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RESEARCH PUBLICATION NO. 91

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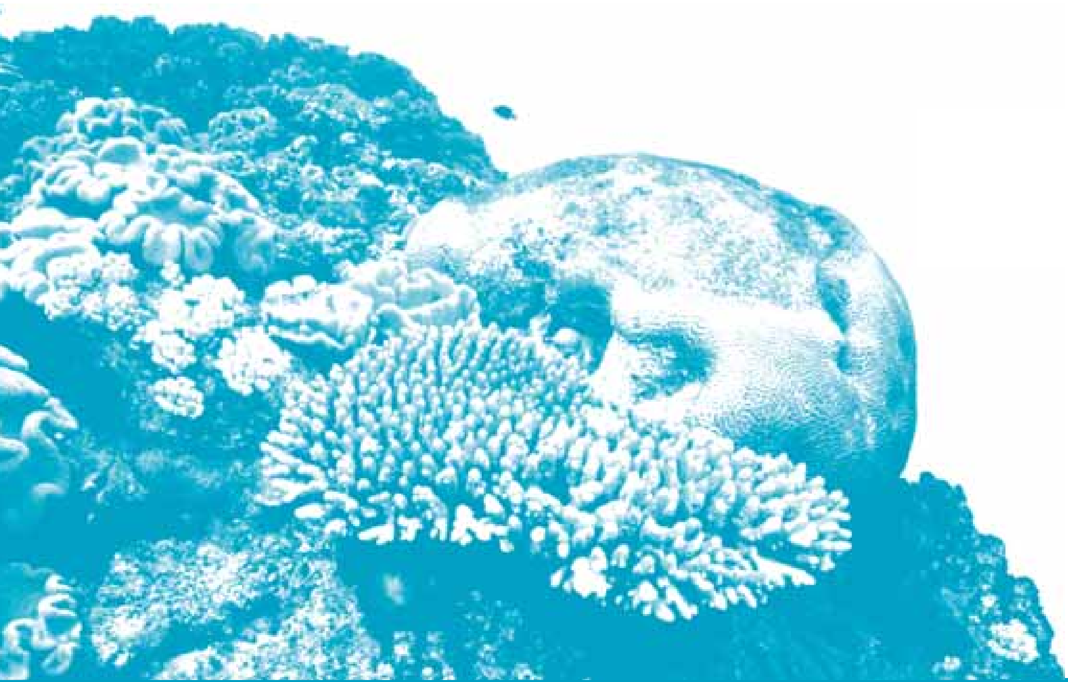
Final report to the Great Barrier Reef Marine Park Authority



A. M. Ayling and J. H. Choat.

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Abundance patterns of reef sharks and predatory fishes on differently zoned reefs in the offshore Townsville region:

Final report to the Great Barrier Reef Marine Park Authority

August 2008

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SUMMARY

Robbins et al. (2006) suggested that reef shark populations on the Great Barrier Reef, northern Australia, are in a state of collapse. They reported densities of reef sharks on two no-go Preservation Zone reefs (pink reefs) five to 40 times greater than those on supposed no-take Marine National Park zoned reefs (green reefs). To see if similar shark abundance patterns were present in other Great Barrier Reef regions we counted sharks and other large predatory fishes on two pink reefs in the offshore Townsville region as well as on three nearby green reefs and three fished Habitat Protection zone reefs (blue reefs).

Sharks were counted in six 500 x 20 m transects on the slope of each reef during late March 2008. Densities of whitetip reef sharks (*Triaenodon obesus*) were twice as high on green reefs as on blue reefs but were twice as high on pink reefs as on green reefs. Similarly, grey reef sharks (*Carcharhinus amblyrhynchos*) were four times as abundant on green reefs as on blue reefs, but twice as abundant on pink reefs as on green reefs. We also recorded the abundance of large teleost reef fishes during all counts. There were similar patterns in the density of the common coral trout (*Plectropomus leopardus*), with 1.5 times as many coral trout on green reefs as on blue reefs but 2.5 times as many on pink reefs compared with green reefs.

Both pink reefs and green reefs are no-take areas and, given a similar zoning history, should support similar densities of sharks and coral trout assuming the reefs are similar in ecology, structure, shelf position and latitude. We found numbers of sharks on reefs open to fishing (blue) are heavily depleted compared to more protected (green and pink) reefs. The pink reef – green reef discrepancies found in the present study were not as extreme as those reported by Robbins et al. (2006) but they are still substantial.

We suggest that these observed density differences in reef sharks and targeted fishes between the supposed no-take green reefs and the no-go pink reefs are likely to reflect real differences in fishing effort rather than differences in shark and fish behaviour between the different zones. We also think that differences in reef type, habitat structure and shelf position for the Townsville survey reefs would be more likely to increase shark and target fish densities on the green and blue reefs relative to the pink reefs rather than to be the driving force behind the observed density differences.

Historically, there has been a degree of non-compliance with green zones in the Marine Park. It is still an open question as to whether compliance effectiveness has improved substantially following rezoning of the Marine Park under the Representative Area Program (RAP) in 2004. Effective compliance will be essential for the re-zoning to have a positive effect on shark populations. Reef managers need to acknowledge that green reefs have not been, and are still unlikely to be, totally effective in excluding fishing effort. Strong deterrent messages and educational campaigns are recommended to improve compliance.

Given the conservative life-history characteristics of reef sharks (e.g. slow growth rate, low fecundity) they are likely to be much more vulnerable to low levels of illegal fishing than major fisheries target species such as coral trout. Conservative life histories also mean that effective conservation measures would take several decades to result in

tangible increases in reef shark populations (Robbins et al. 2006). We suggest that several future, more comprehensive surveys of reef sharks in other areas of the Great Barrier Reef would be important in helping managers to assess trends in reef shark abundances and the extent of non-compliance on green reefs.

INTRODUCTION

There has been growing public and media concern over recent years that sharks worldwide are being overfished (Stevens et al. 2000, Baum et al. 2003, Clarke et al. 2006, Myers et al. 2007). Many shark species have been assessed as facing a high risk of extinction under IUCN Red List criteria. Reef sharks on the Great Barrier Reef, Australia, have been increasingly caught commercially in recent years (Gribble et al. 2005, Rose et al. 2003) and are also killed by recreational fishers (Henry and Lyle 2003).

Robbins et al. (2006) reported the on-going collapse of populations of the two most abundant of the reef sharks: the whitetip reef shark (*Triaenodon obesus*) and the grey reef shark (*Carcharhinus amblyrhynchos*). Their study was based on counts of shark density on two pink reefs near Lizard Island to the north of Cooktown on the Great Barrier Reef (14°S latitude) and on a selection of green and blue reefs. Robbins et al. (2006) found 10 times as many whitetip reef sharks on pink reefs compared to blue reefs and 40 times as many grey reef sharks, but no significant differences in shark populations between blue reefs and green reefs. They suggested that differences in compliance effectiveness with no-take designations between pink and green reefs were the main reason for this discrepancy between the two types of no-take zones. They carried out life history studies which supported their contention that reef shark populations on the Great Barrier Reef are in sharp decline.

Given the suggestion that no-take green zones were not effective in conserving shark populations on the Great Barrier Reef, the Great Barrier Reef Marine Park Authority (GBRMPA) was interested in patterns of shark and fish abundances across zones in another region of the Great Barrier Reef. We were asked to use the same count technique to survey shark and large fish numbers on eight reefs in the offshore Townsville region. This included two pink reefs and three green reefs that had not changed zoning since the Central Section of the Great Barrier Reef Marine Park was first gazetted in 1987 and set in an extensive green zone, and three blue reefs. The survey was based on six replicate counts carried out on the slope around each reef.

Underwater visual counts of sharks and/or large predatory fishes such as coral trout have been made on the Great Barrier Reef and other offshore Australian reefs as part of a number of other studies (Robbins et al. 2006, Mapstone et al. 2004, Choat 2004, Choat et al. 2006, Choat et al 2007, A.M. Ayling unpublished data). We were also interested in comparing the Townsville count results with these other surveys to compare observed shark and fish densities with those from other regions. As the same observer (A.M. Ayling) carried out the counts for most of these studies such comparisons are useful and will have minimal bias. The comparison could also provide useful information on the relative performance of different count techniques.

The study sought to answer a number of questions:

- Was the density of reef sharks on pink reefs higher than on green and blue reefs?
- Was the density of reef sharks on green reefs higher than on blue reefs?
- Was the pattern of density of target fish species on the survey reefs similar to those observed for reef sharks?

- Was the pattern of density of non-target fish species on the survey reefs similar to those observed for reef sharks?
- How did reef shark and target fish density on the offshore Townsville reefs compare with that recorded in other Great Barrier Reef and offshore Australian regions?
- How did the long timed swim count technique compare with other methods in assessing target fish populations?

Table 1. Study Reefs.

Reef	Zoning*	Latitude	Longitude	Length (km)	Width (km)	Reef type	Shelf position	Mean underwater visibility
Centipede	Habitat Protection - Blue	18°44′	147°33′	8.8	4.0	Lagoonal	0.72	20m
Chicken	Habitat Protection - Blue	18°40′	147°43′	3.1	2.2	Lagoonal	0.82	24m
Grub	Habitat Protection - Blue	18°38′	147°26′	6.0	3.0	Lagoonal	0.72	23m
Bowl	Marine National Park - Green	18°30′	147°33′	9.2	2.5	Lagoonal	0.90	26m
Dip	Marine National Park - Green	18°25′	147°27′	3.2	2.2	Platform	0.95	34m
Glow	Marine National Park - Green	18°32′	147°24′	1.9	1.0	Platform	0.79	28m
Cotton	Preservation - Pink	18°29′	147°24′	0.9	0.8	Shoal	0.83	34m
Arc	Preservation - Pink	18°31′	147°27′	0.7	0.5	Platform	0.85	34m

*Zoning:

Habitat Protection – Blue (Robbins et al. 2006: open fishing)

Marine National Park – Green (Robbins et al. 2006: no-take)

Preservation Zone – Pink (Robbins et al. 2006: no entry).

METHODS

Study reefs

Eight reefs were selected in the offshore Townsville region that had stable zoning since the Central Section of the Marine Park was first created in 1987 (figure 1). Three reefs were zoned Habitat Protection Zone (blue reefs) and were open to line fishing, three reefs were Marine National Park Zones (green reefs) and were closed to fishing but able to be visited and two reefs were Preservation Zones (pink reefs) that are no-go zones closed for all activities except emergency anchoring and a limited number of permitted research programs (table 1, figure 1). The area of Marine National Park that included the pink and green study reefs had been extended with the RAP changes in 2004 to include four extra reefs and about double the total area (figure 2).

The survey reefs differed considerably in size and type. Size ranged from Arc, which is only 0.7 kilometre long to Bowl which has a length of over 9 km (table 1). Some of the reefs were lagoonal, with an extensive back reef bommie field while others were platform reefs with a steep reef slope on the back reef edge and very few bommies. Cotton was a shoal, lacking a true reef flat, with an undulating reef top 1-5 m below Australian Height Datum (AHD).

