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RESEARCH PUBLICATION NO. 92

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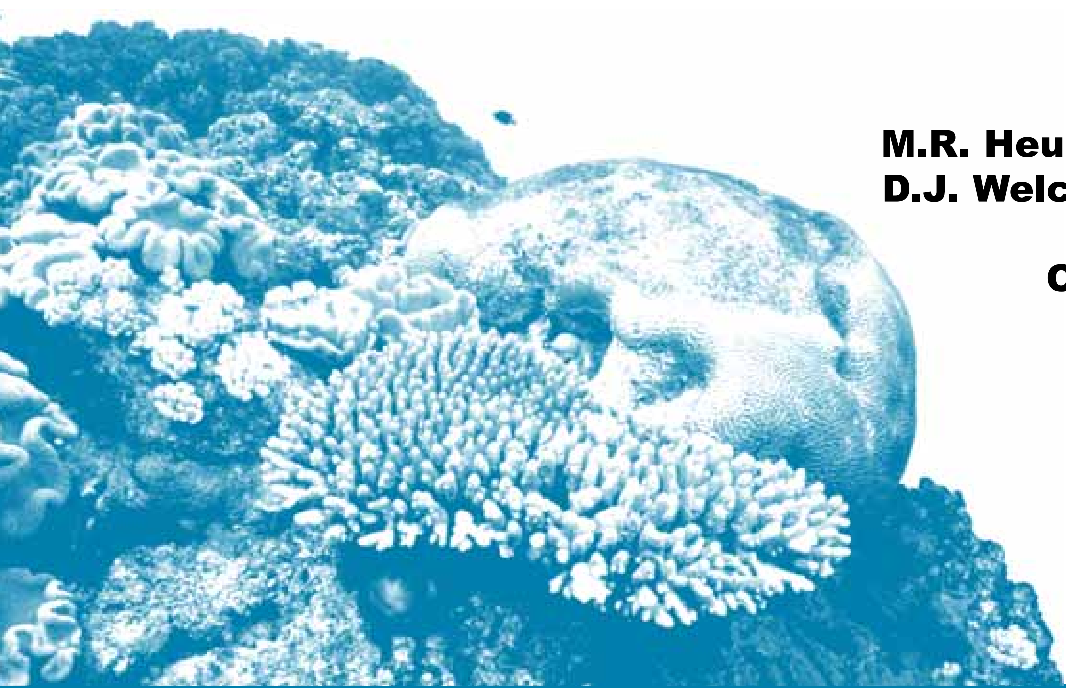
Final report to the Great Barrier Reef Marine Park Authority



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Published by the Great Barrier Reef Marine Park Authority

ISBN 978 1 876945 76 3 (pdf)

This report should be cited as: Heupel M.R., Williams A.J., Welch D.J., Mapstone B.D., Ballagh A. and Simpfendorfer C.A. (2008) Compilation of information on the interaction of reef sharks with the reef line fishery in the Great Barrier Reef Marine Park: Final report to the Great Barrier Reef Marine Park Authority. Research Publication No. 92, Great Barrier Reef Marine Park Authority, Townsville (47pp)

The National Library of Australia Cataloguing-in-Publication entry :

Compilation of information on the interaction of reef sharks with the reef line fishery in the Great Barrier Reef Marine Park [electronic resource] : final report to the Great Barrier Reef Marine Park Authority. / H. R. Heupel ... [et al.]

ISBN 978 1 876945 76 3 (pdf)

Research publication (Great Barrier Reef Marine Park Authority : Online) ; no. 92.

Bibliography.

Sharks--Queensland--Great Barrier Reef.
Fisheries--Queensland--Great Barrier Reef.
Heupel, H. R.
Great Barrier Reef Marine Park Authority.

597.3409943

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ACKNOWLEDGMENTS

Funding from the Great Barrier Reef Marine Park Authority to AJ Williams supported this analysis. Funding for the ELF Experiment was provided by the CRC Reef Research Centre, the Fisheries Research and Development Corporation, the Great Barrier Reef Marine Park Authority, the Queensland Department of Primary Industries and Fisheries (formerly the Queensland Fisheries Management Authority) and James Cook University. The Observer project was funded by the Fisheries Research and Development Corporation. We thank the Queensland Department of Primary Industries and Fisheries for logbook data used in this analysis. The authors would also like to thank the commercial fishers who participated in the Observer program and ELF Experiment.

The report was independently peer-reviewed by three anonymous reviewers.

SUMMARY

Three data sets were examined to define the level of interaction of reef associated sharks with the commercial Coral Reef Fin Fish Fishery (CRFFF) within the Great Barrier Reef. Data were examined from; 1) fishery logbooks from 1989-2006; 2) an observer program within the fishery from 1996-1998; and 3) a fishery-independent survey, the Effects of Line Fishing (ELF) Experiment conducted from 1995-2005. The majority of the identified catch in the data sets was comprised of grey reef (62-72%), whitetip reef (16-29%) and blacktip reef (6-13%) sharks. Logbook data were inadequate for assessing the impact of the fishery on specific populations due to lack of species identification and sex or size data for landed sharks. In addition, no data were recorded in logbooks for hooked and released sharks. Logbook catch data revealed that reported landings of sharks were variable through time and across regions. Despite the observed variation, catch per unit effort was relatively stable through time and did not show any signs of increase or decline over the period for which data were available. The ongoing and consistent catches of reef sharks in the fishery may indicate that shark populations within the Great Barrier Reef Marine Park have remained relatively stable during the last two decades, though population status relative to unexploited levels could not be estimated. Although the CRFFF has a large fleet of vessels, the majority of shark catch appears to be landed by a small number of vessels.

There were no significant differences in catch rates among regions from either the observer or ELF data sets. Catch rate estimates from both sources were in agreement, suggesting that they were representative of fishery activity and harvest. Data from the ELF Experiment also revealed that 2.2 times as many sharks were hooked but not successfully brought to the boat (encountered by the fishery) as were brought to the boat. Estimated encounter rates of reef sharks were between 1.34 and 2.48 sharks per dory day. This suggests that sharks were being encountered regularly and highlights the need to understand post-release survival. The ELF data set demonstrated that catch rates were higher in Marine National Park zones (no fishing) when compared to General Use zones open to fishing. This result suggests that no-take fishing zones provided at least partial refuge from fishing pressure for reef shark populations within the Great Barrier Reef.

Although these data provide insight into the recent history of reef shark encounters with the CRFFF there are limited useful data prior to 1995 (year the ELF Experiment commenced). Declines of shark populations from virgin levels are highly likely, although present data did not detect any recent decline. This analysis suggests that if declines occurred, they were prior to 1989 (first year of logbook analysis) and / or the rate of decline is not detectable given current harvest rates. Regardless, further study is required to better understand fishing mortality and the significance for reef shark populations. The analyses conducted here were based on studies focused on reef fish catch and were not directed at defining shark populations or encounters with the fishery. Research specifically designed to address the questions of shark presence, residence and abundance are required to fully understand these populations. Improved reporting in the fishery and continued management are also necessary for maintaining stocks and defining changes within populations targeted by the fishery.

INTRODUCTION

The catch of chondrichthyan fishes (sharks, skates and rays) in target and non-target fisheries has been examined in numerous studies in recent years, with varying conclusions on the sustainability of catch and harvest of individual species (e.g., Walker 1998; Stevens et al. 2000; Stobutzki et al. 2002; Baum et al. 2003; Burgess et al. 2005). A wide range of data sources have been used to assess these populations, including logbook records from fisheries (e.g., Crow et al. 1996; Stobutzki et al. 2002; Walsh et al. 2002), data from shark control programs (e.g., Simpfendorfer 1992; Wetherbee et al. 1997; Dudley and Simpfendorfer 2006), observer data (e.g., Stevens 1992; Marín et al. 1998), life history data (Stobutzki et al. 2002; McAuley et al. 2007) and fisher surveys (e.g., Carlson et al. 2007). While many previous investigations have examined wide-spread, mobile species that are not limited to specific habitats (e.g., Simpfendorfer et al. 2002; Walsh et al. 2002; Stevens 1992; Marín et al. 1998), there have been fewer studies of species that have high levels of habitat association and so are dependent on specific habitats such as coral reefs.

There are a number of chondrichthyan species that are associated almost exclusively with coral reefs, including the whitetip reef shark (*Triaenodon obesus*), blacktip reef shark (*Carcharhinus melanopterus*), grey reef shark (*Carcharhinus amblyrhynchos*), Caribbean reef shark (*Carcharhinus perezi*) and epaulette shark (*Hemiscyllium ocellatum*) (Compagno 1984). These species may be more susceptible to exploitation and changes in habitat quality because of their high level of habitat association (Wetherbee et al. 1997; Garla et al. 2006a). Reef associated shark species often have complex distributions, however, making the interpretation of data associated with them difficult. There has been a range of studies on coral reef associated shark species, including life history (Randall 1977; Stevens 1984; Robbins 2006; Heupel and Bennett 2007), distribution (Wetherbee et al. 1997; Pikitch et al. 2005; Papastomatiou et al. 2006) and behaviour (Johnson and Nelson 1973; Randall and Helfman 1973; Nelson et al. 1986; Economakis and Lobel 1998). There is little information available on fisheries for these species or the status of populations.

Wetherbee et al. (1997) examined demographics of the grey reef shark in Hawaiian waters based on shark control and fishing logbook data and demonstrated a variable distribution of this species among the Hawaiian Islands. Grey reef sharks were found to be most abundant in the north-west Hawaiian Islands and were less common in the main Hawaiian Islands. This result was substantiated by a subsequent study of reef shark distribution in Hawaiian waters (Papastomatiou et al. 2006). Pikitch et al. (2005) also suggested that Caribbean coral reef associated shark species show specific distributions on a reef platform. Thus, the capture of reef associated elasmobranchs may be highly dependent on location of fishing effort on a fine scale. The results of these studies suggest that understanding catches of habitat-dependent species, such as reef sharks, may be difficult to interpret based on differences in distribution within and among reef platforms.

Robbins et al. (2006) recently raised concern about the population status of grey reef and whitetip reef sharks on the Great Barrier Reef. They concluded that the abundance of these two species had declined by 97% and 80%, respectively, based on visual survey data and demographic analysis. The authors suggested that these species had been overfished within the Great Barrier Reef and that their populations may be at risk of ecological extinction. They also concluded, based on comparisons between fished, no-fishing and no-entry zones that only no-entry zones or highly effective (i.e., enforced) no-take zones were likely to maintain shark populations at levels close to pristine and suggested that adherence to no-take zoning regulations within the Great Barrier Reef Marine Park may have been poor historically.

The Coral Reef Fin Fish Fishery (CRFFF) of the Great Barrier Reef is a multi-species line fishery that targets high value teleost species, often for live export to Asian markets. Atypically for a tropical coral reef fishery, there is currently relatively little targeting of low value species for local consumption. The management arrangements for the fishery enable commercial and recreational fishers to use up to three lines, with no more than six hooks in total, using either a rod and reel or a handline. Commercial fishers almost exclusively use one handline with a single hook, while recreational gear is more varied. Commercial fishing is typically from small dories that work from a main vessel. The number of dories that can be used is limited by licensing (0-7 dories), with most vessels using less than four dories. Sharks are not considered a target species in the fishery, but are taken as bycatch and sold for flesh, fins or both, or are discarded. The catch of shark by commercial line fishing comprises approximately 6% of the reported elasmobranch landings along Queensland’s east coast (Gribble et al. 2005), with the commercial inshore net fishery responsible for the remaining 94%. Commercial line fishing as identified by Gribble et al. includes all line fishing (i.e. inshore line fishing as well as reef line fishing) and therefore is not solely indicative of activity in the CRFFF.

We examined three sources of data associated with the CRFFF to better understand how the fishery interacts with coral reef associated species and estimate trends in catch rate data for sharks reported by the fishery since compulsory reporting was introduced in 1988. The data examined came from compulsory logbooks used by commercial and charter CRFFF vessels, observers on commercial CRFFF vessels and targeted scientific surveys using commercial fishing practices. The scientific survey data were also used to examine the effectiveness of no-fishing areas in protecting reef shark populations from effects of fishing over a large geographic range.

MATERIALS AND METHODS

Data sources

Three data sets were used in this analysis: commercial logbook data from the Coral Reef Fin Fish Fishery (CRFFF); research observer survey data from commercial vessels in the CRFFF (Mapstone et al. 2001); and fisheries-independent data collected during the Effects of Line Fishing (ELF) Experiment (Mapstone et al. 1996a; 2004; Campbell et al. 2001). All data were from fishing efforts within the Great Barrier Reef region. It should be noted that the observer surveys and the ELF Experiment were designed to research harvest of teleost fish (not sharks) and, therefore, the analyses reported here were done opportunistically from existing data rather than as part of a research directed at sharks.

Table 1. Listing of all data sources and data types used in this analysis.

	Logbook data	**ELF data**	**Observer data**
Study period	1989-2006*	1995-2005	1996-1998
Type of data	Fishery dependent	Fishery independent	Fishery dependent
Data source	QDPI&F compulsory logbooks	Fishing and Fisheries Research Centre	Fishing and Fisheries Research Centre
Data validation	Reported shark catches associated with reef teleost species	All data collected by researchers on ELF structured surveys	All data collected by research observers on commercial vessels
Data quality	Variable over time	Increased reporting of shark data from 2000-2005	Consistent throughout

* Note that compulsory logbooks were introduced in 1988 but we excluded data from the first year of reporting because of known low reporting rates in that first year.

