodon curacao;* ***Cat***—*Chromis atripectoralis;* ***Cr***—*Chrysiptera rollandi;* ***Pl***—*Plectroglyphidodon lacrymatus;* ***Pm***—*Pomacentrus moluccensis;* ***Tl***—*Thalassoma lunare;* ***CTO***—Total chaetodons; ***Cb***—*Chaetodon baronessa;* ***Cao***—*Chaetodon aureofasciatus;* ***Cpb***—*Chaetodon plebeius;* ***Ctt***—*Chaetodon trifasciatus;* ***Cv***—*Chaetodon vagabundus;* ***Lc***—*Lutjanus carponotatus*; ***Zs***—*Zebrasoma scopas.*

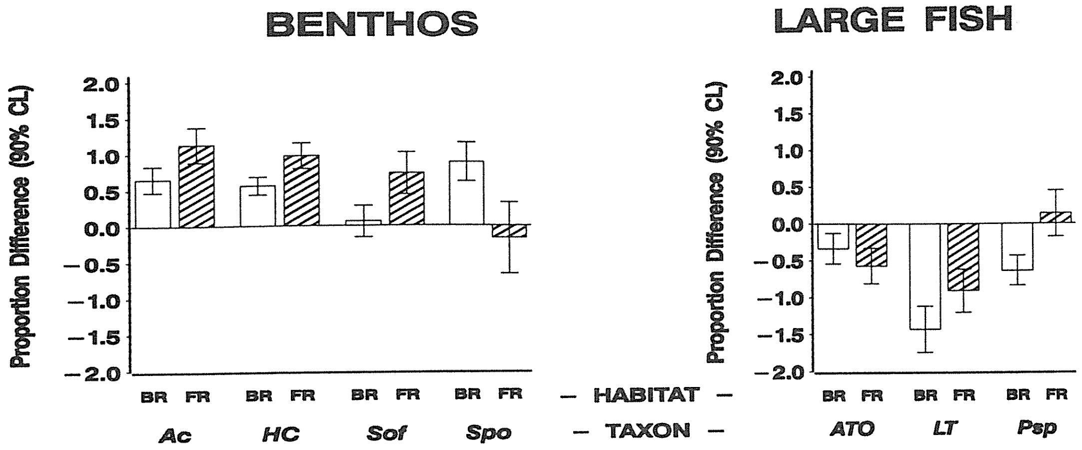

Figure 9. Bar charts of habitat-dependent inter-annual variation in abundances of benthos and large fishes for seven mid-shelf and seven outer-shelf reefs surveyed in both 1990 and 1991. Variation is expressed as the difference in counts between the years divided by their average. **Abbreviations**: **BR**—Back Reef; **FR**—Front Reef; Ac—Acroporid Corals; HC—Total Hard Coral; *Sof*—Soft Corals; *Spo*—Sponges; *ATO*—Total Acanthurids; *LT*—Total Lutjanids; *Psp*—All *Plectropomus* spp. (coral trout).

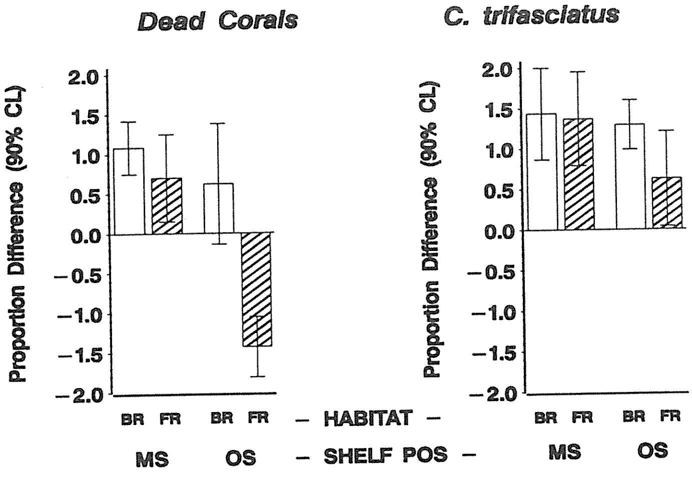

Figure 10. Bar charts showing the effects of significant interactions between shelf position and habitat on inter-annual variation in counts of dead standing coral and *C. trifasciatus.*[12] Variation is expressed for each taxon as the difference in counts between the years divided by their average. **Abbreviations**: **BR**—Back Reef; **FR**—Front Reef; **MS**—mid-shelf reefs; **OS**—outer-shelf reefs.