A shelf position index was calculated for each reef by measuring the distance from the reef to the shore and from the reef to the edge of the shelf. An index of 0 indicates a coastal fringing reef and an index of 1 indicates an offshore reef at the shelf edge. Most of these reefs are on the outer shelf with shelf positions ranging from 0.72 to 0.95 (table 1).

Reef condition

To get some idea of the condition of coral communities on each reef an estimate of per cent live coral cover was made in an estimated 10 m square beneath the observer at approximately 5 minute intervals during each shark count. This gave a total of 10 estimates in each hectare count and 60 estimates per reef.

Count methods

Counts were made over a set time of 45 minutes. The observer maintained a steady swimming rate during each count and covered an approximate linear distance of 500 m. Target sharks and fishes observed within an estimated 10 m each side of the observer were recorded giving an estimated count width of 20 m. Distance swum was confirmed for five counts by GPS measurements and was in all cases within 20 m of 500 m. Each count therefore covered an estimated area of one hectare.

The observer swam 2-6 m above the bottom, constantly scanning around for sharks and large fishes. For the first half of the 45 min count, the observer swam at a depth of 8-12 m covering a count depth range on the reef slope from 8 to over 20 m. On the return sweep, for the second half of the count, the observer moved closer to the reef edge, swimming at a depth of 5-6 m and counting in a depth range of from 0-8 m. Linear separation of the centres of the two sweeps was usually over 50 m but on reef sections with a relatively steep slope the outward and return count strips were sometimes contiguous.

All sharks normally found in open water were counted, including whitetip reef sharks *Triaenodon obesus*, grey reef sharks *Carcharhinus amblyrhynchos*, blacktip reef sharks *C. melanopterus* and silvertip sharks *C. albimarginatus*. The characteristics of all sharks seen were noted, including sex, size, presence of remoras, scars etc to help ensure that individuals were only counted once. All large predatory fishes with an adult length greater than 30 cm total length (TL) were also counted including the common coral trout *Plectropomus leopardus*, bluespot coral trout *P. loaevis*, other large serranids, large lutjanids and lethrinids and Maori wrasse *Cheilinus undulatus*. Individual fishes of less than 20 cm TL were not recorded. Other large reef fishes such as sweetlips (Haemulidae), batfishes (Ephippidae) and large parrotfishes (Scaridae) were also counted.

Accurate counts are hard to achieve using this count technique if the water visibility is less than 15 m and the method does not work if the visibility is less than 10 m (Robbins et al. 2006). During this project underwater visibility ranged from 20-40 m (table 1) and was always at least double the half-transect-width counting distance. This ensured that the counts were unaffected by visibility artefacts.

The estimated total length of all sharks and fish counted was recorded. All counts were made by a single observer: A.M. Ayling, with over 250 hours experience using this method and over 35 years experience estimating lengths of fishes and sharks.

A total of six hectare swim counts were made on the slopes of each reef. Individual counts were separated by at least 500 m. Previous studies of predatory fishes and sharks have shown that many species have significantly different densities in major reef habitats (Ayling and Ayling 1998, Robbins 2006) and three counts were made on the exposed front of each reef and three on the more protected back reef to give equal coverage of both major habitat types.

Analysis

Shark and fish abundances were natural log transformed prior to analysis where appropriate. Data were analysed using mixed model ANOVAs with zone and habitat as fixed effects and reef as a fixed effect nested within zone (table 2). Reef was considered fixed as all the pink reefs available in the offshore Townsville region were surveyed.

Table 2. Shark and fish abundance patterns: analysis of variance design.

Source of variation	**Degrees of freedom**	**Fixed/ Random**	**Denominator**
Zone: pink, green, blue	2	F	Error (counts)
Habitat: front, back	1	F	Error (counts)
Reef (Zone)	5	F	Error (counts)
Zone x Habitat	2		Error (counts)
Habitat x Reef (Zone)	5		Error (counts)
Error (counts)	32	R	

Timing of the surveys

All counts were carried out between the 18th and 27th March 2008.

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LOCATION OF STUDY REEFS

Great Barrier Reef Marine Park Zoning Prior To Zoning Plan 2003

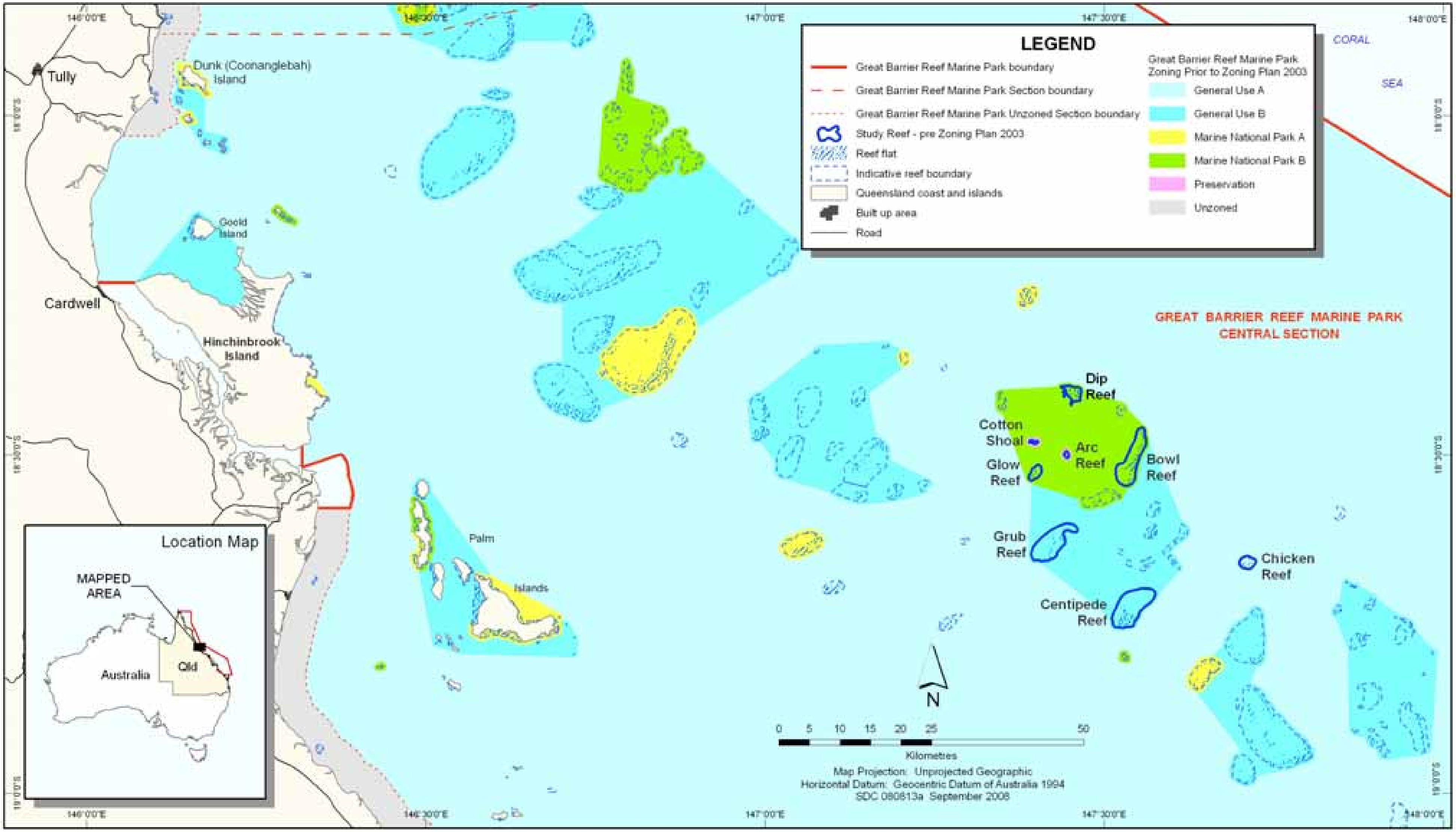

Figure 1. Map of the offshore Townsville region showing the position of the eight study reefs and the original pre-RAP zoning plan.

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LOCATION OF STUDY REEFS

Great Barrier Reef Marine Park Zoning Plan 2003

Note: Some reef extents were updated (due to the availability of more detailed data) with the implementation of the Great Barrier Reef Marine Park ZONING PLAN 2003.

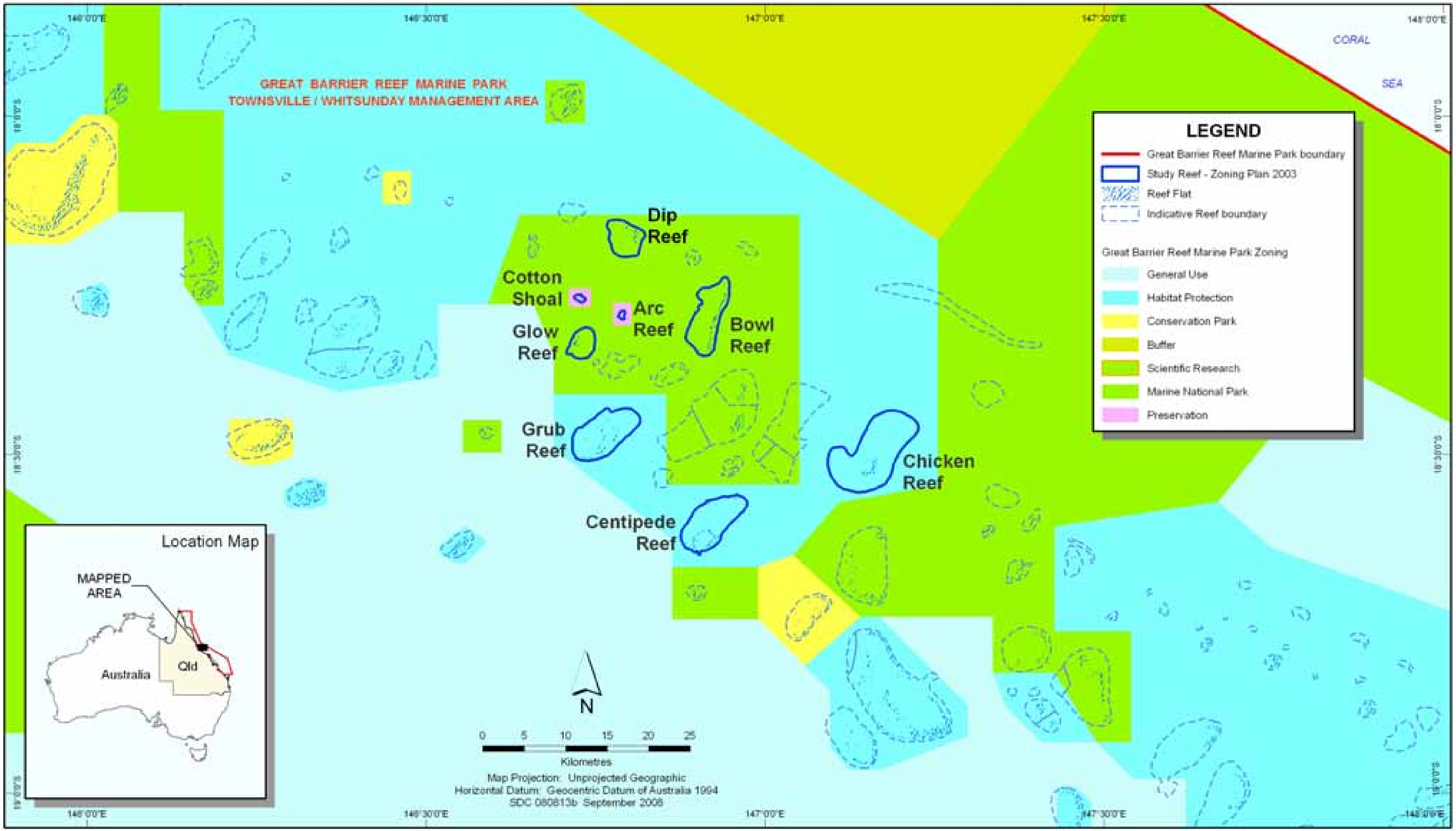

Figure 2. Map of the eight study reefs showing the current, post-RAP zoning plan. (Note the difference in scale compared to Figure 1)

RESULTS

Coral condition on the survey reefs

Coral cover was low on Centipede and Chicken Reefs with 10-15% cover and the damage pattern suggested this was due to previous *Acanthaster* outbreaks. Cover was also relatively low on Cotton where there was evidence that corals were recovering from cyclone damage. Coral cover was moderate on Grub, Bowl, Dip and Glow, with around 30% cover, and relatively high on Arc with over 37% cover (table 3).

