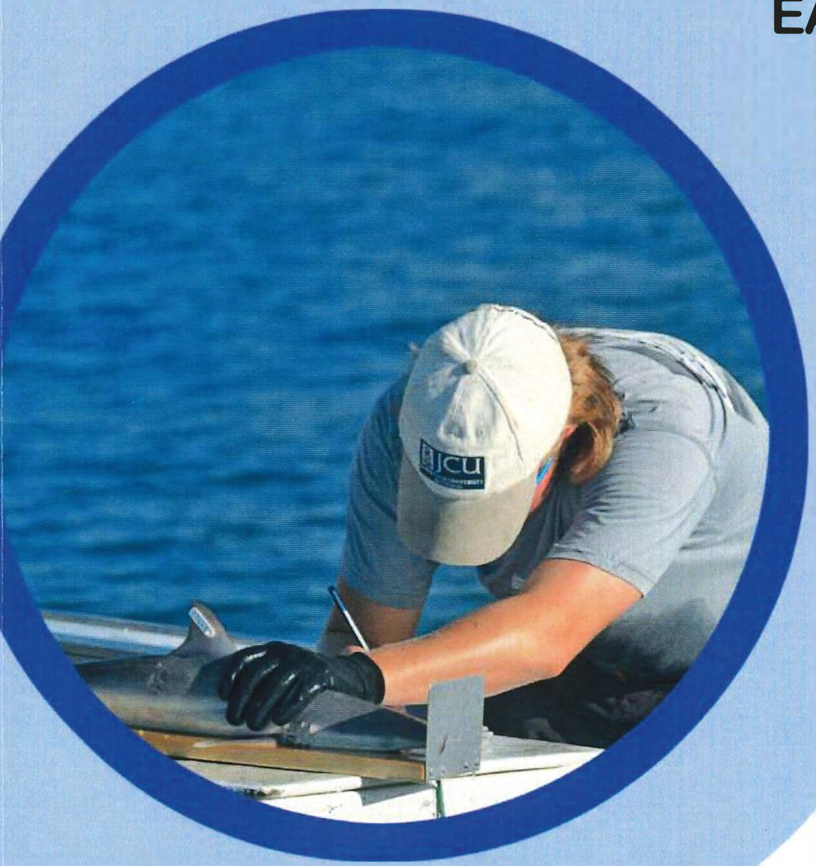
FISHING & FISHERIES RESEARCH CENTRE TECHNICAL REPORT No. 14

ESTIMATING FISHING MORTALITY OF MAJOR TARGET SPECIES AND SPECIES OF CONSERVATION INTEREST IN THE QUEENSLAND EAST COAST SHARK FISHERY



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FRDC Project No. 2010/006

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Abbreviations

CSTFA .... Centre for Sustainable Fisheries and Aquaculture

DoE...................... Department of the Environment

ECIFFF............. East Coast Inshore Fin Fish Fishery

EPBC................ Environmental Protection and Biodiversity Conservation Act 1999

GBR.................. Great Barrier Reef

GBRMP............ Great Barrier Reef Marine Park

GBRMPA......... Great Barrier Reef Marine Park Authority

GBRWHA......... Great Barrier Reef World Heritage Area

JCU .... James Cook University

QDAFF............. Queensland Department of Agriculture, Fisheries and Forestry

QSIA................. Queensland Seafood Industry Association

SEQ.................. South East Queensland

Executive Summary

What the report is about

Fishing mortality rates for the major targeted and byproduct species of sharks landed by the Queensland East Coast Inshore Fin Fish Fishery (ECIFFF) have been estimated. The effects of these fishing mortality rates on population persistence for these species have also been modelled with demographic analyses to predict future population trends. The Centre for Sustainable Tropical Fisheries and Aquaculture has completed this project in response to increasing interest and concern by all stakeholders around the status of shark populations exposed to the fishing activities of the Queensland ECIFFF. A large-scale tag-recapture project was completed across 2010 and 2011 and provided the relevant data to complete this exercise. A total of five tagged shark species realised a total of 324 recaptures. We found that current fishing mortality rates appear generally sustainable. Robust fishing mortality estimates and subsequent demographic modelling outcomes were possible for four of the most dominant species harvested by the fishery – the undifferentiated blacktip shark (*Carcharhinus tilstoni*/*limbatus*) complex, spot tail shark (*C. sorrah*), spinner shark (*C. brevipeenna*) and pigeye shark (*C. ambionensis*). For all species except pigeye sharks fishing mortality rates were found to be low to moderate, but likely within sustainable bounds. For the pigeye shark, fishing mortality estimates were relatively high with several methods indicating harvest rates may have been unsustainable. Less robust estimates of fishing mortality were achieved for an additional six species including milk and sharpnose sharks *Rhizoprionodon acutus* and *R. taylori*; creek whaler *C. fitzroyensis*; bull shark C. leucas; and the scalloped and great hammerheads *Sphyrna lewini* and *S. mokarran*. For these species estimates are likely highly imprecise and should be used cautiously.

Background

The volume of shark captured by commercial net fishers operating with the Queensland East Coast Inshore Fin Fish Fishery (ECIFFF) increased rapidly and peaked early last decade at a level (approximately 1,500t) that concerned many stakeholders. Within a few years, shark catch had increased five-fold. A management review process, including an audit of proposed management measures by the Hon Peter Garrett and the Department (see Gunn et al 2008), resulted in of a raft of new management measures being introduced. The most pertinent of those management changes included a Total Allowable Commercial Catch (TACC) of 600t per annum (split 480t within GBRMP waters, 120t within southeast Queensland waters); the introduction of a shark specific licence (S symbol - without which fishers were restricted to no more than 10 individual sharks per fishing trip); a new logbook reporting system and an observer program to improve data quality; and the designation of a number species as either no-take or subject to strict trip limits to protect species of conservation concern (SOCI).

Aims/objectives

Primarily the project aimed to achieve robust estimates of fishing mortality for the major species harvested by the ECIFFF, as well as fishing mortality estimates for any species of conservation interest (SOCI) that the methodology would allow. Secondarily the project explored dispersal (movement) patterns and growth trends through the opportunistic collection of dispersion and growth data provided by the tag-recapture methods.

Methodology

This study followed the methods used by McAuley et al (2005) and McAuley et al (2007) to evaluate the effects of fishing mortality on the demography of commercially fished sharks in the Queensland ECIFFF. Firstly fishing mortality was estimated via a tagging study where tagged individuals were continuously released into the population and recovered only once. The numbers of tagged sharks of a given age in the population were estimated in monthly time-steps, accounting for losses due to natural mortality, tag-shedding, and recaptures, and additions of any newly tagged animals. The Baranov catch equation was then solved to estimate fishing mortality from the number of recaptured individuals given the total number tagged in the population and estimates of the natural mortality rate. Finally, a demographic analysis was carried out using life tables to estimate the intrinsic rate of population increase with and without fishing. To account for one of the key uncertainties, natural mortality, the analyses were repeated using a range of indirect and empirical estimates. For four commonly captured species (blacktip, spottail, spinner and pigeye sharks), enough recapture data were available to complete the fishing mortality and demographic modelling using monthly time-steps. For an additional 6 species (great hammerhead, scalloped hammerhead, creek whaler, bull, Australian sharpnose and milk sharks), sufficient data were available to estimate fishing mortality using yearly rather than monthly time-steps.

Results/key findings

Overall tag return rates for the two most commonly caught species, the spot-tail (*Carcharhinus sorrah*) and blacktip (*Carcharhinus tilstoni*) sharks were estimated at 5.6% and 16.4%, respectively. These values corresponded to maximum value of *F* of 0.06 and 0.13, respectively. Demographic analysis indicated that this value of *F* would lead to a positive rate of population increase, *r,* for spot-tail shark (*r* = 0.10) and a stable population for blacktip shark (*r ≈ 0*). Overall tag return rates for two larger species of whaler sharks, pigeye (*C. amboinensis*)*,* and spinner (*C. brevipinna*)*,* which were predominantly caught as juveniles, were 35.9% and 11.8%, respectively. These values corresponded to a maximum value of *F* of 0.40 and 0.07, respectively. All demographic analysis indicated that this level of *F* was within sustainable bounds (*r* = 0.04) for spinner shark*,* however three out of four analyses indicated that it was unsustainable for pigeye shark (*r =-0.14*). Notably though, a demographic analysis using recent empirical estimates of natural mortality, *M,* suggested that fishing may still be sustainable (*r= 0.03*). The high recapture rate of *C. amboinensis* observed in this study is potentially a cause for concern, particularly since there is likely to be additional, unquantified mortality on adults from the Queensland Shark Control Program.

Fishing mortality estimated using annual time steps was calculated for the Australian sharpnose shark (*Rhizoprionodon taylori*), milk shark (*R. acutus*), bull shark, (C*. leucas*)*,* scalloped hammerhead (*Sphyrna lewini*)*,* great hammerhead (*S. mokarran*) and creek whaler (*C. fitzroyensis*). These additional species estimates should be treated with caution as the addition or removal of just one tag-return changes the mortality estimates markedly.

Our findings broadly suggest that the range of adaptive management measures undertaken over the past decade has been successful in controlling fishing mortality on target species. However, since *F* values are still at moderate to high levels for some species even after large catch reductions, this may indicate that high catches during the early 2000s were unsustainable.

Implications for relevant stakeholders

Considerable interest and concern has surrounded the uncertain sustainability of the shark harvest taken by the ECIFFF, so the definition here of current fishing mortality rates will be of considerable interest to all stakeholders. In a broad sense, the outcomes of this research should help to convince stakeholder groups that shark fishing can be sustainable. In the previous absence of any demonstrable data to indicate sustainable harvest of sharks by the ECIFFF, some market opportunities have been removed in recent years (for example Coles recently removed shark flesh from their seafood counters). This research may help to re-open lost markets.

Recommendations

The primary recommendation following the outputs of this research is the need to better understand the complexity of issues with the blacktip shark complex. Research suggests the Australian blacktip shark (*Carcharhinus tilsoni*) is more common in northern tropical waters while the common blacktip shark (*C. limbatus*) is more common in cooler subtropical and temperate waters. Recently, hybridisation between the two species has also been recorded. Hybrids are reproductively viable and may represent an evolutionary development towards greater productivity. Alternatively, hybridisation may decrease population productivity. Whether this trait confers greater or lesser resilience of this species complex to fishing is currently unknown. Given the prevalence of these species within the inshore ecosystem and dominance in fishery catches, further research is certainly recommended.

Secondly, as the fishery is very coastal (<10m water) focused, it is possible that significant portions of shark populations live in deeper unfished waters. Some preliminary fishery independent surveys conducted by the CSTFA in deeper waters, suggest many of the species caught in <10 metres depth are also found in waters 10 - 40 metres deep. If the individual sharks within these populations are not freely mixing across available depths, significant portions of the populations may not be exposed to fishing. Similarly, some preliminary research suggests the inshore marine park area (MPA) network offers some degree of protection as some species such as spot-tail and pigeye sharks show strong site attachment within coastal embayments. The dispersal data collected by this project further supports the limited space use hypothesis for juvenile sharks. Again the MPA network combined with the site attachment of some shark species may mean portions of each population are not exposed to fishing. A tag-release program that included the specific capture, tag and release of sharks from within protected zones (or offshore waters) is recommended to better understand the protective benefits the extensive MPA networks of the GBRWHA, Great Sandy Straits and Moreton Bay Marine Parks cumulatively offer inshore sharks.

Thirdly, defining gear selectivity of the main target species should also be a focus of future research. As no current information is available on selectivity, the demographic analyses in this study assumed full selectivity of all age classes that were present in the catch. This approach is likely to have been highly precautionary, but was required in the absence of better data. For many shark fisheries, particularly those focused on juveniles, selectivity is likely to be dome-shaped. Accurately defining selectivity is particularly important in understanding the vulnerability of that target species to capture, and determining whether fishing is likely to be sustainable.

Fisher-dependent data recording of species specific information is likely to remain poor and we would recommend investigating methods for the independent validation of landed species compositions. The nature of the small boat based shark fishing that dominates the ECIFFF means that fishers will continually be challenged by the current reporting requirements. Small, wet, open boats from which large catches may often be landed is not a conducive environment for accurate species identification and data recording. The onus on fishers to record data is well placed, however a common-sense approach considering the logistical constraints of fishers suggests that species specific recording will continue to be a significant issue while fisher-dependent methods persist.

An equally pertinent issue is that of mortality of sharks captured in the ECIFFF by fishers who are not legally licenced to retain and market them yet still interact with large numbers of sharks while targeting other species. The management of the shark component of the ECIFFF includes a shark endorsement (S symbol) that allows holders to retain an unlimited number of sharks per trip. Those net fishers who do not hold an S symbol must return to the water all sharks landed in excess of 10 individuals. There is likely some degree of post-release mortality of these sharks. It is possible that there is a significant level of post-release mortality that occurs within this sub-sector of the fishery (those fishers without an S symbol), and we recommend that methods for assessing and/or mitigating this potential impact need to be considered urgently.

Keywords

Sharks, shark fisheries, fishing mortality, demographic analysis, fisheries management, East Coast Inshore Fin Fish Fishery

Introduction

Globally, shark fisheries make significant contributions to the protein requirements of many regions and countries. Unfortunately though, sharks tend to be characterised by K-selected life history traits that mean populations may be particularly vulnerable to unmanaged fishing. Sharks are generally long-lived, late maturing, and slow-growing fishes with low fecundity (Cortes 2000); traits that have contributed to their over-exploitation and depletion in some locations (Dulvy et al 2008; Blaber et al 2009). Some sharks do however have life history traits that mean populations can be quite productive and support important fisheries. Examples of productive sharks include the small carcharhinid sharks like the spot tail (*Carcharhinus sorrah*) and milk (*Rhizoprionodon acutus*) sharks; both species are characterised by relatively high productivity and may be relatively resilient to fishing (Tobin et al 2010). Conversely some of the larger carcharhinids such as the dusky (*C. obscurus*) and sandbar (*C. plumbeus*) sharks have relatively low productivity, though can still be fished provided robust management measures are based on sound science (McAuley et al 2007; Geraghty et al 2013).

Despite the caution that should be applied to fishing shark populations, even species of shark with low productivities can be fished (McAuley et al 2007), however successful sustainable fishing requires robust management tools and actions based on knowledge of life history traits as well as fishery interaction characteristics. Shark fishery theory suggests that targeting sharks while they are young and small is a much more sustainable technique than targeting larger mature individuals that are actively contributing to the reproductive capacity of a fished population. Natural mortality rates are generally quite high for neonate and young-of-the-year sharks, and increases in fishing mortality on these life history stages may be compensated, to some extent, by increased juvenile survival. The simple logic is that a reduction in population density will lead to higher natural survival rates due to reduced competition for resources. The Western Australian dusky and sandbar shark fisheries are classic examples of where this theory is working well in practice.

In tropical waters, there are significant challenges surrounding the management of shark fisheries. Firstly, tropical waters are often inhabited by a relatively high diversity of sharks, meaning fisheries may interact with dozens of different but often morphologically similar species (Harry et al 2011). Secondly, the life history traits of diverse tropical shark assemblages are likely to be quite varied with some small productive sharks and some much larger and less productive sharks (Tobin et al 2013). More generally, sharks may often interact with fisheries and fishers that are not actively or deliberately targeting them though these sharks may still be retained as important by-product species. Finally, the tropics support a diverse array of fisheries and thus fishing gears that have different interaction rates with sharks and management of shark mortality needs to consider all interactions.

The Queensland East Coast Inshore Fin Fish Fishery (ECIFFF) operates in tidal and near shore waters spanning from Cape York in the north to the New South Wales border in the south (Figure 1). The commercial sector of the ECIFFF is extremely diverse with fishing undertaken using mesh net, haul (seine) net, tunnel net, ring net and line to harvest around 5,700t of shark and fin fish products per year (Tobin et al 2010). Most sharks landed by the fishery are taken in commercial mesh nets as a combination of targeted effort and harvest, as well as some by-product landings. Within the last decade, commercial harvest of shark has been highly variable fluctuating between 300 and 1,500t per annum (Figure 2) with the peak landings early last decade causing concern amongst many stakeholders. Limited data on recreational take of shark in the ECIFFF is also problematic. Although recreational harvest rates are likely to be very low relative to the commercial sector harvest due to high rates of release (Lynch et al 2010), post-release cryptic mortality may be an issue. The most recent state wide survey estimated around 88,000 sharks were caught by recreational fishers with 94% released.

Figure 1 Fishers of the East Coast Inshore Fin Fish Fishery (ECIFFF) may fish in any of Queensland’s east coast waters bounded by the New South Wales border in the south and the Torres Strait Protected Zone in the north. Fishing tends to be focused around the major cities and regional centres identified.

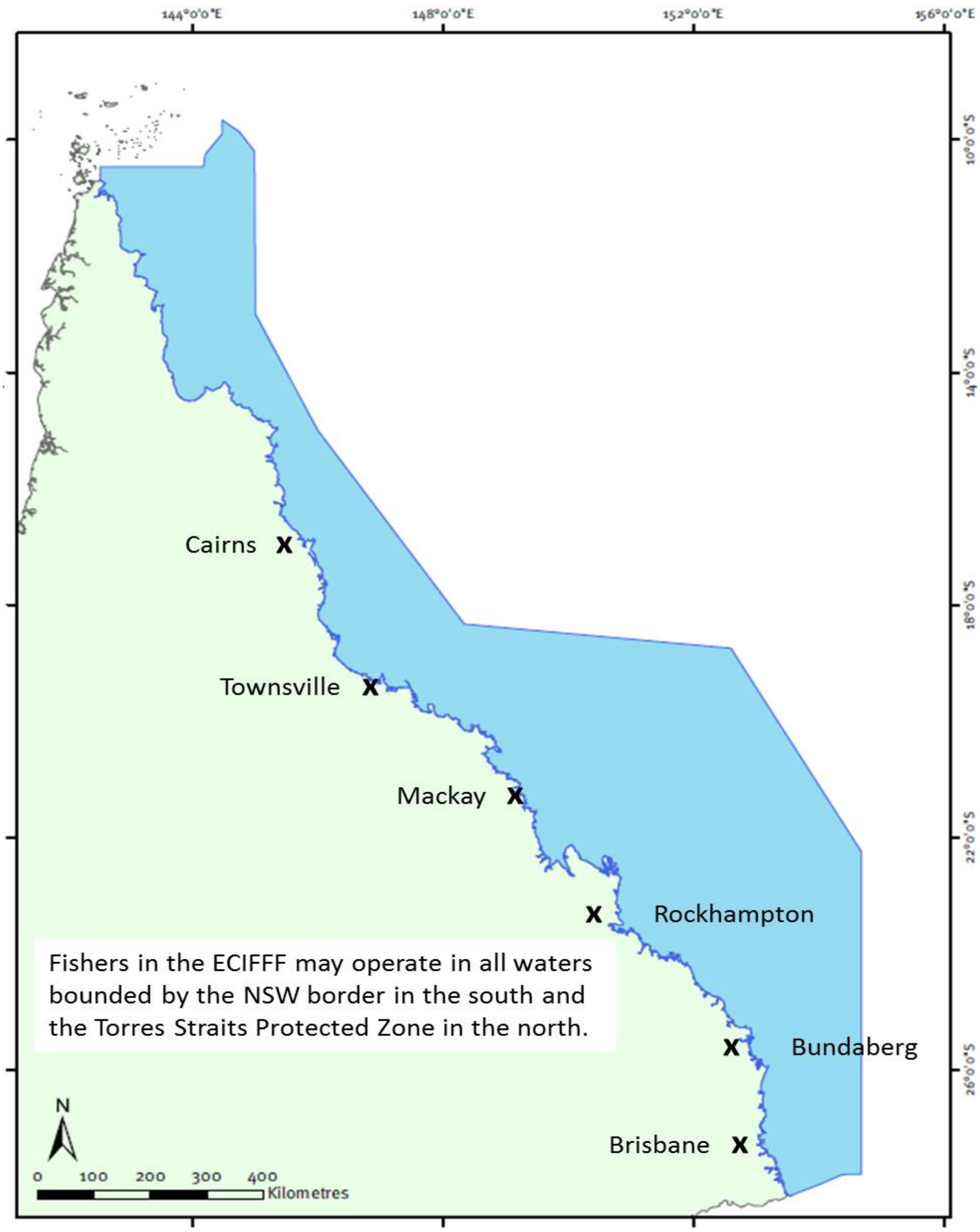
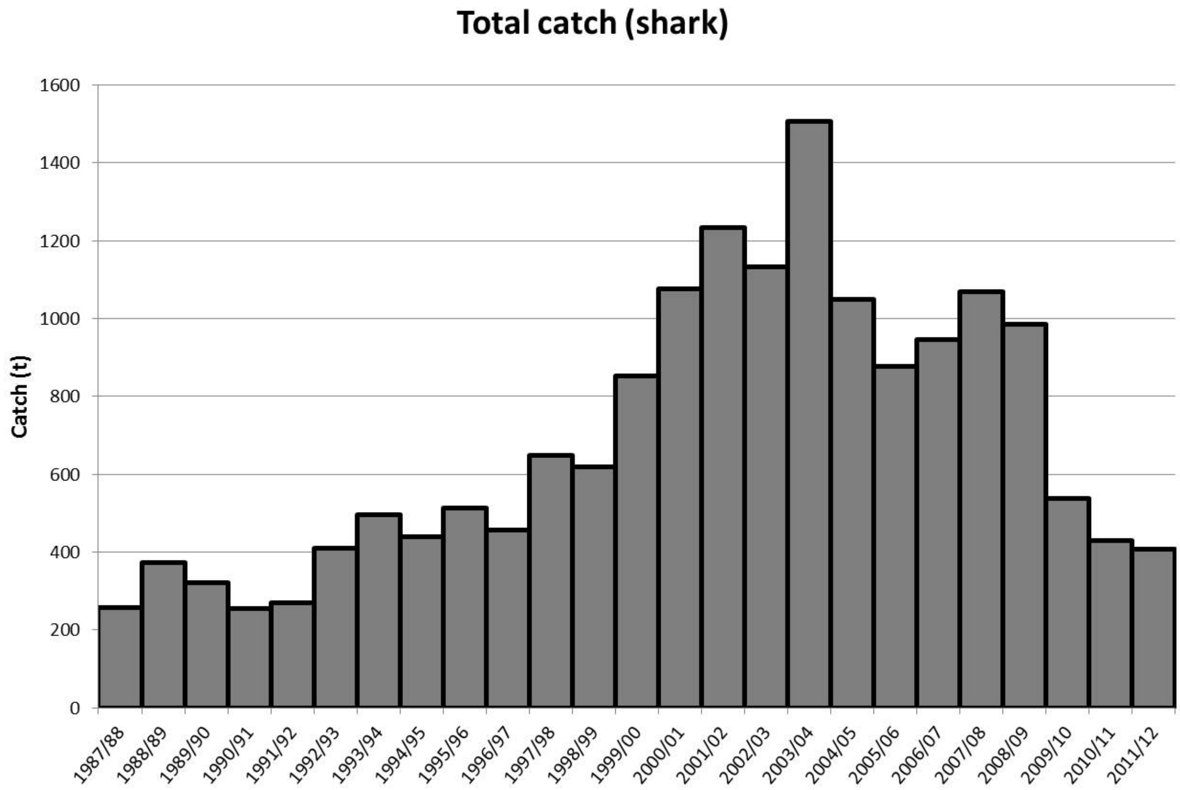


Figure 2 Annual landings of shark as reported by commercial fishers via the compulsory logbook system. Data are presented in financial year time steps.



