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"	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.

[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 (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 **Z**oning History on **r**eefs, given potential effects of **S**helf Position and **H**abitat[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

[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 **U**se and **Z**oning History on **r**eefs, given potential **H**abitat 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: $y_{ijklm} = Z_{i....} + U_{.j...} + H_{..k..} + ZU_{ij...} + ZH_{i.k..} + UH_{.jk..} + ZUH_{ijk..} + r(ZU)_{l(ij)..} + Hr(ZU)_{kl(ij).} + \varepsilon_{ijklm}$
Scope: Tourist and non-tourist reefs, mid-shelf and outer-shelf reefs separate

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

[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.

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

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 ($\alpha_{obs} \leq 0.1$).

SOURCE OF VARIATION	BENTHOS			SMALL FISH			LARGE FISH		
	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 ($\alpha_{obs} \leq 0.1$).

SOURCE OF VARIATION	BENTHOS			SMALL FISH			LARGE FISH		
	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**

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

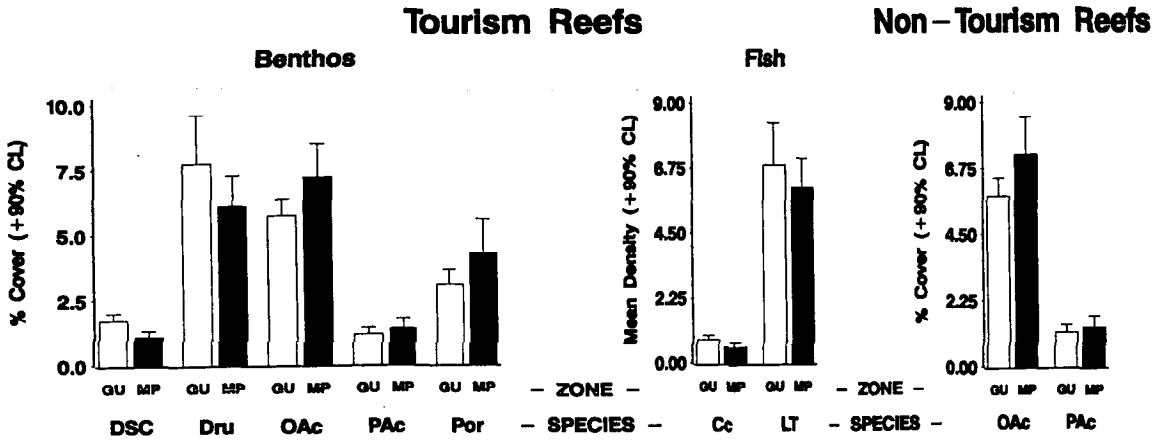

Figure 1. Bar charts of statistically significant main effects of zoning history on abundances of surveyed organisms. Bars represent the mean responses over both habitats in all shelf positions for Benthos and total counts of lutjanids on Tourism Reefs, but the mean of counts from only mid-shelf and 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.

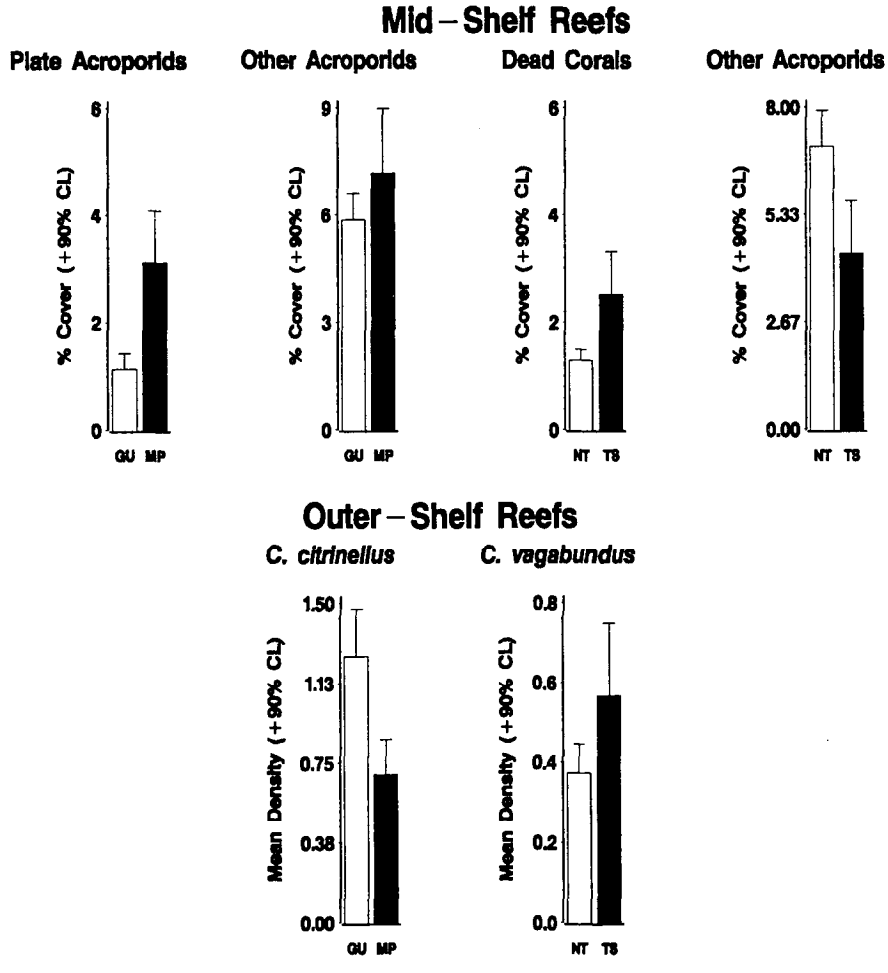

Figure 2. Bar charts of statistically significant main effects of zoning history on abundances of plate and other acroporids (mid-shelf) and *C. citrinellus* (outer-shelf), and of tourist use on abundances of dead corals and other acroporids (mid-shelf) and *C. vagabundus* (outer-shelf). Bars represent 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.