Table 3. Coral condition of the survey reefs. Mean percentage cover of live coral from all surveys on each reef is shown along with the standard error (se).

Reef	**Reef zone**	**Reef type**	**Coral cover (%)**	
			mean	**se**
Centipede	blue	lagoonal	14.2	3.6
Chicken	blue	lagoonal	12.1	3.9
Grub	blue	lagoonal	30.4	5.1
Bowl	green	lagoonal	29.8	4.2
Dip	green	lagoonal	29.5	5.7
Glow	green	platform	32.8	4.1
Cotton	pink	shoal	19.5	3.8
Arc	pink	platform	37.3	4.4

Shark density

The density of both whitetip reef sharks and grey reef sharks was significantly higher on pink reefs than on green reefs and significantly higher on green reefs than on blue reefs (table 4). Densities for both species were similar. Whitetip reef sharks were approximately twice as abundant on green reefs compared to blue reefs and twice as abundant on pink reefs compared to green reefs (table 5, figure 3). Grey reef sharks were about four times as abundant on green reefs as blue reefs and twice as abundant on pink reefs as green reefs (table 5, figure 4). Grey reef sharks were therefore eight times as abundant in pink reefs (Preservation Zones) as on fished reefs. The habitat, reef and factor interactions were not significant for either shark species (table 4). Only two other sharks apart from these common species were recorded, a silvertip shark (*Carcharhinus albimarginatus*) on Bowl Reef and a blacktip reef shark (*Carcharhinus melanopterus*) on Dip Reef. As a result the patterns for total shark numbers were very similar to those for the two common sharks, with almost three times as many sharks on green reefs as on blue reefs and almost twice as many sharks on pink reefs as on green reefs (figure 5). Although there was some variation in total shark numbers within each zone (table 5, figure 6) the reef differences were not significant (table 4).

Table 4. Analysis of variance results: the effect of zone, habitat and reef on shark and fish abundance. Numbers are F values from the tests; df = degrees of freedom for each test; NS = not significant; * = 0.05>p>0.01, ** = 0.01>p>0.001; *** = p<0.001

Species/Group	**Zone** (df 2/32)	**Habitat** (df 1/32)	**Reef(Zone)** (df 5/32)	**Z x H** (df 2/32)	**H x R(Z)** (df 5/32)
Whitetip Reef Shark	11.40 ***	3.39 NS	0.58 NS	0.02 NS	2.62 NS
Grey Reef Shark	9.93 ***	0.15 NS	0.53 NS	0.21 NS	0.18 NS
Total Sharks	16.82 ***	0.99 NS	0.84 NS	0.14 NS	0.61 NS
Plectropomus leopardus	19.09 ***	3.88 NS	4.92 **	6.87 **	1.27 NS
P. leopardus adults	39.99 ***	6.67 *	4.39 **	5.88 **	0.96 NS
Plectropomus laevis	7.13 **	1.77 NS	0.51 NS	3.94 *	1.09 NS
P. laevis adults	8.98 ***	0.99 NS	0.61 NS	2.05 NS	1.80 NS
Total Serranids	34.64 ***	3.77 NS	3.25 *	6.45 **	1.39 NS
Lethrinus miniatus	10.09 ***	0.57 NS	3.94 **	0.20 NS	0.48 NS
Total Lutjanids	7.63 **	1.15 NS	4.20 **	0.49 NS	0.52 NS
Cheilinus undulatus	1.71 NS	0.74 NS	1.86 NS	0.62 NS	1.72 NS
Total Haemulids	2.43 NS	6.53 *	2.26 NS	0.08 NS	0.64 NS
Total Ephippids	1.80 NS	2.38 NS	0.93 NS	2.78 NS	1.33 NS
Total Scarids	2.15 NS	0.25 NS	3.31 *	0.64 NS	0.84 NS

Table 5. Abundance summary of sharks and fishes in the different zones. Mean numbers per hectare are shown along with standard errors.

Species/Group	**Blue reefs**		**Green reefs**		**Pink reefs**	
	mean	**se**	**mean**	**se**	**mean**	**se**
Whitetip Reef Shark	0.72	0.21	1.22	0.21	2.75	0.48
Grey Reef Shark	0.33	0.18	1.61	0.38	2.75	0.49
Total Sharks	1.06	0.27	2.94	0.48	5.50	0.83
Plectropomus leopardus	10.06	1.15	9.17	1.46	19.08	2.24
P. leopardus adults	3.67	0.53	5.56	1.18	13.92	1.44
Plectropomus laevis	2.44	0.38	5.17	0.86	5.83	0.75
P. laevis adults	1.83	0.25	3.89	0.70	5.17	0.67
Total Serranids	6.33	0.81	10.11	1.64	20.0	1.76
Lethrinus miniatus	1.94	0.51	1.50	0.41	4.25	0.48
Total lutjanids	12.78	5.20	12.11	3.03	22.0	3.33
Cheilinus undulatus	1.06	0.26	0.61	0.22	0.50	0.23
Total Haemulids	1.72	0.47	0.72	0.29	0.83	0.32
Total Ephippids	2.67	1.37	0.56	0.29	0.83	0.58
Total Scarids	82.4	13.5	81.8	13.7	107.8	6.5

Shark size and sex

Whitetip reef sharks were nominally longer in blue zones than in green or pink zones (table 6) but these differences were not significant (t tests, p>0.05). Mean length of grey reef sharks was similar on blue and pink reefs (table 6) but was significantly higher on green reefs than pink reefs (t test, p=0.05).

The sex ratio of whitetip reef sharks was biased 62:38 in favour of females. All the grey reef sharks recorded during this survey appeared to be females or immature females.

Table 6. Mean length and standard errors (cm) of both common reefs sharks and the two coral trout species in the different zones.

Species/Group	Blue reefs		Green reefs		Pink reefs	
	mean	se	mean	se	mean	se
Whitetip Reef Shark	153	5.5	149	4.2	143	4.7
Grey Reef Shark	118	15.5	133	8.2	112	6.3
Plectropomus leopardus	37.1	0.4	40.2	0.4	41.0	0.3
Plectropomus laevis	50.8	2.2	52.2	1.7	53.9	1.8

Coral trout density

Both species of coral trout are major targets in the Great Barrier Reef line fishery (Mapstone et al. 2004). The common coral trout (*Plectropomus leopardus*) was significantly more abundant on pink reefs than on green or blue reefs when all size classes were included (table 4, 5, figure 7). Densities on blue and green reefs were not significantly different. However, when only those individuals over the minimum legal length were considered (described here as 'adults'), densities in all three zones were significantly different (figure 8). There were 1.5 times as many adult common coral trout on green reefs than on blue reefs and 2.5 times as many on pink reefs than on green reefs. The proportion of adult individuals in the population was different in the different zones. On pink reefs 73% of common coral trout were adults, on green reefs 61% were adults but on blue reefs only 36% were adults. There were significantly higher densities of common coral trout on the back of green reefs compared to the front but habitat differences were not significant on blue and pink reefs. As a result there was a significant habitat x zone interaction for common coral trout densities (table 4). There were also significant differences in common coral trout densities between the different survey reefs within the three zones (table 4).

The bluespot coral trout (*Plectropomus laevis*) was significantly more abundant on pink and green reefs than on blue reefs but abundance was similar on both pink and green reefs (table 4, 5, figure 9, 10). Patterns were similar for overall densities and for adult densities of this large coral trout species. Densities of adult bluespot coral trout on pink reefs were almost three times higher than on blue reefs.

Coral trout size

The mean length of common coral trout on blue reefs was significantly lower than on green and pink reefs (table 6, t test, p<0.05). Although the mean length of bluespot

coral trout individuals recorded on pink reefs was nominally higher than those from blue reefs (table 6), these differences were not significant.

Density of other target fish groups

The redthroat emperor (*Lethrinus miniatus*) is another important target species in the Great Barrier Reef reef line fishery (Mapstone et al. 2004). Densities of this species were similar on blue and green reefs but were significantly higher on pink reefs where numbers were about 2.5 times greater (table 4, 5, figure 11). Although reef dwelling lutjanids are not major targets in the reef line fishery, many species are caught incidentally in the fishery and retained by fishers. Overall densities of lutjanids were also significantly higher on pink reefs than on green or blue reefs (table 4, figure 12). There were no significant patterns in Maori wrasse *Cheilinus undulatus* abundance on the survey reefs (table 4). This species was previously caught and retained in the reef line fishery but has been totally protected for the past few years.

Density of non-target fish groups

Densities of fish groups that are not targeted by fishers may provide information on ecological differences between the survey reefs in the different zones. If the reefs have similar physical and biological attributes then densities of non-target species should have similar densities in the three zones unless there are indirect effects of fishing on prey species. There were no significant zone effects on densities of sweetlips (Haemulidae), batfishes (Ephippidae) or parrotfishes (Scaridae) (table 4, 5).

Comparisons with other surveys

Surveys of reef shark density on a range of differently zoned reefs in the northern Cairns Section were made by Robbins et al. (2006) using a very similar count technique. They counted sharks along an approximately 400 x 20 m transect compared with the approximately 500 x 20 m transect of the present survey. That study found that densities of whitetip reef sharks on pink reefs were about five times higher than those recorded on blue reefs and almost three times those on green reefs (figure 13). Similarly, grey reef shark densities on pink reefs were more than 10 times those recorded on blue and green reefs (figure 14). On average the abundance of both these reef shark species was twice as high on the Townsville reefs surveyed in the present study as on the Cairns reefs surveyed by Robbins et al. (2006) (figures 13 & 14). Comparisons of the shark counting performance of Robbins and Ayling were made during a previous study of the Cocos-Keeling Islands: the two observers obtained very similar results (Robbins 2006).