The management of the ECIFFF has historically been achieved through a combination of traditional input (limited licenses, area and time restrictions, and netting apparatus limitations) and output (size limits and protected species) controls. Hand-in-hand with these types of controls, assessment of management performance or stock status has largely been based on tracking changes in fishing effort and volumes of fish harvest through time (DEEDI, 2010). Unfortunately, these types of methods are no longer viewed as appropriate for long-term sustainable management as subtle though trends in harvested species' abundance or changes in the effort characteristics of the fishery may go unnoticed (eg Erisman et al 2011).

A change in the effort characteristics of the commercial net sector of the ECIFFF is a real and recent phenomenon, giving rise to most concern. Fishing power has increased in the commercial sector of the ECIFFF through the movement away from traditional hand-hauling netting methods to wide adoption of mechanical net reels

(Figure 3). This type of mechanized equipment is allowing fishers to fish favoured shark habitats much more efficiently than previously possible. Further, the latest management changes introduced for the ECIFFF on 1st July 2009 have indirectly motivated many fishers to increase their fishing power. As of the 1st July 2009, commercial fishers are competing for their share of two competitive Total Allowable Commercial Catch (TACC) limits set for shark and grey mackerel at 600t and 250t per year respectively. Although concomitant management changes on 1st July 2009 introduced a shark fishing symbol (S) to limit the number of fishers (to approximately 120) who can retain more than 10 sharks per fishing trip, a large number of fishers are still legally entitled to continue net fishing for other valuable species such as grey mackerel, in habitats sharks regularly frequent. This forces fishers who legally target grey mackerel without holding an “S” symbol, to discard all further sharks once the 10 shark per trip limit has been landed.

Changing pressures and responsibilities now demand that fisheries management is based on data that measure the responses of populations and to fishing more explicitly. In this light, the management of tropical shark fisheries is particularly problematic as prior research has identified a diversity of species are landed as target, by-product and by-catch species, throughout a diverse array of habitats that are fished by a complex collection of different fishing gears (Tobin et al 2010; Harry et al 2011). Further, for many tropical shark species, simple life history traits such as age, growth and reproductive parameters are largely unknown. For those shark species that life history traits have been determined for, a general trend of slow growth, late maturation and low fecundity make these species vulnerable to intensive fishing pressure.

Figure 3 Fishers in the East Coast Inshore Net Fishery historically fished with hand-hauled nets (top panel). The adoption of more efficient mechanical net reels (bottom panel) has become more common in recent years.

At a time when international and domestic shark markets are increasingly questioned about the status and sustainability of sharks and shark fisheries, the shark component of the ECIFFF requires immediate attention. Indeed, the renewed management arrangements for the ECIFFF introduced in 2009 were in part responding to an independent review of the management arrangements of the ECIFFF by a group of consultants engaged by the Federal Government Department of the Environment, water, Heritage and the Arts (DEWHA, now known as DoE, the Department of the Environment). The Gunn Review (see Gunn et al 2008) identified a number of conditions and recommendations, not limited to but including: 1. Collection and collation of data to better understand the species complexity and spatial variability in shark catches taken from along the Queensland east coast; 2. Conduct research to determine rates of fishing mortality for commonly caught sharks; and 3. Undertake opportunistic research to better understand the biology and ecology of the shark species taken in the ECIFFF.

In addition to the Gunn review, a number of other issues have emerged in recent years that may impact the ECIFFF shark fishery. Recent research has identified hybridisation occurs between two congeneric blacktip sharks, the endemic *Carcharhinus tilstoni* and circum-global *C. limbatus* (Morgan et al 2011). Although it is known that the smaller *C. tilstoni* prefers more northern and tropical waters while *C. limbatus* prefers more southerly waters, the prevalence of hybrids in the east coast shark population is currently uncertain. Although the hybridisation may be a benefit in adaptation to environmental change, conversely hybrid fitness may be low and thus compromise fishery productivity. Another key issue is the recent listing of the hammerheads *Sphyrna lewini* and *S. mokarran* in Appendix II of the Convention on International Trade in Endangered Species (CITES) meaning international trade can only occur through the issuing of a “Non Detriment Finding” by the exporting country.

This project has estimated fishing mortality rates of dominant harvested species and where possible species of conservation concern via a tag-release-recapture study. In addition, the tag-release-recapture data is explored for ability to explore growth parameters and dispersion patterns.

Objectives

1. Estimate fishing related mortality of major target species and species of conservation interest.

2. Utilising the recapture data provided through objective 1, broad scale movement patterns as well as *in situ* growth rates will be estimated.

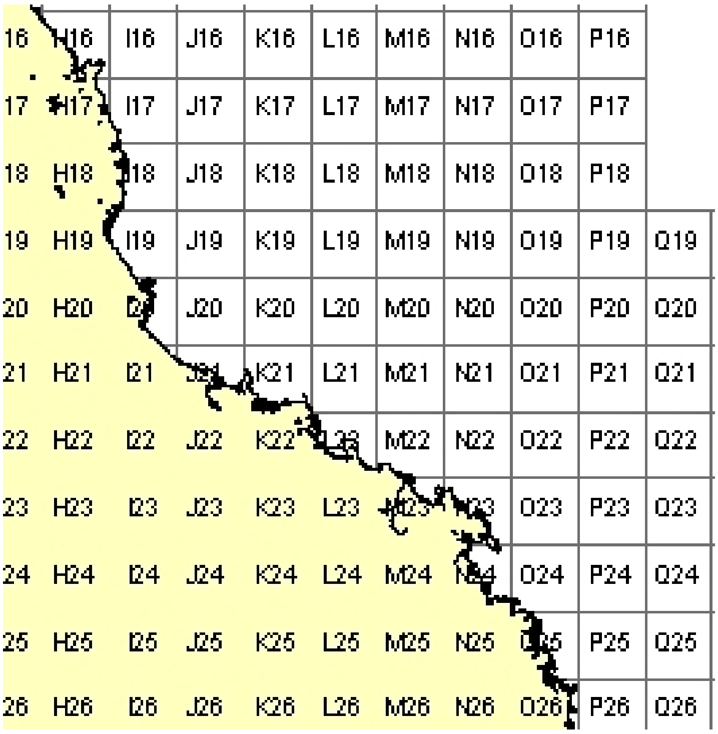
Methods

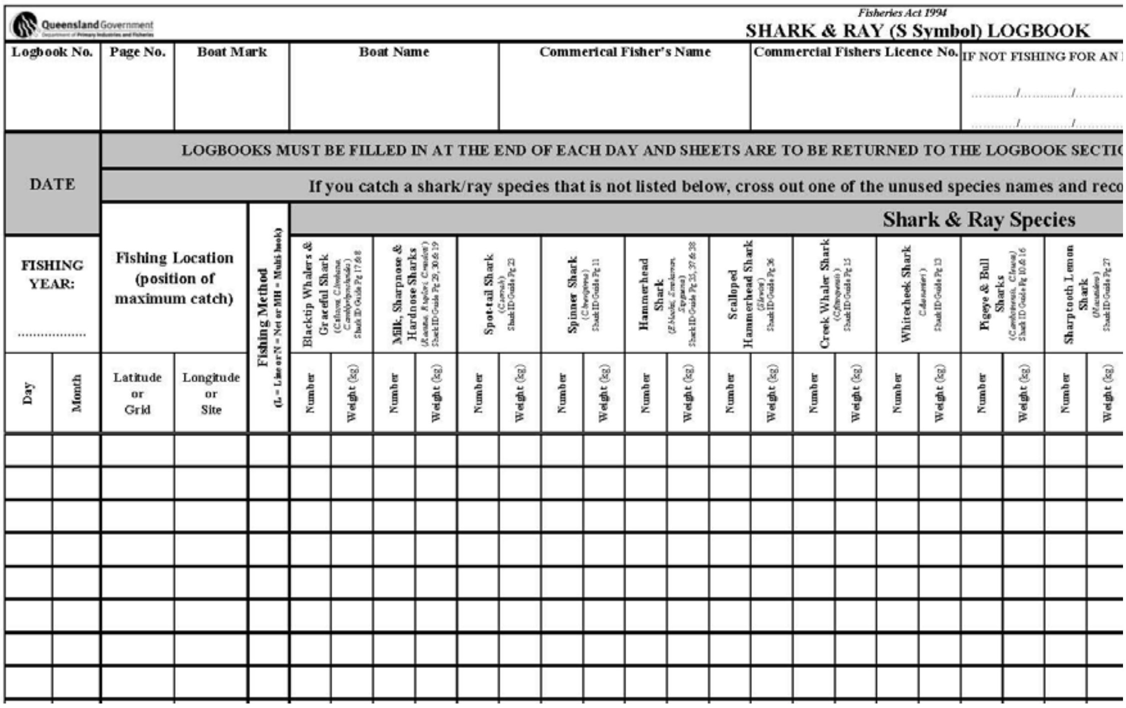
Fishery description, historical trends

As effort and catch of sharks within the ECIFFF is not uniform along the Queensland east coast, and to ensure tag-release efforts of the project were directed to appropriate areas, we first summarised patterns in shark fishing harvest. Commercial fisher logbook data was sourced from QDAFF and annual gross landings were summarised in 30 x 30 nautical mile grid squares (Figure 4) for the time period 1988-2011. In addition, the number of species recorded within logbooks was also tracked through years as reporting requirements, including species reporting groups, have changed through time. Prior to 2009, a single logbook was used by ECIFFF fishers to record shark and finfish catches. In 2009, a dedicated shark logbook was introduced to improve species specific reporting (Figure 4), and although the logbook only nominates 17 species and/or species groups, fishers were encouraged to add species as they may be required.

To ensure tagging was directed to the most dominant species as well as species of conservation interest (SOCI), we considered a number of different data sources to identify regional trends in species composition of shark catches and interactions. For the more recent years of the commercial logbook data, we also considered the patterns of species reporting by commercial fishers. Where possible, these summaries were presented at the broad regional level including the two management regions to which catch limits apply – the waters of the GBRWHA, and the waters of southeast Queensland.

Figure 4 Commercial fishers of the ECIFFF are required to record daily catch and effort information in logbooks. Spatial distribution of effort is collected in 30 by 30 nautical mile grid squares. The bottom panel is an example logbook page where species specific catch of shark is recorded (see also Appendix 3).





Queensland Government

Fisheries Act 1994

SHARK & RAY (S Symbol) LOGBOOK

Logbook No.	Page No.	Boat Mark	Boat Name	Commerical Fisher's Name	Commercial Fishers Licence No.	IF NOT FISHING FOR AN
						........../........../..........
						........../........../..........

LOGBOOKS MUST BE FILLED IN AT THE END OF EACH DAY AND SHEETS ARE TO BE RETURNED TO THE LOGBOOK SECTIO

If you catch a shark/ray species that is not listed below, cross out one of the unused species names and reco

DATE		Fishing Location (position of maximum catch)		Fishing Method (L = Line or N = Net or MH = Multi-hook)	Shark & Ray Species																			
FISHING YEAR:					Blacktip Whalers & Graceful Shark		Milk, Sharpnose & Hardnose Sharks		Spot-tail Shark		Spinner Shark		Hammerhead Shark		Scalloped Hammerhead Shark		Creek Whaler Shark		Whitecheek Shark		Pigeye & Bull Sharks		Sharptooth Lemon Shark	
Day	Month	Latitude or Grid	Longitude or Site		Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)

Estimating Rates of Fishing Mortality

Outline

This study followed the methods used by McAuley et al (2007) to evaluate the effects of fishing mortality on the demography of commercially fished stocks of Western Australian sandbar sharks, *Carcharhinus plumbeus,* and dusky sharks, *Carcharhinus obscurus.* The approach first involves estimating fishing mortality from a tagging study where newly tagged individuals are continuously released into the population and recovered only once. The numbers of tagged sharks of a given age in the population are estimated in monthly time-steps, accounting for losses due to natural mortality, tag-shedding, and recaptures, and additions of any newly tagged animals. The Baranov catch equation is then solved to estimate fishing mortality from the number of recaptured individuals given the total number tagged in the population and the natural mortality rate. Finally, a demographic analysis is carried out using life tables to estimate the intrinsic rate of population increase with and without fishing. The approach is deterministic and, as such, doesn't make any assumptions about uncertainty. To account for one of the key uncertainties, natural mortality, the analyses were repeated using a range of indirect and empirical estimates.

It is important to note that tag return rates for some species were not sufficient for completing the monthly time-step analysis. For these species, the analysis was completed in yearly time-steps. To test the robustness of the yearly time-step approach, it was possible to estimate and compare fishing mortality by both methods (monthly versus yearly time step approach) for a subset of data rich species.

Tagging study

Tag deployment

Between March 2008 and February 2011, a total of 5,174 sharks were tagged off the Queensland east coast. Tags were deployed by research staff working both dependently and independently with commercial net fishers. When working with commercial fishers, net shot or soak times were kept short (generally less than 2 hours) in order to ensure as many as possible sharks were in good condition for tag and release. Methods ensured all tagged sharks were in robust condition postcapture and expected to have low post-release mortality. Moribund or dead sharks were not tagged and retained by the fisher for market.

At the time of capture, each shark was identified to species where possible (see Harry et al 2011), stretched total length measured to the nearest 1cm, before a rototag was fitted to the first dorsal fin (as per Chin et al 2012). The tags included a unique identifying number, the word reward as well as a phone number for recapturing fishers to ring. The presence of tagged sharks and the actions to take should a fisher recapture one were advertised widely through common media channels (newspapers, fishing websites and newsletters) and word-of-mouth. Incentives including free shirts and random lucky draws were also advertised to maximise fisher participation.

Tag recapture

A specific telephone line and number was setup and maintained as a tagging hotline. Where possible calls to the tagging hotline were answered by project staff, though in the absence of staff a pre-recorded message advised callers to leave their details and such messages were answered as soon as practically possible.

Estimation of tag non-reporting

Throughout the duration of the project, reports filtered in from numerous fisheries sources that commercial fishers in particular were not reporting tags. Reasons were varied, though generally hinged on a distrust of science and management. In some cases, well intentioned fishers simply became too busy and/or distracted to remember to report tags at the completion of their fishing trips. However, sufficient numbers of fishers did report appropriately and this subsample of fishers was used to correct for non-reporting rates across the remaining fishery participants. For this subset of “known trusted fishers” we had knowledge of their individual annual catches (tonnes of whole shark) and annual tag returns. We calculated tonnes per tag for this group of fishers and used this ratio to correct for the remaining fishers who did not return tags. Non-return rates were calculated for both 2011 and 2012.

Estimation of natural mortality

As empirical estimates of natural mortality, *M,* were largely unavailable for the shark species in this study, three commonly used natural mortality estimators based on life history theory were used to explore a range of plausible values for this parameter. The first method was that of Jensen (1996), which estimates *M* as a function of age at maturity, α, as:

$$M = \frac{1.65}{\alpha}.$$

The second method used was that of Hoenig (1983) which, when simplified, estimates *M* as a function of maximum age, ω, as:

$$M = \frac{4.3}{\omega}.$$

The third method used was that of Jensen (1996) (Jensen 2) relating the Von Bertalanffy growth rate coefficient, *K,* to *M,* in the following equation:

$$M = 1.5K.$$

These methods were chosen due to their simplicity of calculation, ease of interpretation, and because they utilised a range of different life history parameters that were available for all of the species. Each of these estimators has its strengths and weaknesses, but has been shown to give acceptable results under certain assumptions and circumstances (Kenchington, 2013).

In addition to the indirect estimates of *M*, empirical estimates were available for two species based on acoustic telemetry studies. Knip *et al.,* (2012) tagged young-of-the-year pigeye sharks, *Carcharhinus amboinensis*, in Cleveland Bay during 2009 and 2010 and obtained estimates of 0 and 0.05 yr^{-1}, respectively. Knip *et al.,* (2012) also estimated M = 0.05 yr^{-1} for adult spot-tail sharks, *C. sorrah* during the same period.

Estimation of fishing mortality

The age of each tagged shark was estimated from its length using the inverse function of the von Bertalanffy growth function available for each of the four species (Tillett *et al.*, 2011; Geraghty *et al.*, 2013a; Harry *et al.*, 2013). The age of recaptured sharks was their age at tagging, plus the duration at liberty. To allow for mixing of newly tagged individuals, only recaptures at liberty >30 days were included in the analysis. Recaptures were also only included from the commercial and recreational sectors. Any recaptures made by researchers, and small number of recaptures reported by the Queensland Shark Control Program were excluded.

Two broad geographic regions were defined for statistical analysis coinciding with the quota reporting regions defined and used by QDAFF. The GBR region included all waters within the GBRMP, while the SEQ region included all waters south of the GBRMP and north of the Tweed boarder. Analysis of *C. amboinensis, C. sorrah* and *C. tilstoni* was restricted to samples tagged and recaptured in the GBRMP region, while analysis of *C. brevipinna* was restricted to the SEQ region. For one species, *C. tilstoni*, it was not possible to distinguish between a morphologically identical congener, the common blacktip, *C. limbatus,* with which the species hybridises (Morgan *et al.*, 2012). The implications of this are treated in the discussion.

The estimated number of recaptures of tagged sharks, $\hat{C}_{x,t}$, of age, *x,* during each month, *t,* of the study was calculated as

$$\hat{C}_{x,t} = \frac{C_{x,t}}{D_{i,T}},$$

where $C_{x,t}$ is the number of sharks that were recaptured, and $D_{i,T}$ is the non-reporting rate in region *i,* during year *T.* The number of tagged sharks of age *x* estimated to be in the population at the start of month *t,* $n_{x,t}$, was calculated as

$$n_{x,t} = \left(n_{x,t-1} - \hat{C}_{x,t-1}\right)e^{-(M+S)/12} + R_{x,t-1},$$

where *M* is the rate of natural mortality (estimated using the methods described above), *S*, is the instantaneous annual tag shedding rate, and $R_{x,t-1}$is the number of sharks of age, *x,* tagged in month *t-1*. Tag shedding for all species was estimated at 0.0358 yr-1 based on experimental work on juvenile *C. obscurus* using the same type of tags (Simpfendorfer, 1999). For most study species parturition occurs just prior to the monsoonal wet-season during December to January, so tagged individuals were assumed to move from age group *x* to *x*+1 on January 1st each year.

After estimating $n_{x,t}$,the Baranov catch equation (Ricker, 1975)

$$\hat{C}_{x,t} = \frac{F_{x,t}}{Z_{x,t}} n_{x,t}(1 - e^{-Z_{x,t}}),$$

was solved using the Optimize routine in R to obtain a point estimate of the instantaneous monthly rate of fishing mortality $F_{x,t}$. In this equation $Z_{x,t}$ is the instantaneous rate of total mortality on age group, *x,* in month, *t,* and is equal to$F_{x,t} + M/12$. Monthly values of $F_{x,t}$ were multiplied by 12 and averaged to obtain an estimate of the annual instantaneous rate of fishing mortality during each year of the study. Because tagged individuals were typically only from a small number of age classes and recapture rates were low, age classes were pooled and excluded on a species-by-species basis.

Demographic analysis

Demographic analysis was carried out using life tables based on the discrete Euler-Lotka equation (Stearns, 1992):

$$\sum_{x=0}^{\omega} l_x e^{-r} m_x = 1$$

where ω is maximum age, l_x is the proportion of female sharks surviving to age *x, r* is the intrinsic rate of population increase, and $m_x$is the annual number of females produced by females of age *x.* Age specific survival schedules were calculated as:

$$l_x = l_{x-1} e^{-F_{x-1}} e^{-M}.$$

Annual female fecundity was calculated as:

$$m_x = \begin{cases} 0 & x < \alpha \\ \dfrac{f}{2F} & x \geq \alpha \end{cases}$$

where *f* is average female fecundity, *F* is the annual frequency of reproduction, and total reproductive output was divided by 2, assuming a 1:1 sex-ratio. For each estimate of natural mortality, *M,* the intrinsic rate of increase, *r*, was solved, both with and without fishing mortality to indicate if populations would be capable of replenishing themselves.

All life history parameters required for mortality estimation and demographic analysis were taken from published studies on species in Queensland and northern Australia (Stevens and McLoughlin, 1991; Sumpton *et al.*, 2010; Tillett *et al.*, 2011; Geraghty *et al.*, 2013a; Harry *et al.*, 2013).

Opportunistic growth and dispersion data

The tag recapture data collected for estimating fishing mortality also permitted an exploration of any dispersal patterns as well as an assessment of *in situ* growth rates.

Accurate growth data is often not available for fishery exploited shark species so the opportunistic collection of data is often beneficial for our knowledge. Observed growth increment data from in situ sharks can be modelled to estimate growth rates (eg Simpfendorfer 2000, Simpfendorfer *et al* 2002), or can be useful for validating growth models generated from traditional vertebral analysis (eg Chin *et al* 2013). To encourage and expedite the collection of growth increment data from recaptured tagged sharks, we contacted a number of fishers who operated within areas of high tag returns to explore opportunities for these fishers to collect accurate length information. In addition, when fishers called the tag hotline to report recaptures, those fishers were asked to measure recaptures where at all possible in the future and report those measured lengths. Supplemental growth increment data was also collected via fishery independent research.

