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Recreational fishing of sharks in the Great Barrier Reef World Heritage Area: species composition and incidental capture stress

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"Discovery only comes about by exploration and in many ways this includes taking risks. Knowledge itself can only be advanced by those who have the courage of their convictions"
Neville Coleman

"Knowing is not enough, we must apply. Willing is not enough, we must do"
Johann Wolfgang

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ABSTRACT

Even though recreational fishing is a very popular activity in the Great Barrier Reef World Heritage Area (GBRWHA), with approximately 180,000 recreational fishers living in the area, catch composition data for sharks caught by this sector are very limited. Fisheries Queensland conducted diary and telephone surveys and estimated the recreational catch of sharks to be higher than the state's commercial catch; however such surveys have not provided information on the species composition of the catch. Despite the large number of sharks being caught by recreational fishers in the GBRWHA, the surveys conducted by Fisheries Queensland found that most of the sharks are released. While this may be positive, there is potential for high post-release mortality rates, which is likely to be the greatest effect of recreational fishing on sharks in the GBRWHA.

Different shark species have distinctive life history characteristics which can influence their relative vulnerability to fishing pressure; therefore the effective assessment and management of shark fisheries require collection of catch data on a species-specific basis. Because previous research has shown that most recreational fishers cannot accurately identify their shark catch, collection of species composition information cannot rely solely on recreational fishers' knowledge. The aims of this project were to engage the recreational fishing community of the GBRWHA in shark research to describe the species composition of the recreational incidental catch of sharks, and assess capture and handling effects on their post-release survival to determine appropriate handling and release protocols.

Catch composition data were collected through individual fishers, charter operators and fisheries-independent sampling. Individual fishers and charter operators provided photos and tissue samples of sharks they caught. Charter operators also allowed the

researcher to go on board free of charge to collect data. A total of 209 sharks were identified during the study consisting of 17 species representing four families. The family Carcharhinidae was the most diverse, with 12 species, and the most abundant constituting 86.8% of the catch. The morphologically identical Australian blacktip shark *Carcharhinus tilstoni* and common blacktip shark *Carcharhinus limbatus* were the most abundant species. Size ranged from 420 mm for a milk shark *Rhizoprionodon acutus* caught inshore to 2200 mm for a tawny nurse shark *Nebrius ferrugineus* caught on a mid-shelf reef. The species composition of the recreational catch of sharks in the study area had an 80% overlap with the composition of the inshore commercial gill-net catch. The results demonstrate that recreational catch of sharks is very diverse in the GBRWHA waters and the overlap with the commercial catch composition means that both sectors need to be involved in the assessment and management of these species.

Capture and handling physiological stress was measured using whole blood lactate concentration as an indicator of stress caused by angling duration and air exposure in five species of shark. Increased angling and air exposure durations caused a significant increase in whole blood lactate concentration in all five species of shark examined. However, the maximum whole blood lactate concentrations measured in line-caught sharks were lower than in individuals of the same species caught by other fishing methods such as gill-net and longline. There was some degree of individual variation in response to stressors within each species but there was limited variation between species and between sexes. Post-release monitoring, good release conditions and relatively low whole blood lactate concentrations suggested that all sharks caught in the study had a high likelihood of post-release survival.

The results of this study demonstrated that the capture and handling practices of recreational fishers that do not target sharks have only limited impact on shark's post-release survival. As such, their practices are unlikely to directly cause mortality of sharks however there is potential to sub lethal effects not measured in this study to have significant effects on shark populations. Nevertheless, until recreational catches are properly quantified and identified and are included in stock assessments together with other sources of mortality it is not possible to conclusively affirm that recreational fishing is not impacting on shark populations.

Chapter 1. General Introduction

Plate 1. Sunset in the Outer Great Barrier Reef on board charter vessel

1.1 Introduction

Many studies have highlighted the need and importance of measuring the potential impacts of recreational fishing practices on aquatic animals in response to the increased popularity of the activity (Arlinghaus et al., 2007, Alós, 2009, Greiner and Gregg, 2010) and potential synergistic effects with other sources of mortality such as commercial fishing, habitat degradation and climate change (Walker, 1998, Lynch et al., 2010, Chin et al., 2010). However very few studies have actually incorporated recreational catches in the assessment and management of fish populations.