Shark counts using the same method have also been made by A.M. Ayling on the offshore north-west Australian reefs of Ashmore (12 counts), Scott (6 counts), Clerke (9 counts) and Impereuse (11 counts), as well as on the Coral Sea reefs of Herald Cay (17 counts), and the Indian Ocean outpost of Cocos-Keeling Island (Choat 2004). Whitetip reef shark density on Townsville pink reefs was higher than that recorded in any of these other locations but the density recorded on the relatively undisturbed Cocos-Keeling Island was almost 75% of this level. Densities of whitetips on Townsville green and blue reefs were similar to those recorded in the other locations with the exception of Scott Reef where no sharks were seen (figure 15). Grey reef shark densities on

offshore Townsville pink reefs were more than twice those recorded in the other locations with the exception of the pink reef densities recorded by Robbins et al. (2006) (figure 16).

Comprehensive coral trout counts were made by A.M. Ayling on six offshore Townsville reefs, including Glow and Dip Reefs, as part of the Effects of Line Fishing (ELF) Experiment (Mapstone et al. 2004). These counts used six sites of five 50 x 5 m transects on each reef to search a total area of 7500 sq m (0.75 ha) on each reef compared with 6 Ha per reef for the present survey. Densities of adult common coral trout recorded in the 2004 and 2005 ELF surveys were very similar to those recorded during the present survey (figure 17) despite the very different count methodologies.

Densities of common coral trout on the Great Barrier Reef vary markedly depending on the shelf position of the reef (Ayling and Ayling 1988). This species is rare or absent on turbid inshore and coastal reefs but increases in abundance toward the midshelf, with peak densities found on reefs between 0.4 and 0.8 of the distance across the shelf. Densities then fall rapidly toward the outer edge of the shelf and this species is again rare to absent on the front of reefs on the outer edge of the continental shelf (figure 18). To evaluate whether coral trout densities recorded during the present survey were affected by the relative shelf position of the reefs, the present data were compared with a comprehensive cross-shelf survey of reefs in the Central Section of the Great Barrier Reef Marine Park carried out in 1984 that included many of the present survey reefs (Ayling and Ayling 1986). Coral trout densities on six of the survey reefs were within the expected density range for their shelf position but densities on the two blue reefs Centipede and Grub were well below what would be expected (figure 18).

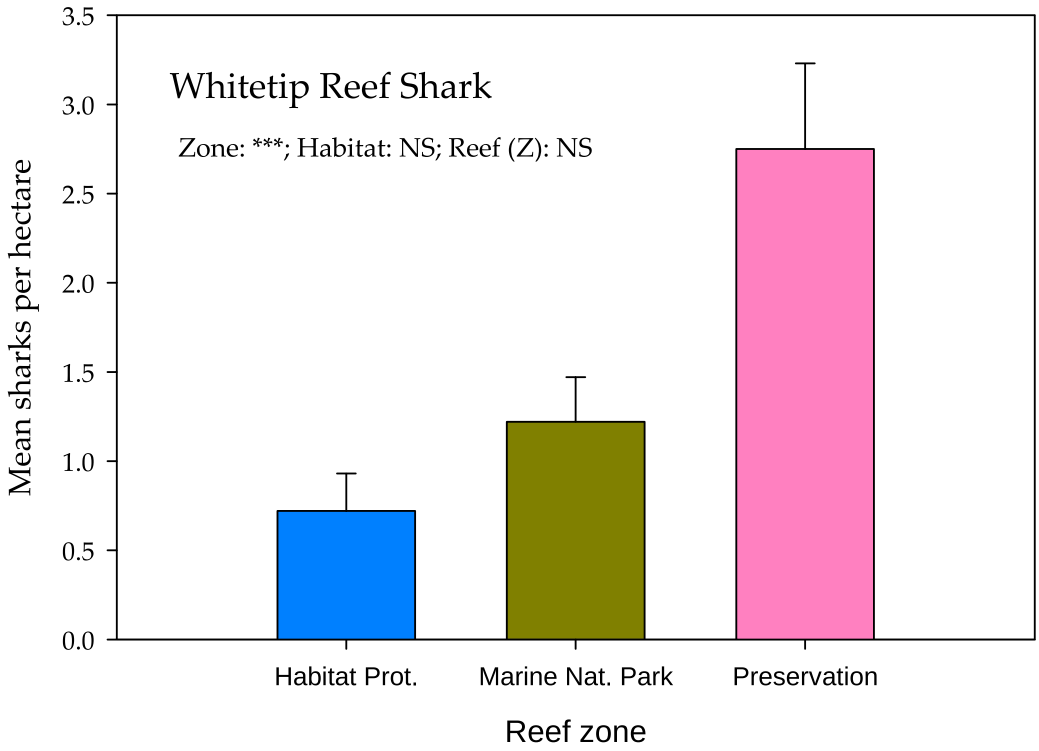

Figure 3. Abundance summary for whitetip reef sharks in the different Marine Park zones. Mean number of sharks per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors. Prot. = Protection, Nat. = National.

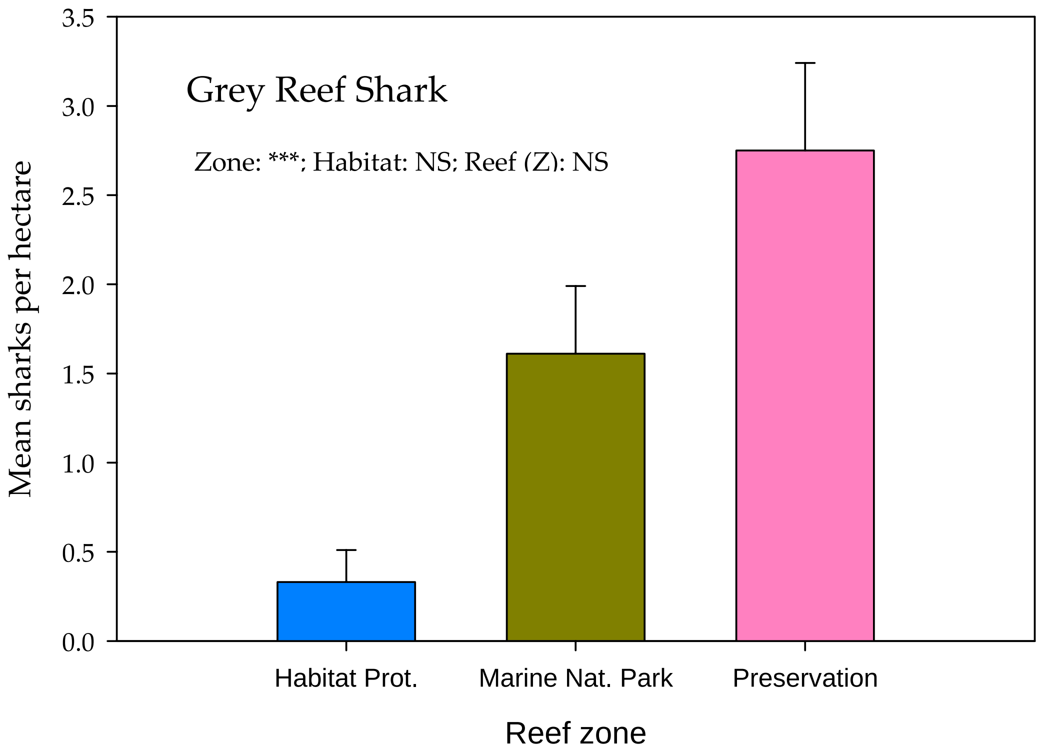

Figure 4. Abundance summary for grey reef sharks in the different Marine Park zones. Mean number of sharks per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

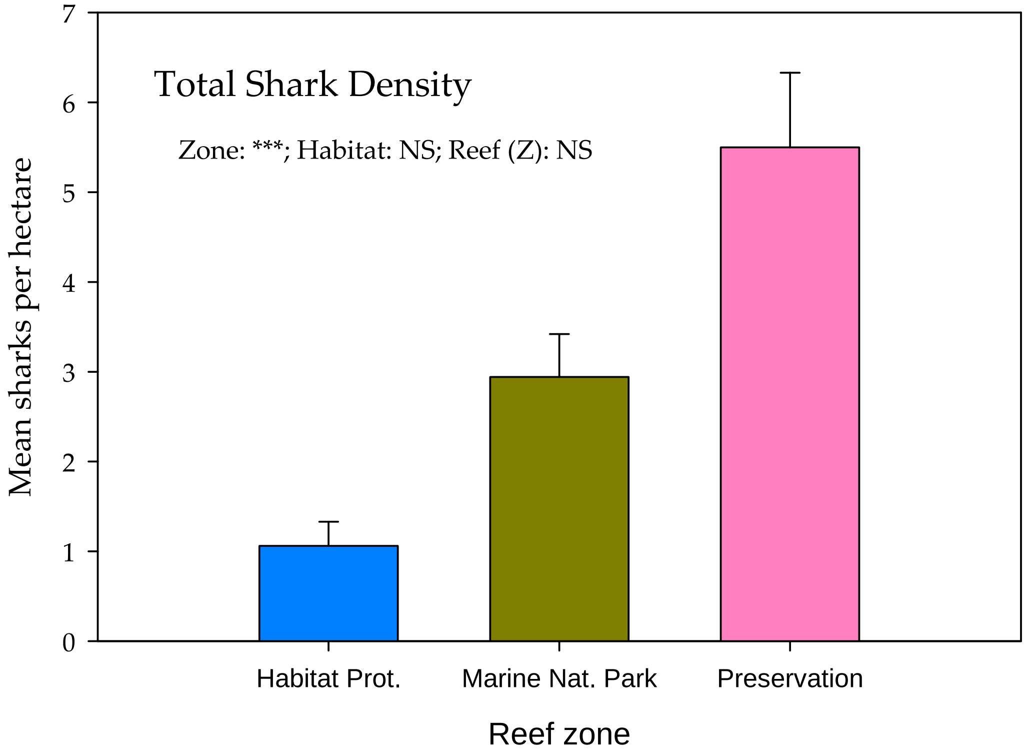

Figure 5. Abundance summary for total sharks* in the different Marine Park zones. Mean number of sharks per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors. *Species: grey reef, whitetip, silvertip and blacktip.