Fishery logbook data

Compulsory fisheries logbook data from the CRFFF are collated and managed by the Queensland Department of Primary Industries and Fisheries (QDPI&F). Data collected include: vessel identification information, date, geographic grid (30’ × 30’) and site (6’ × 6’) or latitude and longitude location data for each fishing activity, number of dories, number of lines, weight of catch by species or species groups, number of individuals (occasionally and for some species only) and product type (i.e., gutted, whole, fillet, fin, etc). Data from all commercial fisheries are collated into a single database, which was queried to select shark catch data from line fishing vessels that also captured other reef fish species. This strategy ensured that effort from non-reef regions and non-line fishing was excluded and the reported catch represented reef associated sharks rather than other coastal species. The approach meant a small number of reef shark landings were excluded (e.g., reefs sharks harvested when no reef teleosts were harvested), but it ensured that the data were unambiguous about the origin of the sharks captured. Data included in this analysis were from commercial and charter fishery logbook entries (referred to as ‘commercial’ for all data) from all full years of data (1989 to 2006). Charter logbook entries comprised <1% of all commercial catch. Fishing effort was divided into six regions: the Far North, Cairns, Townsville, Mackay, the Swains Reefs and the Capricorn-Bunker Group (figure 1).

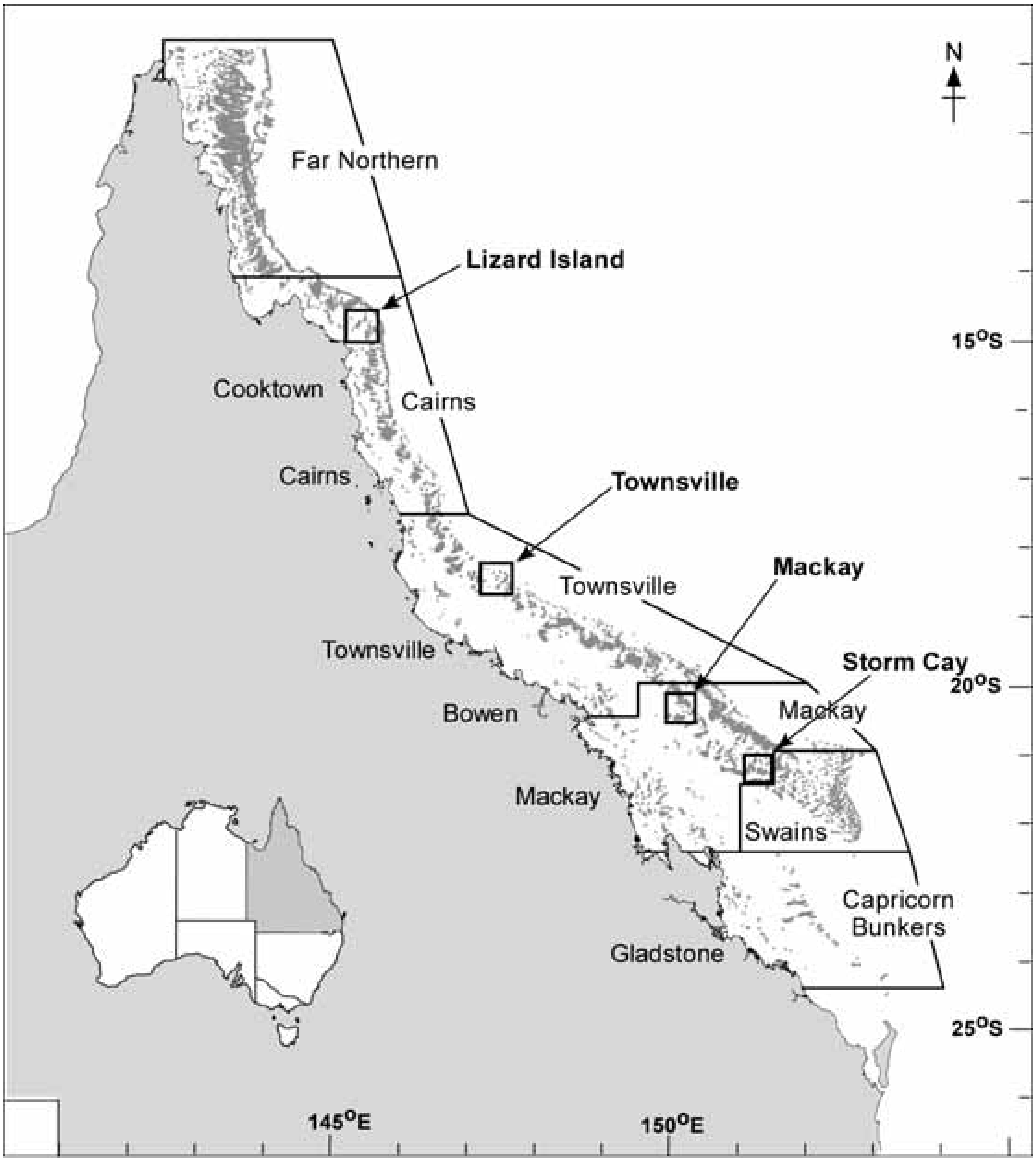


Figure 1. Map of the Great Barrier Reef region off the east coast of Australia showing sampling regions used in this analysis. Broad zones (lines) were those used for CRFFF and OBS data, squares indicate locations of ELF reef clusters.

Observer data

Scientific observers were deployed on 29 fishing trips of up to three weeks duration (a total of 238 observer days) by commercial fishing boats within the CRFFF during 1996 to 1998 to observe fishing procedures and record catch. All observers were deployed to observe general fishing practices, not specifically to record shark catch. Observers recorded the date and location of fishing, fishing start and end times, identification of individuals captured and fate of captured individuals. Fishing effort was calculated as the time each hook was in the water on an observed dory. Specific reefs or sampling locations were not chosen prior to each trip, since data were collected directly from the commercial fishery under normal operating conditions. Fishing effort was categorised post-hoc into four regions: the Far North, Cairns, Townsville and Mackay (figure 1). These regions were slightly different to those defined in CRFFF data, but were chosen to allow direct comparison to the Effects of Line Fishing Experiment data (below). The fate of captured individuals was recorded as dead, released or not recorded. Fishing methods were those described above for the CRFFF.

Effects of Line Fishing (ELF) data

The Effects of Line Fishing (ELF) Experiment was a large-scale manipulative fishing experiment that sampled 24 reefs spanning 7˚ of latitude, approximately half of the length of the Great Barrier Reef. The 24 reefs were grouped into four regional clusters of six adjacent reefs. Clusters were located at Lizard Island, off Townsville, off Mackay and at Storm Cay in the north-west Swains Reefs (figure 1). Four reefs in each cluster were zoned as Marine National Park (MNP) (closed to fishing) and so were designated no fishing zones for 10-12 years prior to the start of the experiment in 1995. Two of these MNP reefs remained closed for the duration of the sampling period aside from annual sampling for the ELF Experiment (MNP-Control). These reefs provided data on natural fluctuations of reef fish populations. The remaining two MNP reefs were opened to line fishing for one year during the experiment before being returned to their previous protected status (MNP-Fished). One MNP-Fished reef in each cluster was opened from March 1997 to March 1998 and the other from March 1999 to March 2000. These reefs were used as treatments to examine impacts of pulsed fishing and recovery rates of stocks following the year of fishing. The remaining two reefs in a cluster were General Use (GU) reefs that had historically been open to fishing and were open to fishing during the early years of the experiment but were closed to fishing for a five year period (GU-Fished) as part of the experiment. One GU reef in each cluster was closed from 1998-2002 inclusive and the other from 2000-2004 inclusive (Mapstone et al. 2004).

All reefs were sampled in the Austral spring and early summer (September – December) in each year from 1995-2005 inclusive (Mapstone et al. 2004) by line fishing catch surveys, comprising fishing by commercial fishermen under supervision of research staff. Additional surveys of some of the reefs were completed in March-April and August in 1997 and 1999. All fishing was done by handline using the same gear as used in the operational CRFFF, but survey effort was stratified to ensure roughly equal distribution around each reef and over two depth strata (above and below 12 m). Fishing gear was standardised among fishers and consisted of 80lb monofilament fishing line with a “running sinker” rig, a bean or ball sinker rigged on the mainline above a single 8/0 hook (Mustad 4279). Western Australian pilchards were used as bait, as was the case in the CRFFF. Effort was recorded as the time (number of minutes) each hook was in the water.

As with the CRFFF, sharks were not a target of sampling for the ELF Experiment but were captured incidentally as happens generally in the CRFFF. This meant that less detailed information was collected for sharks than for target species. Shark catch was typically not brought aboard the vessel but rather identified whilst in the water and then released. In early years of the experiment, the collection of shark data was limited to records of species hooked, but in later years the fate of hooked sharks was recorded to define encounters with sharks. After 2000, directed reporting of shark catch and fate was included in collected data to define how many sharks were brought to the boat and if sharks were released or kept. In 2005, increased data reporting was implemented to examine the number of sharks that interacted with the fishery. Data recorded included species identification and whether the shark was released or lost. Released sharks were those that had been brought to the boat and intentionally released by removing the hook or cutting the line. Lost individuals included those that were observed but were not intentionally released (i.e., came unhooked or bit through the line). Any sharks retained were recorded in all years.

Data analysis

All three data sets were examined to define species composition of the catch and explore any differences among data sets. Logbook data contained limited shark identification data, so observer data was used to refine the unidentified portion of the CRFFF catch, since observers were well trained in species identification and this data set was representative of sampling by the commercial fishery. Chi-square contingency tests were used to examine differences in species composition in catch within and among data sets. Where minor species were reported (i.e., <5% of catch) these were combined with 'unidentified shark'. No size, sex or age frequency data were recorded in any of the data sets, so demographic analysis of catch was not possible.

Fishery logbook data

Logbook data from the CRFFF were examined to define the number of vessels reporting shark landings, the magnitude and geographic extent of shark catches and the weight of shark catch landed. Shark landings were examined per day and the number of times shark was reported was examined by region and through time. Catch by weight was examined and weights for product categories other than whole animals (i.e., fillet or trunk) were calculated based on QDPI&F conversion factors (3.3 for fillet, 1.66 for trunk). In instances where fin was reported as a product without a body product (whole, trunk or fillet) for the same day, fin weights were converted to whole weight based on a 5% fin to whole weight ratio. This occurred 263 times (1.8%) in the reported data. The 5% ratio is that used by the US National Marine Fisheries Service and validated by studies by the University of Florida Commercial Shark Observer Program (Meliane 2003). Reporting of fins without body products decreased following management changes requiring fins and bodies of harvested sharks to be landed. Catch reported only by numbers of individuals was converted to estimated whole fresh weight by application of a number-to-weight conversion derived from those data where catch was reported by both numbers and weight. This calculation was based on the assumption that the reported weight of catch was the aggregate weight of the reported number of individuals. A composite conversion factor was applied to estimate whole fresh weight where product type was not reported. The composite conversion factor was derived as the average of conversion factors for records where product type was reported in the same year and region, weighted by the catch of each product type reported. This approach was based on the assumption that catch reported without product type would have been processed in similar ways to catch that was reported with product type in the same year and region. Weights were examined and reported by fishing region, year and, where possible, by species. Fishery regions were defined by Mapstone et al. (1996b) based on operational characteristics and home port fidelity of the CRFFF fleet.

Location information was occasionally not reported or reported values were not valid (16.9% of records). These fishing events were assigned to locations based on the reported activities of that vessel where location was reported according to a three-step process. If other fishing by the same vessel was reported within 15 days of the event with invalid location data, then the mean location of the other reports (within 15 days) was assigned to the missing location field, with the reported locations weighted inversely by their distance (in time) from the event without location data (1.1% of records). If no other fishing events were reported within 15 days, then the modal location of fishing by the same vessel in the same year was used, provided that at least 10 fishing events were reported and at least 90% of them were within a 2^{o} latitude range (8.0% of records). If these criteria were not met in the same year as the event without location information, then the modal location for fishing events by the same vessel over all years was calculated and assigned, providing at least 10 events were reported and 90% of the events were within the specified range (7.8% of records). Records that could not be so assigned locations were retained but assigned null location values and so could not be attributed to specific regions in analyses.

Effective line fishing effort was estimated from reported data as follows. Line-days of effort was set equivalent to the number of fishers or guests (charter fishing logbooks) reported where these data were available. If these values were not reported but the number of tenders or crew were reported (commercial line fisheries), then effective effort was assigned as the maximum of the two. Where none of these metrics was reported, effective effort was estimated as the modal effort reported by the vessel in the same year and broad region (e.g., Great Barrier Reef, South East, Gulf) provided that at least 10 such reports were available. If such estimates were not available, effective effort was assigned as the number of tenders a vessel was licensed to use for commercial line fishing operations or an average of 10 fishers for charter operations. Effort based on only the number of tenders reported or licensed for commercial line operations was increased by one additional unit of effort to allow for fishing from the primary vessel. Effort for reported line-catches from non-line fisheries (e.g., trawl, net) was generally assumed to be just one line-day since it was considered likely that such fishing was incidental to the primary fishing methods and unlikely to sum to more than one effective day of fishing by one professional line fisher. Where single records in the database reported fishing for multiple days, the estimated daily effort was multiplied by the number of days in the interval to estimate total line-days of effort for the period. Finally, the resulting effort estimates were filtered to remove unusually large values that seemed non-credible on the basis of knowledge of the fisheries. Records with ‘high’ effort were those where commercial line fishing effort was greater than twice the number of legal tenders plus two (allowing for fishing by two fishers from each tender and the primary vessel) or where charter fishing was reported for more than 30 fishers or guests. These records were compared to other ‘legitimate’ records by the same vessel within the same year and broad region (e.g., Great Barrier Reef, South East, Gulf) and set to the modal value of those other fishing activities. If no such other records were available, effort was set to 9 for commercial line operations, given that no license in the reporting period was attributed more than 7 dories and 9-line days would allow for 2 lines being fished from the primary vessel, and 30 for charter operations.