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[12] Although only habitat effects were significant in the MANOVA for chaetodon fishes at both shelf positions (table 11), the univariate ANOVA for *C. trifasciatus* indicated a significant habitat x shelf position interaction, as well as a significant main effect of habitat. The interaction is plotted here as the more cautious interpretation of the mismatch between the significant habitat effect in the MANOVA and the significant interaction effect in the ANOVA.

DISCUSSION

We have reported here a comprehensive survey of reefs in the Cairns Section of the GBRMP. Despite surveying 50 reefs, however, we found no clear evidence of an emerging outbreak of crown-of-thorns starfish (*Acanthaster planci*), with the numbers of individuals seen similar overall to those seen in the same region in the previous year (1990) (Mapstone et al. 1998a). It was perhaps noteworthy that most of the *A. planci* we saw were small-medium sized, but apart from at Endeavour Reef, they were uncommon. The emergence of boom populations of *A. planci* since 1994 (Engelhardt 1997; Engelhardt and Lassig 1996) suggests either that those individuals present in the boom populations were not present in 1991, or that they were small and sufficiently cryptic that non-destructive visual surveys would not have detected them.

The inter-annual variation in abundances from 1990 to 1991 we report suggest that monitoring the effects of management strategies will require considerable investment in longitudinal data to be sensitive to effects of management in the context of natural and/or observational variation. For most taxa, abundances differed substantially between years, though the origin of such variation cannot be certain. Given the expected longevity of many of the fishes (Brown 1994; Brown et al. 1993, 1996; Fowler 1990; Ferreira and Russ 1995; Mapstone 1988; Russ et al. 1996; Williams 1997; Choat unpub. data) and the multi-species nature of most measures of coral abundances, one- or two-fold real changes in abundance from year-to-year seem unlikely to be typical. Accordingly, it seems likely either that one or both of the years we considered was aberrant, or that the apparent differences reflected sampling variation and/or confounding of observers with survey.

The passage of cyclone Ivor through the Cairns Section of the Marine Park in mid-March 1990 (Done et al. 1993; van Woesik et al. 1991), after most of the data for that year had been collected, may represent an unusual event. Although cyclones *per se* are not unusual, the amount of habitat damage caused by cyclone Ivor was extreme on several reefs and apparently more than usual for cyclonic disturbances (Done et al. 1993, van Woesik et al. 1991). Such damage might have precipitated the large differences we saw between 1990 (pre-cyclone Ivor) and 1991, 12 months later. The relatively high frequency of counts of sessile benthos that were less in 1991 than in 1990 would be consistent with such an hypothesis. The greater counts of many of the fishes in 1991 compared with 1990 would be less conspicuously consistent with an hypothesis of cyclone disturbance, however, unless the habitat damage from the cyclone had increased visibility of some of the more secretive species.

The possibility of changed observer bias precipitating high inter-annual variation cannot be ruled out since, for both the fish and benthic taxa, observers in 1991 were not the same as those in 1990. Whilst this is clearly not desirable, it is likely to be a facet of most long-term monitoring programs. Since we were unable to train observers from one year against those from the previous year, however, the variation we saw might be expected to represent the worst case of change in observers that will have to be managed in long-term monitoring. Thompson and Mapstone (1997) considered the implications of observer-related bias and variation for long-term monitoring and, despite careful training of observers, they found substantial residual variation between observers for several taxa of reef fish. Such operational problems with long-term monitoring procedures indicate that if longitudinal monitoring for management strategy evaluation is commissioned, it should probably be commissioned through an institutional facility where multiple observers are available, adequate training of them is properly managed, and where the effects of staff-turnover can be minimised.

The results we present here do not indicate a clear, unequivocal set of patterns in abundances of several organisms related to either zoning history or notional tourist use. For many taxa, our sampling was insufficient to detect whatever effects of either past zoning or tourist use might have occurred. For other taxa, the zoning-related patterns frequently depended on either where across the continental shelf we looked, on the habitat considered, or on the notional history of consistent tourist use. Similarly, patterns in abundances related to frequency of tourist use also varied with habitat, zoning status, or shelf position.

Abundances of organisms were greater on non-tourist reefs than on tourist reefs in 12 cases, whilst the reverse was true in nine cases. If either result (TS>NT or NT>TS) was considered equally likely, this arrangement (or one more extreme) of 21 cases in which a significant difference occurred would have a probability of 0.33. At face value, therefore, it seems unlikely that the effects of tourist use were manifest predicably as either increasing or decreasing abundances of biota.