The same tag-recapture data also allowed for some characteristics of dispersion to be investigated. Mean time at liberty and distance travelled were calculated for each species. A circular mean was calculated for dispersal direction. Linear regression analyses explored possible relationships between time at liberty and distance travelled for each species. Vectors (direction and distance) for each recaptured animal were plotted by species on circular-linear plots. Hotelling's test was done using Oriana for each species to test for directionality.

Results

Fishery characteristics

Shark catch within the ECIFFF varies spatially between years, however a general trend remains where most catch is reported close to the major regional centres along the Queensland east coast. Figure 5 demonstrates the spatial distribution of ECIFFF shark catch in recent years, though the “less than 5 boat rule” (for business privacy, when fewer than 5 boats report catch from within one reporting grid, the details of that catch are not available) precludes a complete assessment of spatial catch trends at the 30 x 30 nmile grid square level. However grouping by latitude provides a slightly coarser level of catch description. Tag deployment efforts focused on the regional centres (listed north to south) of Cairns, Townsville, Mackay, Rockhampton, Bundaberg and Sunshine Coast.

Species identification problems and/or reluctance to correctly report are still commonplace in the ECIFFF despite recent efforts to improve the species specific data reporting of the shark. Figure 6 demonstrates the increased capacity and improved fisher attempts to report species specific information, with fishers reporting >25 species or species groups in both the northern and southern fisheries in recent years. However, the species components recorded by fishers (Table 1) appears at odds with validated species community and dominance patterns by Harry et al (2011)(Table 2). In addition, for each of the three years of logbook data summarised in Table 1, in both the northern and southern regions between 10-20% of landed catches remain classified as simply whaler shark (categories used include “a whaler shark”; “Shark – whaler unspecified” and “shark unspecified”). Accordingly, the species specific information contained in the shark specific logbook of the ECIFFF is likely to be of limited use.

Despite the improved capacity for fishers to report species specific catches accurately within the new shark specific logbook, the summary of reported landed catches is not validated by known independently verified landed catches.

Figure 5 The distribution of recent shark catch taken by commercial fishers in the ECIFFF as mapped to the 30 x 30 nmile grid squares and by latitude. Due to confidentiality, catch data are only available for those grid squares where at least 5 boats reported catch. Subsequently, catch was also summarised at the latitude level by grouping grid data within single bands of latitude. Catch by latitude is listed on the right side of each panel.

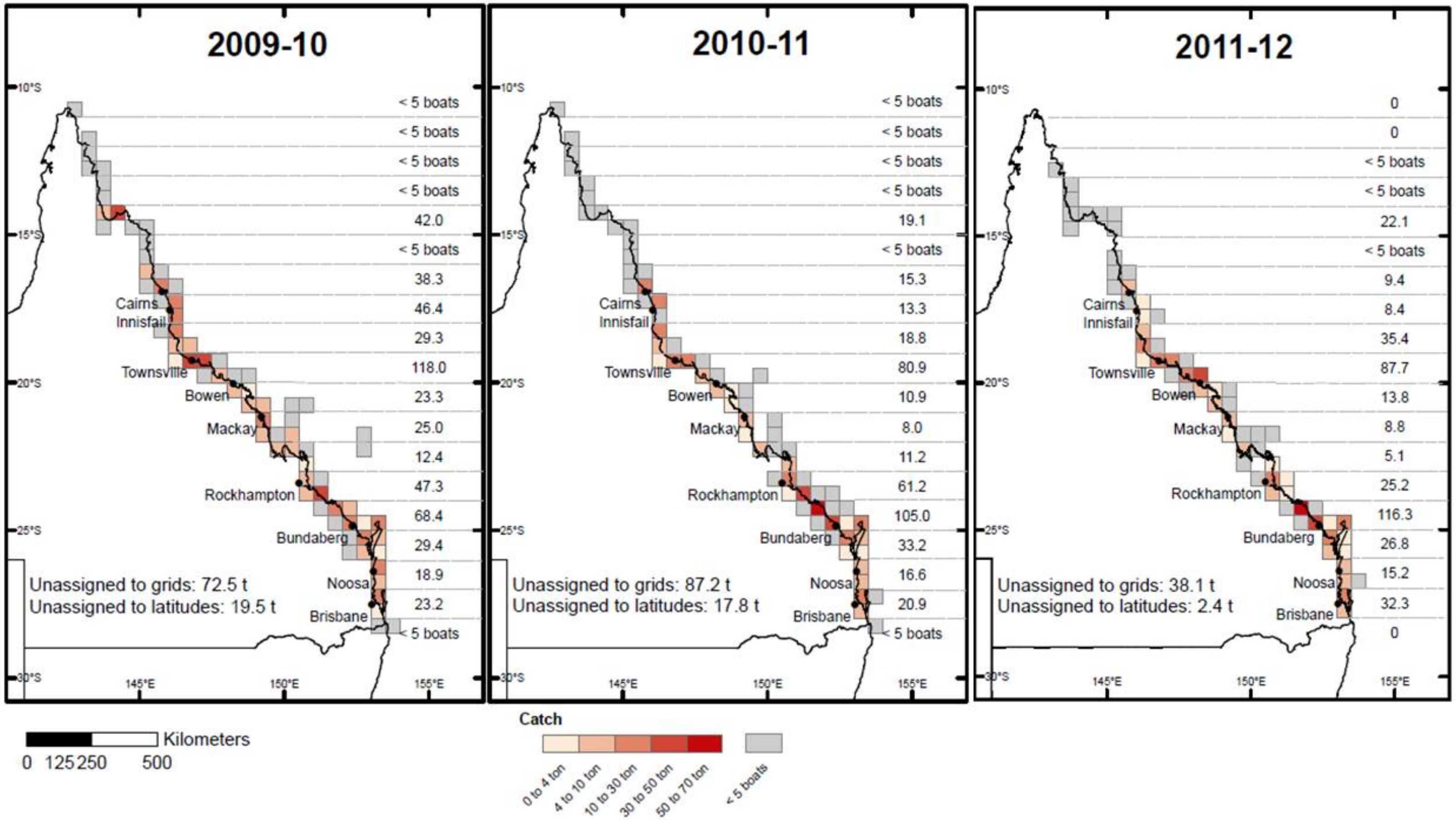


Figure 6 The number of shark species and /or species groups able to be reported against in the ECIFFF logbooks.

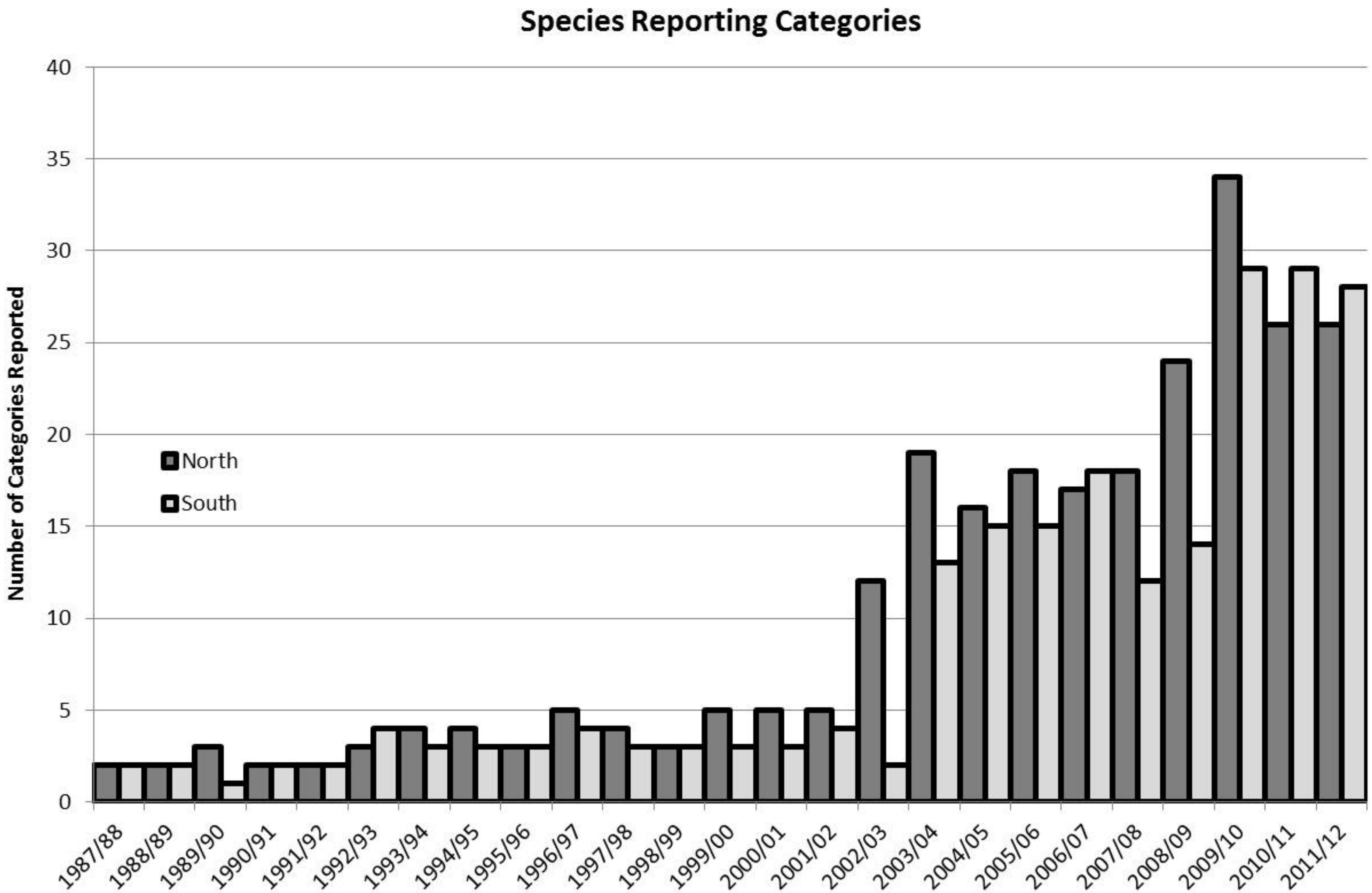


Table 1 ECIFFF shark catches as reported in the shark logbook summarised for the north and south regions.

		NORTH			
Species	**2009/10**	**Species**	**2010/11**	**Species**	**2011/12**
Shark – blacktip whaler & graceful	34.2	Shark – blacktip whaler & graceful	44.9	Shark – blacktip whaler & graceful	45.9
Hammerhead shark	13.3	Hammerhead shark	15.5	Hammerhead shark	12.9
Shark – whaler unspecified	12.9	[a whaler shark]	8.8	Pigeye & bull sharks	12.1
[a whaler shark]	5.4	Shark – whaler unspecified	8.8	Shark – whaler unspecified	8.7
Blacktip reef shark	5.3	Pigeye & bull sharks	8.0	Shark – sorrah	4.6
Shark – tiger	4.8	Shark – scalloped hammerhead	2.9	[a whaler shark]	4.0
Shark – scalloped hammerhead	4.2	Shark – spinner	2.2	Creek whaler	3.2
Shark – sorrah	4.2	Milk, Sharpnose, Hardnose shark	1.7	Shark – spinner	1.6
Shark – unspecified	3.5	Creek whaler	1.6	Shark – scalloped hammerhead	1.3
Shark – spinner	2.8	Shark - tiger	1.3	Blacktip reef shark	1.2

		SOUTH			
Species	**2009/10**	**Species**	**2010/11**	**Species**	**2011/12**
Shark – spinner	26.0	Shark – spinner	31.7	Shark – blacktip whaler & graceful	25.2
Shark – blacktip whaler & graceful	24.8	Shark – blacktip whaler & graceful	23.3	Shark – spinner	20.4
Shark – whaler unspecified	10.5	Milk, Sharpnose, Hardnose shark	10.6	Hammerhead shark	11.2
Milk, Sharpnose, Hardnose shark	8.2	Pigeye & bull sharks	8.5	Milk, Sharpnose, Hardnose shark	9.1
Pigeye & bull sharks	6.4	Shark – whaler unspecified	5.8	Shark – whaler unspecified	8.5
Hammerhead shark	4.5	Hammerhead shark	4.4	Pigeye & bull sharks	8.3
Blacktip reef shark	4.5	Shark - unspecified	2.9	Shark – snaggletooth & weasel	4.1
Shark – sorrah	3.0	Shark – scalloped hammerhead	2.4	Shark – scalloped hammerhead	3.8
Shark – snaggletooth & weasel	2.9	[a whaler shark]	2.4	Shark – sorrah	2.3
[a whaler shark]	2.4	Shark – snaggletooth & weasel	2.4	Shark - unspecified	1.7

Table 2 Catch per unit effort and catch composition of carcharhiniform sharks caught by the East Coast Inshore Finfish Fishery within the boundaries of the Great Barrier Reef World Heritage Area. Species are sorted by the proportion of total observed catch by number. Data are from a total of 126 observer trips.

Species	**Mean size (mm)**	**Mean weight (kg)**	**Number (%)**	**Weight (%)**
Carcharhinus tilstoni/C. limbatus	910	4.1	28.2	30.6
Carcharhinus sorrah	963	4.7	16.6	20.5
Sphyrna lewini	809	2.3	11.4	6.8
Rhizoprionodon acutus	746	1.8	7.8	3.8
Rhizoprionodon taylori	623	1.1	6.9	1.9
Carcharhinus brevipinna	943	3.7	6.7	6.5
Carcharhinus dussumieri	829	3.0	4.8	2.9
Carcharhinus macloti	836	2.6	3.7	2.5
Carcharhinus leucus	879	4.2	2.7	3.7
Sphyrna mokorran	1563	15.5	2.4	9.7
Carcharhinus ambionensis	955	5.9	2.4	3.9
Carcharhinus melanopterus	753	2.5	2.4	1.6
Carcharhinus fitzroyensis	881	4.0	1.4	1.5
Negaprion acutidens	891	3.1	0.7	0.6
Hemipristis elongate	1318	9.7	0.5	1.2
Galeocerdo cuvier	1283	8.8	0.4	1.0
Eusphyra blochii	1363	8.3	0.4	0.9
Hemigaleus australiensis	940	3.1	0.3	0.3
Carcharhinus cautus	955	5.7	0.1	0.2
Carcharhinus altimus	839	2.3	0.2	0.1
Loxodon macrohinus	872	2.3	<0.1	<0.1

Tag deployment

Tags were deployed by project staff, in-kind contributions of allied research and monitoring projects as well as JCU post-graduate students. A total of 5,563 sharks were tagged and released.

The more common species tagged (Table 3) corresponded closely with the known dominant species within the ECIFFF (Table 2; Tobin et al 2010, Harry et al 2011). Each of the seven most common tag-released species - the undifferentiated blacktip complex of *Carcharhinus limbatus* and *C. tilstoni*; spinner shark *C. brevipinna*, spot-tail shark *C. sorrah*; pigeye shark *C. ambionensis*; Australian sharpnose shark *Rhizoprionodon taylori*; milk shark *R. acutus* and scalloped hammerhead (*Shyrna lewini*) – contributed at least 5% of the total tag sample. A notable difference in species number and diversity was present between Great Barrier Reef (GBR) and south east Queensland (SEQ) waters with more than twice as many species in GBR waters (32 species) compared with SEQ waters (15 species). Diversity was considerably higher in the tag sample of GBR waters (Shannon Wiener index = 2.55) as compared with SEQ waters (Shannon Wiener index = 0.87). The SEQ tag sample was clearly dominated by a single species, the spinner shark *C. brevipinna*; while the GBR tag sample was dominated by four species Australian sharpnose shark *Rhizoprionodon taylori*, undifferentiated blacktip shark *C. tilstoni/limbatus*, spot-tail shark *C. sorrah* and pigeye shark *C. ambionensis*.

Table 3: Numbers and species diversity of sharks tagged by the current and other concurrent Fishing and Fisheries Research Centre (FFRC) projects.

Species	Common name	GBR	SEQ
Rhizoprionodon taylori	Australian sharpnose shark	967	13
Carcharhinus tilstoni/limbatus	Undifferentiated blacktip shark	905	17
Carcharhinus brevipinna	Spinner shark	30	643
Carcharhinus sorrah	Spot-tail shark	432	26
Carcharhinus amboinensis	Pigeye shark	388	
Rhizoprionodon acutus	Milk shark	381	18
Sphyrna lewini	Scalloped hammerhead shark	216	80
Carcharhinus melanopterus	Blacktip reef shark	210	
Rhynchobatus australiae	Whitespotted guitarfish	183	
Glaucostegus typus	Giant shovelnose ray	177	
Carcharhinus fitzroyensis	Creek whaler	157	1
Carcharhinus coatesi	White cheek shark	127	1
Anoxypristis cuspidata	Narrow sawfish	83	
Sphyrna mokarran	Great hammerhead shark	77	
Carcharhinus macloti	Hardnose shark	64	
Carcharhinus leucas	Bull shark	61	1
Carcharhinus cautus	Nervous shark	43	
Chiloscyllium punctatum	Brown banded cat shark	37	4
Stegostoma fasciatum	Leopard shark	30	
Carcharhinus amblyrhynchos	Grey reef shark	28	
Hemigaleus australiensis	Australian weasel shark	14	5
Hemipristis elongata	Fossil shark	14	1
Eusphyra blochii	Winghead shark	14	
Galeocerdo cuvier	Tiger shark	13	
Nebrius ferrugineus	Tawny nurse shark	9	
Triaenodon obesus	White tip reef shark	8	
Negaprion acutidens	Lemon shark	7	
Loxodon macrorhinus	Sliteye shark	1	1
Carcharhinus plumbeus	Sandbar shark	1	1
Carcharhinus tilstoni	Australian blacktip shark	1	
Carcharhinus albimarginatus	Silver tip shark	1	
Carcharhinus obscurus	Dusky shark		1
		4752	811
		5,563	

Recaptured sharks

Tagged sharks were recaptured from all regional locations where deployments occurred (Figure 7). Harvest rate varied among species, and were highest for some of the infrequently tagged species (Table 4). For example a cohort of young-of-the-year bull sharks was opportunistically tagged in the Fitzroy River in February 2009. The resulting high harvest rate is likely due to the pulse of fishing pressure that occurs each February when the barramundi season opens. Conversely, some of the more commonly tagged sharks such as the smaller milk and Australian sharpnose sharks, had very low harvest rates.

Although a total of 224 tagged sharks were reported as being recaptured by commercial and recreational fishers, not all of these recaptures were applicable to the mortality estimation exercise. To allow for mixing of tagged individuals throughout the population, only recaptures at liberty >30 days (n = 163) were included in the analysis. Recaptures were also only included from the commercial and recreational sectors. Any recaptures made by researchers, and small number of recaptures reported by the Queensland Shark Control Program were excluded.

Figure 7. Tag deployment and recapture locations by 30 x 30 nautical mile grids of latitude and longitude.

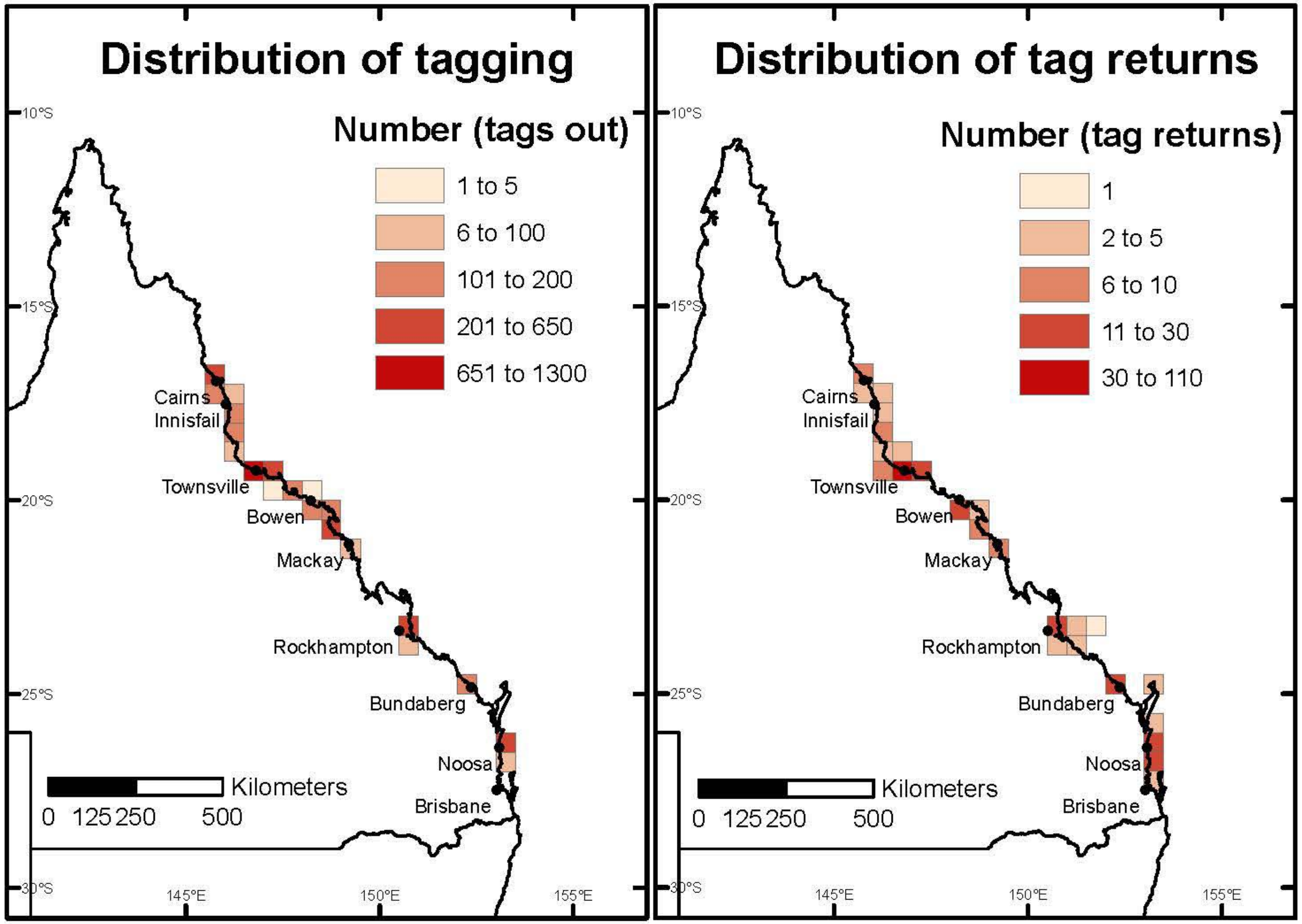


Table 4: Tag deployment, recapture numbers and harvest rate for all species across the period 2008-2012. Tagged species with no recaptures have not been included.