Observer data

Data from the observer program (OBS) were used to determine the catch characteristics of reef sharks by the fishery (species composition, CPUE) and examine the number of sharks captured per reef, per year. Due to limited numbers of sharks captured, however, effort data were condensed into morning or afternoon fishing sessions (AM or PM), since in usual practice each fisher returned to the primary vessel for lunch. The time for all sets in a morning or afternoon session were summed and this summed effort used to examine the number of sharks caught per session and calculate catch per unit effort (CPUE, number of sharks caught per hour). This compilation of hook set data into morning and afternoon sessions reduced the number of zeros in the data set.

Since sampling via the observer program was subject to normal fishing operations and no specific sites were chosen or sampled repeatedly, it was not possible to compare CPUE data among or across reefs fished. Thus, CPUE data were compared between the four defined Great Barrier Reef regions using Analysis of Variance (ANOVA) of log (x+1) transformed data from all reefs sampled within each region (reefs being replicates). The CPUE of sharks among years was examined using a Kruskal-Wallace non-parametric test. Chi square contingency table analysis was used to examine sharks caught by hour of the day (including 11 hours, 0700-1700) in relation to the three main species.

ELF data

Data from the ELF Experiment were used to estimate CPUE and examine the number of sharks captured per reef, per year and to compare catch rates on MNP with those on GU reefs. The number of sharks caught by hour of day was examined by species as described for OBS data. Similarly, the number of sharks caught by hour was examined via Chi square contingency table analysis to examine catch among the four main study regions. Annual Spring survey data were the only data used for ELF data analyses apart from species composition, where data from additional surveys from 1997 and 1999 were included. Increased reporting on shark catch from 2000-2005 resulted in different levels of data collection, thus ELF data could be defined in two sections: early (1995-1999) and late (2000-2005) in comparative analyses.

Fishing effort was recorded as the amount of time an individual hook was in the water (‘set’) from each dory. Due to the relatively low numbers of sharks captured, however, catch and effort data were aggregated by reef and CPUE (sharks per hour) calculated by year and reef from these data. This compilation of data reduced the number of zeros in the data set.

Two repeated measures Analysis of Variance (RM-ANOVA) were used to test for differences in the CPUE of reef sharks between MNP and GU zones. First, reefs were grouped by the ELF experimental treatment to which they had been assigned in 1995 and surveys aligned according to the years of pulse fishing. The years 1995 and 1996 were assigned as Baseline (B) years 1 and 2 (designated B1, B2 respectively) for all reefs. The years in which pulse fishing occurred on one MNP reef and one GU reef in each region (1997, 1999) were designated as Pulse (P) years, meaning that the 'P' treatment years were represented by data from the reefs that were pulse fished in each year (1997 or 1999) and one of the control (unfished MNP) reefs in the same year. This designation meant that the 'P' treatment-year comprised data from three reefs sampled in 1997 and three reefs sampled in 1999. The six years following the pulse fishing years were designated 'Recovery' years (R1-R6) and comprised the calendar years 1998-2003 for the reefs pulse fished in 1997 and the Control reefs assigned to that group, and 2000-2005 inclusive for reefs pulse fished in 1999 and the second set of control reefs. These assignments meant that: a) each Pulse (P) and Recovery (R1-R6) effect would encompass variation between two years, two years apart (e.g., P years were 1997, 1999); and b) data from 2004-05 for reefs pulse fished in 1997 and from 1997-98 for reefs pulse fished in 1999 were excluded from the analysis. The assignment of reefs to treatment-years is shown in Table 2.

The RM-ANOVA was applied to only the spring survey data collected in all years and comprised the between subject (reefs) factors Region (Lizard Island, Townsville, Mackay, Storm Cay) and Treatment (MNP Control, MNP Fished, GU Fished) and the within subjects (reefs) factor 'Treatment-Year" (B1, B2, P, R1-R6). All factors were considered fixed effects. Missing data from three cells (one in each of B1, R3 and R5) were replaced with means estimated from all other years for the reef for which data was missing and relevant degrees of freedom in tests reduced accordingly. This analysis was run to test for effects of the experimental manipulations, which would be signalled by a significant interaction between Treatment and Treatment-Year.

Table 2. ELF experiment treatment designation of each reef (GC1 … BF2) in each year and survey data included or *dropped* from analyses to test for experimental treatment effects. B1, B2 – baseline (pre-manipulation) years; P – years in which GF and BF reefs were pulse fished and then closed; R1-R6 – recovery years following closure after pulse fishing.

	MNP Controls		**MNP Fished**		**GU Fished**	
Year	**GC1**	**GC2**	**GF1**	**GF2**	**BF1**	**BF2**
1995	B1	B1	B1	B1	B1	B1
1996	B2	B2	B2	B2	B2	B2
1997	**P**	*Dropped*	**P**	*Dropped*	**P**	*Dropped*
1998	R1	*Dropped*	R1	*Dropped*	R1	*Dropped*
1999	R2	**P**	R2	**P**	R2	**P**
2000	R3	R1	R3	R1	R3	R1
2001	R4	R2	R4	R2	R4	R2
2002	R5	R3	R5	R3	R5	R3
2003	R6	R4	R6	R4	R6	R4
2004	*Dropped*	R5	*Dropped*	R5	*Dropped*	R5
2005	*Dropped*	R6	*Dropped*	R6	*Dropped*	R6

Second, if no effects of experimental manipulations were detected, then the full data set (including data from non-spring surveys) was analysed by a RM-ANOVA based on annual average CPUE derived from catch and effort data aggregated over all surveys in each year. The analyses comprised the within subject (reefs) factors Region (as above) and Zone (MNP, GU) and the between subjects (reefs) factor Year (1995-2005). Missing data were replaced with averages over all years from the reef for which data were missing, as above.

Both analyses were run first as multivariate analyses to test the sphericity assumption prior to doing univariate analyses if possible. Both analyses were also first done as full models (with all factors and interactions tested) and then re-run omitting any effects that were considered trivial ($p > 0.25$, Winer et al 1992), provided that all higher-order interactions for those effects could also be omitted. This model reduction was done to increase the power of tests for the retained effects.

RESULTS

Species composition

The main species recorded in OBS and ELF data sets in order of prevalence were: grey reef (*Carcharhinus amblyrhynchos*), whitetip reef (*Triaenodon obsesus*), and blacktip reef (*Carcharhinus melanopterus*) sharks. Leopard (*Stegastoma fasciatum*) and tawny nurse sharks (*Nebrius ferguiensis*) were also reported in the OBS data set, but these two species combined only comprised 2.9% of the total catch (Table 2). The ELF data set included the main species as well as silvertip (*Carcharhinus albimarginatus*) and wobbegong (*Orectolobus* sp.), but these species combined comprised less than 1% of the total catch (Table 3). Although the main species caught were the same between the OBS and ELF data sets, there were significant differences in the proportion of species in each data set (Chi-square = 44.86, df = 3, $p < 0.0001$) (figure 2).

In contrast to the OBS and ELF data, CRFFF logbooks rarely reported species identification and the majority of the catch (95%) was listed as unidentified shark, though very minor landings of additional species (e.g., hammerhead shark) not observed in the OBS or ELF data were also reported. The large proportion of unidentified catch was allocated among species in the proportions reported in the OBS data and added to those catches that were identified to estimate total landings of sharks by species from the CRFFF. As a result, the CRFFF species composition was very similar to the OBS data.

Shark catches in the fishery logbook data

CRFFF logbook data were difficult to interpret due to lack of species identification and limited reporting of catch. For example, shark catches were reported as weight, but the number of individuals was rarely reported and so it was not possible to determine how many sharks were captured in the fishery. Mean weights were calculated for the most commonly caught species when number of individuals captured was provided. Grey reef sharks were typically larger (mean: 7.1 kg) than blacktip reef (mean: 5.0) or whitetip reef sharks (mean: 2.4 kg). It was not possible to examine if mean size of individuals captured varied through time. Although the number of individuals landed wasn't always reported, the number of times shark or shark products (e.g., fins) were reported in the logbooks was examined resulting in 15,073 records from 1989–2006. During this period, there were approximately 555 vessels reporting shark catch associated with reef fish catch with anywhere from 33-162 vessels reporting shark as catch in a given year. The number of vessels reporting shark landings increased steadily from 1989 to 1997, remained stable from 1997 to 2000 with a peak of 162 vessels in 2001, and then declined to around 75 vessels reporting shark in 2006 (figure 3). Of the vessels reporting shark as catch, no more than 23 boats in a single year reported landing sharks more than 25 times in a year (mean: 6.8), a maximum of seven boats per year (mean: 1.8) reported shark catches 50 times per year, and a maximum of one vessel per year reported shark 100-150 times in a single year. No vessels reported shark more than 150 times in a single year. Although under-reporting of shark catch may have occurred in this data set this was impossible to quantify. Examination of the weight of shark catch landed by a single vessel within a year revealed 13 to 75 (mean: 37.6) vessels landed less than 100 kg of shark products, 6 to 57 (mean: 23.2) vessels landed 100-200 kg of shark and 2 to 25 (mean: 9.9) vessels landed more than 500 kg of shark products. Higher weight categories resulted in fewer vessels per category. For example, less than 10 vessels per year landed 1,000 kg (mean: 4), 2,000 kg (mean: 2.5) or 5,000 kg (mean: 0.5) of shark product (figure 4).

Table 3. Species composition of sharks reported in each of the three data sets examined including the number of individuals caught and the per cent of total in brackets. CFISH normal data are direct records from logbooks, while CFISH adjusted includes re-allocation of unknown individuals into species categories based on observer data catch composition. ELF data only include individuals that were brought to the boat (i.e., no encounter data were included).

	Observer Data	**ELF Data**	**CFISH Normal**	**CFISH adjusted**
blacktip reef	6 [5.8%]	62 [9.1%]	130 [0.9%]	1,008 [6.9%]
grey reef	63 [60.6%]	349 [51.1%]	68 [0.5%]	9,289 [63.7]
hammerhead	0	0	2 [0.0%]	2 [0.0%]
leopard	1 [1.0%]	0	1 [0.0%]	1 [0.0%]
unknown	3 [2.9%]	189 [27.7%]	14,343 [95.2%]	
unidentified fin	0	0	494 [3.3%]	
silvertip		3 [0.4%]	0	
tawny nurse	2 [1.9%]	0	0	
whitetip reef	29 [27.9%]	77 [11.3%]	35 [0.2%]	4,279 [29.4%]
wobbegong	0	3 [0.4%]	0	
Total	104	683	15,073	14,579

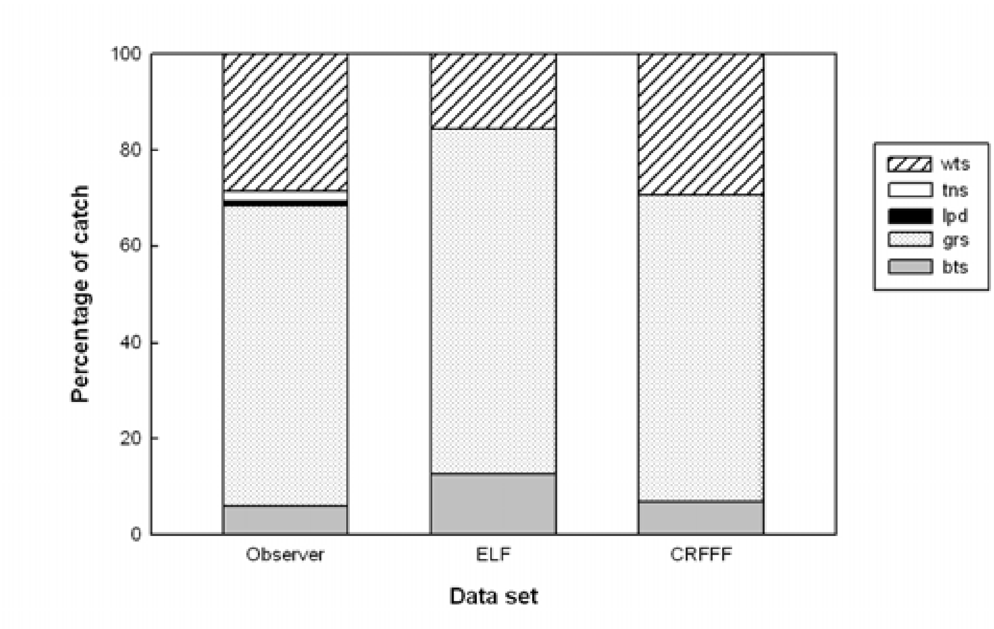


Figure 2. Species composition from OBS, ELF and CRFFF databases. Identifications of 'unknown' or 'shark' were removed as were any species that comprised less than 1% of total catch in a given data set. Legend lists species in order of display (i.e., bts is on the bottom of the graph). Abbreviations are: bts = blacktip reef shark, grs = grey reef shark, lpd = leopard shark, tns = tawny nurse shark and wts = whitetip reef shark.