Where recreational fishing catches have been incorporated it has mainly concerned teleosts species (bony fish) with very little incorporation of research/monitoring regarding shark populations. The Great Barrier Reef World Heritage Area (GBRWHA) (Queensland, Australia) has both a large number of potentially vulnerable shark species and a large recreational fishing community with over 180,000 active recreational fishers living in the region adjacent to the GBRWHA (McInnes, 2006). The purpose of this thesis is to examine the potential effects of recreational fishing on shark populations of the GBRWHA and provide information to facilitate the incorporation of recreational fishing impacts in shark risk assessments and management and conservation strategies.

1.2 Global shark fisheries and threats to shark populations

In 2008, estimates based on reporting by major fishing countries indicated that total world fishery production reached about 142 million tonnes (FAO, 2010). While production is high, some of the world's fish populations, including sharks, are declining (Granek et al., 2008). The estimated total worldwide production of sharks in 2007 was 780,000 tonnes (Lack and Sant, 2009). Sharks are harvested globally in commercial, artisanal, traditional and recreational fisheries. Such fisheries, coupled with shark control programs and habitat modification (Walker, 1998) are considered the main causes of declines of shark populations where they have occurred. The International Union for Conservation of Nature (IUCN) Red List assessment of pelagic sharks and rays assessed 64 pelagic species of sharks and rays. The assessment found that 26% are considered vulnerable, 24% are near threatened, 25% are data deficient and 19% are of least concern (Dulvy et al., 2008). Three-quarters of oceanic pelagic sharks and rays have an elevated risk of extinction due to overfishing. This high risk is a result of intense fishing effort, lack of catch restrictions and the rising value of shark fins and meat (Dulvy et al., 2008). As a consequence of these declines, concerns about the impacts of fishing on shark populations around the world have been raised (FAO, 1999, Shark Advisory Group and Rose, 2001, Shark Advisory Group and Lack, 2004, Camhi et al., 2007, FAO, 2008, FAO, 2010) yet such concerns have not been translated into management action in most situations. As such, human effects on shark populations are increasing and need to be addressed (Simpfendorfer et al., 2011).

The effects of potential declines in abundance of sharks have been poorly studied. Most sharks are predators at, or near, the top of the food chain and therefore their removal is predicted to affect structure and function of marine ecosystems directly and indirectly (Baum and Worm, 2009). Direct effects include size structure alterations, changes in abundance and shifts in community composition. The indirect effects include species replacement and changes in trophic interactions (Stevens et al., 2000).

Vulnerability of individual species to fishing is dependent on life-history parameters and population distribution (Harry et al., 2011b) as well as their productivity and susceptibility to fisheries (Tobin et al., 2010). Importantly, major population declines can lead to a real threat of extinction, especially for already rare species and species with restricted ranges (Stevens et al., 2000). In addition, some species of sharks are also known to spatially segregate by sex (Klimley, 1987, Mucientes et al., 2009) and/or size (Guttridge et al., 2009, Mucientes et al., 2009) which can have profound implications to fishery exploitation if differential harvest of certain components of the population occurs (Harry, 2011).

Compared to teleosts that produce millions of small eggs that are fertilised externally, fertilisation in sharks occurs internally and fewer large eggs or young are produced. This reproductive strategy allows for high survival rates of the young because the offspring are born larger and precocious, minimising predation. However, sharks generally grow more slowly than teleosts and take longer to attain sexual maturity (Last and Stevens, 2009). These life history traits result in sharks having a low rate of population increase making them more susceptible to overexploitation (Walker, 1998, Stevens et al., 2000, Camhi et al., 2007, Garcia et al., 2008).

A key step towards the management of shark harvest at sustainable levels is the completion of rigorous stock assessments for the target species. Assessments are needed to confirm that fishing at current levels is not resulting in declines of target shark populations (Musick and Bonfill, 2005). A fundamental requirement for species stock assessments is knowledge of the catch composition and the basic biology of exploited species. In addition, accurate identification of the catch by fishers is important where catch and effort data for stock assessment are collected directly from fishers (Musick and Bonfill, 2005). There is very limited or no data on species and landings of sharks around the world (Stevens et al., 2000) because sharks have historically been considered to have low economic value in most countries, and because research priorities are usually linked to the economic value of the fisheries. Further, the available shark catch data usually combines sharks and rays and does not specify the species making it difficult to assess stocks and quantify the total shark catch. Because of the different life history characteristics of individual shark species, the effective management, assessment and conservation planning of shark fisheries requires collection of catch data on a species-specific basis (Shivji et al., 2009).