Species	Tags	Recaptures	Recapture rate
Bull shark	62	13	0.21
Lemon shark	7	1	0.14
Pigeye shark	388	38	0.10
Spinner shark	673	63	0.09
Winghead shark	14	1	0.07
Undifferentiated blacktip shark	922	51	0.06
Creek whaler	158	7	0.04
Great hammerhead shark	77	3	0.04
Scalloped hammerhead shark	296	10	0.03
Hardnose shark	64	2	0.03
Spot-tail shark	458	12	0.03
Brown banded cat shark	41	1	0.02
Blacktip reef shark	210	5	0.02
Milk shark	399	7	0.02
Narrow sawfish	83	1	0.01
Giant shovelnose ray	177	2	0.01
White cheek shark	128	1	0.01
Whitespotted guitarfish	183	1	0.01
Australian sharpnose shark	980	5	0.01

Mortality Estimation

Mortality estimation (monthly time-step)

For four species – undifferentiated blacktip (*Carcharhinus limbatus/*tilstoni), spot tail (*C. sorrah*), spinner (*C. brevipinna*) and pigeye (*C. amboinensis*) sharks – sufficient recapture data was available to complete mortality estimates using monthly time-steps. A total of 2512 sharks of the four species were tagged and released between 2008 and 2012 (Table 5, Figure 8). Overall 9.3% of tagged *C. amboinensis* were recaptured, 3.9% of *C. brevipinna,* 1.4% of *C. sorrah*, and 3.4% of *C. tilstoni*. Tag-reporting rates by commercial fishers in the GBRMP were estimated to be 23.7% for 2011 and 28.5% for 2012 compared to an estimated 31.1% and 40.8% for fishers in SEQ in 2011 and 2012, respectively (Table 6). After adjusting reporting rates for tag non-reporting in the commercial sector, an estimated 28.9% of tagged *C. amboinensis* were recaptured*,* 9.0% of *C. brevipinna*, 4.5% of *C. sorrah* and 13.1% of *C. tilstoni*. For *C. amboinensis* and *C. brevipinna,* recaptures by the recreational sector made up a 25% and 28% of observed recaptures, respectively. Only a single recreational recapture was made of each of the other two species.

All tagged and recaptured *C. amboinensis* were likely to have been juveniles (Figure 9). Furthermore, most were young of the year (YOY) 0–1 year olds, although a small number as old as 12 were tagged. The age structure of recaptures was similar to that of tagged sharks, with predominantly 0–1 year olds caught, interspersed with a small number of older individuals. The age-structure of tagged *C. tilstoni* included both juveniles and adults between 0–17 years. Recaptures were mostly of 0–1 year olds and no sharks >8 were recaptured. The age-structure of tagged *C. brevipinna* was less informative. Almost all *C. brevipinna* were YOY with a small number of 1 and 2 year olds, and since tagging only occurred during 2011 and 2012, recaptures were accordingly comprised of 0–2 year-old fish. Most tagged *C. sorrah* were likely to have been adults and were close to or exceeding the species' published asymptotic length(s). As such, estimated ages were unlikely to be particularly accurate. Although some YOY *C. sorrah* were tagged and recaptured, these were exceptions since most individuals did not appear to recruit to the fishery until around 1–2 years. In the absence of selectivity information, all ages (0–14) were treated as fully selected into the fishery.

Table 5 Summary of annual tag deployments and recaptures separated by commercial and recreational sectors. Values of estimated commercial recaptures were obtained by dividing observed values by the estimated annual reporting rate of commercial fishers. Only recaptures made after 30 days of deployment are included.

Species	Year	Tags out	Recaptures			
			Commercial		Recreational	Total
			Observed	Estimated		
C. amboinensis	2008	27	2	8.4	1	11.4
	2009	54	2	8.4	0	10.4
	2010	39	2	8.4	2	12.4
	2011	60	6	25.3	1	32.3
	2012	208	15	52.6	5	72.6
	Total	388	27	103.3	9	139.3
C. brevipinna	2011	556	9	28.9	5	42.9
	2012	87	9	22.1	2	33.1
	Total	643	18	51.0	7	76.0
C. sorrah	2008	60	0	0	0	0.0
	2009	132	0	0	0	0.0
	2010	33	0	0	0	0.0
	2011	104	1	4.2	1	6.2
	2012	103	4	14.0	0	18.0
	Total	432	5	18.3	1	24.3
*C. tilstoni**	2008	68	1	4.2	0	5.2
	2009	74	2	8.4	0	10.4
	2010	135	2	8.4	0	10.4
	2011	415	12	50.6	1	63.6
	2012	213	13	45.6	0	58.6
	Total	905	30	117.3	1	148.3

* Assuming all 'undifferentiated blacktip' tags deployed were *C. tilstoni*

Table 6. Data used to estimate non-reporting rates across two years and two regions. Reliable returns were from fishers known to report all of their recaptures, unreliable returns were from fishers known to report some of their recaptures and unassigned returns were from unknown fishers.

2011	GBR				SEQ			
	Tags returned	Percent of catch	Catch (t)	Expected tags	Tags returned	Percent of catch	Catch (t)	Expected tags
Reliable returns	25	11.2	35.6	25	15	23.3	29.1	15
Unreliable returns	4	8.4	26.7	19	0	8.7	10.9	6
Unassigned returns	24	80.4	255.2	179	5	68.0	84.9	44
Totals	53	100	317.4	223	20	100.0	124.9	64
Tag return rate (tags/ton)*	0.70				0.52			
Percent tags returned	23.7				31.1			

2012	**GBR**				**SEQ**			
	Tags returned	Percent of catch	Catch (t)	Expected tags	Tags returned	Percent of catch	Catch (t)	Expected tags
Reliable returns	23	11.1	25.7	23	18	29.4	36.8	18
Unreliable returns	16	13.5	31.2	28	0	5.7	7.1	3
Unassigned returns	20	75.4	174.3	156	7	64.9	81.2	40
Totals	59	100	231.2	207	25	100.0	125.2	61
Tag return rate (tags/ton)	0.90				0.49			
Percent tags returned	28.5				40.8			

Figure 8 Distribution of tag deployments and recaptures for the four focal species

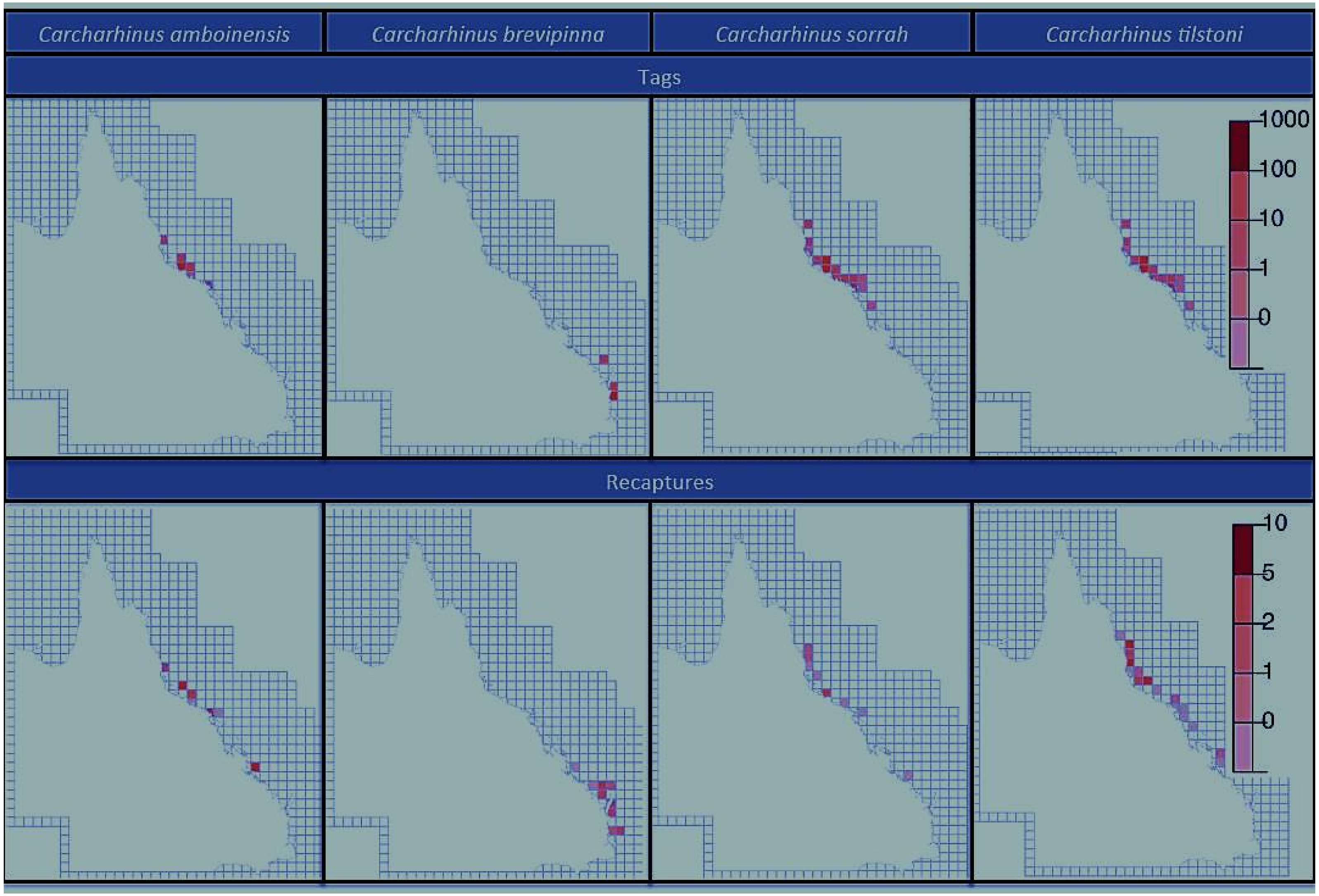
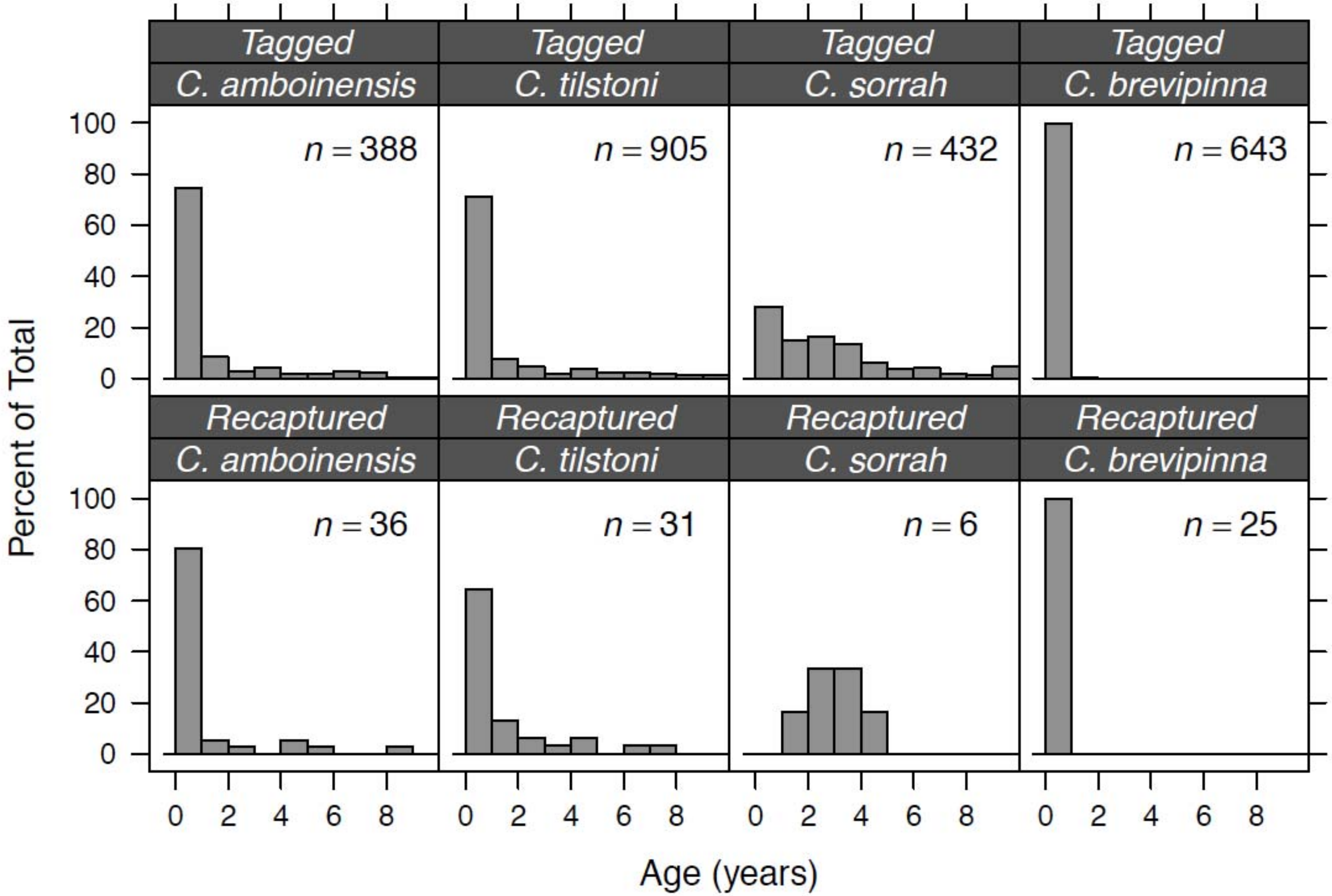


Figure 9. Estimated age composition of tagged species



Estimation of natural mortality

Overall, variability between mortality estimates was substantial, highlighting the inherent uncertainty in this parameter. The first Jensen method based on age at maturity tended to give highest values of *M*, with the Hoenig and Jensen 2 method both giving lower values (Table 7). Intra-species variation was greatest for *C. sorrah* where *M* varied by more than an order of magnitude from 0.05–0.73 yr^{-1}. *C. amboinensis* had the lowest variability. For both *C. sorrah* and *C. amboinensis* empirical values of *M* were far less than values predicted by life history theory, potentially indicating that indirect mortality estimators were inaccurate, or that survival was exceptionally high during Knip's (2012) two year study.

Table 7 Life history parameters used in demographic analysis and to estimate natural mortality, *M* (yr^{-1}). Mean fecundity (*f*), frequency of reproduction (F), is age at maturity (*α*), maximum age (ω), and the Von Bertalanffy growth rate constant *(K).*

						M			
Species	*f*	F	*α*	*ω*	*K*	*Jensen 1*	*Hoenig*	*Jensen 2*	*Empirical*
Carcharhinus sorrah	3.04	1	2.27	14	0.336	0.73	0.31	0.50	0.05
Carcharhinus tilstoni	3.67	1	5.22	20	0.089	0.32	0.22	0.13	
Carcharhinus amboinensis	9	2	13	30	0.085	0.13	0.14	0.13	0.05
Carcharhinus brevipinna	9.5	2	7.14	31	0.124	0.23	0.14	0.19	

Estimation of fishing mortality

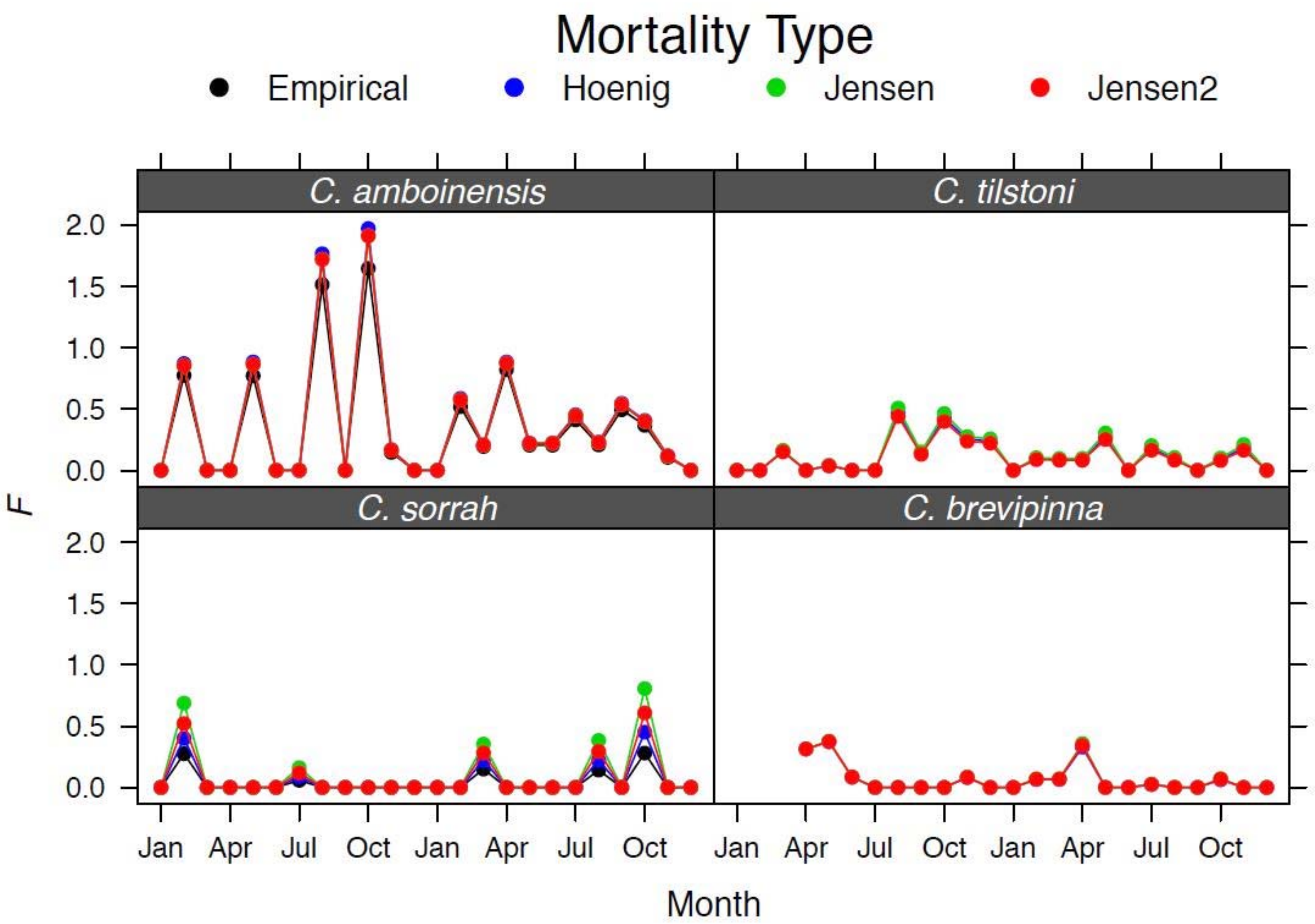
Due to the relatively small sample sizes, it was not possible to generate meaningful estimates of *F* for individual age classes as originally intended. As such, the full range of recaptured age-classes was pooled for each species and a single value of *F* generated for each study year: *C. amboinensis,* 0–9 years; *C. brevipinna,* 0–2 years*; C. sorrah,* 0–14 years*;* and *C. tilstoni* 0–8 years. *F* estimates were by far the greatest for *C. amboinensis* ranging from 0.32–0.36 yr^{-1} for the commercial sector in 2011/12, and 0.35–0.40 for both the commercial and recreational sectors combined (Table 8, Figure 10). *F* estimates were also substantial for *C. tilstoni*, ranging from 0.11-0.13 yr^{-1} for 2011/12 combined, however given there was only a single recreational recapture, including this sector had little impact on the results. Under most natural mortality scenarios, *F* was fairly low for both *C. brevipinna* and *C. sorrah,* ranging from 0.04–0.10*.* Recreational fishing mortality was a substantial component of total fishing mortality for *C. brevipinna,* although not for *C. sorrah.*

Table 8 Estimated fishing mortality, *F,* for four whaler sharks in the Great Barrier Reef Marine Park and Southeast Queensland for 2011, 2012 and both years combined under a range of assumptions about natural mortality. *F* was estimated for both the commercial and recreational fishing sectors combined (C & R) and the commercial sector only (C). Age is the range of ages for which *F* was estimated for.