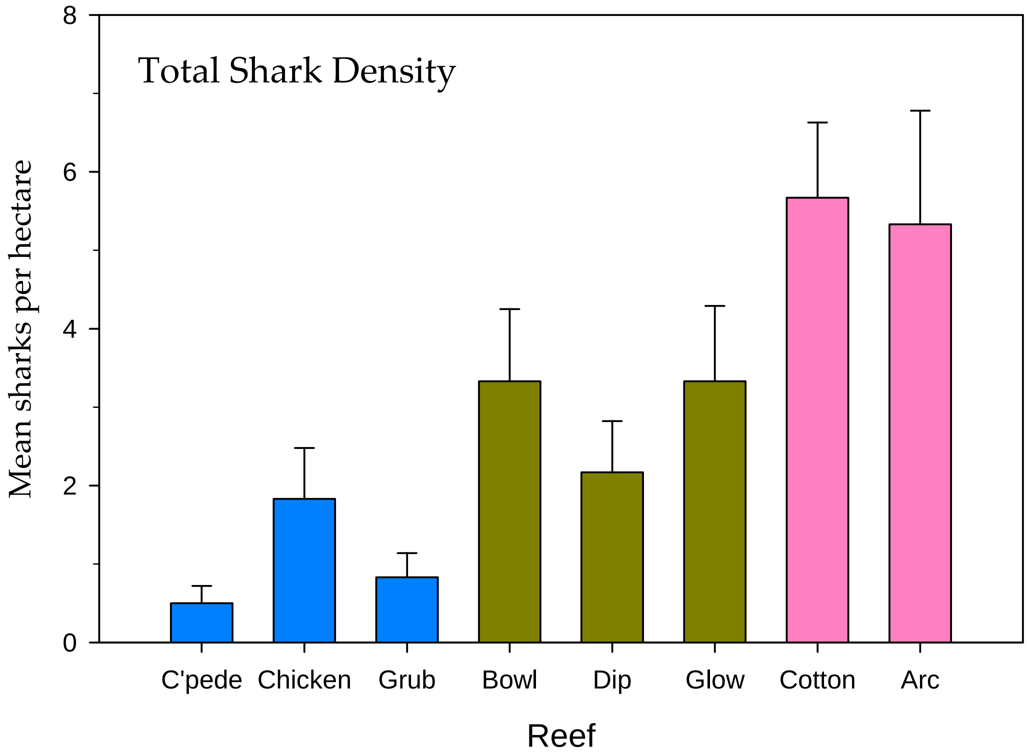

Figure 6. Mean density of all sharks on the eight offshore Townsville survey reefs. Means from six hectare counts on each reef are shown. Error bars are standard errors. C'pede = Centipede Reef.

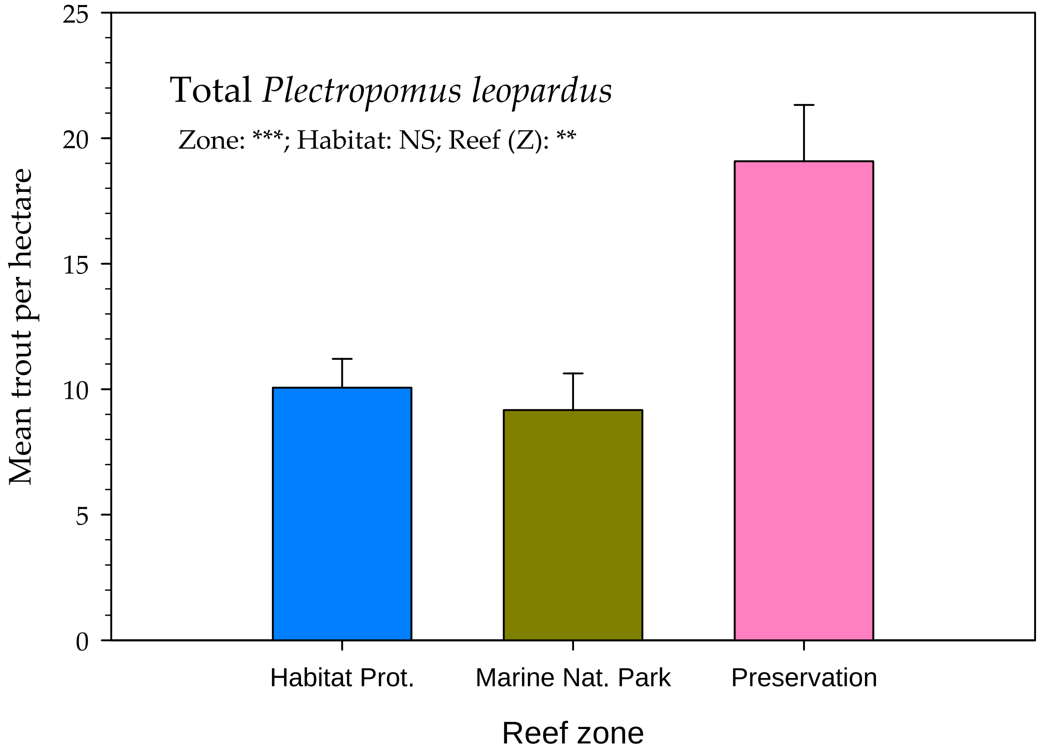

Figure 7. Abundance summary for total *Plectropomus leopardus* in the different Marine Park zones. Mean number of trout per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

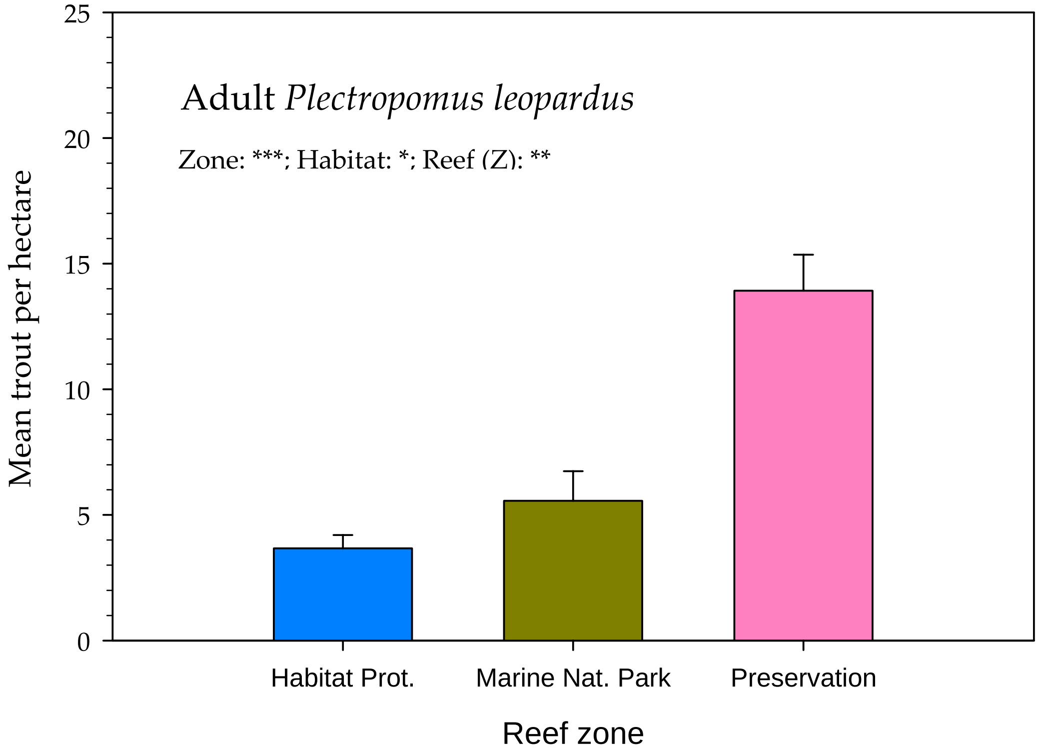

Figure 8. Abundance summary for adult *P. leopardus* (>38 cm) in the different Marine Park zones. Mean number of trout per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

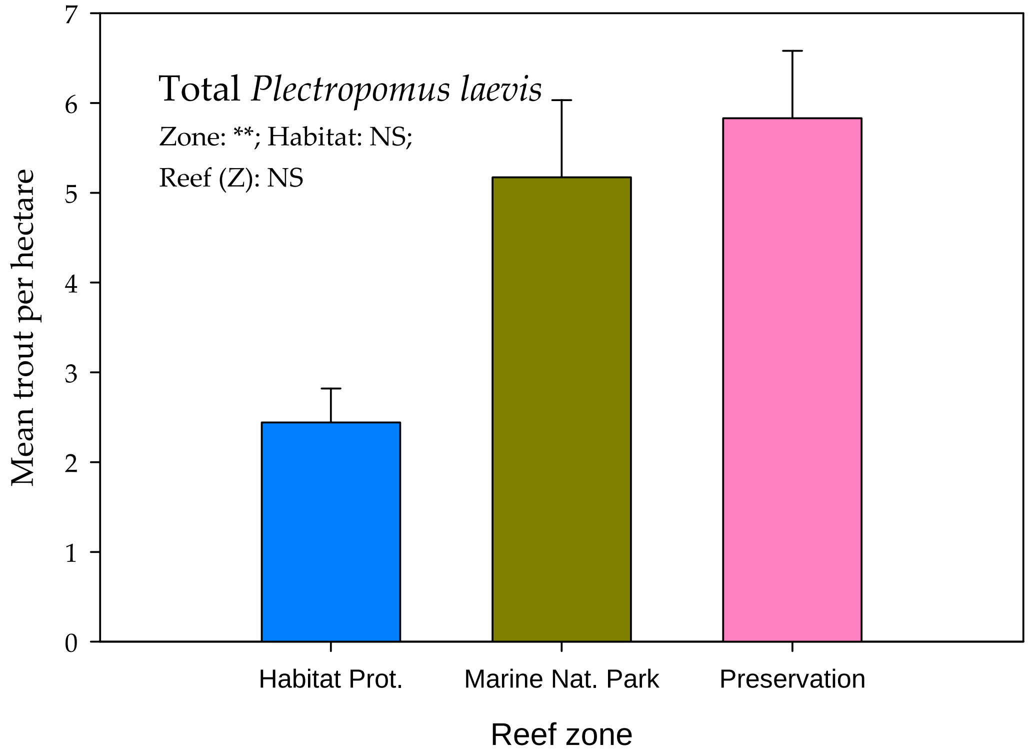

Figure 9. Abundance summary for total *Plectropomus laevis* in the different Marine Park zones. Mean number of trout per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

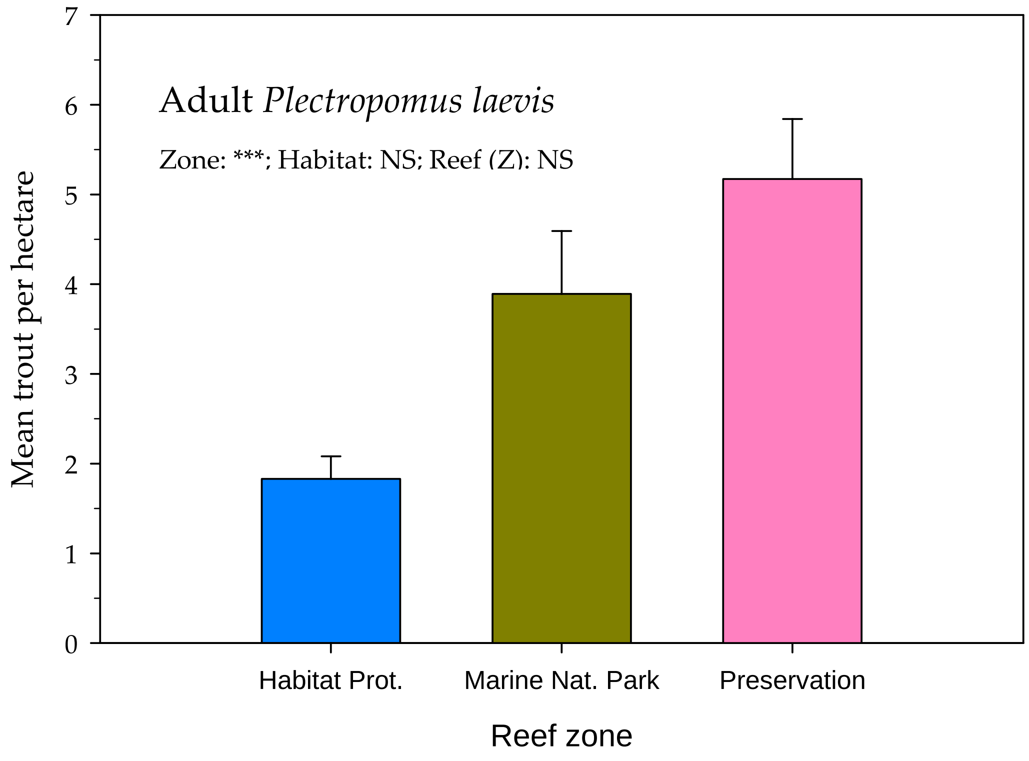

Figure 10. Abundance summary for adult *P. laevis* in the different Marine Park zones. Mean number of trout per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