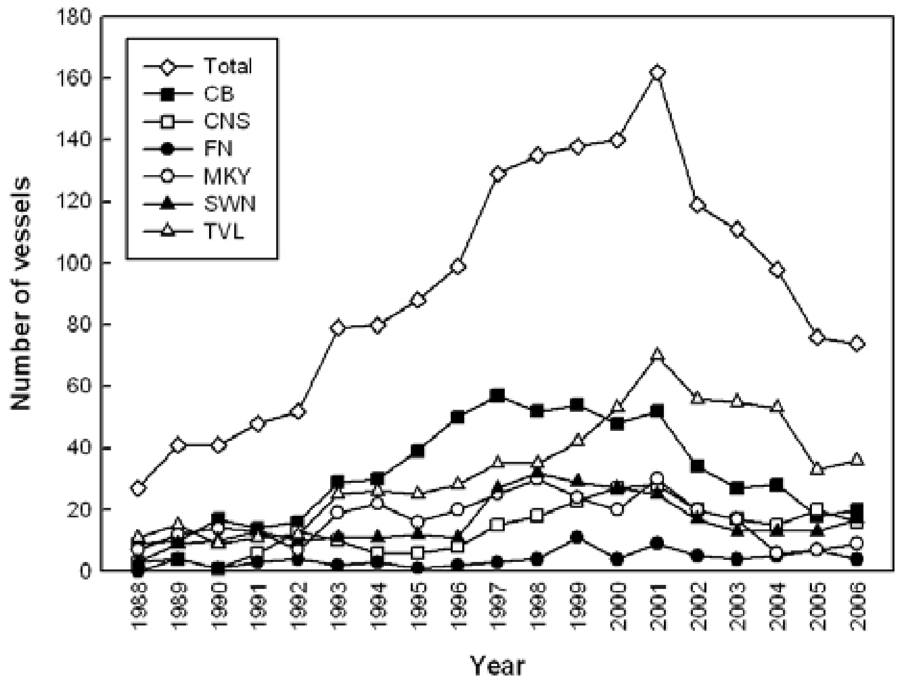


Figure 3. Number of vessels reporting shark catch from 1988 to 2006 showing total number of vessels and vessels by region. Regions: CB = Capricorn-Bunker, CNS = Cairns, FN = Far North, MKY = Mackay, SWN = Swains and TVL = Townsville.

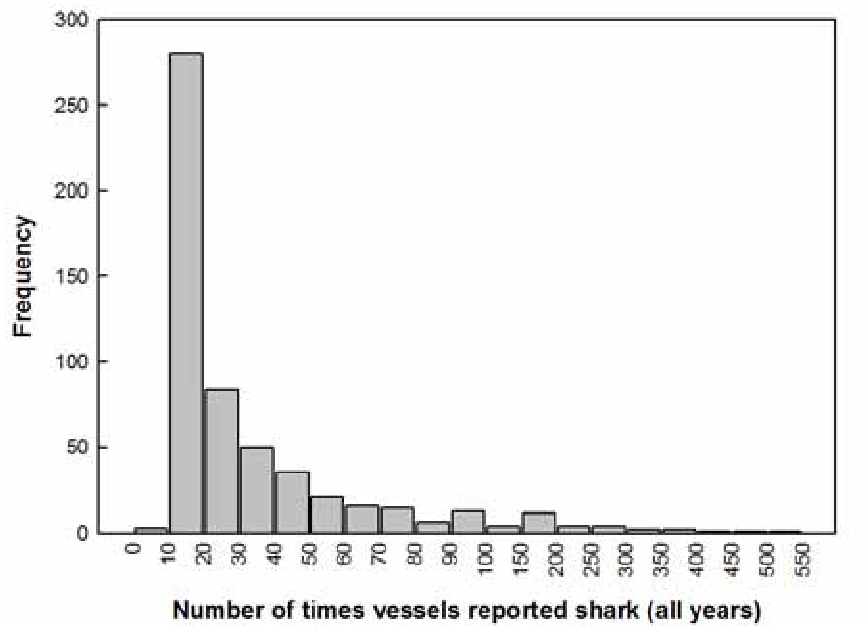


Figure 4. Number of times vessels reported shark catch from 1988 to 2006.

The number of times shark was reported as catch varied through time and across regions (figure 5a). There was a general trend for the number of times shark was reported to increase after 1996. Reports within the Townsville region increased in 2001 subsequent to an increase in vessels during that year. Townsville region reports declined after that point and by 2006 was similar to that for other regions. Reports from most regions declined after 2003, while the Swains region showed increases from 2004 to 2006. Examination of the weight of landings reported shows a somewhat different pattern. The weight of shark landed in Townsville increased to correspond with the increased number of reports in 2001, but also showed an increase in 1994 (figure 5b). Increased numbers of sharks reported in conjunction with increased weight reported suggest larger numbers of individuals were landed in those years. This does not elucidate any trend in the size of individuals captured. A large increase was evident in the Far North in 1995, but typically remained low in all other years. Despite periodic increases, landings were stable for most regions in most years and typically remained below 5,000 – 10,000 kg per year (per region).

Estimated total weight of shark reported over the period from 1989 to 2006 by region was highest in Townsville (159,998 kg). The Swains (60,045 kg), Capricorn-Bunkers (59,298 kg), Mackay (58,475 kg), Cairns (57,745 kg) and the Far North (36,825 kg) all reported less than 100,000 kg for the 18 year period. Blacktip reef and grey reef sharks comprised the majority of the identified catch, but represented only a small fraction of the total reported (including the aggregate category 'shark'). Allocation of unidentified species catch in proportion to the species composition from OBS data (figure 2) to the identified catch indicated that the highest catch weights were likely to have been of grey reef sharks (258,095 kg) and whitetip reef sharks (118,491 kg), with blacktip reef sharks at much lower levels (29,869 kg).

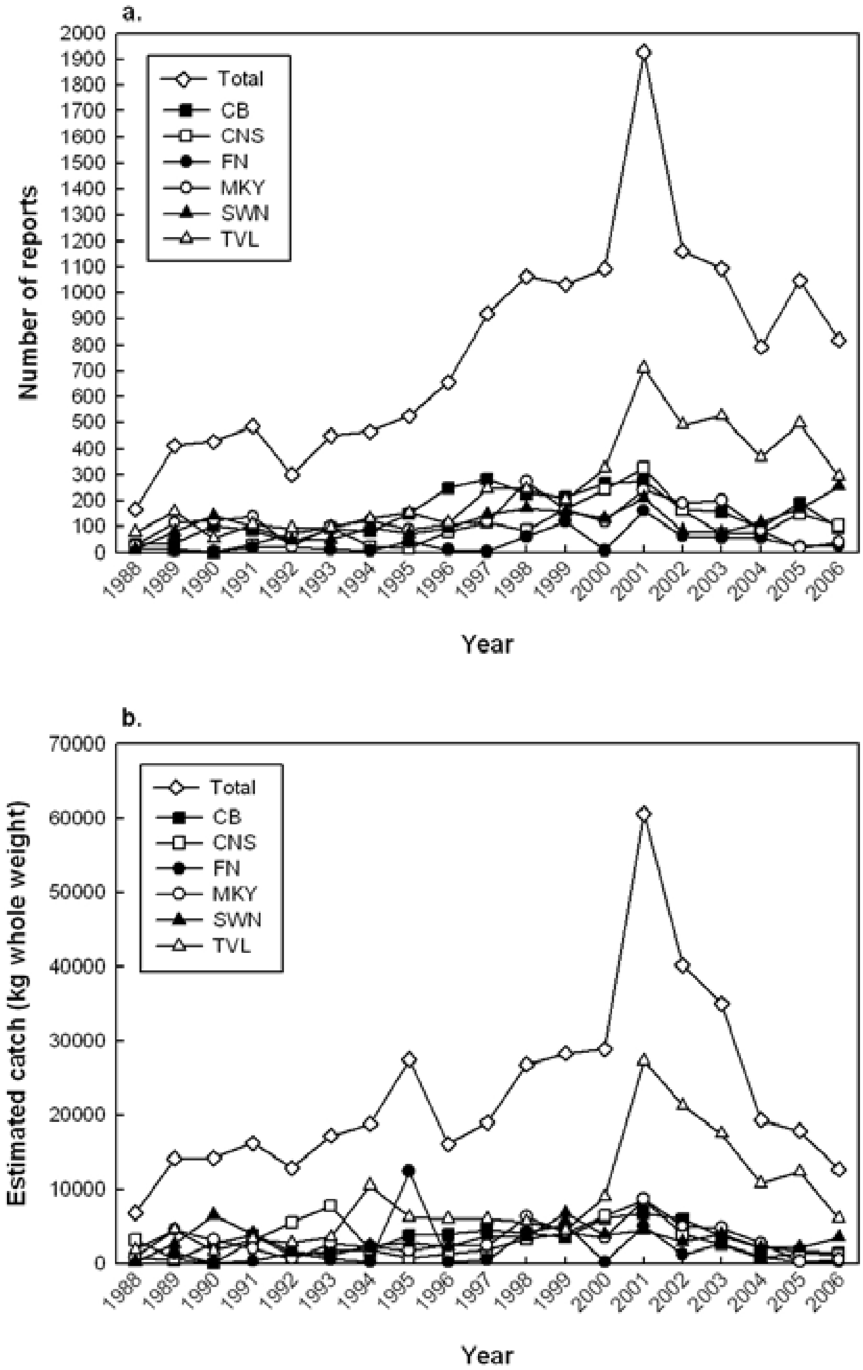


Figure 5. a) Number of times shark was reported as catch through time by fishing region; b) Estimated catch (by weight) for each region through time and total for all regions. Regions: CB = Capricorn-Bunker, CNS = Cairns, FN = Far North, MKY = Mackay, SWN = Swains and TVL = Townsville.

Examination of catch by product revealed that the majority of product landed was in the form of trunked or whole bodies (figure 6). In 2005 and 2006 trunked product decreased with whole animals or fillets at higher levels during these years. An increase in the weight of fillets landed occurred in 1995, and again in 2005, but was otherwise a relatively stable and minor part of the landings. Both reporting and weight of fins landed were low in comparison to these categories aside from a spike in 2001. Examination of amount of each product landed by region revealed higher landings in all categories for the Townsville region (figure 7).

Examination of estimated catch by weight on a geographic scale (based on 6 x 6 grid squares) revealed that average catch per vessel varied along the Great Barrier Reef (figure 8). Catches were spread along the length of the Great Barrier Reef with most grid squares showing low (<30 kg) average annual catch across all vessels. This low value is the result of a small number of vessels reporting high shark catch and a large number of vessels reporting low or no shark catch in addition to the low weights reported for individual species. Highest catches were observed between Cairns and Bowen and probably reflected the home port and fishing regions of individual fishers that retained more shark than others. This trend matched catch by product and catch by report estimates which revealed Townsville as the region with highest shark landings.

Reported catch and effort related to retention of sharks revealed that catch and effort were variable through time (figure 9). Effort was high in early records before declining, but remaining variable through most of the 1990s, while catch remained steady most of this time. A spike in catch and effort were observed in 2001, commensurate with the increase in number of vessels in that year. It is unclear what caused this increased effort in the fishery. After 2001, both catch and effort declined to levels previously reported in the 1990s. Catch per unit effort (sharks per line day) was variable with a significant but weak relationship through time showing a slight increase in catch rate ($a = 0.266$, $y = 0.111$, $r^2 = 0.265$, $p = 0.029$). Given the variability in the data, it appears that catch rates were relatively steady through time with no real longer term increasing or decreasing trend (figure 9c).