Despite the heterogeneity in effects of zoning history, it was more often the case that MNP reefs had significantly greater abundances of organisms than GU reefs (23 cases) than the reverse (GU>MNP – 11 cases). If it was considered equi-probable that MNP reefs or GU reefs would have the greater abundances of organisms, then in a set of 34 differences between GU and MNP reefs approximately 17 would be expected to show greater abundances on MNP reefs and 17 would be expected to show greater abundances on GU reefs. The probability that GU reefs would be greater than MNP reefs in only 11 (or fewer) of the 34 contrasts by chance alone would be only 0.029. In most cases, greater abundances on MNP reefs than on GU reefs would be interpreted as evidence of a desirable effect of protection from exploitative use (protective zoning). Such an inference rests on the premise that greater abundances are desirable, and that the lack of protection from some uses on GU reefs had resulted in declines in abundances of some organisms.

Whilst it may be tempting to infer that this is evidence of an effective zoning strategy, such an inference is weak and should be regarded with great caution because of the limited information from which it arises. Mechanisms by which such declines might have been caused are not obvious for some of the organisms for which effects were apparent, and for others that are known to be targets of harvest (e.g. some emperors, snappers, and coral trout—Mapstone et al. 1996a), no effects of zoning history were apparent. In some cases the lack of effects may be at least partly related to the inappropriateness of underwater visual survey for counting those species that are most targeted by fishing (e.g. *L. miniatus, L. nebulosus*) (Mapstone and Ayling 1998), or because many species are not generally targets of a fishery or collection activity (e.g. several of the lutjanids and lethrinids) (Mapstone et al. 1996a). Coral trout (*Plectropomus* spp.), however, are fairly amenable to underwater visual survey (Mapstone and Ayling 1998) and are the fishes most targeted by the reef line fishery (Higgs 1996; Trainor 1991; Mapstone et al. 1996a).

The absence of effects of zoning history for many of these species could reflect several alternative situations. First, it may be that fishing pressure on GU reefs in the Cairns Section has been relatively ineffective in reducing numbers of target species such as coral trout. The gross levels of commercial reef line fishing effort and catch over most of the Cairns Section apparently has been low relative to elsewhere on the GBR (Mapstone et al. 1996a). On the other hand, Blamey and Hundloe (1993) reported that recreational fishing on the GBR in the Cairns region was greater than elsewhere. There are insufficient data available, however, to describe the patterns in recreational fishing over the whole of the Cairns Section, although it seems likely that recreational reef line fishing would be more common in the southern half of the Section simply because of the greater coastal settlement south of Mossman (Higgs 1996). Alternatively, reductions in numbers of larger coral trout (through fishing) might have been compensated by increased numbers of smaller coral trout, most likely because of increased survivorship of juveniles (Ayling et al. 1991). Such a pattern has been documented previously elsewhere on the GBR (Ayling et al. 1991), and cannibalism by coral trout (St John 1995) provides a potential mechanism for such an effect. A third alternative is that infringements of reef closures have erased any benefits from notional protection from fishing. Movement of coral trout among reefs, such that any benefits of reef closure would be diluted through migration of fish to and from areas where they can be caught (a fourth alternative), seems unlikely given recent work by Davies (1995a, b) which found very little evidence of inter-reef migration of *P. leopardus*. It is impossible to discriminate conclusively among these models without better reef-specific information about the amount of fishing effort and catch or levels of closure infringements, and without information about the relative status of reefs prior to the implementation of the previous zoning strategy.

Greater abundances of several other taxa on MNP reefs than on GU reefs are also difficult to explain. The fishes for which zone-related patterns were apparent were generally either a few chaetodon or pomacentrid species. At least some of these species are likely to be targets of the aquarium fish industry, and so might be expected to have suffered from collection on the GU reefs. Again, however, the dearth of information about the distribution and amount of such collection effort makes it impossible to correlate patterns in abundances with the (putative) cause of lower abundances. Although chaetodons have not been found to be major dietary items of target species for reef fisheries (e.g. coral trout), several pomacentrid species are commonly eaten by coral trout (St John 1995; Kingsford 1992). The consequence of reduced coral trout abundances on GU reefs (because of fishing), however, would be expected to be reduced predation pressure on such target species, which would presumably lead to increased abundances. Thus, we would have expected to see secondary effects of fishing (on GU reefs) manifest as increased abundances of prey species such as pomacentrids. Such effects were not apparent, however.