Species	Sector	Ages (yrs)	*M* type	*F* (yr^{-1}) 2011	s.e.	2012	s.e.	2011/12	s.e.
Carcharhinus amboinensis	C & R	0-9	Jensen	0.46	0.21	0.32	0.07	0.39	0.11
	C & R	0-9	Hoenig	0.47	0.21	0.32	0.08	0.40	0.11
	C & R	0-9	Jensen2	0.46	0.21	0.32	0.07	0.39	0.11
	C & R	0-9	Empirical	0.41	0.18	0.30	0.07	0.35	0.09
	C	0-9	Jensen	0.43	0.20	0.28	0.07	0.36	0.10
	C	0-9	Hoenig	0.44	0.21	0.29	0.07	0.36	0.11
	C	0-9	Jensen2	0.43	0.20	0.28	0.07	0.36	0.10
	C	0-9	Empirical	0.38	0.17	0.26	0.07	0.32	0.09
Carcharhinus brevipinna	C & R	0-2	Jensen	0.10	0.05	0.05	0.03	0.07	0.03
	C & R	0-2	Hoenig	0.10	0.05	0.05	0.03	0.07	0.03
	C & R	0-2	Jensen2	0.10	0.05	0.05	0.03	0.07	0.03
	C	0-2	Jensen	0.08	0.04	0.05	0.03	0.06	0.02
	C	0-2	Hoenig	0.08	0.04	0.04	0.03	0.06	0.02
	C	0-2	Jensen2	0.08	0.04	0.04	0.03	0.06	0.02
Carcharhinus sorrah	C & R	0-14	Jensen	0.07	0.06	0.13	0.07	0.10	0.05
	C & R	0-14	Hoenig	0.04	0.03	0.08	0.04	0.06	0.03
	C & R	0-14	Jensen2	0.05	0.04	0.10	0.06	0.08	0.04
	C & R	0-14	Empirical	0.03	0.02	0.05	0.03	0.04	0.02
	C	0-14	Jensen	0.06	0.06	0.13	0.07	0.09	0.05
	C	0-14	Hoenig	0.03	0.03	0.08	0.04	0.05	0.03
	C	0-14	Jensen2	0.04	0.04	0.10	0.06	0.07	0.04
	C	0-14	Empirical	0.02	0.02	0.05	0.03	0.04	0.02
*Carcharhinus tilstoni**	C & R	0-8	Jensen	0.16	0.05	0.10	0.03	0.13	0.03
	C & R	0-8	Hoenig	0.14	0.05	0.09	0.03	0.12	0.03
	C & R	0-8	Jensen2	0.14	0.05	0.08	0.02	0.11	0.03
	C	0-8	Jensen	0.15	0.05	0.10	0.03	0.13	0.03
	C	0-8	Hoenig	0.14	0.05	0.09	0.03	0.12	0.03
	C	0-8	Jensen2	0.13	0.05	0.08	0.02	0.11	0.03

* Assuming all 'undentified blacktip' tags deployed were *C. tilstoni*

Figure 10. Estimates of the annual rate of fishing mortality, F, on four species of whaler sharks during 2011 and 2012. For each month during the study F was calculated based on the numbers of recaptured sharks in that month under four different types of natural mortality, M. F was multiplied by 12 to give the annual estimate.



Demographic analysis

Base estimates of the intrinsic rate of population increase, *r,* varied substantially both among and within species when different mortality estimates were considered (Table 9). Three methods gave *r* estimates that were close to zero or negative in the absence of fishing; the Jensen and Jensen 2 methods for *C. sorrah,* and the Jensen method for *C. tilstoni*. Assuming both species have viable, self-recruiting populations within the GBRMP, these particular results seemed unrealistic and weren't considered further. The unrealistic *r* estimates could have been caused by inaccurate biological parameters or inaccurate tag recapture estimates.

Base estimates of *r* for *C. amboinensis* were similar for all three indirect mortality estimates, ranging from 0.05–0.07 yr^{-1} and indicative of a species with a relatively low biological productivity (Table 9). All three suggested that the rate of *F* experienced during 2011 and 2012 would likely lead result in a decreasing population trend ($r<0$). In contrast, base estimates of *r* using empirical values of *M* indicated much higher productivity (0.19 yr^{-1}), and suggested that the rate of *F* experienced in both years was sustainable.

Base estimates of *r* for *C. brevipinna* were suggestive of a species also with low to moderate productivity (0.05–0.14yr^{-1}). Since *F* was only applied to the first three age classes and was relatively low, all demographic analyses indicated that fishing levels would likely be sustainable for this species.

For *C. sorrah,* the two analyses that gave biologically realistic results were indicative of a species with relatively higher biological productivity (r = 0.16–0.47yr^{-1}). Both analyses suggested that the rates of *F* experienced during 2011 and 2012 were well within the sustainable range for this species.

For *C. tilstoni* the two feasible analyses were indicative of a moderately productive species (r = 0.10–0.18yr^{-1}). Both analyses suggested that the rate of *F* would lead to either a stable or increasing population, although using the Hoenig method the 2011 rate of *F* may have been unsustainable.

Table 9 Estimated values of intrinsic rate of natural increase, *r,* from demographic analysis. Values are for no fishing (base), and estimated fishing mortality during 2011, 2012 and both years combined under a range of assumptions about natural mortality.

Species	Sector	*M* type	*r* (yr^{-1})			
			Base	2011	2012	2011/12
Carcharhinus amboinensis	C & R	Jensen	0.07	-0.15	-0.09	-0.12
	C & R	Hoenig	0.05	-0.17	-0.11	-0.14
	C & R	Jensen2	0.07	-0.15	-0.09	-0.12
	C & R	Empirical	0.19	0.00	0.05	0.03
	C	Jensen	0.07	-0.13	-0.07	-0.10
	C	Hoenig	0.05	-0.16	-0.09	-0.12
	C	Jensen2	0.07	-0.14	-0.07	-0.10
	C	Empirical	0.19	0.01	0.07	0.04
Carcharhinus brevipinna	C & R	Jensen	0.05	0.03	0.04	0.04
	C & R	Hoenig	0.14	0.13	0.14	0.13
	C & R	Jensen2	0.10	0.08	0.09	0.08
	C	Jensen	0.05	0.04	0.04	0.04
	C	Hoenig	0.14	0.13	0.14	0.13
	C	Jensen2	0.10	0.08	0.09	0.09
Carcharhinus sorrah	C & R	Jensen	-0.26	-0.33	-0.39	-0.36
	C & R	Hoenig	0.16	0.12	0.08	0.10
	C & R	Jensen2	-0.04	-0.09	-0.14	-0.11
	C & R	Empirical	0.47	0.44	0.42	0.43
	C	Jensen	-0.26	-0.32	-0.39	-0.35
	C	Hoenig	0.16	0.13	0.08	0.11
	C	Jensen2	-0.04	-0.08	-0.14	-0.11
	C	Empirical	0.47	0.44	0.42	0.43
Carcharhinus tilstoni	C & R	Jensen	0.00	-0.13	-0.08	-0.10
	C & R	Hoenig	0.10	-0.02	0.03	0.00
	C & R	Jensen2	0.18	0.07	0.11	0.09
	C	Jensen	0.00	-0.12	-0.08	-0.10
	C	Hoenig	0.10	-0.01	0.03	0.01
	C	Jensen2	0.18	0.08	0.11	0.09

Mortality estimation (annual time-step) of secondary species

For both Australian sharpnose shark, *Rhizoprionodon taylori,* and milk shark, *R. acutus,* a large number of tags were deployed in the GBRMP, however only a very small number were recaptured (Table 10). This suggests that although estimates of *F* obtained are probably highly imprecise, they are also probably very low (<0.05 yr^{-1}). Given the extremely fast growth and low ages at maturity of these species (Simpfendorfer, 1993; Harry *et al.*, 2010), the low rates of *F* during 2011 and 2012 probably had a minimal or negligible effect on population sizes.

Estimates of *F* for three other species of large coastal sharks, the bull shark, *Carcharhinus leucas,* the scalloped hammerhead, *Sphyrna lewini,* and the great hammerhead, *S. mokarran* were all relatively high (0.17–0.22)(Table 10). This is consistent with the findings for *C. amboinensis* that suggest that *F* may still be relatively high on some age-classes (mostly juveniles) of large coastal sharks in the GBRMP and SEQ, despite the fact that they aren't typically or actively targeted by shark fishers of the ECIFFF. For *C. leucas* the estimates are likely biased by the pulse fishing effort that occurs during barramundi season opening.

For the creek whaler, *C. fitzroyensis,* estimates of *F* were moderate, and similar to that of the similar-sized Australian blacktip, *C. tilstoni* (Table 10). Again, although this species is not a preferred target of the shark fishers of the ECIFFF, the species appears to prefer habitats similar to targeted species and is thus encountered as a byproduct species.

Notably, estimating *F* on an annual time-step instead of monthly time-step gave similar results in most cases for the four species for which both time-step estimates were completed. In all instances annual *F* was lower than monthly *F,* and values differed by between 1% and 22%.

Table 10. Estimates of *F* for 10 species of sharks based on number of tag returns in 2011 and 2012. ω is maximum age in years used to estimate natural mortality, *M*. *F*-comparison is the value obtained using the full analysis with a monthly time-step for the four main study species.

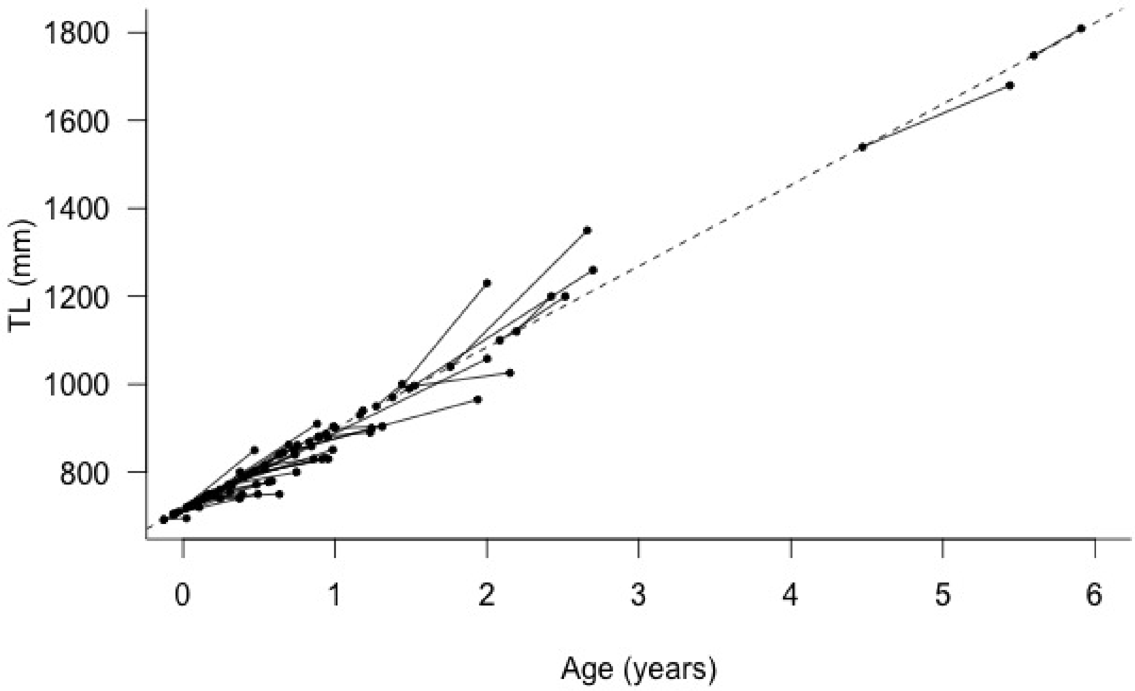
Species	Region	ω	Tags	Recaptures		*F*			*F*-comparison (monthly analysis)
				Observed	Adjusted	2011	2012	Average	
Carcharhinus amboinensis	GBRMP	30	388	27	103.3	0.29	0.27	0.28	0.36
Carcharhinus fitzroyensis	GBRMP	13	145	5	19.7	0.09	0.10	0.10	
Carcharhinus leucas	GBRMP	27	53	3	10.5	0.00	0.39	0.20	
Carcharhinus sorrah	GBRMP	14	432	5	22.5	0.02	0.06	0.04	0.05
Carcharhinus tilstoni	GBRMP	20	905	30	117.3	0.12	0.09	0.10	0.12
Rhizoprionodon acutus	GBRMP	8	386	3	11.2	0.02	0.02	0.02	
Rhizoprionodon taylori	GBRMP	7	949	3	11.9	0.03	0.01	0.02	
Sphyrna mokarran	GBRMP	39	74	5	19.7	0.27	0.17	0.22	
Carcharhinus brevipinna	SEQ	35	643	18	53.4	0.07	0.05	0.06	0.06
Sphyrna lewini	SEQ	35	97	5	16.1	0.35	0.00	0.17	

In situ growth

Although a large number of recaptures were recorded via both fishery dependent and independent methods, the collection and reporting of length information was generally poor. In addition, when length was recorded negative growth was common as indicated by a length at recapture smaller than the length recorded at initial capture and release. The inconsistent recording of length of recaptured sharks by fishers is probably reflective of the often limited time and/or space for fishers to adequately collect record and store this information while fishing from small open vessels. The prevalence of negative growth estimates is likely reflective of the error that is associated with accurately and precisely measuring a live struggling shark and methods for controlling this error are likely to limited when the primary goal is to tag and release sharks in as good as condition possible.

For only one species of shark was enough reliable growth increment data collected to allow growth modelling. A total of 48 recaptured pigeye sharks provided positive values of incremental growth. Time at liberty varied between 7 and 624 days, and growth increment values varied between 0 and 310 millimetres. For each individual recapture, a growth increment was calculated as Δ length (millimetres) / Δ time (years). As the growth increment data was mostly confined to the first few age classes (0-2 years) a simple constant growth rate model was constructed using linear regression that estimated length at birth and annual growth rate for the juvenile years (0-6 years). Length-at-birth was estimated to be 728mm while growth occurred at 128mm per year for the first six years (Figure 11).

Figure 11 The early life stage of pigeye shark, *Carcharhinus ambionensis*, was described by a simple linear model fitted to growth increment data collected from recaptured sharks.



Dispersion trends

The relationship between distance travelled and time at liberty was weak for all species except *Rhizoprionodon acutus* (Table 11, Figure 12). No evidence of directional dispersal was found for any species except *Sphyrna lewini* (P=0.04) which were mostly recaptured south of the initial release location (Figure 8). In some cases, such as *Carcharhinus brevipinna* and *C. fitzroyensis*, movements appeared to be mostly north-westerly (Figure 12). However, Hotelling's test for directionality was non-significant at the 0.05 level for either species. This may be because short (<5 km) within bay movements dominated the dataset, masking any directionality in longer possibly more purposeful movements. Too few long distance movements were recorded to analyse these separately.

Table 11. Relationships between time at liberty and dispersion distance and bearing.

		Time (days)		Distance (km)		Bearing (°)	
Species	Sex	Mean ± s.e.	n	Mean ± s.e.	n	Mean direction ± s.e.	n
Carcharhinus amboinensis	All sexes	191.1 ± 22.4	86	18.7 ± 2.9	86	307.5 ± 67.9	85
	F	198.6 ± 34.1	39	22.5 ± 5.7	39	360.8 ± 23.5	39
	M	190.4 ± 30.9	45	14.8 ± 2.5	45	127.4 ± 15.5	44
Carcharhinus brevipinna	All sexes	81.8 ± 13.2	62	51.6 ± 9.8	62	356.5 ± 48.5	62
	F	98.7 ± 21.2	32	43 ± 12	32	18.4 ± 31.9	32
	M	65.4 ± 16.2	28	62.4 ± 16.9	28	302.1 ± 63.4	28
Carcharhinus fitzroyensis	All sexes	505.1 ± 147.4	13	30.4 ± 10.8	13	268.3 ± 19.8	13
	F	546.2 ± 153.9	12	32.8 ± 11.5	12	276.4 ± 19.1	12
	M	12	1	0.9	1	192*	1
Carcharhinus leucas	All sexes	83.3 ± 22.6	14	7.5 ± 2.4	14	135.3 ± 10.6	14
	F	77.6 ± 29.4	7	10.1 ± 4.3	7	142.6 ± 20.6	7
	M	89 ± 36.6	7	4.8 ± 2.3	7	129.4 ± 12.18	7
Carcharhinus sorrah	All sexes	418.4 ± 65.5	37	32.3 ± 18.6	37	9.6 ± 46.1	36
	F	371.8 ± 71.4	25	12.5 ± 4	25	7.9 ± 66.8	12
	M	515.6 ± 137	12	73.4 ± 56.5	12	11.9 ± na**	24
Carcharhinus tilstoni/limbatus	All sexes	232.8 ± 31.8	72	50.5 ± 8.7	72	179.7 ± 42.0	69
	F	224.6 ± 51.0	38	42.9 ± 11.3	38	185.6 ± 46.0	36
	M	222.1 ± 40.7	31	61.5 ± 14.7	31	171.6 ± 55.1	30

Table 11 continued.

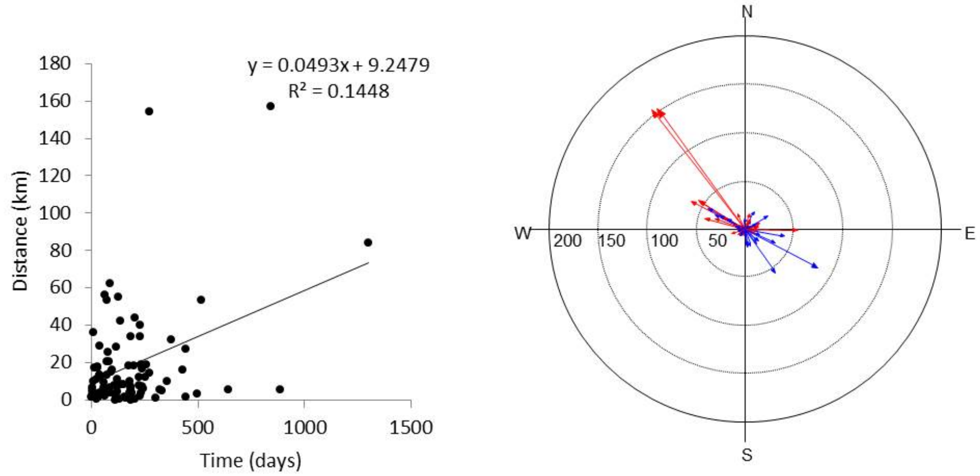
		Time (days)		Distance (km)		Bearing (°)	
Species	Sex	Mean ± s.e.	n	Mean ± s.e.	n	Mean direction ± s.e.	n
Rhizoprionodon acutus	All sexes	205.1 ± 78.1	8	181.3 ± 149.8	8	142.3 ± 17.9	8
	F	100.7 ± 36.4	3	10.9 ± 5.2	3	99.1 ± 33.5	3
	M	267.8 ± 118.5	5	283.6 ± 236.4	5	168.5 ± 23.2	5
Rhizoprionodon taylori	All sexes	143.2 ± 42.1	9	23.9 ± 7.1	9	227.4 ± 43.4	9
	F	130.7 ± 53.7	7	24.8 ± 8.5	7	248.8 ± 37.6	7
	M	187 ± 25	2	20.7 ± 17.7	2	156.0 ± 54.7*	2
Sphyrna lewini	All sexes	157.6 ± 40.2	21	26.4 ± 7.6	21	141.5 ± 20.0	21
	F	36.6 ± 20.6	5	7 ± 3	5	109.0 ± 70.5	5
	M	195.4 ± 49	16	32.5 ± 9.5	16	149.6 ± 20.9	16
Sphyrna mokarran	All sexes	528.4 ± 201.4	7	118.8 ± 93.7	7	327.5 ± 151.5	7
	F	475 ± 279.2	4	196.6 ± 161.1	4	339.1 ± na**	4
	M	599.7 ± 351.4	3	15.2 ± 10.5	3	324.3 ± 59.5	3

*should be interpreted with caution as very low sample numbers

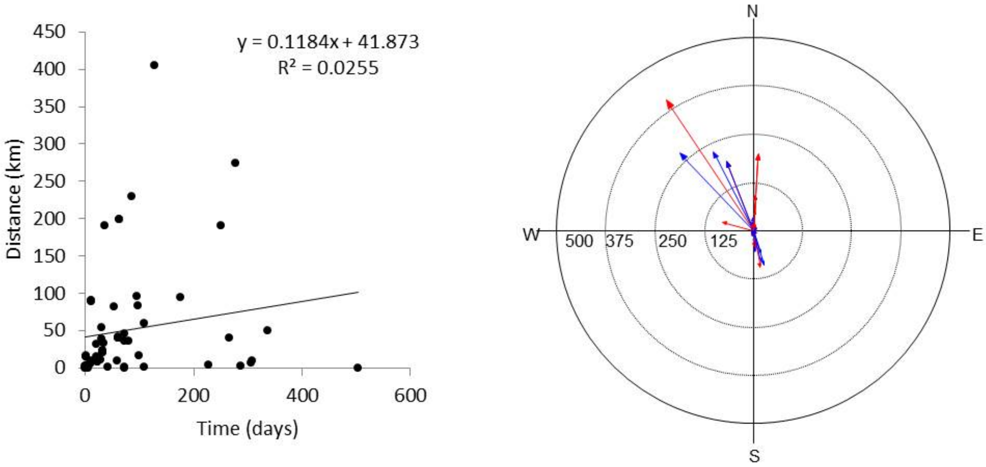
**data extremely spread resulting in mean ± s.e.being unreliable

Figure 12 For ten of the commonly recaptured sharks, the relationship between time at liberty and dispersion distance (left); and the presence of preferential dispersion direction were tested (right).