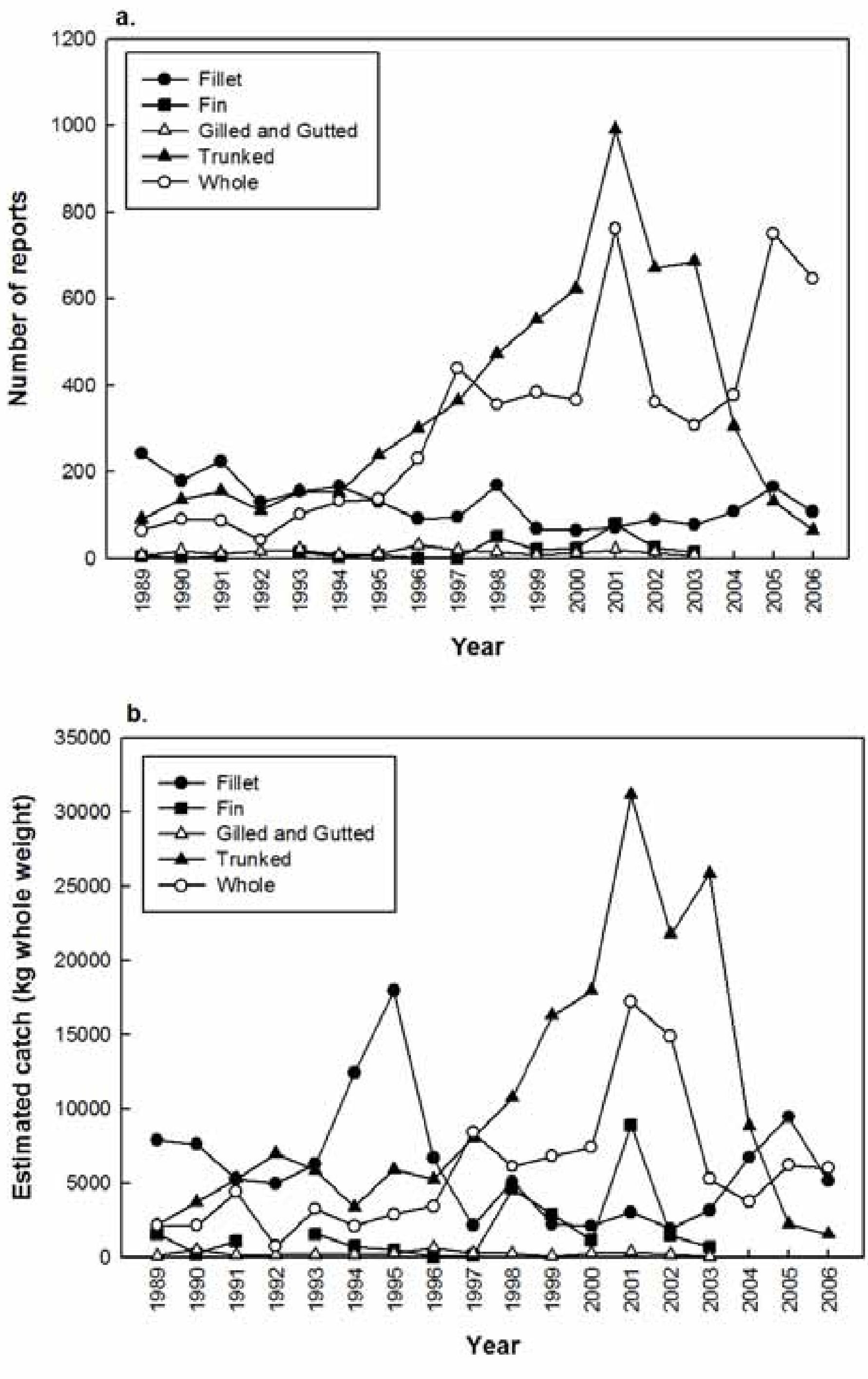


Figure 6. a)Number of times shark products were reported through time by fishing region; b) Estimated catch (by weight) for each product by region through time.

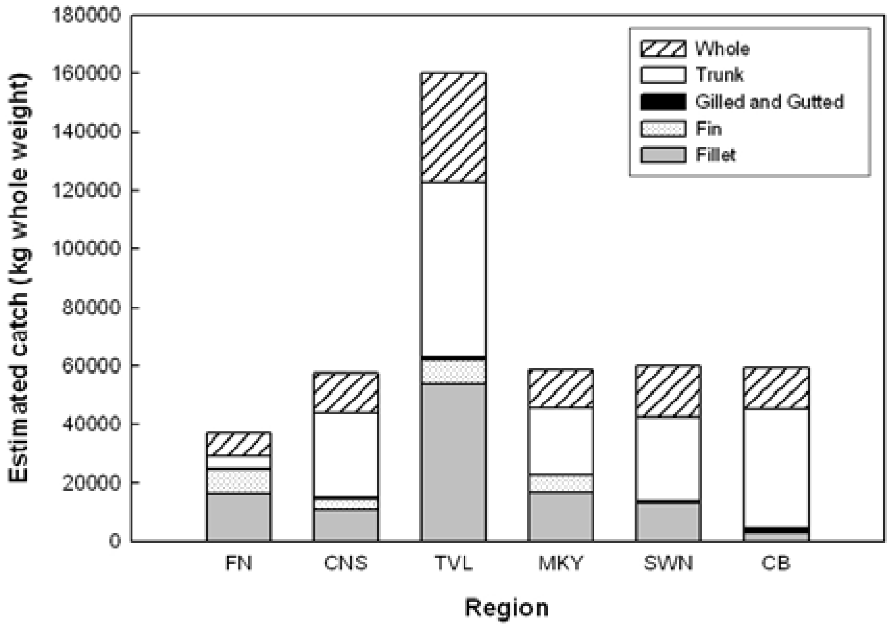


Figure 7. Estimated catch (by weight) for product category by region showing highest numbers for all product categories in the Townsville region. Regions: CB = Capricorn-Bunker, CNS = Cairns, FN = Far North, MKY = Mackay, SWN = Swains and TVL = Townsville.

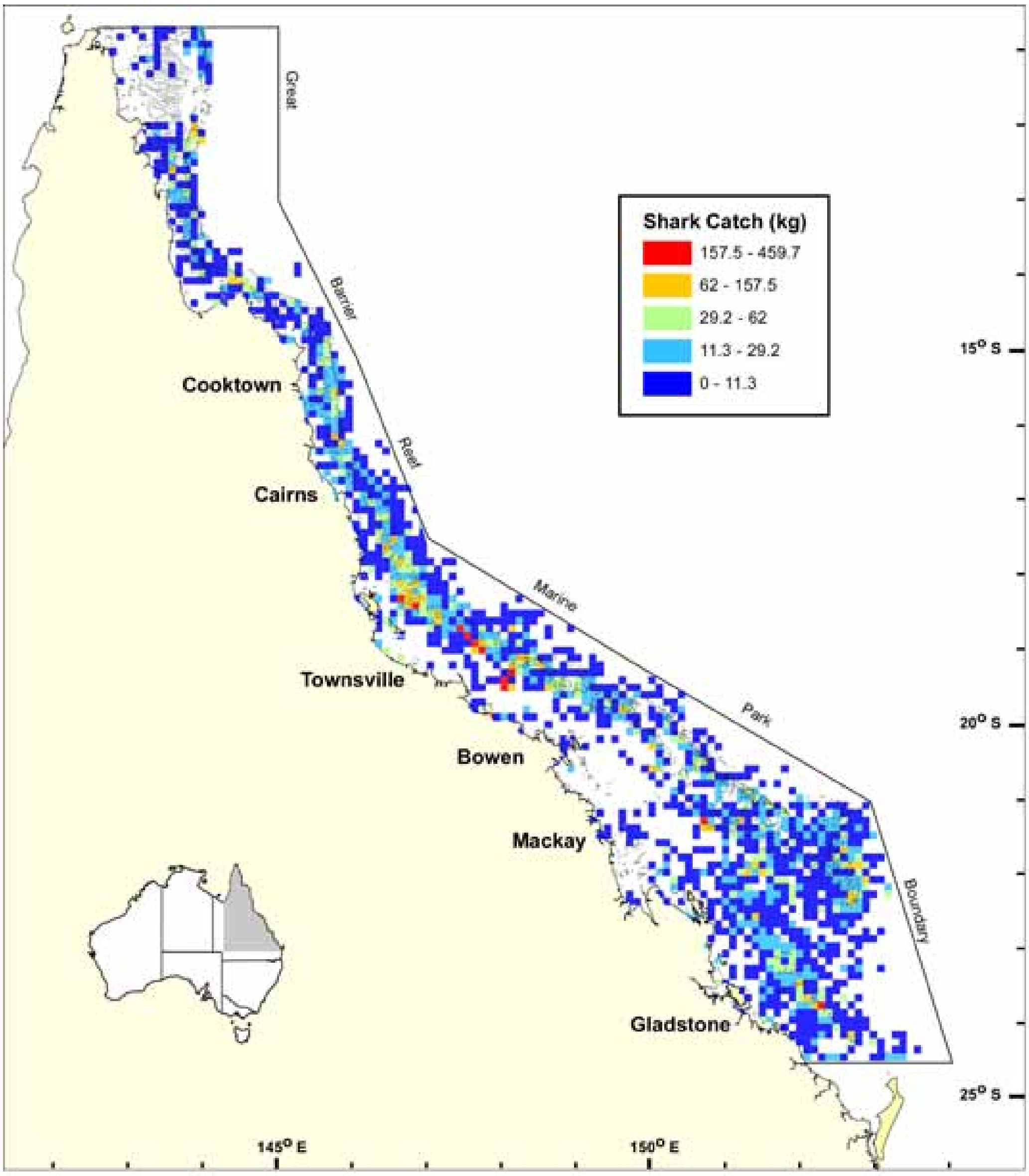


Figure 8. Map of the study region displaying average annual estimated catch (by weight) from boats reporting shark catch in CRFFF logbook data based on 6 nm grids. The majority of take is low and is distributed widely across the region.

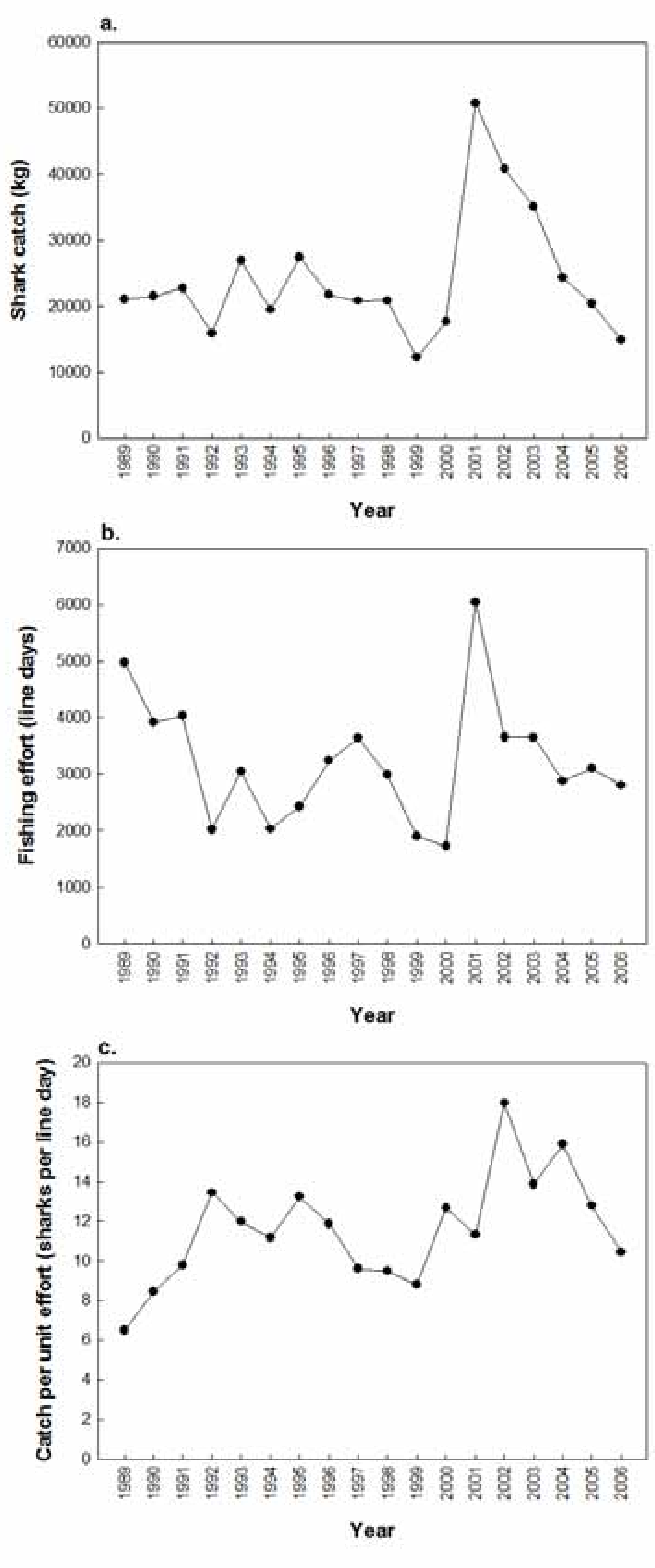


Figure 9. Data from CRFFF logbooks through time reporting a) weight of all sharks reported; b) amount of fishing effort resulting in shark catch; and c) catch per unit effort (kg / line day) for all sharks reported.

Observer data

Observer surveys conducted from 1996 to 1998 recorded a total of 106 reef sharks captured (but not necessarily retained). Recorded catch was low in 1996 (n = 6) when observer coverage was low, and increased in 1997 (n = 51) and 1998 (n = 49) (figure 10). There was a significant difference from equal proportions of the main species in the catch composition (Chi-square = 176.39, df = 5, $p < 0.0001$) with grey reef sharks comprising the majority (60%) of the catch, followed by whitetip reef and then blacktip reef sharks. The fate of captured individuals varied, with 26% reported as dead, 6% released and 68% having no data. Lack of fate data are likely due to observers focusing on fates of teleost (target) species.