Perhaps of greater interest were the patterns in abundances of acroporid corals (both plates and others) and dead corals in relation to both zoning and tourist use. Acroporids were generally more abundant on non-tourist reefs than on tourist reefs, and more abundant on MNP reefs than on GU reefs. Dead corals, however, were more abundant on the more used reefs (tourist and/or GU) than on the putatively less-used reefs (non-tourist and MNP). It might be hypothesised that activities such as diving and anchoring might cause physical damage to corals and vessel discharges such as oil and waste might have adversely affected corals, both of which would be factors expected to vary with zoning history and use. As with other patterns related to use, however, there is little information about the relative intensities of use or about the cause-effect relationship between use and damage with which to substantiate or counter such an hypothesis (but see Rouphael and Inglis 1995). For example, whilst there is sound information about the presence of tourist pontoons on some reefs and the knowledge that those and other reefs are destinations of daily visits by large numbers of tourists, the level of use of many other reefs is poorly documented. Moreover, where moored structures provide a focus for tourist activity it might be expected that any impacts of those activities would be fairly localised. The effects that we found were based on the scale of entire reefs or habitats, substantially greater scales than the scales of activity of most site-specific tourism. There is no demonstrated mechanism by which such localised activities might affect benthos over greater scales, and even for the fishes, whose mobility might provide a vehicle for effects to be dispersed widely, previous research has found no demonstrable effects of high use sites on abundances (Sweatman 1996; Nelson and Mapstone 1998).

Although it cannot be inferred from this report that zoning history or notional intensity of tourist use have clearly been influential on the abundances of many reef biota, it would also be inappropriate to conclude that zoning was an ineffective or inappropriate conservation management strategy. In other arenas, area closure strategies have proved to be effective mechanisms for enhancing abundances of fished taxa locally, and relaxations of closures have clearly resulted in reductions in abundances of those taxa (Alcala 1988; Russ 1984, 1989, 1991; Russ and Alcala 1989). Although these few examples stem from environments in which the effects of local harvest were taxonomically more diverse, more destructive, and far more intense than is likely on the GBR, they do demonstrate that closure strategies can be effective, at least locally. There is a growing body of opinion, based largely on theory rather than empirical evidence, that area closure strategies may be the most productive conservation management strategies available for marine environments (Bohnsack 1994; Hilborn and Walters 1992; Plan Development Team 1990).

The patterns we describe, or lack of pattern, relative to the history of reef zoning also might reflect the effects of the initial choices of reefs to be included in each zone. Throughout the history of the GBRMP, the selection of reefs over which restrictions on use would be applied apparently has been heavily influenced by the public participation processes involved in the development of zoning plans. Combined with a shortage of information about the status of reefs, and no clearly documented reef selection policy, these influences may have precipitated the selection of reefs for protection that were 'less productive' or 'less desirable' for activities such as fishing. The consequences of such confounding between past experience of use on reefs and future zoning status, if it occurred, cannot be known in the absence of good pre-zoning data.

Irrespective of the cause(s) of the patterns we recorded, the potential to infer effects of management strategies from simple one-off 'before and after' estimates of abundance or community structure seem poor. The considerable inter-annual variation in counts also suggest that simple paired surveys will be likely to produce large differences unrelated to effects of management strategy. As has been recommended repeatedly for assessments of environmental impacts, of which management might be seen as one, unequivocal inferences of effects of human activities will require repeated measurements over extended periods at both the impacted (managed) and control (used) locations (Keough and Mapstone 1995; Stewart-Oaten et al. 1986; Underwood 1991, 1993, 1995). Such a strategy does not currently exist on the GBR. Although it will now be possible to use data from the only long-term monitoring program under way (the AIMS Long-term Monitoring Program, Oliver et al. 1998) and targeted research such as the CRC Effects of Fishing Project (Mapstone, Campbell and Smith 1996) to infer effects of reef closure, such *ad hoc* inferences should not be seen as replacements for dedicated monitoring.