Carcharhinus amboinensis



Carcharhinus brevipinna



Carcharhinus fitzroyensis

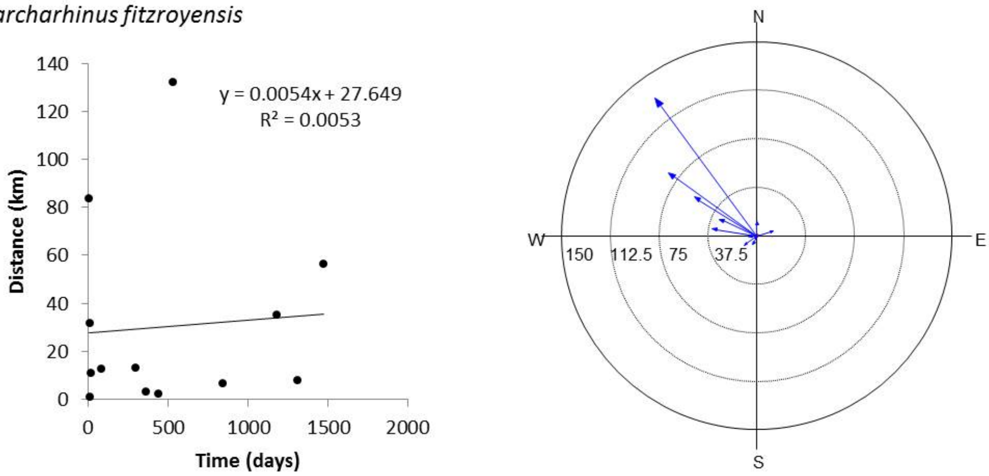
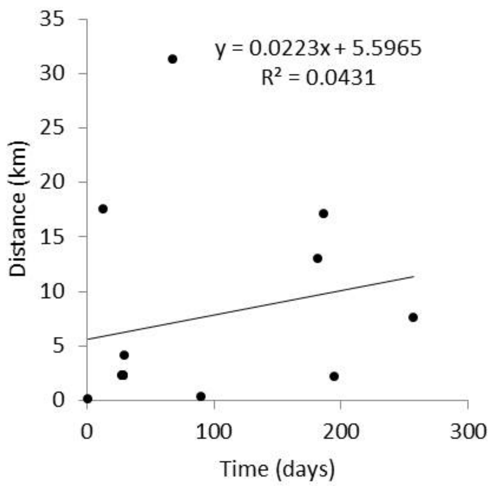
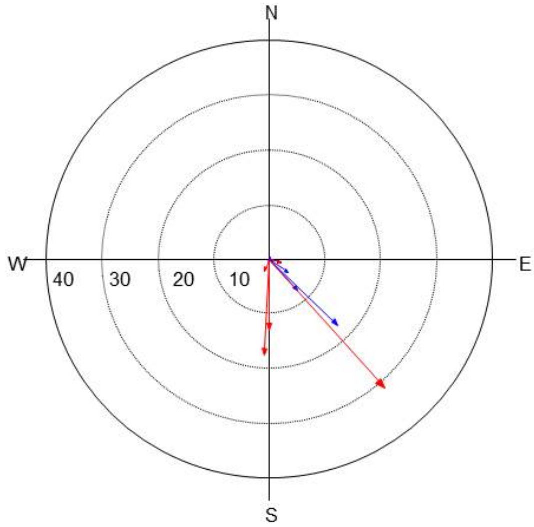


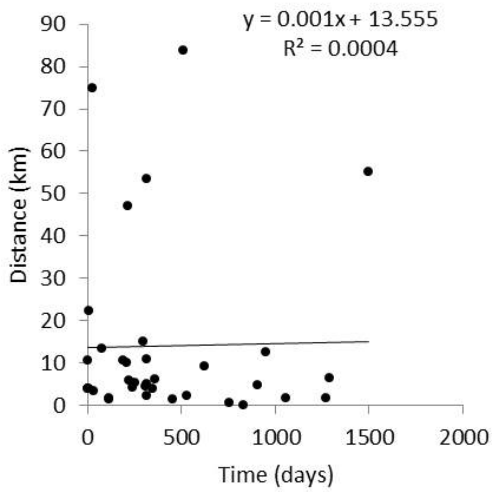
Figure 12 continued.

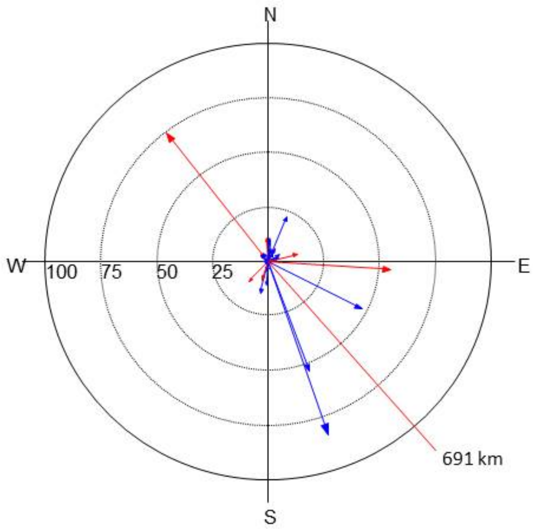
Carcharhinus leucas



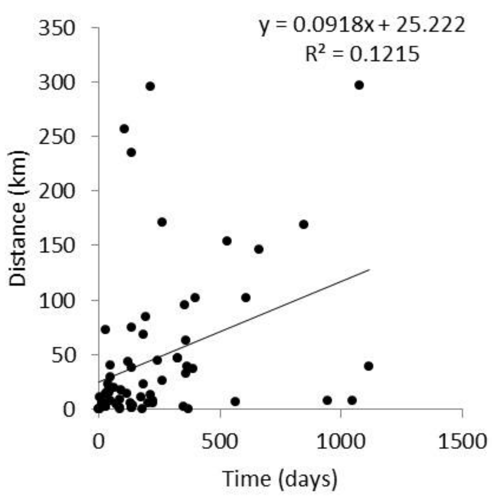


Carcharhinus sorrah * removed outlier





Carcharhinus tilstoni/limbatus



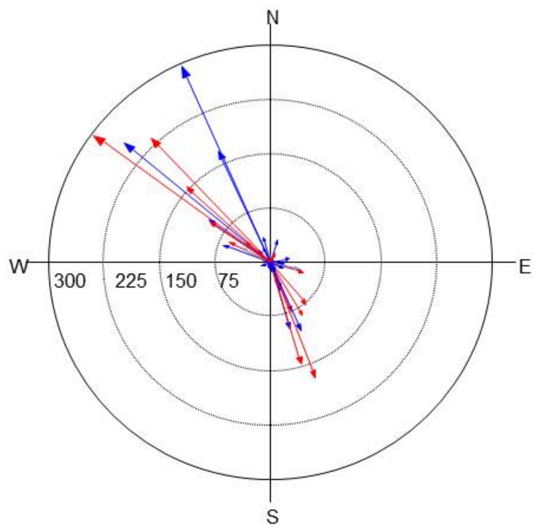
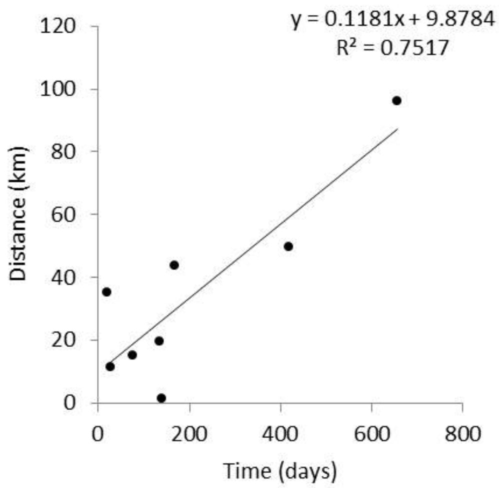
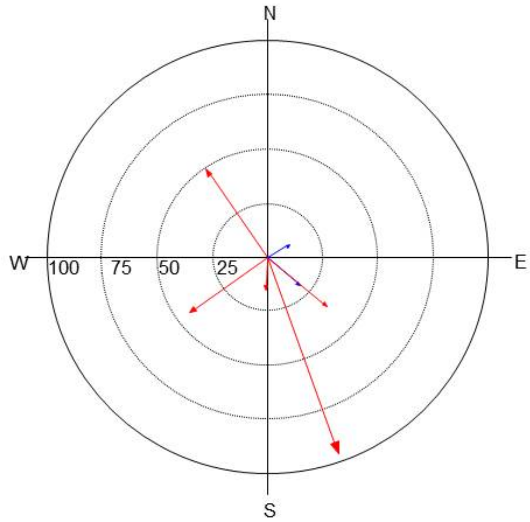


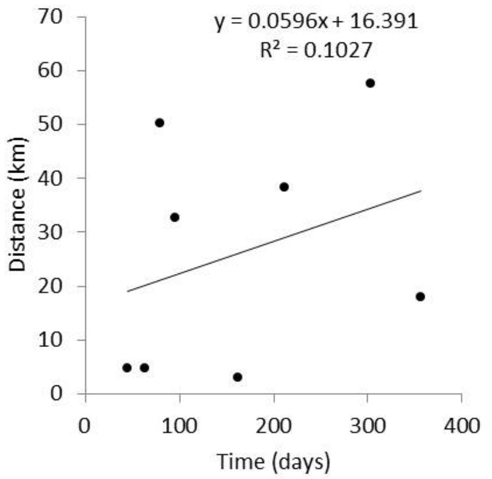
Figure 12 continued

Rhizoprionodon acutus





Rhizoprionodon taylori



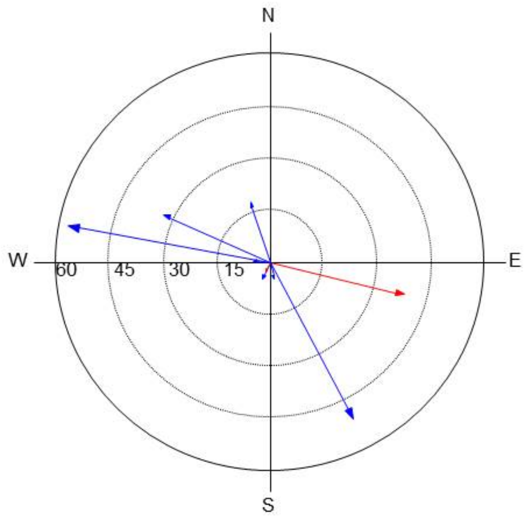
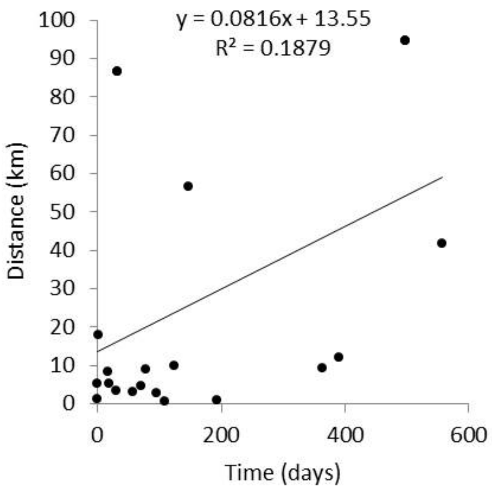
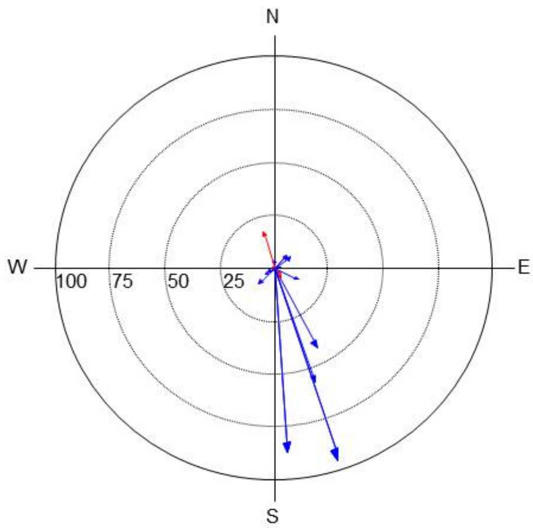


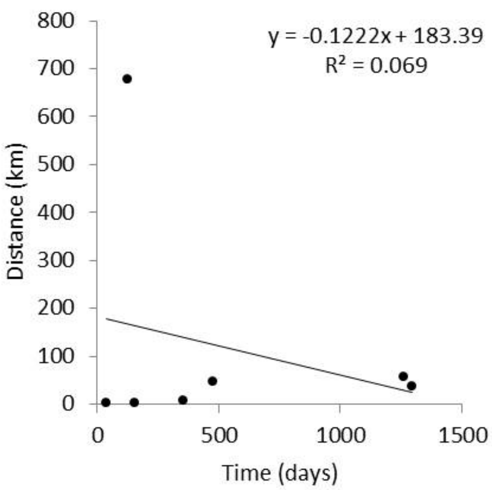
Figure 12 continued

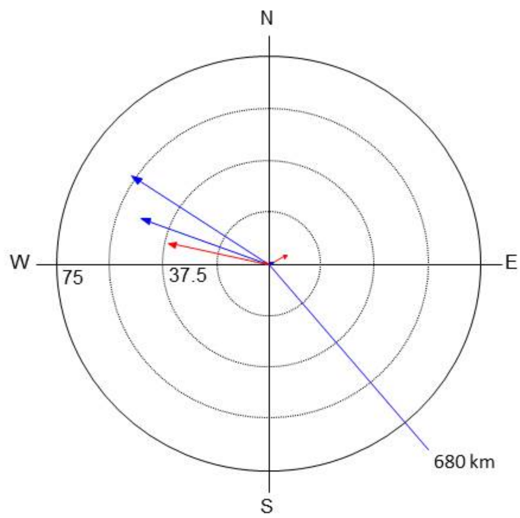
Sphryna lewini





Sphyrna mokarran





Discussion

Fishing mortality

The results of this study indicated that fishing mortality rates of sharks in the ECIFFF were likely to be well within sustainable bounds for two species, *C. brevipinna* and *C. sorrah*. For a third species, *C. tilstoni,* the results suggested that *F* was likely to lead to a stable population with a capacity for some growth. For *C. amboinensis,* three out of four scenarios indicated that fishing was unsustainable. The results, based on tagging 2368 of these four shark species between 2008 and 2012, provide the first quantitative assessment of commercial fishing on inshore sharks in the GBRMP. In addition, this study provides some indication of potential levels of recreational fishing mortality, although these should be viewed cautiously since the study was primarily designed to investigate fishing by the commercial sector.

Carcharhinus amboinensis

The high number of commercial and recreational recaptures of tagged *C. amboinensis* that were directly observed (9.3%) and estimated (35.9%) during 2011 and 2012 was surprising given this species is not typically targeted by either sector. A recent observer survey of the ECIFF found that this species made up 3.9% of the catch of carcharhiniform sharks by weight, and was the 6th most commonly caught species (Harry *et al.*, 2011). The apparently high vulnerability of this species to both recreational and commercial fishers likely relates to neonates' and juveniles' use of shallow coastal embayments as nursery habitat (Knip *et al.*, 2011). While other nursery-using species such as *C. tilstoni* disperse rapidly from nearshore habitats, young *C. amboinensis* consistently remain in these areas year-round, particularly adjacent to creek and river mouths (Knip *et al.*, 2011; Tobin *et al.*, 2013). Thus they are highly susceptible to capture by commercial net fishers targeting estuarine species such as barramundi, *Lates calcarifer,* and threadfin salmon (family Polynemidae). They are also accessible to boat-based and shore-based recreational fishers, even if not directly targeted.

Previous observation of the length structure of the commercial catch for *C. amboinensis* indicated that fishing was most likely restricted to only one or two age classes, potentially resulting in a gauntlet or slot fishery (Harry *et al.*, 2011). Such fisheries have, in some instances, been shown to be quite resilient, even when targeting long-lived and slow growing sharks (Simpfendorfer, 1999). The distribution of tag returns included sharks aged 0–9 years, though was clearly dominated by sharks aged 0-2 years (86% of recaptures) validating the gauntlet fishery suggestion by Harry et al (2011). Given the assumption of equal susceptibility of all age classes in the demographic analyses, the mortality estimates for *C. amboinensis* are likely overly pessimistic.

Although all three indirect methods used to estimate *M* suggested that the 2011 and 2012 rates of *F* were highly unsustainable (r = -0.14 – -0.10), the empirical estimate of *M* still gave slightly positive values for r (0.03–0.04). The empirical estimate of *M* was based on sampling of the 2009 and 2010 cohorts of YOY *C. amboinensis* (n= *39*), where only a single death was recorded during 2010 (Knip *et al.*, 2012). It's not known whether these values of *M* are representative of the whole population, but they do provide an indication that juvenile survival may be very high for this species under certain circumstances. With such low levels of *M* the observed rates of *F* were still marginally sustainable, possibly indicative of a density dependent response to fishing. Importantly, though, even if this most optimistic scenario is true, there is no capacity for any further increase in *F* (since $M \approx 0$).

A further issue of concern for *C. amboinensis* is that in addition to removal by commercial and recreational fishers, this species is also captured by the Queensland Shark Control Program (QSCP). During this study, at least two individuals (not included in our estimates of *F*) were known to have been killed by the QSCP. If adult *C. amboinensis* are also being killed in even relatively small numbers it may have serious long-term consequences for populations in parts of the GBRMP. This was the case in Western Australia where targeting of adult *C. plumbeus* for fins compromised an otherwise sustainable gauntlet fishery focused on juveniles (McAuley *et al.*, 2007). It should be noted however, that the fishery targeting adult *C. plumbeus* was removing 100s of tonnes each year. Future research priorities should involve accurately quantifying the numbers of *C. amboinensis* taken by the QSCP and examining the age-structure of the commercial catch to better inform future demographic analyses. The findings highlight the potential challenges of conserving long-lived and slow growing species that overlap with areas of high levels of anthropogenic use.

Carcharhinus brevipinna

Tagging of *C. brevipinna* only occurred during 2011 and 2012 and was limited to sampling mostly YOY and young juveniles (1–2 years old) in a nursery area around Noosa, southeast Queensland. Although it was not possible to evaluate *F* for older age classes, the tags deployed were reflective of the commercial fishery at the time, which was mainly directed at these younger age classes. Levels of *F* in both years of the study were well within sustainable bounds for this species. Nonetheless, it is important to note that other sources of mortality were not quantified or included in this study and could be important. These include substantial mortality on adults from the QSCP (Sumpton *et al.*, 2010) and direct targeting of adults in northern New South Wales by the Ocean Trap and Line Fishery (Macbeth *et al.*, 2009).

The Noosa region also appears to be a major nursery area for this species. In contrast to other species where tagging occurred opportunistically throughout the study, almost all tagging of *C. brevipinna* was within nursery areas during a short period of time. For example, in 2011, 568 sharks were tagged with the aid of commercial fishers during only two mornings of fishing directly behind the surf zone at Noosa. Anecdotal evidence and tag recaptures suggest that sharks remain in these nursery areas for only a few months before dispersing, although during this time they can be exceptionally vulnerable to both commercial and recreational fishers. Management intervention could be needed should interest in targeting, or inadvertent interaction (such as increased net fishing effort targeting another species) of these dense aggregations of YOY sharks increase. It is also worth noting that two separate stocks of *C. brevipinna* have been identified on the east coast of Australia (Geraghty *et al.*, 2013b). Useful future research could involve determining whether the Noosa region is a nursery area for the northern or southern stock (or both), as it would have important implications for management.

Carcharhinus sorrah

Despite tagging 432 *C. sorrah*, only six recaptures were reported by one recreational and five commercial fishers. This indicates that *F* is probably low for this species and likely to be within sustainable bounds (but also that the accuracy of estimates of *F* may be quite uncertain). Furthermore, *C. sorrah* is more productive and resilient to fishing than the other species evaluated since it attains sexual maturity by ~2 years and reproduces annually thereafter (Harry *et al.*, 2013). Although two of the demographic analyses gave negative base estimates for *r* (-0.04 and -0.26), this was probably due to the unsuitability of either the Jensen and Jensen 2 mortality estimators or inaccurate biological parameters for *C. sorrah*. Its low age at maturity and high growth rate are typically life history traits associated with species that have high natural mortality, which is not the case for *C. sorrah* (Knip et al., 2012).

Undifferentiated blacktip (*Carcharhinus tilstoni* / *C. limbatus*)

The rate of *F* estimated for *C. tilstoni* during this study suggests that fishing was relatively high, but still likely within a sustainable range for this species. Interestingly, although *C. tilstoni* also uses coastal nursery habitats and is more actively targeted by commercial fishers, it had substantially lower commercial fishing mortality than *C. amboinensis,* and apparently little mortality from the recreational sector. Pupping by *C. tilstoni* in coastal nurseries occurs in early December on the east coast of Queensland (Harry *et al.*, 2012) but YOY sharks appear to disperse from this habitat into the wider inshore area by February (Tobin *et al.*, 2013). This period coincides with seasonal fishing closures (November to January inclusive) for *L. calcarifer,* which may inadvertently provide some protection for *C. tilstoni* by reducing both commercial and recreational fishing effort in nearshore areas. The tropical wet-season also commences during this time, potentially further reducing potential fishing mortality as flooding conditions dissuade fishing efforts. opportunities for fishers.

Although this analysis suggested that current levels of *F* are likely to be sustainable, a complicating factor is the presence of the morphologically similar *C. limbatus* as well as hybrids of the two species (Morgan *et al.*, 2012). In this study we assumed all tagged individuals were *C. tilstoni*, even though molecular evidence indicates that proportions of the two species vary with latitude, changing from *C. tilstoni* dominated in the north to *C. limbatus* dominated in the south (Welch *et al.*, 2010). Additionally, little is still known about the prevalence of hybridisation and the effects of hybrid fitness on the commercial fishery (Morgan *et al.*, 2012). Without the use molecular techniques to discriminate between the two species it is not possible to establish whether *F* varies between species. A study on the life history of *C. limbatus* life history is presently nearing completion and it could be possible to run the analysis using these data to assess the potential effects of fishing (Geraghty, unpublished PhD thesis).

A study of modern and historical rates of fishing mortality in the Northern Territory Offshore Net and Line Fishery suggested that the greater the proportion of *C. limbatus* in the catch, the lower the rate of sustainable harvest would be (Bradshaw *et al* 2013). This is because *C. limbatus* attains a much larger size than *C. tilstoni,* matures later, and is likely to reproduce biennially. As such it is likely to have a lower overall productivity and resilience to fishing. However, this may not necessarily apply to the ECIFF since both species are not equally available to capture by the fishery. Observer-based study of the catch indicates that adult *C. limbatus* are not frequently captured (Harry *et al* 2011). If only a small number of juvenile age-classes are subject to fishing, as is the case for similar sized species such as *C. brevipinna,* sustainable harvest rates may be relatively higher.

Comparison with other fisheries

Given the costs and challenges associated with stock assessment of sharks, which are more robust than risk-based approaches, e.g. Gribble *et al.,* (2005), Tobin *et al.,* (2010), this study is one of only three that has attempted to estimate *F* for commercially fished sharks across northern Australia. Building on the method of Simpfendorfer (1999), McAuley *et al.,* (2007) estimated *F* of 0.21 and 0.17yr^{-1} on 1994 and 1995 cohorts of YOY *C. obscurus* in Western Australia, and found these values to be sustainable. However, values of *F* of 0.10–0.28 yr^{-1} on 3–9 year old *C. plumbeus* between 2001 and 2004 were found to be unsustainable, especially in conjunction with adult mortality. More recently, Bradshaw (2013) used Brownie mark-recapture models to estimate *F* of 0.02 and 0.008 *C. tilstoni* and *C. sorrah,* respectively, in the Northern Territory. This indicates that contemporary exploitation rates in that part of northern Australia are substantially less than in the GBRMP.