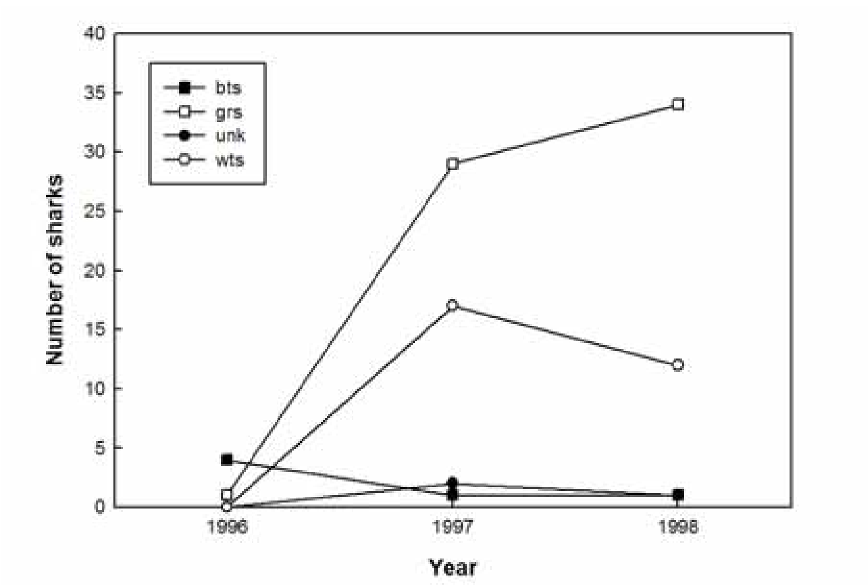


Figure 10. Catch of main species groups through time in OBS samples. N = 106 sharks. Where bts = blacktip reef shark, grs = grey reef shark, unk = unknown and wts = whitetip reef shark.

A total of 195 reefs were fished in the four main regions during trips on which observers were present. CPUE differed over the three years (Kruskal-Wallace test, H = 12.238, p = 0.0022). Catch rates in 1996 and 1997 were similar as were 1997 and 1998, but differences were observed between 1996 and 1998, with mean CPUE per year increasing through the study period (1996: 0.038 sharks / hr, 1997: 0.095 sharks / hr, 1998: 0.186 sharks / hr). This difference may have been due to lesser sampling effort in 1996 than the other two years.

Examination of OBS data by region revealed large differences in the amount of fishing observed in each region. The majority of sampling occurred in Mackay (97 reefs) and Townsville (67 reefs), with lesser sampling in Cairns (23 reefs) and the Far North (8 reefs). The amount of observer hours among regions reflected this distribution of sampling (figure 11a). CPUE on individual reefs ranged from 0.0 to 2.43 sharks per hour (figure 11b). No significant difference in catch between regions was identified

(ANOVA, F = 0.488; df = 3, 191; p = 0.691). There also was no significant difference among regions in the relative frequencies of reefs with and without catches of shark (Chi square = 1.754, df = 3, p = 0.625). On average, catches were reported for 30% of reefs except in the Far North region, where sharks were caught on 50% of reefs. The higher incidence of catches in the Far North region, however, may reflect the small sample size for this region.

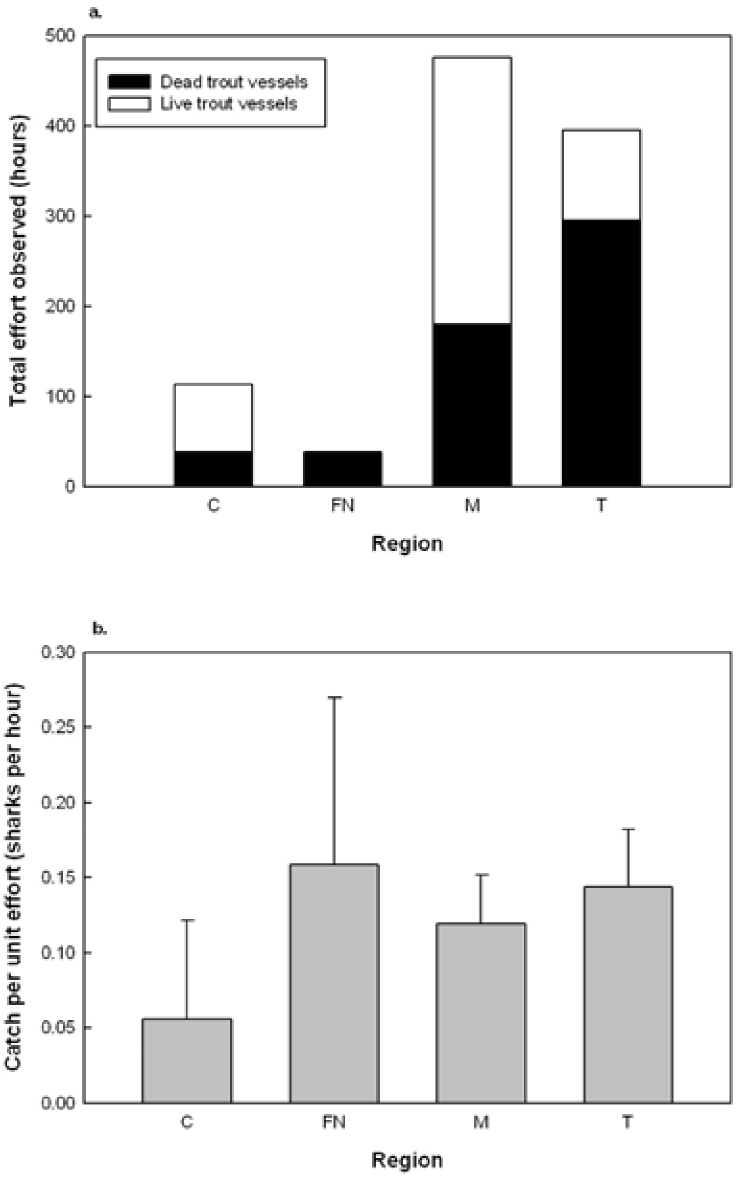


Figure 11. a) Number of hours observers monitored vessels within the CRFFF. Effort is displayed as hours on vessels based on target method of the vessel (e.g., for the live fish trade or dead market). b) Catch per unit effort for sharks landed by vessels in the CRFFF monitored by observers. Regions: C = Cairns, FN = Far North, M = Mackay, T = Townsville.

The OBS program conducted surveys on vessels that harvested target species for the fillet or whole dead fish market (dead) while others targeted individuals for the live fish market (live). Results of OBS surveys were examined to determine if catch of reef sharks differed based on the target product of the fishing vessel. There were 189 sessions monitored on live vessels resulting in the landing of 39 sharks with a catch per unit effort of 0.098. In comparison 204 sessions were monitored on dead vessels resulting in the landing of 63 sharks resulting in a catch per unit effort of 0.11. There was no significant difference in catch rate between live and dead vessels (one-way ANOVA, $F = 0.163$, $df = 1, 391$; $p = 0.687$) suggesting no difference in the number of sharks landed using either target approach.

ELF data

A total of 563 sharks were captured (brought to the boat) in annual Spring catch surveys, and an additional 121 sharks were collected in other sampling for the ELF Experiment. An additional 186 sharks were recorded as having been encountered in 2005, but were not brought to the boat (and thus not considered captured). The number of sharks captured per year in Spring surveys ranged from 12–111 (mean: 51, median: 45). The number of sharks caught per reef over all sampling years ranged from 2–54 (mean: 23.6, median: 22).

The species composition of the main shark species caught differed significantly (Chi-square = 547.77, $df = 5$, $p < 0.0001$). Grey reef sharks were the most commonly caught (51%), blacktip reef and whitetip reef sharks comprised about 10% each, and 28% were unidentified. The total number of sharks caught annually from ELF Spring surveys varied among years, with increased catches in the late 1990s and again in 2005 (figure 12). Increased catch after 1999 was likely due to improved recording of shark data over previous years. Increased reporting also occurred in 2005 when the fate of individuals was more closely documented than in other years.

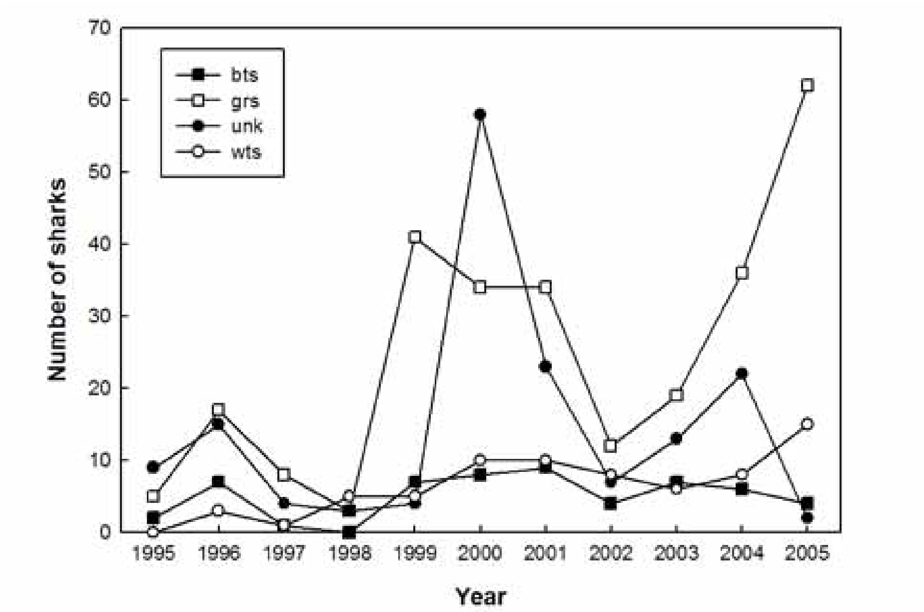


Figure 12. Number of individuals of main species groups caught through time in ELF Spring surveys. Where bts = blacktip reef shark, grs = grey reef shark, unk = unknown and wts = whitetip reef shark.

The fate of captured individuals was recorded for the entire study period although most records before 2000 list fate for sharks as 'not recorded'. From 2000 onwards, improved shark records were maintained and non-reporting of shark fate declined to less than 15% per year (figure 13). Most captured individuals were released alive, with deaths never above 20% and typically 1-4% of hooked individuals. All deaths recorded in the ELF data set were the result of death at the vessel of individuals retained for research purposes. Overall, fate data showed 42.2% of individuals did not have a fate recorded, 33.9% were released, 21.4% were hooked but were lost before they could be brought to the boat and 2.5% were retained by fishers. Based on more detailed fate data collected in 2005, the number of sharks encountered but not brought to the boat was 2.2 times that captured (brought to the boat). A total of 214 encounters occurred where catch was lost prior to bringing to the vessel. Of these, 186 were attributed to encounters with a hooked shark (87%) that cut the line or wasn't properly hooked and the remaining 28 were due to unknown causes (figure 14). Encounters with sharks were based on times when a shark was observed and identified. Unknown encounters may have included other large fish, snags on coral or other reasons for hook loss or line cutting, or could have been sharks that were not observed. There was no significant difference in species composition of captured or encountered sharks (Chi-square = 4.47, df = 2, p = 0.107) (Table 4). Based on the encounter rate recorded in 2005, it was assumed that encounter rates in previous years would have been at a similar level. Table 5 shows the number of each species captured during ELF sampling and the potential number of individuals encountered during the project based on 2005 encounter rate.

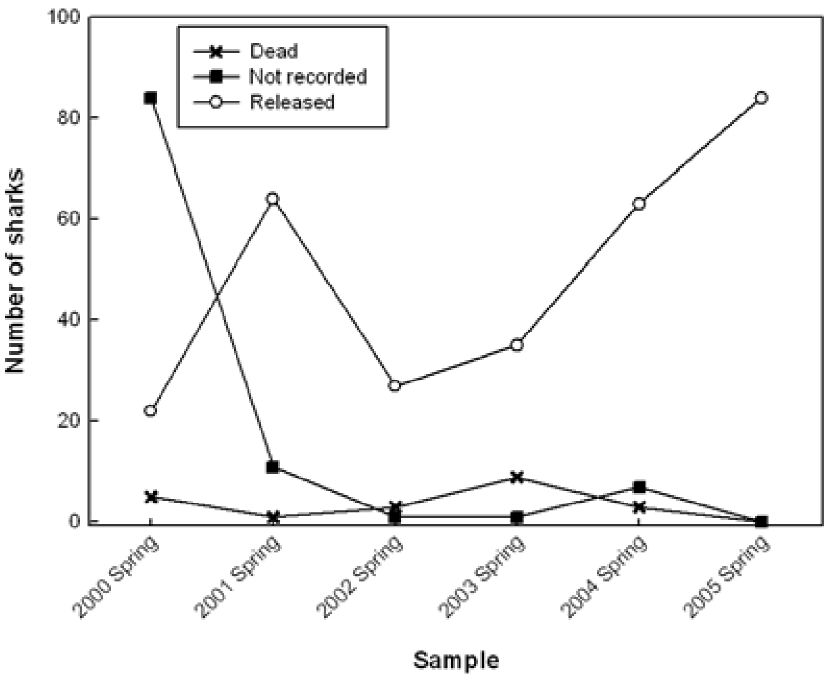


Figure 13. Reporting of the fate of individual sharks after capture during 2000 to 2005 ELF Spring surveys. Reporting appears to have improved over time.