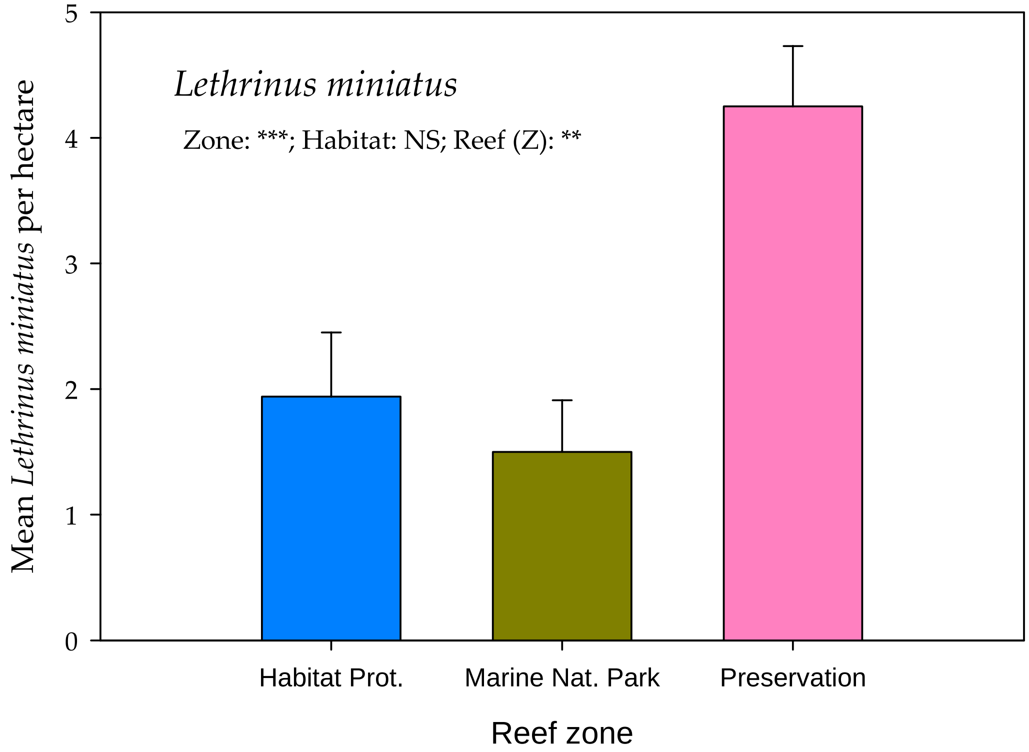

Figure 11. Abundance summary for *Lethrinus miniatus* in the different Marine Park zones. Mean number of fish per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

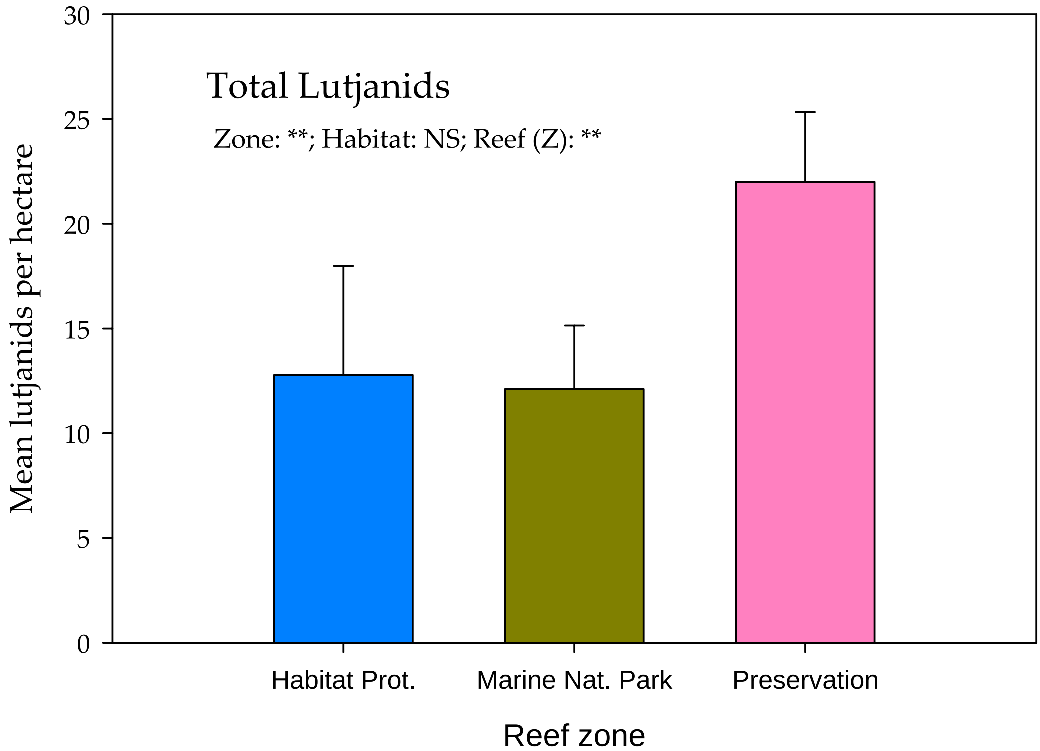

Figure 12. Abundance summary for total Lutjanids in the different Marine Park zones. Mean number of lutjanids per ha is shown from six 500 x 20 m counts on each reef. Error bars are standard errors.

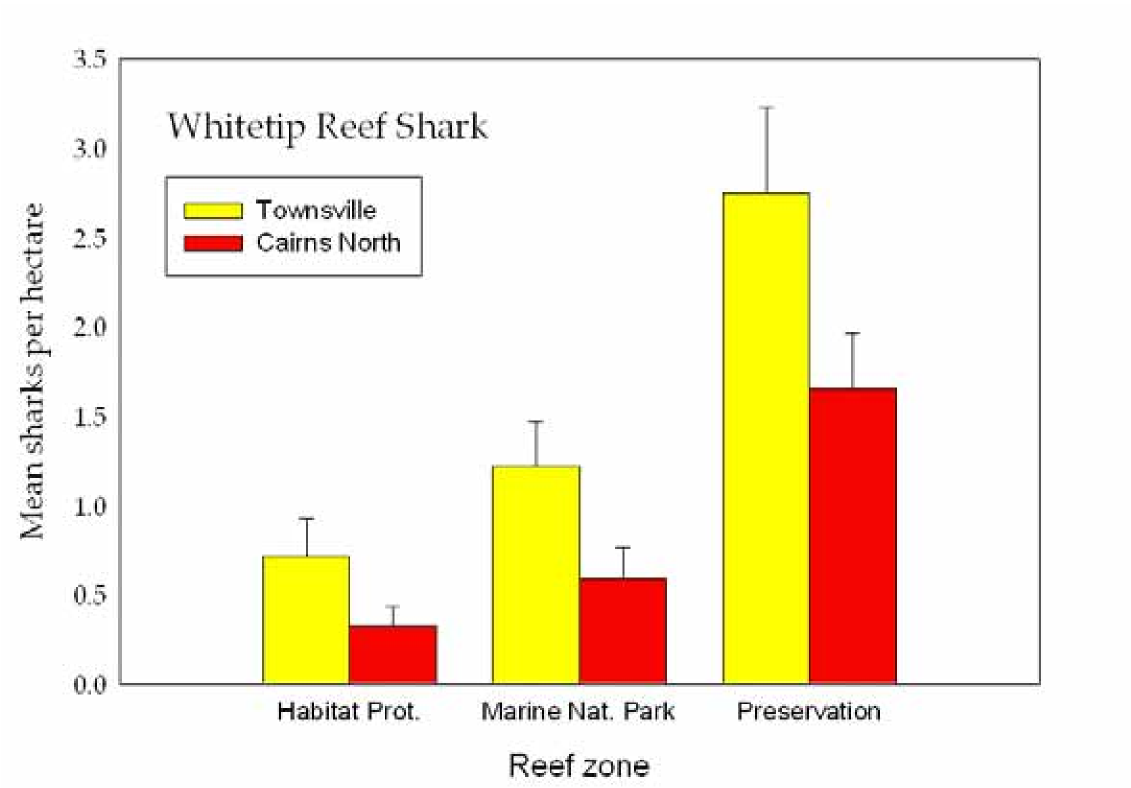

Figure 13. Comparison of whitetip reef shark density on Townsville reefs with that on northern Cairns Section reefs from Robbins et al. (2006). Mean number of sharks per ha is shown from all survey reefs in each zone. Error bars are standard errors.

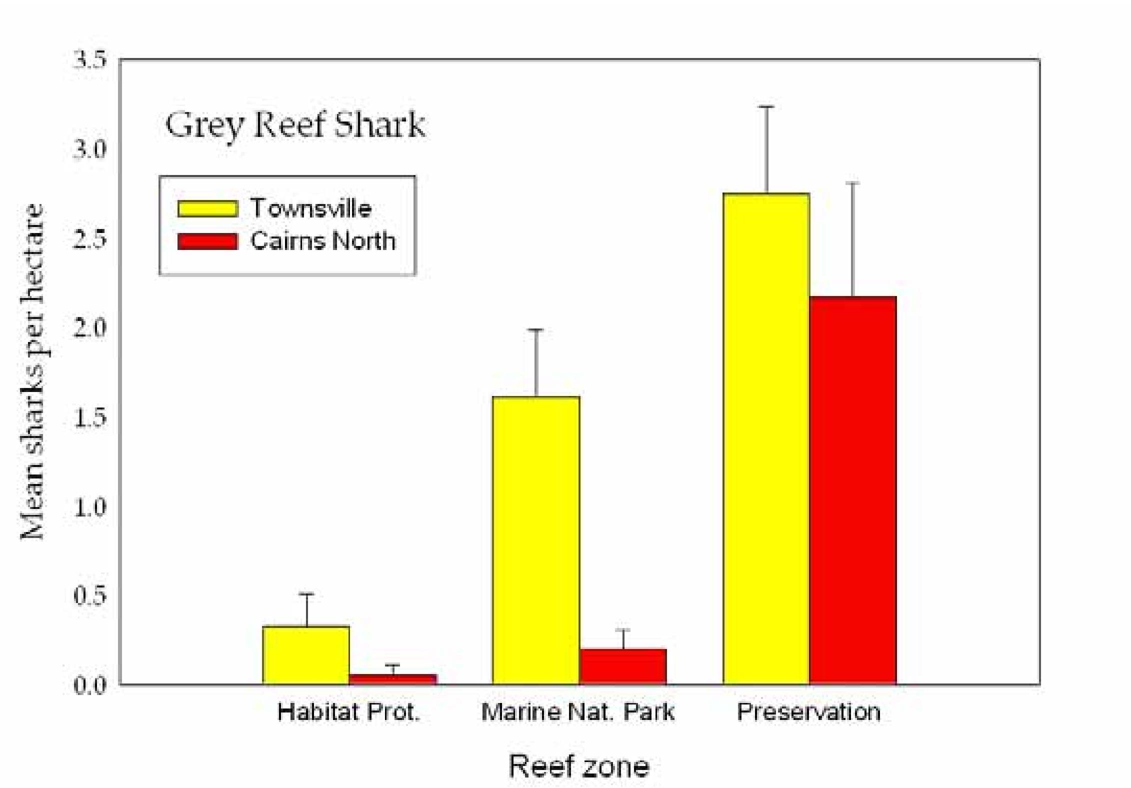

Figure 14. Comparison of grey reef shark density on Townsville reefs with that on northern Cairns Section reefs from Robbins et al. (2006). Mean number of sharks per ha is shown from all survey reefs in each zone. Error bars are standard errors.