Mortality estimation limitations

The analytical approach used in this study, although simple, provided a method of assessment that was appropriate for the size and scale of the fishery being investigated. Incorporating the most recently available and region-specific life history information we estimated *F* and *r* for a range of different assumptions about natural mortality. One major limitation was the deterministic nature of the model used, which does not allow confidence intervals on *F* (although Figure 11 and the standard errors presented in Table 8 give some indication of variability). Although we attempted to account for factors such as tag loss, non-reporting, and incomplete mixing of tags, there is not presently information available on a range of other important factors such as fishing gear selectivity, emigration and immigration rates, and population structures. Further development of the model to specify sources of uncertainty may be one way of potentially improving on the results obtained here. Alternatively, using a more conventional Brownie recovery model that accounts for uncertainty may also be possible (Bradshaw *et al.*, 2013). Using a stochastic approach for estimating *r* (Cortes, 2002) may also be one way of quantifying some of the uncertainty in life history parameters, notably *M.*

In addition to estimating values of *F* for the commercial sector, this study also provided an estimate for both the commercial and recreational sectors combined. These estimates should also be viewed as indicative only, since the study was initially planned to estimate commercial fishing mortality, and no attempt was made to estimate non-reporting rates of the recreational sector. Surveys of recreational fishers indicate that sharks are typically not retained and it's possible that the tags, which offered a reward, could have increased retention rates by this sector (Lynch *et al.*, 2010) as recreational fishers would not necessarily fear further management restrictions that are often used by commercial fishers in explaining why they do not return recapture information.

A further limitation of the study was the relatively small and geographically-discrete tag samples (both release and recapture samples). As the deployment of tags was fisher dependent and many areas of the Queensland east coast are isolated and difficult to access, tags were invariably deployed close to major fishing ports and fishing grounds. While the theory behind tag-release-recapture experiments assumes animals are tagged throughout the natural range of the population and that tagged animals mix freely amongst that population, in this exercise this assumption was likely invalid. However, with the tag deployment focusing on major fishing ports and grounds, it is plausible to argue that the recapture and subsequent harvest rate estimates may be conservatively high. While the methodology in estimating harvest rate included ignoring tag-recaptures occurring within 30 days of tag-release to ensure adequate dispersion of tags throughout the population, more robust estimates may have been likely if tags were deployed right along the coast.

In situ growth and dispersion trends

Insufficient tag-recapture data were collected to model growth from growth increment and time at liberty data. As the infrequent collection of growth increment information provided few data, as well as the regular estimation of negative growth (length at recapture < length at tag-release), modelling growth was only possible for pigeye shark *Carcharhinus ambionensis*. Growth was modelled for the first six years and the estimated length-at-birth was consistent with field observations. Modelling the early years of growth of C. ambionensis by this study agree with the published work of Tillett et al (2011), though some form of validation of growth rate is still required. It does appear however, that successful growth modelling from tag-recapture data is limited to the initial few years of growth, particularly for long lived species. While Simpfendorfer (2000) successfully modelled the early years of growth for the long-lived dusky shark, *Carcharhnius obscurus*, when McAuley et al (2006) considered a much broader age range for the congeneric *C. plumbeus,* implausible results were produced. A number of contributing factors are given by McAuley et al (2006), though it appears that the high variability in growth rates estimated from the tag-recapture data (particularly common from sharks captured less than 3 months after tagging) may have driven the implausible results.

Insufficient data were also a limitation when exploring possible species-specific dispersion patterns. For most of the examined species, recapture numbers were low and thus detecting any trend(s) among the individual dispersion tracks was unlikely. Interestingly, for those species commonly tagged and released in the northern GBR region, where large protected northward facing coastal embayments are predominant, recaptures were largely confined to within bays. Fidelity to individual embayments is not uncommon among particularly juvenile and young-of-the-year sharks. For example, juvenile scalloped hammerhead sharks (*Sphyrna lewini*) remain resident within Kane'ohe Bay, Hawaii for their first year of life (Duncan & Holland, 2006), while juvenile blacktip sharks (*Carcharhinus limbatus*) have been demonstrated to remain resident in a Florida embayment as young-of-the-year sharks (Heupel & Hueter, 2002). Although the data available via this project are sparse, the data does suggest a level of bay fidelity that future research may further consider.

Conclusion

The primary objective of this project was to determine is the current rate of shark fishing with the Queensland East Coast Inshore Fin Fishery sustainable? The findings of this study suggest that during 2011 and 2012, rates of commercial fishing on three of the main target shark species, *C. brevipinna, C. sorrah* and *C. tilstoni,* and on the east coast of Australia was within sustainable bounds. This is encouraging since it implies that the broad range of direct and indirect management measures introduced to protect sharks over the past decade has been successful in controlling harvest rates. Furthermore, rates of *F* are presumed to be substantially lower in parts of the GBRMP that are closed to commercial fishing, and in many of the more remote and largely un-fished areas (e.g. the significant expanse of water north of Cairns where fishing effort was too low to justify any tagging). Alternately, it must also be recognised that rates of F could be underestimated in some areas of concentrated fishing effort and reporting rates of recaptured sharks may have been low for some sectors of the fishery. Fishers who cannot harvest commercial quantities of shark may have been less inclined to report recaptured sharks that they are not able to legally retain for market.

Despite this, there may still be room for improvement in management of sharks in the GBRMP. In particular, the high rate of *F* on *C. amboinensis* indicates that the incidental capture of some long-lived sharks by the ECIFF may still be a concern. In addition, the finding that *F* was still relatively high on the main target species, *C. tilstoni*, even after a large reduction in fishing, suggests that the high levels during the 2000s were probably unsustainable. In recent years, the catch of sharks has dropped substantially in the GBRMP, and commercial fishers are yet to reach the full TACC of 480 t for this region. This suggests that market/economic factors (possibly linked to new management changes) are likely the main driver of reduced shark catches in recent years rather than over-exploitation. The activation of latent effort may still pose a risk for this fishery.

In addition the 2008 changes to management have, at least partly, encouraged unreported discarding. Since most sharks are caught incidentally and non 'S' symbol holders can now only retain a maximum of 10 sharks, accurately measuring the true catch could be confounded by discarding. Also, if in the future the TACC for sharks is reached then this could lead to high and unquantified discarding in sectors such as the grey mackerel fishery that have historically had a large by-product of shark.

Estimating rates of fishing mortality for species of conservation interest was problematic and incomplete. The naturally rare abundance of some species meant too few tags were deployed and thus recapture data was unlikely. This was true for the narrow sawfish *Anoxypristis cuspidata* and whitespotted guitarfish *Rhynchobatus djiddensis*. Estimates were possible for the two hammerhead species (scalloped hammerhead *Sphyrna lewini* and great hammerhead *Sphyrna mokarran*) and suggested fishing mortality may be relatively high, however these estimates need to be treated with some caution due to the low numbers of recaptures observed.

The objective of using the recapture data to describe broad scale movement patterns and estimate in situ growth was also incomplete. While broad scale movement could be described by knowledge of both release and recapture locations, sufficient data to estimate in situ growth was only available for pigeye shark *Carchahinus ambionensis*. No clear directionality was observed in the movements of sharks with most sharks recaptured within the coastal bay within which they were tagged. Small scale movement behaviour is affirmed by recent acoustic telemetry observations that showed some coastal shark species use small home range areas within coastal bays (eg Knip et al 2011, Knip et al 2012, Chin et al 2013). Estimates of length of recaptured sharks were too infrequent to allow estimating *in situ* growth rates for all species bar pig eye shark. The growth estimated for pigeye shark is congruent and an important validation of Tillet et al (2011).

Implications

The planned outcomes for the project were

- Improved management of shark through the provision of key information that will direct careful and informed management decisions into the future. Information will be collected on protected species and species of conservation interest to help mitigate any possible negative effects of fishing on them.

- Robust estimates of the fishing mortality imposed on shark and ray species.

The project has provided key information to further direct and inform the management of shark fishing in future years. The implications for the fisheries managers are significant in light of the recommendations of Gunn et al (2008) who reviewed the proposed fisheries management arrangements for shark. This research provided outputs that directly address three of the key Gunn et al (2008) recommendations: 1. Collection and collation of data to better understand the species complexity and spatial variability in shark catches taken from along the Queensland east coast; 2. Conduct research to determine rates of fishing mortality for commonly caught sharks; and 3. Undertake opportunistic research to better understand the biology and ecology of the shark species taken in the ECIFFF.

The project demonstrated that shark catches from within Great Barrier Reef Marine Park coastal waters are diverse with a number of species common in catches. In contrast shark catches from sub-tropical waters south of the GBRMP were much less diverse and dominated by a single species. While simple data, this key information about shark catch composition has not been previously available. Further, comparing the project defined species composition against the species composition recorded by fishers in daily commercial logbooks highlights two important facts. Firstly, the correct identification of many tropical shark species is difficult and fisher logbook records are unlikely to accurately reflect true catch composition. Secondly, a fisher independent source of information (such as the recently cancelled fisheries observer program (FOP)), is mandatory for robust and accurate data collection.

The project defined robust estimates of rates of fishing mortality for the dominant species in both regions and with the exception of one species (pigeye shark) mortality rates were within sustainable bounds. The implications of this outcome are significant as the sustainability of shark fishing in the ECIFFF has long been questioned. Clearly, the project outputs will assist QDAFF managers in meeting the sustainability requirements of the Queensland Fisheries Act, and ecological sustainability requirements of the GBRMPA and the DoE (EPBC Act).

For the commercial fishery, the definition and statement of sustainability of the major targeted and harvested species (blacktip shark, spinner shark, spot-tail shark) may have a positive impact on the marketing opportunities for the shark products the fishery harvests. In recent years numerous social media campaigns have worked hard to publicise the negative outcomes of targeted shark fishing, ignoring the fact that well managed shark fishing may be sustainable. As a result of these persistent negative messages, and in an absence of independent robust quantitative data that demonstrates sustainability, marketing options for shark fishery products have contracted in recent years. The outcomes of this project may help to expand marketing options once again and allow fishers to confidently operate within this fishery. Similarly for the wholesale and retail sector as well as consumers of shark products, the implications of the project's outputs should be positive with confident proactive marketing of a sustainable product by marketers and retailers, and less confusing purchase and consumption decisions by consumers.

Recommendations

For this PROJECT, provide recommendations on the activities or other steps that may be taken to further develop, disseminate or to exploit commercially the results.

1. Extensive dissemination of the results of this research to arrest any further erosion of consumer confidence in shark products. IF the end users, wholesalers, retailers and consumers, continue to avoid shark products as is currently occurring due to widespread anti-shark fishing campaigning, realising any tangible benefits from the outputs of this research will be unlikely.

2. Monitor closely the interaction and discard rates of those commercial net fishers who do not possess an S symbol and are thus limited to ten sharks per trip. The interaction rates for some of these fishers may be quite high, and so too the incidental mortality of those sharks captured and discarded. This may contribute to a high level of wastage in the fishery, and should be monitored and managed as necessary.

3. Address remaining information gaps including the accuracy of life history data and age specific fishery selectivity for each species.

4. Shark fishing effort in the ECIFFF is targeted in shallow coastal waters generally less than 10 m (Harry et al. 2011) but many species utilise habitats across the continental shelf (Espinoza et al 2014). The degree of protection afforded by the current distribution of fishing effort relative to the target species is unknown. To understand the cross-shelf dynamics of shark populations and whether these characteristic offer protection from fishing can only be addressed by directed research effort in these deeper lightly fished waters.

5. More research to understand the efficacy of the current Marine Park Zoning network to protecting sharks from fishing is required. Where robust quantified benefits are demonstrated for MP offering protection to sharks (eg Knip et al 2012), incorporate this information into fisheries management strategies.

Further development

Where this project DOES NOT fully solve or address all issues and more research and/or actions such as management changes are required provide recommendations for next steps.

The shark catches of non-S holding commercial net fishers are unknown and uncertain. Interactions may be very low, however it is known that in some sub-sectors of the fishery (such as offshore netting for grey mackerel) large incidental catches of shark can occur. While there are approximately 266 netting endorsements that can legally access the grey mackerel fishery and only 147 S symbols, there are a possible 100+ gill net vessels that may catch and discard large numbers of sharks. The rates of incidental capture, discarding and post-release mortality of sharks should be investigated as a priority.

The project did miss an opportunity to estimate the rates of shark interaction of non-S symbol holders relative to fishers who held an S symbol and whether or not shark was actually being targeted. An estimate could have been achieved by simply asking fishers who reported recaptured sharks whether or not they were fishing under an S symbol, and what species they were targeting. We flag this suggested process for any future research or monitoring to consider implementing to allow this vital information to be collected. There are limitations in the data held in the licence structure database and catch effort database held by Fisheries Queensland that prevents their use for this exercise. As the shark component of the ECIFFF is largely taken as incidental rather than targeted catch, it is possible that fishers without an S symbol discard large numbers of sharks and that those discards are not reported. Future research and/or monitoring should attempt to better understand these traits.

The project also missed an opportunity to gauge fisher ability to correctly identify sharks to species level. As is evident in the records of commercial fisher logbooks, species identification and recording by fishers does not agree with the known species as determined by expert independent sources such as the QDAFF Fisheries Observer Program staff, or staff members of this project. Even trained and skilled observers misidentify around 10% of Australia’s tropical sharks (Tillet et al 2012). To help remedy this situation, knowledge of how wide spread and what specific species cause identification issues could be very informative in improving this situation.

Recreational shark catches may be relatively high, and although most recreationally captured sharks are reported to be released (Lynch et al 2009), post-release mortality rates are uncertain. For both spinner and pigeye sharks, 28% and 25% of recaptures respectively, were reported by recreational fishers. It appears that the preferred habitat of young-of-the-year and juvenile sharks of both species overlap with preferred fishing areas of recreational fishers. Further research is required to better understand the rates of interaction and fate of captured and released sharks.

Extension and Adoption

Chronologically the project was extended and communicated to stakeholders in the following ways:

August - September 2010. The project was initially advertised amongst the fishing sectors by a short information article that was widely disseminated among fishing magazines and social media (fishing chat forums such as AUSFISH - http://www.ausfish.com.au/vforum/). See Appendix D for article.

Oct 2010: Formal project media release (See Appendix E)

Mar 2011: Formal project media release (See Appendix E)

Oct 2011: Fisher stakeholder story in Queensland Seafood Magazine (see Appendix F)

Project coverage

Coverage in Escape with ET – see Appendix G

Project materials developed

If the project creates any products such as books, scientific papers, factsheets, images these should be outlined in this section outline and attach them where possible.

Manuscript (complete draft) + Conference presentation at Sharks International 2014 (see Appendix H).

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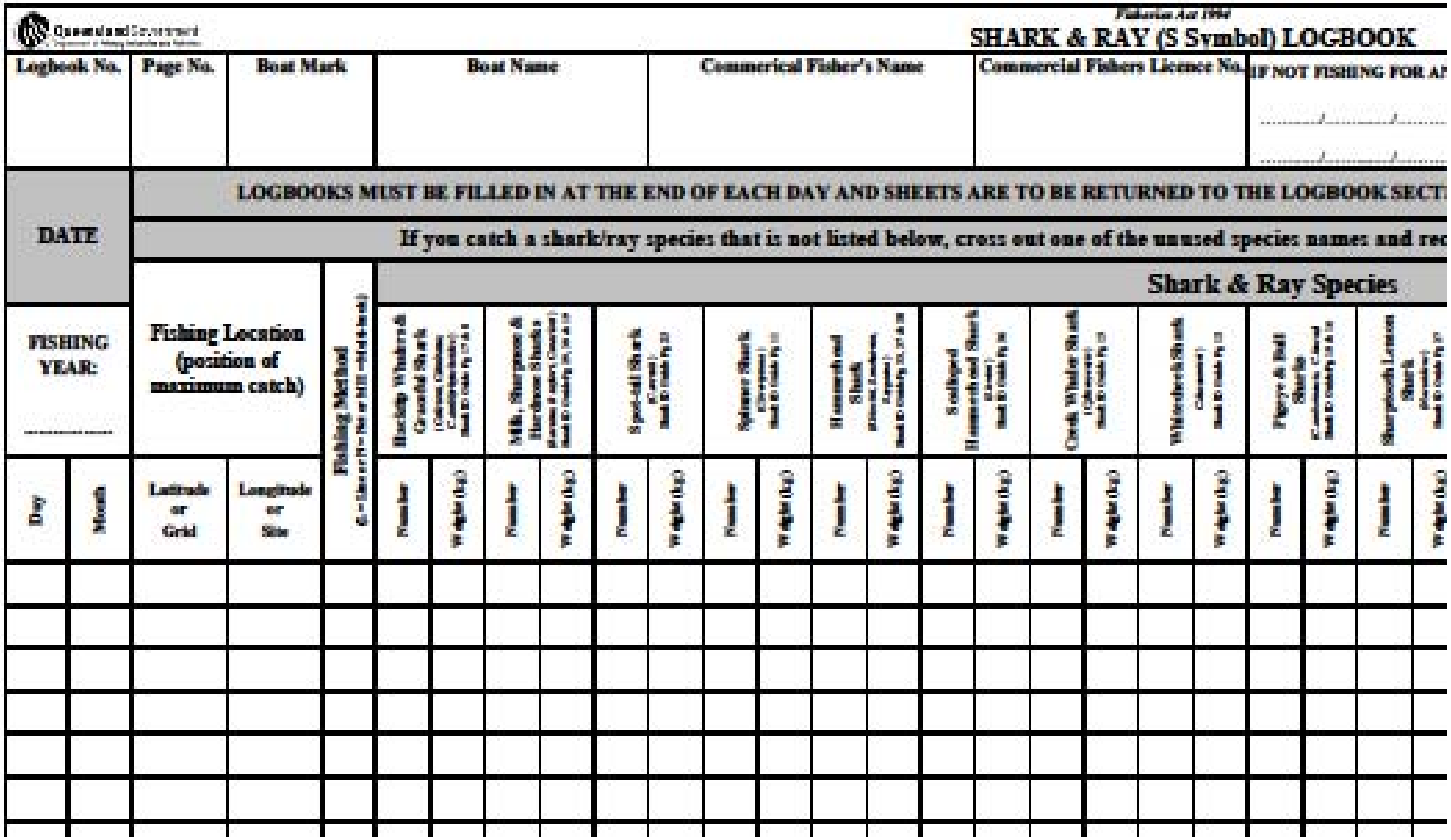
Appendix A Intellectual Property

No patentable or marketable products or processes have arisen from this research. All result will be published in scientific and non-technical literature. The raw data from compulsory fishing logbooks remains the intellectual property of QDAFF. Raw catch data provided by individual fishers remains the property of the fishers. Intellectual property accruing from the analysis and interpretation of raw data rests jointly with JCU and QDAFF.

Appendix B Researchers and project staff

Andrew Tobin	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Jonathon Smart	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Amos Mapleston	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Alastair Harry	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Steve Moore	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Colin Simpfendorfer	Centre for Sustainable Tropical Fisheries & Aquaculture, James Cook University
Richard Saunders	Queensland Department of Agriculture, Fisheries & Forestry
Julia Davies (and staff)	Fisheries Observer Program, Queensland Department of Agriculture, Fisheries & Forestry

Appendix C – Shark and Ray Logbook 2009.



Queensland Government

Fisheries Act 1994

SHARK & RAY (S Symbol) LOGBOOK

Logbook No.	Page No.	Boat Mark	Boat Name	Commerical Fisher's Name	Commercial Fishers Licence No.	IF NOT FISHING FOR A…
						……/……/……
						……/……/……

DATE

FISHING YEAR: ……………

LOGBOOKS MUST BE FILLED IN AT THE END OF EACH DAY AND SHEETS ARE TO BE RETURNED TO THE LOGBOOK SECT…

If you catch a shark/ray species that is not listed below, cross out one of the unused species names and re…

Shark & Ray Species

Day	Month	Fishing Location (position of maximum catch): Latitude or Grid	Longitude or Site	Fishing Method	Blacktip Whaler & Graceful Shark: Number	Weight (kg)	Milk, Sharpnose & Hardnose Sharks: Number	Weight (kg)	Spot-tail Shark: Number	Weight (kg)	Spinner Shark: Number	Weight (kg)	Hammerhead Shark: Number	Weight (kg)	Scalloped Hammerhead Shark: Number	Weight (kg)	Creek Whaler Shark: Number	Weight (kg)	Whitecheek Shark: Number	Weight (kg)	Pigeye & Bull Sharks: Number	Weight (kg)	Sharptooth Lemon Shark: Number	Weight (kg)

Appendix D – Initial briefing article

This common language article was widely disseminated amongst fishing industry stalkeholders.

Shark Research Update

Shark fisheries are often seen as controversial, mostly thanks to media coverage of poor fishing practices that occur in other parts of the world. Within Australia, some conservation groups such as AMCS have a policy that shark fisheries cannot be sustainable and should not be allowed. However, with appropriate research and management shark fisheries can be sustainable for long term community and economic benefit. To the surprise of many fishers, the conservation group World Wildlife Fund (WWF) has recently endorsed the sustainability of the gummy shark fishery in south-eastern Australia recognising that ongoing research and monitoring has demonstrated sustainable fishing.

Shark Biology – negatives and positives

The biology of sharks (slow growth, late maturity and low reproductive capacity) means their ability to replace themselves when removed by fishing is generally low particularly when compared with fish. However, these biology traits can be an advantage as the number of new recruits (pups) born each year can be very stable compared with the often variable recruitment of fishes. For example, barramundi recruitment can vary significantly between years, dependent mostly on wet season conditions; in contrast shark populations will produce relatively even amounts of new pups each year regardless of environmental conditions. This is a significant benefit in managing shark fisheries as recruit levels each year can be very stable provided mature adult sharks are not fished.

Sustainable harvest – what is the goal for sharks?

Sustainable harvest of sharks can be achieved by harvesting small juveniles while leaving enough in the water to mature as adults and reproduce. Recent FFRC research on the Queensland east coast fishery has demonstrated the fishery targets mostly juvenile sharks. The need now is to identify how many juvenile sharks can be removed each year without compromising future populations and fishery catch rates.