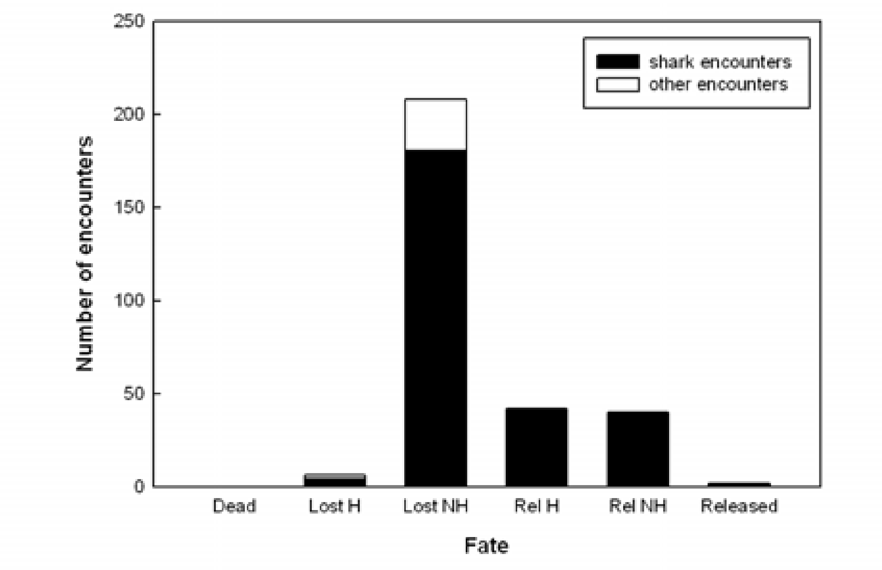


Figure 14. Reporting of the fate of individual sharks during the 2005 ELF Spring survey. Encounters are listed as Lost H (hook still on the line) and Lost NH (no hook remaining on the line). Encounters attributed to sharks include where sharks were observed and identified, but were not successfully brought to the vessel. Individuals reported as released were sharks that were brought to the boat and subsequently released. The released category also included another component where Rel H (released individual with the hook still on the line) and Rel NH (released individual with no hook remaining on the line) were used to further describe releases.

Table 4. Species composition of all sharks caught (brought to the boat) in 2005 ELF surveys and species composition of sharks hooked but not brought to the boat.

	Total caught	**Total hooked**
blacktip reef	4 [4.8%]	3 [1.6%]
grey reef	62 [73.8%]	108 [58.1%]
unknown	2 [2.4%]	63 [33.9%]
whitetip reef	15 [17.9%]	12 [6.5%]
wobbegong	1 [1.2%]	0
Total	**84**	**186**

Table 5. Total of all sharks caught in 1995-2005 ELF Spring surveys by species and the potential number of additional sharks that would have been encountered based on encounter rates calculated from 2005.

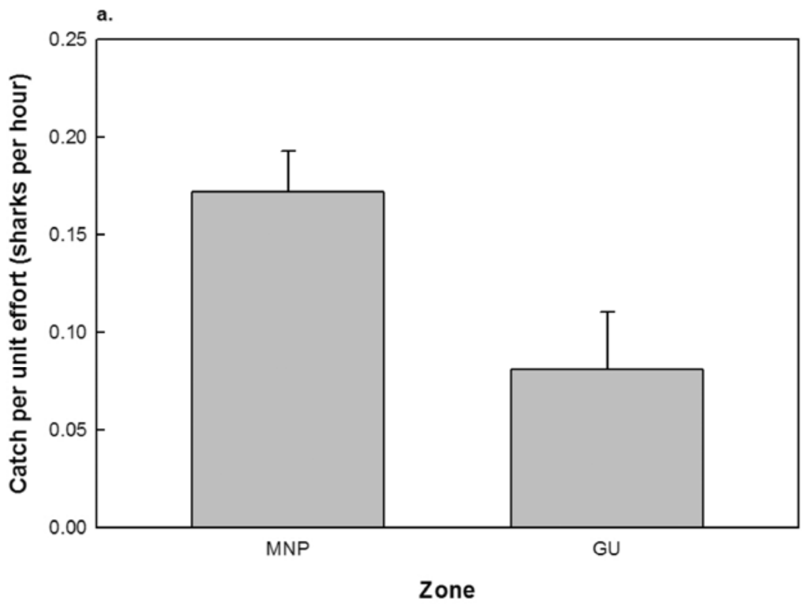
	Number of sharks captured	Possible number of sharks encountered	Total sharks
blacktip reef	62	130	192
grey reef	349	739	1,088
unknown	189	474	663
silvertip	3	7	10
whitetip reef	17	16	33
wobbegong	63	136	199
Total	**683**	**1,504**	**2,187**

The interaction between ELF experimental Treatment and Treatment-Year was non-significant and trivial (MV tests, $p > 0.25$). The main effects of Treatment (averaged over all years and regions) was significant ($p = 0.009$) but the effect corresponded to the zoning status of the reefs (GU Fished < MNP Control ≈ MNP Fished). Accordingly, the manipulations of fishing or reef closure were considered unimportant and all data analysed without consideration of treatment effects.

Effects of Region and its interaction with Zone and Year were all non-significant ($P > 0.05$) and trivial ($p > 0.25$) when annual CPUE was analysed across all reefs and years. Hence, all Region effects were omitted and the data reanalysed to test only for the effects of Zone (between subjects) and Year (within subjects) and their interaction. Both main effects were significant (Year: MV tests, $p = 0.014$; Zone: $F_{1,19} = 5.98$, $p = 0.024$) but their interaction was non-significant (MV tests, $p = 0.614$). Catch rates of sharks on reefs historically open to fishing (GU reefs) were less than half those on reefs that had been closed to fishing since the mid 1980s (MNP reefs) (figure 15). Catch rates varied substantially among years (figure 15) but not in any conspicuous pattern related to chronology or the years in which experimental manipulations occurred, except perhaps that catch rates tended to be higher in 2000 and beyond, possibly as a result of increased attention to reporting shark encounters in those years.

Comparison of CPUE between data sets

ELF survey catch rates on GU reefs (0.0810 sharks/hr) were similar to catch rates from OBS data (also fishing on GU reefs) (CPUE = 0.1220 sharks/hr) (figure 16), suggesting that the ELF data reflected catch rates from the operational fishery. Catch rates estimated from ELF data from GU reefs from 2000-2005 only (when reporting of shark catch was improved) (0.1507 sharks/hr) was not significantly different from the OBS catch rate. Daily catch rate (estimated from the average effort per day from OBS data) result in 0.42 sharks per dory per day for all ELF GU data, 0.63 sharks per dory per day for OBS data and 0.78 sharks per dory per day for ELF late (2000-2005) GU data (figure 16b). Integration of calculated encounter rates (2.2 times as many sharks hooked as captured) with catch rates suggest that vessels could encounter a combined total 1.34 sharks per dory per day for all ELF GU data, 2.01 sharks per dory per day for OBS data and 2.48 sharks per dory per day for ELF late (2000-2005) GU. Differences in effort data made direct comparison of CRFFF reported catch to ELF and OBS data sets impossible, but examination of catch trends through time revealed steady catch rates through time in CRFFF (figure 9c) and ELF late data (figure 15b).



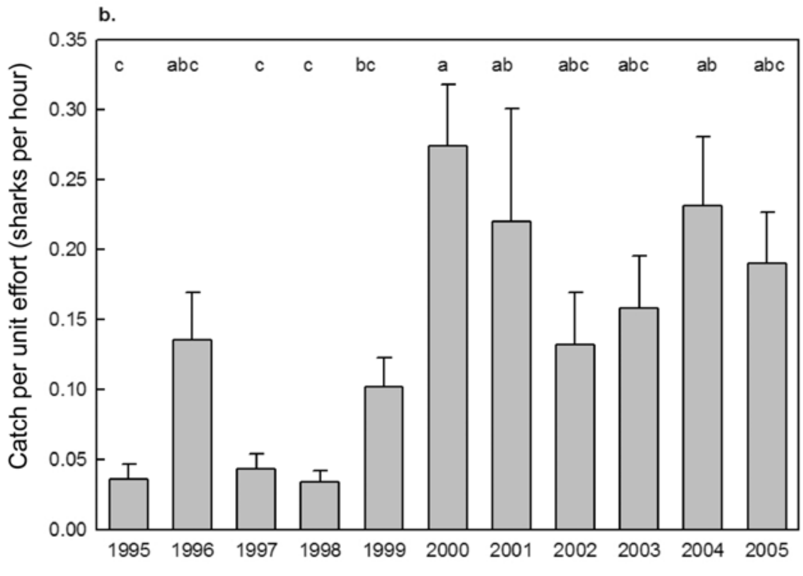


Figure 15. a) Mean daily catch rates of all shark species from catch surveys in 11 years (1995-2005 inclusive) on reefs closed (MNP) and open (GU) to fishing. b) Mean daily catch rates of all shark species from catch surveys on 24 reefs over 7° latitude in each of 11 years (1995-2005 inclusive). a, b, c indicate groups of reefs identified by post-hoc multiple comparisons. Error bars represent standard error on both.

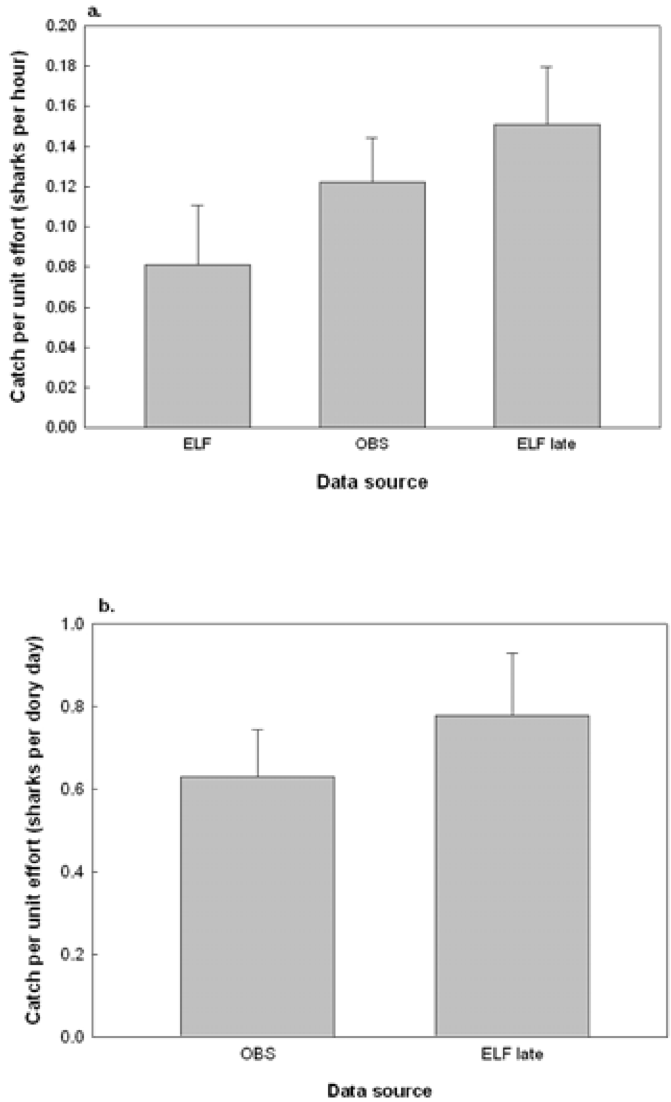


Figure 16. a) Catch per unit effort of reef sharks revealing no significant difference in catch rate in the ELF and OBS data sets. b) Catch per unit effort of reef sharks in observer and ELF late data based on dory days. Error bars represent standard error.

DISCUSSION

These results demonstrate that the commercial line fishery operating on the Great Barrier Reef has a substantial interaction with shark species commonly considered to have strong coral reef associations. Observer data from the fishery indicated that grey reef sharks were the most commonly encountered species, while whitetip reef and blacktip reef sharks were less commonly encountered. We found the relative abundances of species to be similar between the ELF and OBS data sets. The ELF Experiment data indicate that the species composition of reef sharks was likely to have been relatively stable over the period from 1995 to 2005. The limited encounters with other, non-reef shark species might suggest that other species have limited exposure to impacts of incidental capture by the CRFFF.

Variation between regions and through time in shark landings reported in the CRFFF logbook data may have resulted from several factors. First, there are likely to have been some differences in the CPUE across time and regions within the Great Barrier Reef related to natural fluctuations in abundances of sharks. Second, there were large changes in the number of vessels fishing in the Great Barrier Reef through time and some ephemeral regional redistributions of effort (Mapstone et al. 2001) which would be expected to have resulted in changes in temporal or spatial patterns in harvest. Third, the introduction of a quota management system and re-zoning the Great Barrier Reef in 2004 coupled with a structural adjustment package for the fishery may have caused changes in the amount and distribution of fishing effort. For example, decreased catches from 2003 onward were likely the result of the introduction of a new management plan for the fishery. Changes included limiting the amount of catch of both target species (coral trout and red throat emperor) and all bycatch species (other reef fish) that could be landed under three separate quota allocations to each operator. In addition, this catch decline corresponded to the widely published ban on shark finning in the tuna industry that may have lead to changes in fishing practice or reporting (Carlos, pers. obs.). Further, the re-zoning of the Great Barrier Reef under the Representative Areas Program (RAP) closed large additional areas of the Marine Park to fishing (Fernandes et al. 2005), though the increase in coral reef habitat closed was only around 9%. Finally, the growth of trade in live reef fish during and since the late 1990s, combined with increased adoption of view buckets[1] to aid targeting may have resulted in changes in fishing behaviours and the rate of incidental hooking of sharks. It is likely that shark landings reported in the CRFFF logbooks were sensitive to these changes and not faithfully indicative of changes in the abundance of sharks although it is unclear what level of effect each change had on the type and amount of data collected in CRFFF logbooks. It is not possible to define reasons for increases in vessels and effort in the fishery over time as it is not possible to deduce what species individual vessels were targeting. Results from the ELF catch surveys over the transition period, showing higher catch rates than during the 1990s seem consistent with this hypothesis.