In this context, then, the most important message from this report may be that greater attention needs to be paid to the assessment and monitoring of management strategy than has been the case to date. In particular, we recommend that in developing amended zoning plans, the Great Barrier Reef Marine Park Authority explicitly consider the means by which the effectiveness of their management will be assessed and, as far as possible, accommodate the design of such assessments in the zoning plans. Facilitation of elegant designs for monitoring purposes is unlikely to be particularly influential in the allocation of areas to different uses, but should not be ignored. Of greater importance will be the explicit acknowledgment of the need for empirical assessments of management strategies, both in terms of socioeconomic and biological variables, the incorporation of such assessments into the 'learning' objectives of management planning, and the allocation of appropriate levels of funding for those assessments (Hilborn and Walters 1992; Ludwig et al. 1993; Walters 1986). There is increasing argument that explicitly constructing management strategy to maximise the potential for assessment and learning may be the fastest way to fine tune management to specific environments (Hilborn and Walters 1992; Ludwig et al. 1993; McAllister and Petermen 1992; Walters 1986; Walters and Hilborn 1976; Walters and Hilborn 1978; Walters and Holling 1990; Walters and Sainsbury 1990). The spatial extent and structure of the GBR, together with the relatively low use and stable political conditions in Australia relative to many other tropical countries, perhaps presents one of the greatest opportunities to implement such adaptive management strategies (Mapstone et al. 1996b). In the absence of such an explicit assessment and refinement approach, or formal and regular monitoring strategies targeted specifically at management strategy evaluation, most, perhaps all, interpretations of surveys of the type we have completed will be impaired by inadequate information and there will continue to be little empirical evidence from which to justify or refine existing management strategies.

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APPENDIX 1

Table A1.1 Taxa counted during surveys of 50 reefs in the Cairns Section of the Great Barrier Reef in 1991, and the proportion of reefs in each shelf position in which they were recorded in each habitat

	SHELF POSITION					
	Inner-Shelf		Mid-Shelf		Outer-Shelf	
TAXON ⇓ // HABITAT⇒	Back	Front	Back	Front	Back	Front
CORAL TROUT						
All *Plectropomus* spp.	100	100	100.00	100.00	100.00	87.50
P. leopardus	25	50	100.00	100.00	100.00	54.17
P. laevis	0	0	27.27	22.73	66.67	79.17
Plectropomus areolatus	0	0	4.55	0.00	16.67	8.33
P. maculatus	75	75	0	0	0	0
SNAPPERS						
All Lutjanids	100	75	100.00	100.00	100.00	100.00
L. carponotatus	100	75	95.45	100.00	12.50	8.33
L. fulviflamma	50	25	54.55	72.73	33.33	54.17
L. fulvus	25	0	36.36	27.27	29.17	12.50
L. vitta	25	25	36.36	31.82	4.17	8.33
L. lemniscatus	25	50	22.73	22.73	8.33	0.00
Lutjanus bohar	0	0	77.27	95.45	95.83	100.00
L. gibbus	0	25	72.73	86.36	83.33	91.67
L. quinquelineatus	0	0	59.09	45.45	33.33	0.00
L. russelli	0	25	40.91	4.55	12.50	0.00
L. monostigma	0	0	18.18	0.00	20.83	12.50
M. niger	0	0	13.64	4.55	83.33	83.33
Other Lutjanids	0	0	4.55	0.00	0.00	0.00
Macolor macularis	0	0	0.00	4.55	37.50	41.67
L. kasmira	0	0	0.00	0.00	20.83	29.17
L. biguttatus	0	0	0.00	4.55	4.17	8.33
L. rivulatus	0	0	0.00	0.00	4.17	25.00
Symphorichthys spilurus	0	0	0.00	0.00	4.17	0.00
L. semicinctus	0	0	0.00	0.00	0.00	8.33
EMPERORS						
Total Lethrinids	50	0	90.91	95.45	100.00	91.67
Lethrinus atkinsoni	25	0	72.73	81.82	95.83	79.17
L. obsoletus	25	0	63.64	54.55	79.17	4.17
L. harak	25	0	27.27	22.73	0.00	0.00
Monotaxis grandoculis	0	0	100.00	90.91	100.00	100.00
L. nebulosus	0	0	22.73	22.73	25.00	8.33
L. miniatus	0	0	13.64	18.18	12.50	4.17
L. ornatus	0	0	9.09	13.64	8.33	29.17
L. erythracanthus	0	0	4.55	0.00	41.67	29.17
L. xanthochilus	0	0	0.00	9.09	20.83	45.83
L. olivaceus	0	0	0.00	9.09	0.00	0.00

Table A1.1 (continued)