New research to define sustainable harvest

A new research program is tagging and releasing sharks (more than 3000 in total) from multiple locations along the Queensland east coast. The recapture rate of these tagged sharks will allow harvest rates to be identified. An example of where this type of research has been applied before is in the Western Australian gill net fishery that targets sandbar and dusky sharks. Both these species are less productive than any of the shark species fished in Queensland, yet the fishery can still harvest up to 30% of one-year old sharks each year provided larger juveniles and mature adult stock are not fished. Presently, 120 t of sandbar and 180-280 t of dusky sharks can be sustainably removed by fishing each year.

How can fishermen help?

If you capture a tagged shark, please call the phone number on the tag (07 4781 5973) to report the recapture. The information the project requires includes tag number, date and location (can be a general area such as Hervey Bay, though a GPS point would be preferred) of the recapture. The data generated through this project will also go a long way to securing future certainty in the sustainable harvest of sharks from the Queensland east coast.

Fishers who report this information will receive a recapture letter that includes the initial capture information as well as a free T-shirt. Two $500 gift vouchers from Net Supplies Australia will be awarded to two lucky fishers through two random draw events throughout the project. Each recapture a fisher reports will give that fisher a chance of winning a gift voucher. These two draws will occur on the 15th March 2012 and the 15th March 2013. Thanks to all those fishers who have already reported recaptured sharks - you are already in the running for the first $500 gift voucher.

For further information please contact Andrew Tobin at the Fishing & Fisheries Research Centre, James Cook University 07 4781 5113.

Appendix E – Formal media releases

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JAMES COOK UNIVERSITY AUSTRALIA

News and Media

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- Current Media Releases
- News Archive
- Discover - Magazine

Ultimate ocean predators now the target of research

First published 7 October, 2010

James Cook University researchers are working on a project to determine how to balance the economically important industry of shark fishing while sustaining their populations.

JCU Senior Research Fellow Dr Andrew Tobin, from JCU's Fishing and Fisheries Research Centre, said the three-year project funded by the Fisheries Research and Development Corporation would determine the balance between shark fishery catch levels and shark conservation.

Dr Tobin said the new research project was identified by the Department of the Environment, Water, Heritage and the Arts as a necessary step for the long-term sustainability of both the sharks and the fishery.

"Sharks are harvested because shark fillet, often sold as flake, is an important and valuable product within the domestic seafood trade," he said.

"However, we also need to maintain healthy shark populations because they are important for keeping marine ecosystems in balance."

Dr Tobin said that the fishery targets species like blacktips and spot-tail, but more than 20 other species are also caught.

Recent research by JCU's Fishing and Fisheries Research Centre has shown that shark species captured within the Great Barrier Reef World Heritage Area are likely to have variable ability to sustain fishing, so further research needed to be done to define appropriate catch levels.

Dr Tobin said the project would determine appropriate catch levels through a large-scale tag–release–recapture exercise.

"Over the next two years, we will be capturing and tagging up to 3000 sharks within the GBRWHA. The recapture of these sharks by fishers will help to determine what current catch levels – or how many individuals are caught - are."

Dr Tobin said fishers were being asked to keep an eye out for tag sharks, with each reported recapture to be in the running for an annual prize.

The project is supported by the Queensland Seafood Industry Association with spokesperson Bill Gilliland saying sustainable catch levels need to be determined to ensure the sharks we catch as well as the ecosystem we fish from remains healthy in the long-term.

The project is funded by the Fisheries Research and Development Corporation on behalf of the Australian Government, and supported by the Great Barrier Reef Marine Park Authority, Fisheries Queensland and the Queensland Seafood Industry Association.

Contacts:

FFRC Andrew Tobin 07 4781 5113

FRDC Peter Horvat 0415 933 557.

JAMES COOK UNIVERSITY AUSTRALIA

News Release

March 17, 2011

Tagging fishy predators for the future

Local Sunshine Coast commercial fishers Bill and Ben Gilliland were busy last week fishing and tagging sharks to ensure the future of the sharks, themselves and the seafood consumers.

The shark fisheries on the Sunshine coast supply an affordable seafood product for local seafood retail outlets and fish and chip shops. However many shark fisheries come with controversial baggage better associated with global examples of poor fishing practices and unsustainable catches.

A shark research project lead by Dr Andrew Tobin of James Cook University is looking to address these issues and identify what long-term sustainable catch levels of shark should be in Queensland.

[Eds Note: Andrew says he has great images available of the tagging please contact him at 07 4781 5113 or andrew.tobin@jcu.edu.au]

"Sharks are important apex predators in the marine environment that need to be managed carefully, but that does not mean they cannot be fished," Dr Tobin said.

"Of the species of shark taken by commercial fishers in Queensland, most are quite productive meaning fisheries can harvest them, but we need to identify at what level."

Sustainable catch levels in some shark fisheries have been identified at 30% of annual production, meaning 30% of each year's recruitment can be removed by fishing without long-term negative consequences.

Shark fisheries are most sustainable when smaller juvenile sharks are taken while leaving enough in the water to mature and reproduce.

"The Queensland east coast fishery takes mostly small and juvenile sharks, which is a good tactic, but we need to make sure the right amount are taken," Dr Tobin said.

To work out how many sharks are taken by fishers in Queensland, a large scale tag and release study has recently begun.

"Bill and Ben Gilliland have been instrumental in tagging almost 600 sharks in the last week," Dr Tobin said. "The future recapture of these tagged sharks will allow sustainable harvest rates to be defined."

The project, which is funded through the Fisheries Research and Development Corporation from the Australian Government, will run for the next two years.

JCU Media Jim O'Brien 07 4781 4822 or 0418 892449

Appendix F – Queensland Seafood

The following article was published in Queensland Seafood Magazine, Jan 2012.

Shark fisheries are often seen as controversial, mostly thanks to media coverage of poor fishing practices that occur in other parts of the world. Within Australia, some conservation groups have a policy that shark fisheries should not be allowed. However, with appropriate research and management shark fisheries can be sustainable for long term community and economic benefit. Recently, the World Wildlife Fund (WWF) has endorsed the sustainability of the gummy shark fishery in south-eastern Australia recognising that ongoing research and monitoring has demonstrated sustainable fishing of this shark species.

The biology of sharks (slow growth, late maturity and low reproductive capacity) means their ability to replace themselves when removed by fishing is generally low particularly when compared with fish. However, these biology traits can be an advantage as the number of new recruits (pups) born each year can be very stable compared with the often variable recruitment of fishes. This is a significant benefit in managing shark fisheries as sustainable harvest of sharks can be achieved by harvesting small juveniles while leaving enough in the water to mature as adults and reproduce.

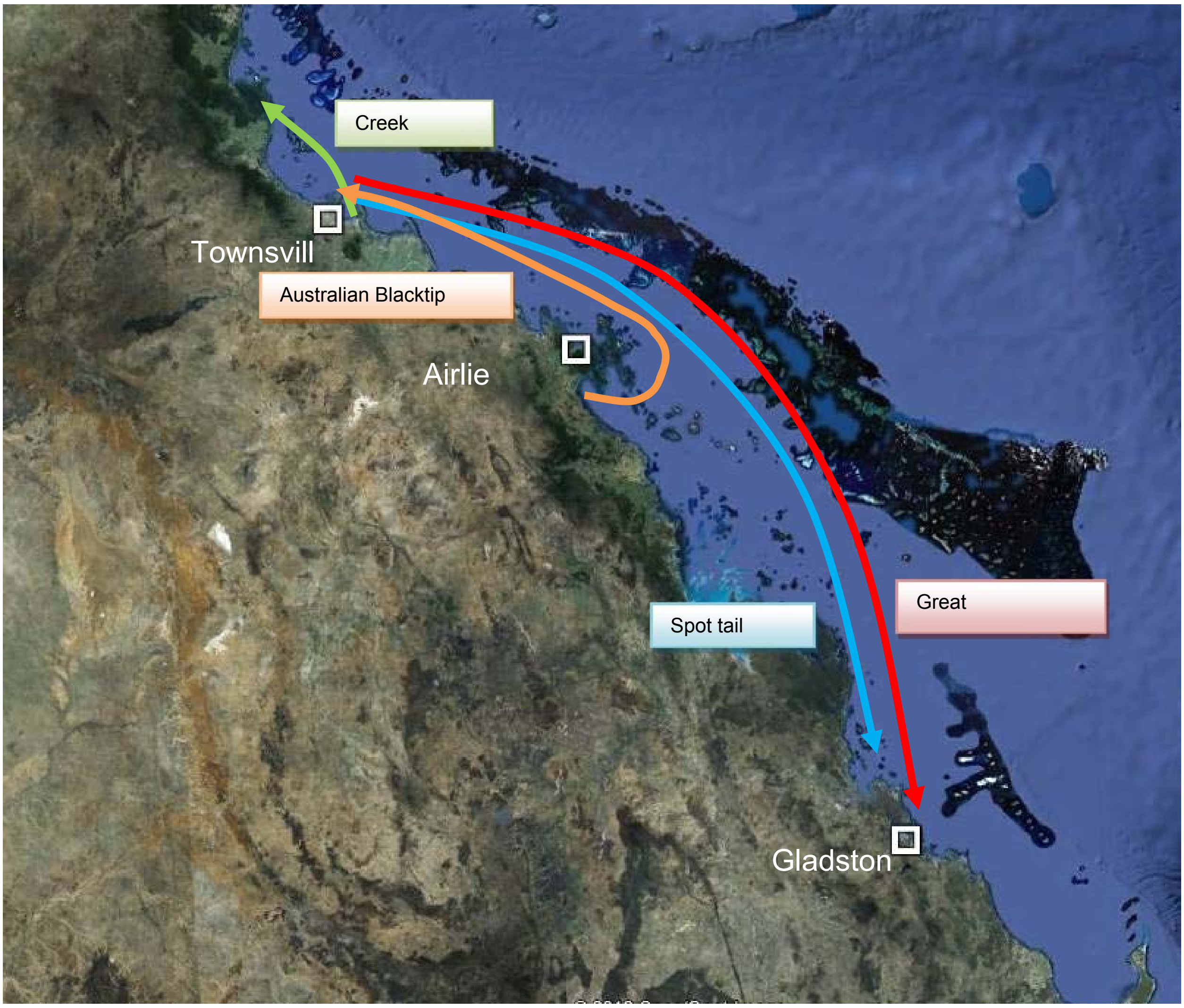
Recent James Cook University research on the Queensland east coast fishery has demonstrated the fishery targets mostly juvenile sharks. The need now is to identify how many juvenile sharks can be removed each year without compromising future populations and fishery catch rates. In order to determine this a joint research program being conducted by James Cook University and Queensland Fisheries is tagging and releasing sharks from multiple locations along the Queensland east coast. The recapture rate of these tagged sharks will allow harvest rates to be identified.

The project began in 2010 and so far 3650 sharks have been tagged with the help of commercial fishermen and a further 1000 tags will be deployed by the end of 2012. While the primary objective of the project is to determine sustainable harvest rates for Queensland shark species, the recapture information provided by fishers is providing additional information about shark species such as their movements with some individuals travelling as far as 700 km (Pictured).

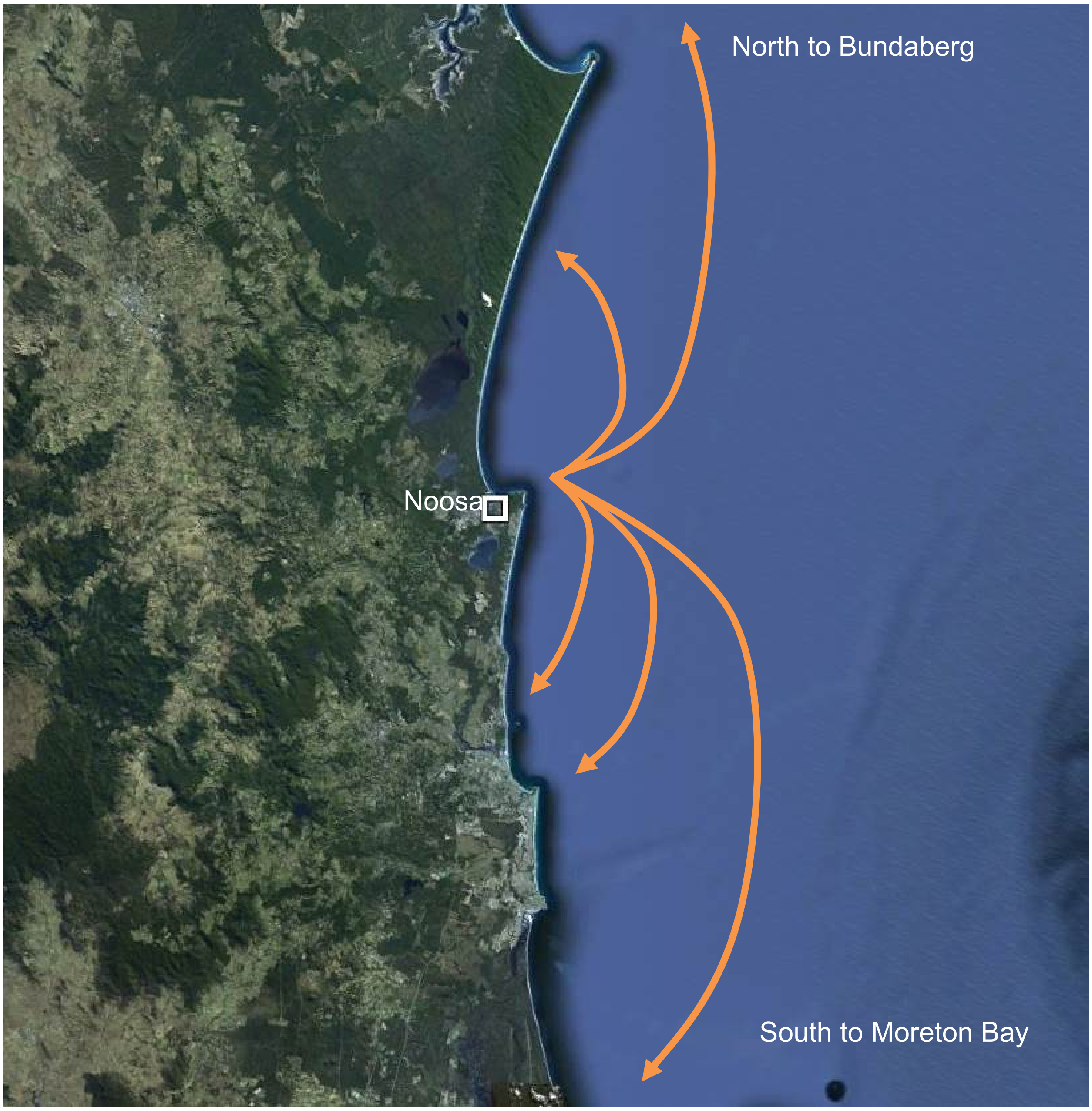
If you capture a tagged shark, please call the phone number on the tag (07 4781 5973) to report the recapture. The information the project requires includes tag number, date and location (can be a general area such as Hervey Bay, though a GPS point would be preferred) of the recapture. The data generated through this project will go a long way to securing future certainty in the sustainable harvest of sharks from the Queensland east coast.

Fishers who report this information will receive a recapture letter that includes the initial capture information as well as a free T-shirt. Two $500 gift vouchers from Net Supplies Australia will be awarded to two lucky fishers through two random draw events throughout the project. Each recapture a fisher reports will give that fisher a chance of winning a gift voucher. These two draws will occur on the 15th March 2012 and the 15th March 2013. Thanks to all those fishers who have already reported recaptured sharks - you are already in the running for the first $500 gift voucher.

For further information please contact Andrew Tobin at the Fishing & Fisheries Research Centre, James Cook University 07 4781 5113. This project is funded by the Fisheries Research and Development Corporation on behalf of the Australian Government.

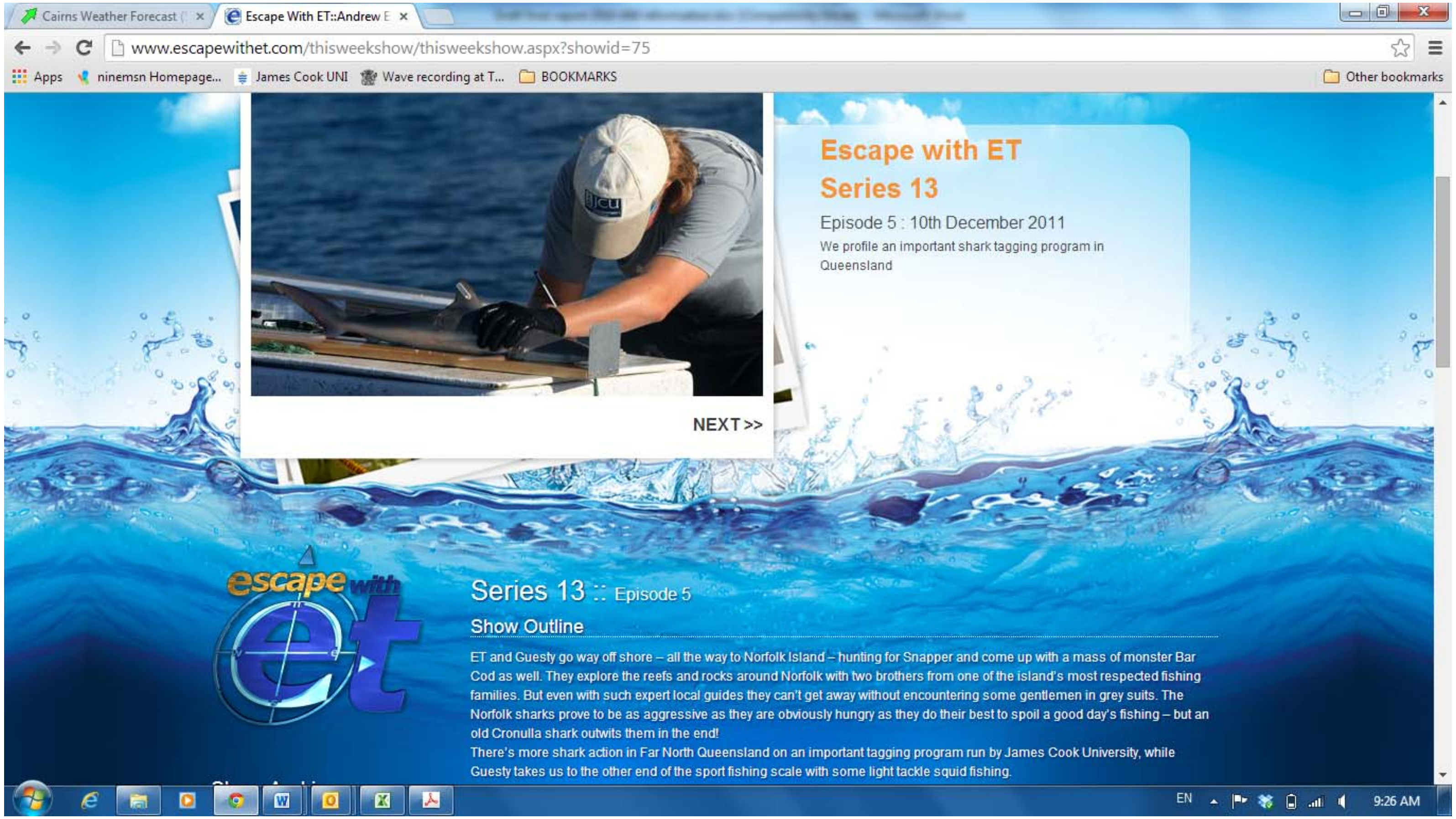


A few of the many interesting movement patterns to be discovered by tag recapture information. The greatest of which was great hammerhead shark which travelled over 700 km from Townsville to Facing Island near Gladstone between November 2008 and April 2009.



In early 2011, a group of juvenile spinner sharks were tagged out from Noosa. Since then 36 of them have been recaptured by both commercial and recreational fishers. Most were recaptured within the general Sunshine Coast area, though some swam south into Moreton Bay while others swam north to Bundaberg.

Appendix G – Escape with ET, Series 13, Episode 5



Appendix H – Sharks International 2014 conference presentation

Management of shark fishing in the Great Barrier Reef Marine Park and southeast Queensland; has it successfully controlled fishing mortality?

Alastair V. Harry[1*], Andrew J. Tobin[1], Richard J. Saunders[1], Jonathan Smart[1], Colin A. Simpfendorfer[1]

Abstract

The rate fishing mortality, *F,* during 2011 and 2012 was estimated for four species of commercially fished whaler sharks (genus *Carcharhinus*) in the Great Barrier Reef Marine Park and southeast Queensland from a five year tagging study. Values of *F* were then used in a range of demographic models to assess whether fishing by the East Coast Inshore Finfish Fishery (ECIFF) and the recreational sector was likely to be have been sustainable. Tag return rates for the two most commonly caught species, *Carcharhinus sorrah* and *Carcharhinus tilstoni,* were estimated at 5.6% and 16.4%, respectively. These values corresponded to maximum value of *F* of 0.06 and 0.13, respectively, for 2011 and 2012 combined. Demographic analysis indicated that this value of *F* would lead to a positive rate of population increase, *r,* for *C. sorrah* (*r* = 0.10) and a stable population for *C. tilstoni* (*r ≈ 0*). Overall tag return rates for two larger species of whaler sharks, *C. amboinensis,* and *C. brevipinna,* caught only as juveniles, were 35.9% and 11.8%, respectively. These values corresponded to a maximum value of *F* of 0.40 and 0.07, respectively. All demographic analysis indicated that this level of *F* was within sustainable bounds (*r* = 0.04) for *C. brevipinna,* however three out of four analyses indicated that it was unsustainable for *C. amboinensis* (*r =-0.14*). Notably though, a demographic analysis using recent empirical estimates of natural mortality, *M,* suggested that fishing may still be sustainable (*r= 0.03*). Our findings broadly suggest that the range of management measures have been undertaken over the past decade has been successful in controlling fishing mortality on target species. The high recapture rates for *C. amboinensis,* a species not typically targeted, suggests that incidental capture of some long-lived and slow growing sharks by the ECIFF could still be an issue.