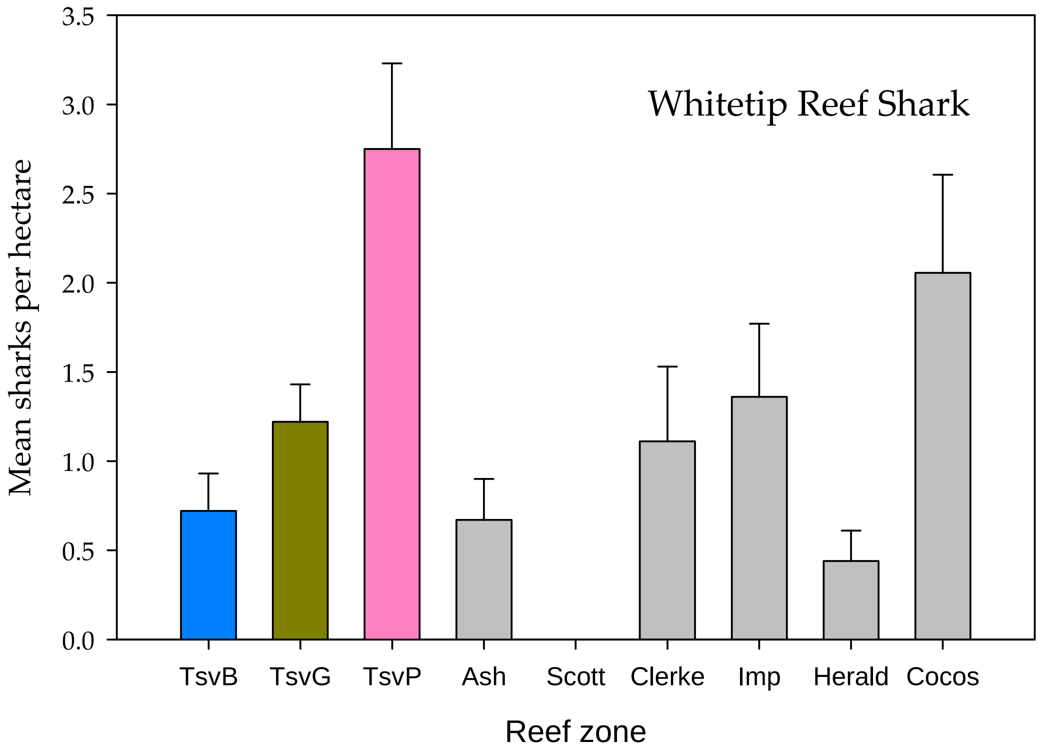

Figure 15. Comparison of whitetip reef shark density between the Townsville reefs and other offshore reefs. TsvB=Townsville blue reefs; TsvG=Townsville green reefs; TsvP=Townsville pink reefs; Ash=Ashmore Reef; Imp=Imperieuse Reef; Herald=Herald Cay Reef; Cocos=Cocos-Keeling Island.

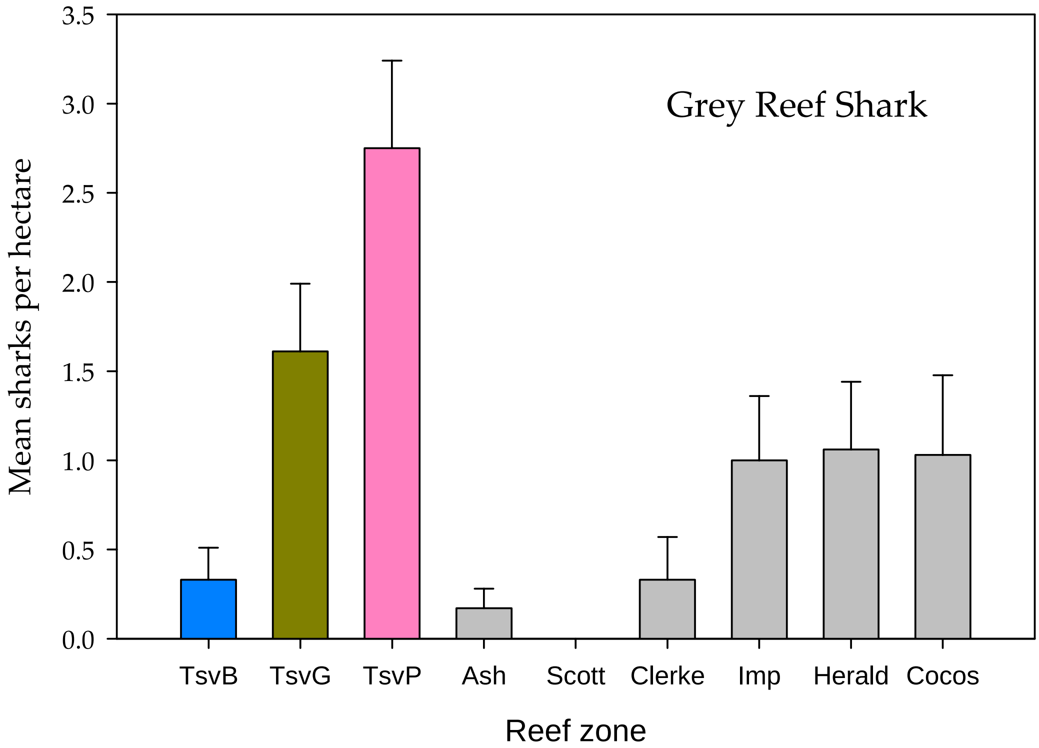

Figure 16. Comparison of grey reef shark density between the Townsville reefs and other offshore reefs. Abbreviations as for figure 15.

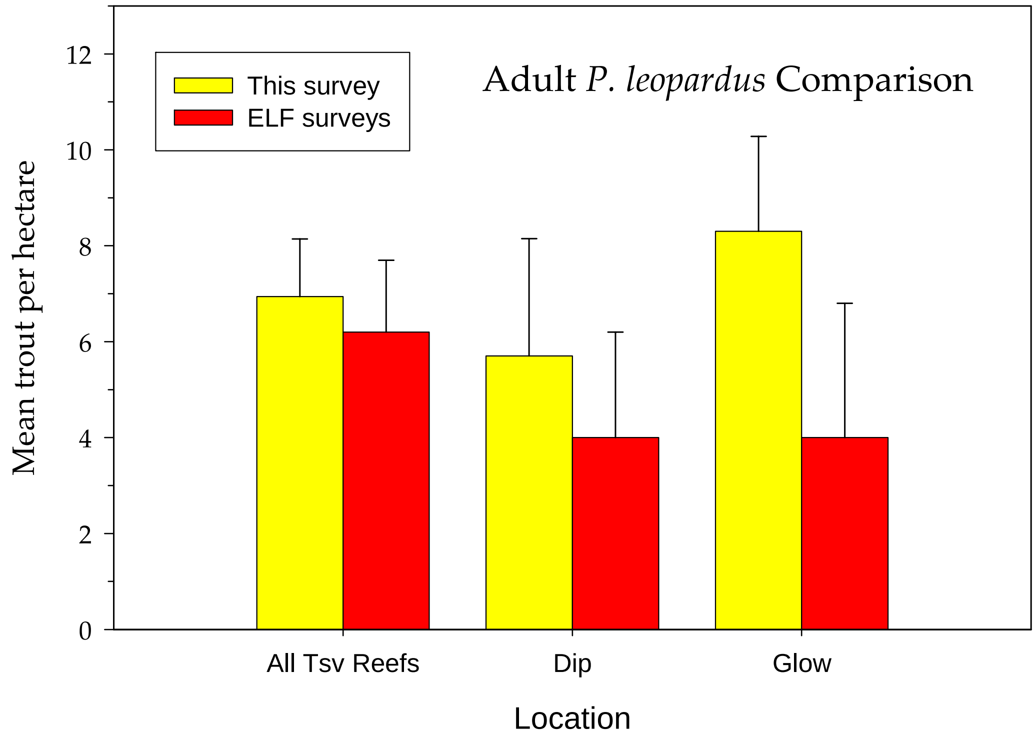

Figure 17. Comparison of *Plectropomus leopardus* density from the present survey with that recorded during the 2004 and 2005 Effects of Line Fishing surveys of offshore Townsville reefs. Error bars are standard errors.

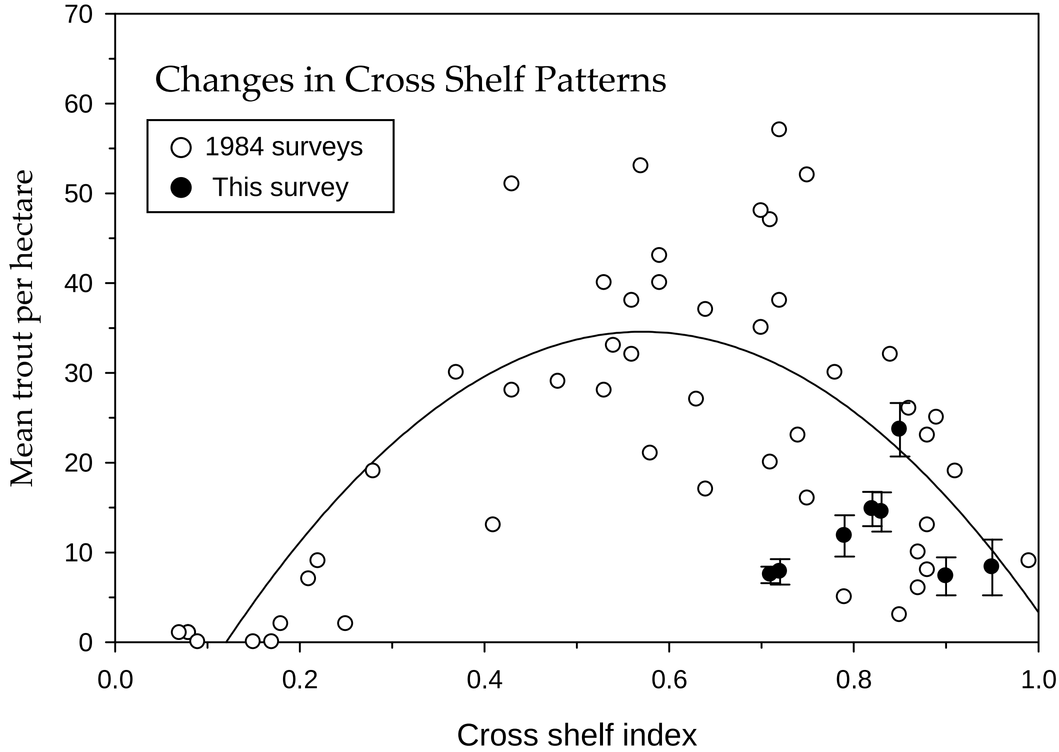

Figure 18. Comparison of cross shelf patterns of *Plectropomus leopardus* density from the present survey with those from comprehensive surveys made in the Central Section in 1984. A 2nd order polynomial curve is fitted to the 1984 data.