	SHELF POSITION					
	Inner-Shelf		Mid-Shelf		Outer-Shelf	
TAXON ⇓ // HABITAT⇒	Back	Front	Back	Front	Back	Front
SURGEON FISH						
Total Acanthurids	100	100	92.00	96.00	100.00	100.00
Other Acanthurids	100	100	92.00	96.00	100.00	100.00
Zebrasoma scopas	0	100	72.00	76.00	100.00	100.00
Acanthurus dussumieri	0	0	24.00	24.00	33.33	66.67
BUTTERFLYFISH						
All Chaetodons	100	100	100.00	100.00	100.00	100.00
C. vagabundus	100	75	90.91	95.45	87.50	70.83
Chaetodon aureofasciatus	100	100	81.82	77.27	0.00	0.00
Chelmon rostratus	75	50	45.45	27.27	4.17	0.00
C. lineolatus	75	50	40.91	40.91	33.33	25.00
C. trifascialis	50	50	100.00	100.00	100.00	95.83
C. rainfordi	50	50	100.00	81.82	16.67	8.33
C. baronessa	50	25	95.45	100.00	95.83	75.00
C. auriga	50	25	95.45	86.36	91.67	45.83
C. melannotus	50	50	81.82	63.64	87.50	87.50
C. ephippium	25	0	40.91	59.09	70.83	66.67
C. rafflesi	25	25	18.18	45.45	16.67	58.33
C. plebeius	0	50	95.45	95.45	100.00	91.67
C. trifasciatus	0	25	72.73	68.18	87.50	83.33
C. citrinellus	0	0	68.18	45.45	95.83	87.50
C. kleinii	0	0	63.64	45.45	66.67	62.50
C. ulietensis	0	0	45.45	22.73	91.67	70.83
C. unimaculatus	0	0	22.73	27.27	50.00	54.17
C. speculum	0	0	18.18	22.73	16.67	16.67
Other Chaetodons	0	0	13.64	4.55	0.00	0.00
C. bennetti	0	0	9.09	0.00	20.83	4.17
C. lunula	0	0	9.09	9.09	0.00	0.00
C. pelewensis	0	0	4.55	4.55	83.33	79.17
Forcipiger flavissimus	0	0	0.00	0.00	66.67	66.67
C. ornatissimus	0	0	0.00	13.64	54.17	83.33
C. flavirostris	0	0	0.00	4.55	4.17	8.33
C. reticulatus	0	0	0.00	0.00	4.17	25.00
C. meyeri	0	0	0.00	0.00	0.00	8.33
Hemitaurichthys polylepis	0	0	0.00	0.00	0.00	45.83
DAMSELFISH						
Pomacentrus moluccensis	100	75	100.00	100.00	95.83	16.67
Thalassoma lunare	100	50	100.00	100.00	66.67	8.33
Amblyglyphidodon curacao	50	50	100.00	100.00	95.83	16.67
Chrysiptera rollandi	25	25	95.45	68.18	87.50	0.00
Chromis atripectoralis	25	25	95.45	68.18	79.17	25.00
Plectroglyphidodon lacrymatus	0	25	86.36	86.36	100.00	91.67
Pomacentrus philippinus	0	0	22.73	27.27	91.67	91.67
Plectroglyphidodon dickii	0	0	13.64	27.27	37.50	91.67
Neoglyphidodon melas	0	0	0.00	4.55	0.00	0.00

Table A1.1 (continued)

	SHELF POSITION					
	Inner-Shelf		Mid-Shelf		Outer-Shelf	
TAXON ⇓ // HABITAT⇒	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**
BENTHOS						
Poritids	100	100	100.00	100.00	100.00	95.83
Other Hard Coral	100	100	100.00	100.00	100.00	100.00
Dead Corals	100	75	100.00	100.00	100.00	95.83
Soft Corals	100	75	100.00	100.00	100.00	100.00
Sponges	100	75	100.00	95.45	95.83	95.83
Acroporids – Other	75	75	100.00	100.00	100.00	100.00
***Drupella* Infestation**	75	75	100.00	100.00	100.00	100.00
Acroporids – Plate	50	0	95.45	86.36	91.67	83.33
Tridacna gigas	75	50	86.36	86.36	79.17	16.67
Linckia laevigata	25	50	90.91	63.64	50.00	4.17
Tridacna derasa	25	0	72.73	77.27	91.67	4.17
Acanthaster planci	0	0	31.82	18.18	4.17	0.00