[1] View buckets are plastic cylinders with Perspex bases that are placed over the side of fishing dories to allow fishers to view fish approaching baits and pull baits away from undesirable species, so enhancing targeting of higher valued species.

Reporting behaviour might have influenced patterns in shark landings inferred from the logbook data. Several previous studies have reported that elasmobranch bycatch often goes unidentified and unreported in non-target commercial fisheries (e.g., Stevens 1992; Bonfil 1994; Walsh et al. 2002), with under-reporting suggested to range from 10 to 40%. If such under-reporting was manifest in the CRFFF logbook data, there would have been more encounters between sharks and the fishery than recorded. Although some level of under-reporting is likely, it was not possible to determine how much under-reporting occurred for shark or teleost catch in the CRFFF data set. Reporting errors may be intentional, but Walsh et al. (2002) state that at least some non-reporting was simply a matter of human error. There may have also have been reason for over-reporting. Given the complexities of this data set (e.g., changes within the fishery) and the difficulty in estimating the impacts of the above factors (i.e., movement of fishers in and out of the fishery, etc) on catch estimates, results from the CRFFF data should be considered with some caution. The high number of encounters observed in 2005 ELF data also suggest that large numbers of reef sharks are encountered by commercial fishers even if not captured. The fate of hooked and released and hooked and bite/break off individuals is unknown.

Fisher behaviour may also have affected reporting shark landings due to variable retention practices. Based on catch rates observed in ELF and OBS data sets it seems likely that most fishers would have caught sharks at least occasionally, but would not have retained them as part of the saleable catch. In addition to the potentially high rate of release (and hence low levels of reported catch) for sharks brought to the side of a boat, the ELF results for 2005 suggest that 2.2 times as many sharks are encountered but lost than are brought to the boat. In this case, even greater numbers of sharks may interact with the fishery than indicated by landings. Based on observer data of actual fishing activity, few individuals were reported as dead upon capture or were dead due to retention by the fishers. It is unclear how fishing practices such as the deliberate killing of sharks may have impacted populations. This information is not recorded and is only known anecdotally, making it impossible to incorporate into this analysis. It is widely accepted that this practise did occur at some level, especially in the earlier years of the CRFFF (1950s – 1980s) but how much and if it was directed more at one species over another is unknown. Given the lack of information on shark handling and release condition, post-capture and post-release mortality should be priority areas of research for future reef shark studies of fisheries activities. It is also unclear how many sharks are harvested as part of recreational fishing activities. Such an analysis was outside the scope of the current analysis but should be considered in future research.

The absence of significant regional differences in shark encounters on either the ELF or OBS trips suggests that there is no indication of localised depletions of sharks in specific regions, presuming that virgin densities were also relatively uniform. No data exist, however, about the level of shark populations prior to or in the early years of fishing. Lack of baseline data on reef shark populations makes it difficult to determine levels of depletion within the Great Barrier Reef. There were, however, differences in landings by region from the CRFFF, most likely related to the substantial regional differences in effort and fishing practice among the regions (Mapstone et al. 1996b). Overall catches of shark from the Capricorn-Bunker Region were ranked higher (2nd) than expected from effort in the region (relative to other regions), however, perhaps reflecting the different fishing practices and catch composition of reef fish from the region (Mapstone et al. 1996b).

The evidence from ELF data that shark catch rates on reefs historically open to fishing were less than half those on closed reefs when sampled with standardised methods suggests that Marine Park zoning has had a significant impact on the effects of fishing and potential abundance of reef sharks on the Great Barrier Reef. This result differs to some degree with results presented by Robbins et al. (2006) who reported that “abundances on no-take reefs ... were also heavily depleted and remarkably similar to the legally fished zones”. In fact, the numbers of reef sharks in zones closed to fishing (MNP) were on average above (by approximately 50%) but not significantly different from numbers in open zones (GU), while those in no-entry zones were much higher than either GU or MNP (Robbins et al. 2006, Figure 2). They suggested that the decreased numbers of sharks in MNP and GU zones in comparison to no-entry zones was the result of overfishing and that illegal fishing in MNP zones had likely caused numbers of sharks within these zones to approach those in the open zones. The results of the current study suggest that MNP zones do provide some protection from fishing and may be an effective tool in managing reef sharks, though it is also possible that no-entry zones provide an additional safeguard against effects of fishing. The difference in significance of results between the studies may reflect differences in statistical power of the tests, since the current study analysed more data from several years of structured surveys. The RAP rezoning of the Great Barrier Reef is likely to enhance the effects of no-take areas due to the increase in area of coral reef habitat protected by MNP zones (from 21% to approximately 30%) (Fernandes et al. 2005).

Data on movement and residency patterns of reef sharks are integral to the interpretation of how fishing is affecting populations. Available data suggest that whitetip reef, blacktip reef and grey reef sharks show some level of site fidelity and may remain on a single reef for extended periods of time (Randall 1977; Stevens 1984; Wetherbee et al. 1997), but data are limited. High levels of site fidelity have also been reported in Caribbean reef sharks (*Carcharhinus perezi*) in the south-western Atlantic. Caribbean reef sharks at Fernando de Noronha Archipelago, Brazil, were reported to display long-term site fidelity on a reef, particularly when young (Garla et al. 2006a). In a subsequent study at the same location, Garla et al. (2006b) reported that abundance was greater within a marine reserve area than outside the reserve. These authors suggest declines in shark numbers outside the marine reserve may have been due to anthropogenic effects (e.g., boat traffic or fishing pressure) on sharks and prey species. The results of these studies in Brazil are similar to the findings presented in this analysis, suggesting that marine reserves may be effective for protecting at least some portions of reef shark populations.

There have been numerous publications within the last decade examining the feasibility of shark fisheries and the sustainability of shark catch in target and non-target fisheries (e.g., Walker 1998; Stevens et al. 2000; Stobutzki et al. 2002). Lack of detailed data on species identification and numbers landed within the Queensland fishery logbook reporting system made it difficult to assess the impacts of fishing activity on reef shark populations. In this analysis we have examined three data sets representing commercial fishing and fishery independent surveys using commercial fishing techniques. All three data sets revealed that sharks were encountered and captured relatively frequently. The CRFFF CPUE from logbooks was relatively stable over time. Results from this analysis suggest that a large proportion of sharks are lost or released after being hooked (e.g., during OBS trips), most likely because shark is a lower value product than most coral reef teleosts. In fact, more than twice as many sharks were likely to be hooked and lost than were successfully brought to the boat, suggesting that many more individuals are encountered than harvested. Little or no data exist on the fate of encountered or caught and released animals in non-target fisheries. It is unknown what the condition, behaviour or survival rate of individuals is post-release. This lack of information coupled with high encounter rates between fishers and sharks suggests that shark handling and post-release condition should be examined in future research to define any ghost impacts on shark populations.

The landings data from the commercial line fishery operating on the Great Barrier Reef indicate that there is an ongoing harvest of reef sharks. While it was difficult to determine the exact trend in the landings due to limitations of the logbook data and changes in fisher behaviour and reporting, recent annual landings (2003-2006) appear to be around 10 t (10,000 kg) while historic annual landings (1988–1996) were around 20 t. The size of individuals harvested is also difficult to define due to data reporting issues. However, limited weight data for individuals suggest many of the harvested sharks are of a reasonably small size (e.g., 5 kg). It is unclear if this is an effect of market demand for small sharks, targeting (i.e., lack of freezer space for retaining large individuals), limited size classes, increased difficulty in handling larger individuals, or another unidentified factor.

Robbins et al. (2006) estimated that grey reef sharks, the most commonly encountered species in all data sets we examined, were reduced by 97% in fished areas of the Great Barrier Reef compared to no-entry zones and, on the basis of population modelling, projected that population decline would be on-going at current fishing levels with the sharks being at risk of ecological extinction. We cannot estimate the extent of depletion of shark populations from unexploited levels from the catch and effort data for the fishery or research surveys. The relatively stable CPUE of reef sharks in the fishery over 18 years, however, is not consistent with an hypothesis of rapidly or continually declining populations at rates of 7-17% per year estimated by Robbins et al. (2006), though hyperstability of catch rates in the face of some decline cannot be ruled out. Subtle or even moderate changes in catch rate might have gone undetected because of the uncertainties in reporting and data quality discussed earlier. Further research is required to verify the status of shark populations relative to unexploited levels and to assess what level of harvest, if any, can be sustained without endangering those populations.

Several conclusions can be drawn from the above analyses. First, catch rates of reef sharks within MNP zones was more than double those in GU zones. This result suggests that reef sharks are being afforded some protection by past and current zoning. Second, it is apparent that the fate of released individuals is critical given high release rates within the fishery. Greater information on release rates and current practices of fishers are now required due to recent changes in the fishery. Directed study of post-release survival is needed to define any delayed mortality within these populations. Third, additional directed reef shark studies are required to resolve the status of reef shark abundances on the Great Barrier Reef compared to unexploited levels and establish appropriate harvest rates that will avoid further depletion or over-exploitation of the populations. Mark-recapture studies of reef sharks would help elucidate levels of movement among reefs as well as provide data to estimate absolute population sizes. Finally, improved reporting in fisheries data would help define how the fishery is interacting with reef sharks and what effects may be occurring on these populations because of these encounters. Better identification of species, size and age composition of catches and more detailed effort data would be invaluable in defining the effects the fishery is having and what segment of the population is being affected (e.g., neonates, juveniles, adults). An ongoing observer program for the commercial fishery would allow additional data to be obtained (e.g., sex) for sharks as well as additional data for other aspects of the fishery. These efforts should attempt to define the encounter rate of sharks under current fishery guidelines to determine how often sharks are captured and released and in what condition they are returned to the water (i.e., wounded, dead).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- Current commercial logbook data are not adequate for a full understanding of impacts of the Coral Reef Fin Fish Fishery on reef sharks based on a lack of species identification, size or sex of the catch.

- Catch data are directly dependent on reporting in all data sets.

- A small number of boats appear to land the majority of reef shark catch.

- The majority of reef shark catch appears to be discarded although condition upon release and post-release mortality are unknown.

- The majority of the catch was grey reef (62-72%), whitetip reef (16-29%) and blacktip reef (6-13%).

- Catch rate data from Observer and ELF data are in agreement suggesting they are representative of fishery activities.

- Catch rate within the CRFFF data did not show increases or declines within the study period from 1989 to 2006.

- Data from the ELF Project show higher catch rates of reef sharks within MNP zones than in GU zones, suggesting no-take zones provide some protection for reef shark populations.

- Although a decline from virgin levels is highly likely in reef shark populations, these data do not provide information to define the amount or rate of decline or current population status. However, there was no apparent decline during the study period suggesting declines may have occurred previously or are undetectable at current harvest rates.

- The lack of evidence of decline and relatively stable catch rates within the CRFFF over 18 years and research surveys over 11 years is not consistent with an hypothesis of rapidly or continually declining populations at rates of 7-17% per year and suggests that reef shark populations remain viable in the Great Barrier Reef, albeit at a level below unexploited status that could not be resolved.

Recommendations

Directed research is required. This analysis was based on non-directed research (i.e., it was designed to study reef teleosts and considered sharks as bycatch or byproduct). We recommend the GBRMPA initiate or support research in the following areas:

- Direct abundance data are needed. These can be obtained via mark-recapture studies and we recommend a large scale tagging program as soon as possible to accurately define reef shark populations.

- Research should focus on the main species encountered, especially grey reef and whitetip reef sharks.

- Movement data are required to determine if sharks remain within protection zones and for how long. Estimation of exposure to the fishery by life stage is critical to understanding current and future exploitation of these stocks. We recommend studies of reef shark residence and movement via mark-recapture or acoustic telemetry.

- Based on movement data further analysis is required to determine if localised depletions are occurring. We recommend collection of data on home range size and movement patterns to determine if sharks move among reefs. This will define their risk of exposure to fishing and determine if localised depletion is likely.

- Improve logbook reporting to provide more useful data for assessing the number and type of individuals taken by the fishery. Data needed include species identification, size and sex.

- Age based demographic studies should be conducted within the fishery region.

- Information should be gathered on the impacts of recreational shark harvest on reef shark populations within the Great Barrier Reef. The scale of that effort may cause additional unmonitored declines in shark populations.

- We recommend continued collection of shark encounter data from annual catch surveys and potentially from observer programs to define how many sharks are being hooked and released and in what condition they are returned to the water.

- Collation and analysis of data sufficient to estimate likely unexploited population status for selected species, most likely current levels of depletion and acceptable rates of future harvest, if any.

- Management action should be considered to ensure ecological sustainability of reef shark harvest within the commercial fishery.

- Education programs for fishers about shark identification, handling and release procedures. We recommend identification guides for fishers and studies of post-release mortality.

- Research into socio-economic drivers for shark fishing (past and present) should be conducted. This should include gaining an understanding of fishers' attitudes toward sharks and how individuals are handled when captured (e.g., cut off with tackle attached, deliberately killed, etc).

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GLOSSARY OF TERMS

captured/caught – sharks that were hooked and successfully brought to the boat

encounter – to meet with; in this case we refer to sharks that took a bait and escaped or were released, a short-term exchange between sharks and fishermen

discarded – sharks that were successfully captured and brought to the boat but subsequently released (condition upon release is unknown)

landed – sharks that were successfully brought to the boat and harvested

lost – sharks that were caught on a hook but not retained long enough to bring to the side of the boat

released - sharks that were successfully captured and brought to the boat and subsequently released in a healthy condition