1.3 Commercial fishing in Australia

Australian commercial fisheries are managed by a combination of State/Territory and Commonwealth agencies. The fisheries in waters from the shore of each State/Territory to 3 nautical miles offshore are under State/Territory jurisdiction while waters from 3 nautical miles to the edge of the 200-mile Exclusive Economic Zone are under Commonwealth jurisdiction (Lacombe and Beggs, 2008). In 2009-10 the total volume of Australian fisheries production (i.e. commercial fishing and aquaculture) was 241,123 tonnes, with a gross value of $2.18 billion. The product composition has not changed substantially over the past few years with the top five fisheries products (by value) being rock lobster, prawn, salmonids, abalone and tuna (ABARES, 2011).

On a global scale, Australia's annual commercial shark catch is relatively low; however, shark landings represented 4.9% of Australia's total capture fisheries production in 1994-98, the fourth highest percentage in the world (Bensley et al., 2010). The total value of Australian shark catch has varied markedly and has been declining since 2000-01. The decline is attributed to reductions in overall catch and low prices for some products as well as increase in fuel prices and fluctuations in the Australian dollar (Bensley et al., 2010). The total reported commercial catch of sharks in Australia in 2005-06 was 9,412 tonnes. The majority of these sharks caught by commercial fishers is sold for consumption in fish and chip shops, with the main market in south-eastern Australia (Last and Stevens, 2009). Shark fins are mostly exported, although a small portion goes to the domestic market. Where markets are available, shark liver oil and cartilage are also sold (Shark Advisory Group and Rose, 2001).

The majority of Commonwealth managed fisheries do not target sharks; however, many species of sharks are caught as byproduct and bycatch in a range of different fisheries (Bensley et al., 2009). Sharks are targeted mainly in the Southern and Eastern Scalefish and Shark Fishery and the Western Australian Temperate Demersal gill-net and Demersal Longline Fisheries. In addition, sharks are also taken in a range of multispecies State/Territory managed fisheries. The main target species by commercial fishers in southern Australia are gummy shark *Mustelus antarcticus,* whiskery shark *Furgaleus macki,* dusky shark *Carcharhinus obscurus* and sandbar shark *Carcharhinus plumbeus*. In northern Australia the main harvested species are Australian blacktip shark *Carcharhinus tilstoni*, common blacktip shark *Carcharhinus limbatus*, spot-tail shark *Carcharhinus sorrah* and hammerheads *Sphyrna* spp. (Bensley et al., 2009). Even though most fisheries are not primarily targeting sharks it is important to acknowledge and take byproduct harvest and bycatch post-release mortality into account when estimating fishing impacts.

In addition to the Australian commercial catch, sharks are also taken by indigenous and recreational fishers and beach protection programs. However, there is more accurate knowledge regarding the commercial catch because commercial fishers are required to report their catch using logbooks. Moreover, some Commonwealth and State fisheries also have fisheries observer programs that provide more reliable data on catch composition, fate of target and non-target species and fishing effort. There is little understanding of the species that are important to the indigenous and recreational communities because of the difficulties in surveying these sectors and the fact that they do not have to report their activities to a management agency.

1.4 Recreational fishing in Australia

Recreational fishing in Australia is an important activity for over 5 million Australians, contributing an estimated $2.5 billion to the economy (e.g. in services, tackle and bait) (Recreational fishing advisory committee, 2011). The majority of recreational fishing occurs in coastal waters and the most common method is line fishing. In 2000-01 recreational fishers alone were estimated to have harvested 136 million aquatic animals (Henry and Lyle, 2003). Given the large number of recreational fishers, recreational fishing is likely to have a significant effect on some species they target.

The management of recreational and charter fishing in Australia is mostly the responsibility of each State/Territory authoritygiven that most common fishing areas are in coastal waters (McPhee, 2008). The different states have different management measures in place such as bag and size limits, gear restrictions and seasonal closures (ABARES, 2011). These measures also vary depending on the target species. In most cases, recreational fishers are not required to report their catch to a management agency and thus most statistics concerning the recreational catch are collected by surveys (e.g. Henry and Lyle, 2003, McInnes, 2006, McInnes, 2008, Lynch et al., 2010). Data collected through these surveys is important for the management of the sector. However, at present, accurate information on the species composition and quantities taken, particularly at a regional level, is very limited making it difficult to assess and manage most recreationally caught species.