DISCUSSION

It is now generally accepted that sharks are suffering worldwide population reductions (Baum et al 2003) with some estimates of the global catch for shark fins approaching 75 million sharks annually (Clarke et al. 2006). Estimates of the total global catch from all sources have ranged as high as 100 million sharks (Griffin et al. 2008). Sharks in the Great Barrier Reef region may also be in decline, with the commercial catch of inshore sharks quadrupling over a recent ten year period (Gribble et al. 2005) and a substantial recreational catch of sharks (Henry and Lyle 2003). Robbins et al. (2006) surveyed sharks in different Great Barrier Reef Marine Park zones using the same method as the present study and found whitetip and grey reef sharks to be 5 times and 40 times respectively more abundant on two northern Cairns Section no-go Preservation Zone reefs (pink reefs) compared with nearby fished Habitat Protection zone reefs (blue reefs). More disturbingly, Robbins et al. (2006) found these sharks to be 3 times and 10 times more abundant on pink reefs than on supposedly no-take Marine National Park zoned reefs (green reefs). The present study was designed to extend the comparison of shark numbers between zones from the northern Cairns Section to the offshore Townsville area where there are also two pink reefs.

We found that the two common reef sharks were four to eight times more abundant on no-go pink reefs compared with fished blue reefs. However, these sharks were also approximately twice as abundant on pink reefs as on nearby green reefs that were also supposedly closed to fishing. Although the results from this study were not as skewed toward no-entry pink zones as those reported by Robbins et al. (2006), the overall patterns of shark abundance were the same, with lowest numbers on fished blue reefs, moderate numbers on green reefs and high numbers on pink reefs. Robbins et al. (2006) suggested this was due to a higher level of illegal fishing on the no-take green reefs where entry of boats was permitted than on the more easily policed no-go pink zones. Fishing has been documented on protected reefs, even those in well-policed inshore areas (Gribble and Robertson 1998, Williamson et al. 2004, Davis et al. 2004, A.M. Ayling personal observations). There is also evidence that fishing relatively naïve fish populations on green reefs produces very high catch rates compared to fishing on blue reefs and a small amount of illegal fishing can have a large impact (Russ et al. 1995, Mapstone et al. 2004).

Another possible explanation for the density discrepancy between protected pink reefs and protected green reefs is differences in shark behaviour between the two zone types. It has been suggested that reef sharks become habituated to the presence of divers and do not bother to investigate their presence in regularly visited and dived areas unless they are stimulated by spearfishing or fish feeding activities. If this is the case, naïve sharks on pink reefs may be more likely to come close to the observer and be counted than their habituated counterparts on regularly visited green and blue reefs. However, there was no apparent difference in sharks' response to the observer in the three zones during the present study. Sharks did not approach more closely or act more aggressively on the pink reefs compared to the green and blue reefs. In fact, there were more aggressive reactions from grey reef sharks on the blue reefs than the other two zones during this study. Frequent diver activity over the last decade on Dip and Glow Reefs from the ELF surveys and Australian Institute of Marine Science monitoring surveys has apparently not led to shark habituation and low shark

sightings on these reefs (figure 6). The high diver-observer counts of both species of reef sharks on Cocos-Keeling Island, where there is constant diver activity but very limited shark fishing, supports the idea that these counts represent real differences in density rather than differences in shark observability. The present lack of shark appearance in response to spearfishing activities on many blue and green reefs (J.H. Choat personal observations during scientific collecting over two decades) also indicates that sharks are just rare on these reefs rather than habituated to non-stimulating divers.

Abundance of both reef sharks on offshore Townsville pink reefs was equivalent to the highest densities that we or Robbins et al. (2006) have recorded in all other similar shark surveys. However, densities of these sharks on Townsville blue reefs are similar to the lower limit recorded in previous surveys. This suggests that reefs in this region potentially support healthy reef shark populations but that present densities on blue reefs are well below this level and similar to other fished areas.

Abundance patterns of the major reef dwelling target species of the regional fishery were similar to those recorded for reef sharks. Common coral trout were four times as abundant on pink reefs as on blue reefs and 2.5 times as abundant on pinks reefs as on green reefs. Coral trout usually swim slightly toward diver observers and are consistent in their reactions (A.M. Ayling personal observations) so it is unlikely that these density patterns are due to differences in coral trout behaviour between pink and green reefs. This adds support to the idea that it is differences in compliance effectiveness that are responsible for the observed differences in shark densities between pink and green reefs.

Another possible reason for the observed differences in density between pink and green reefs is intrinsic ecological differences in the reefs themselves: the pink reefs may just happen to be more attractive to sharks than the blue and green reefs. However, this study and that of Robbins et al. (2006) have now surveyed four pink reefs in two widely separated regions and it is unlikely that these reefs all by chance support high densities of reef sharks. GBRMPA documentation suggests that the offshore Townsville pink reefs were selected as being representative of reefs in the area not as having any special attributes. In fact, the two Townsville pink reefs were very small reefs with relatively low habitat heterogeneity and could be considered as relatively unattractive to large predators compared with much larger reefs with more varied habitat such as Bowl and Dip Reefs. It is possible that the reason for the lack of significance difference in bluespot coral trout density between green and pink reefs is that the green reefs are much more suitable large predator habitat than the two small, relatively homogeneous pink reefs. The lack of increased density for the three non-targeted fish groups (haemulids, ephippids and scarids) on pink reefs compared to green and blue reefs adds further support to our suggestion that it is not reef ecology differences that are driving the shark and predatory fish density differences between zones.

Robbins et al. (2006) found no significant differences in density between fished reefs and no-take green reefs but in the present study both shark species were significantly more abundant on green reefs than on blue reefs. The most likely reason for this difference is relative compliance effectiveness. The offshore Townsville green reefs

have always been part of a relatively large green patch that is about 20 km across and includes six green reefs and two pink reefs that have been stable in zoning since first gazetted in 1987. This large protected zone probably makes policing easier and increases fisher compliance, at least within the core area. With the RAP re-zoning in 2004 this green area approximately doubled in size and probably improved overall compliance on individual reefs within it. However, this offshore green and pink area is not totally effective and we observed line fishing within these reefs on several occasions prior to the RAP re-zoning (A.M. Ayling personal observations).

Since the implementation of the RAP zoning changes on the Great Barrier Reef that increased no-take green zones dramatically to more than 30% of the Marine Park area there is a perception that compliance has improved and that green zones are now more effective. Enforcement is unlikely to have increased to the same extent as the no-take area and there is a need to measure compliance effectiveness. The local context to this concern includes unfavourable messages from a recent court decision on GPS effectiveness and political commentary defending fishers caught fishing in green zones. Compliance messages must be firm and unambiguous to be truly effective.

Given that there has been very little increase in the number of pink reefs in the RAP, effective compliance will be essential for the re-zoning to have a positive effect on shark populations. Because reef sharks take about a decade to reach maturity and females only produce 12-15 young during their lifetime (Robbins 2006) recovery of shark populations following improved compliance, or on newly created green zones, will take decades. Most studies suggest that although reef sharks are easily capable of moving between reefs they are predominantly site attached (Randall 1977) and it is unlikely that spill-over of increased populations from areas such as pink zones that appear to offer good protection will significantly boost populations in fished zones or non-compliant green zones. This is especially so given the small number of pink reefs in the Great Barrier Reef Marine Park.

Previous methodological studies looking at visual count methods for coral trout have suggested that wider counts are less effective than narrow 5 m wide transects (Mapstone and Ayling 1998). However, comparison of the common coral trout results from this survey with those from recent ELF visual surveys on the same reefs using traditional 5 m wide transects suggests that wider counts can give accurate results, at least when the underwater visibility is 20 m or greater as it was during the present study. This assumes densities have not changed significantly over the past two years on these reefs. The timed 20 m wide transect has been used over the past decade to survey sharks, Maori wrasse, large predatory fish and large herbivorous fish such as the parrotfishes *Chlorurus microrhinus* and *Bolbometopon muricatum* (Choat and Pears 2003). This method has proven to be cost effective and is a powerful way of assessing population densities of large, relatively rare or uncommon reef fishes and elasmobranchs.

The results from this survey when combined with those reported by Robbins et al. (2006) have important implications for reef managers. There is good evidence that protected reefs have been subjected to illegal fishing in the past (Gribble and Robertson 1998, Williamson et al. 2004, Davis et al. 2004). Despite current perceptions managers should not assume that the increased no-take area provided under the RAP program

will give real increases in the level of protection for shark populations on the Great Barrier Reef. It is clear that increased effort on policing is required, especially now that the protected area is much greater. At the same time, deterrents to illegal fishing should be increased and all efforts should focus on getting unambiguous compliance messages out to the fisher community. It has been reported that the majority of committed fishers, (i.e. those that spend the most time fishing and catch the most fish) believed that the RAP extensions to the zoning plan were unnecessary and unlikely to reduce the impact of fishing on the Great Barrier Reef (Sutton and Li 2008). Improved education campaigns, such as pushing the message that protection is good for future fishing, should be implemented to overcome these poor perceptions of the value of protection amongst committed fishers. Consideration should also be given to a substantial increase in the size and number of no-go Preservation Zones. Incorporating a number of adjacent reefs into more extensive pink zones would further increase their effectiveness.

This study suggests a number of avenues for further research into reef shark abundances and the effectiveness of the Great Barrier Reef Marine Park zoning. Shark and large predator counts could be extended to other regions of the Great Barrier Reef, notably the offshore Whitsunday/Hydrographers Passage area where there are four long established pink reefs and long established green reefs and the Swain Group where there are also four long-established pink reefs and long established green reefs. The Swain Group reefs would make very effective comparisons because there is a wide selection of green and blue reefs close to the pink reefs that have very similar sizes and shelf positions. This would minimise potential confounding factors. It would also be very useful to carry out surveys in the Far Northern Management Area of the Marine Park where reef shark numbers were very high in the late 1970s and 1980s (A.M. Ayling personal observations).

It would be very useful to investigate the issue of shark counts possibly being affected by behavioural differences between naïve sharks on pink reefs and those from visited green and blue reefs that are habituated to divers. One possible way would be to carry out three surveys at approximately weekly intervals on two pink reefs and see if shark sightings decrease over successive counts. Logistically this could easily be combined with a survey of the Swain Group reefs.

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