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.

REEF	~LAT. (°:'S)	SHELF POS"	ZONE – 83–91 →	92–97	PRIOR – 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.

[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.