The recreational catch of sharks in Australia encompasses game fishing and general recreational fishing. Game fishing for sharks mostly relates to the catching of pelagic shark species undertaken when fishing for large pelagic fish using heavy tackle (Shark Advisory Group and Rose, 2001). The Game Fishing Association of Australia has defined eight species/families of sharks that are eligible for fishing competitions. These species are blue shark *Prionace glauca*, tiger shark *Galeocerdo cuvier*, *M. antarcticus*, porbeagle *Lamma nasus*, hammerheads *Sphyrna* spp., shortfin mako *Isurus oxyrinchus*, thresher sharks *Alopias* spp. and whalers *Carcharhinus* spp. Game fishing is very popular in south-eastern Australia (Pepperell, 1992), yet, few game fishers target sharks in the states of Queensland (QLD), Western Australia (WA) and Northern Territory (NT) (Shark Advisory Group and Rose, 2001).

The total catch of sharks in general recreational fisheries is not well quantified due to the difficulties in collecting and aggregating data for the sector. The NRIFS estimated that Australian recreational fishers catch over 1.2 million sharks each year. However, because recreational fishers in Australia do not usually target sharks (FAO, 2008) one million of these sharks are estimated to be released each year (Henry and Lyle, 2003). The vast majority of the harvest is taken in Victoria (VIC) followed by QLD (Henry and Lyle, 2003) (Table 1.1).

Table 1.1 Estimated annual harvest (numbers) of sharks and rays harvested by recreational fishers by State and Territory (Henry and Lyle 2003).

Fishery	Harvest of sharks and rays (numbers)
Victoria	89, 423 (SE=20,585)
Queensland	35, 899 (SE=8,095)
South Australia	30, 722 (SE=8,428)
New South Wales	30, 093 (SE=6,617)
Western Australia	24, 432 (SE=3,260)
Tasmania	9, 808 (SE=3,917)
Northern Territory	7, 942 (SE=1,391)
Total	228, 320 (SE=25,140)

1.5 Other fishing pressures

Indigenous fishing is defined as fishing activities carried out by traditional inhabitants for their own or their dependants' consumption, for educational or ceremonial purposes or non-commercial communal needs (Fisheries Research and Development Corporation and Ridge Partners, 2010). Henry and Lyle (2003) estimated that 186,200 Indigenous Australians participated in non-commercial fishing during the national recreational and indigenous fishing survey year (2000-01) and that the sector had a financial value of $22.52 million. The same survey found that Indigenous fishers harvested aquatic animals from a range of environments, but inshore waters accounted for more than half the fishing effort. Indigenous fishers were estimated to have harvested more than 3 million aquatic animals from the waters of northern Australia including approximately 910,000 finfish. The management of Indigenous fishing is complex and involves co-management and some State/Territory laws. Indigenous fishers do not have to report their catch and statistics relating to the sector are collected by surveys (e.g. Henry and Lyle, 2003).

Sharks are an important source of protein for Australian indigenous communities and are harvested seasonally (Last and Stevens, 2009) in the NT, WA and QLD. The National Recreational and Indigenous Fishing Survey (NRIFS) estimated the annual harvest of sharks by indigenous fishers to be a total of 18,294 individuals where 12,464 were harvested in the NT alone (Henry and Lyle, 2003). Compared to other sectors, indigenous take is relatively small; however, it should also be considered in stock assessments of species that are also taken by other fisheries.

Beach protection programs operate in New South Wales (NSW) and QLD. Current data shows that the NSW shark meshing program has 51 netted beaches and catches on average 106 sharks per year (Bensley et al., 2009). The QLD shark control program has 35 nets and 348 drumlines deployed adjacent to major population centres along a 1,760 km stretch of the coast (Sumpton et al., 2011) and catches an average of 565 sharks per year (Bensley et al., 2009). Even though these catches are low compared to other fisheries, beach protection programs target larger species (considered potentially dangerous) that are usually less productive which may have a larger effect on local shark populations.

A lack of focus on data collection for sharks in the past currently limits the scope for quantitative assessments for the majority of shark species caught in Australia (Bensley et al., 2010). Quantitative stock assessments are typically only conducted for the more commercially valuable species or species seen to be at higher risk. For instance the Commonwealth Fisheries Status Report 2010 assessed *M. antarcticus* as not overfished/not subjected to overfishing while school sharks *Galeorhinus galeus* were considered overfished/subjected to overfishing (Woodhams et al., 2011). State/Territory managed fisheries stock assessments have also focused on commercially targeted species (e.g. *F. macki* in WA). However, species that are also taken by other fisheries should have all sectors taken into consideration when estimating fishing impacts and assessing stocks. The effective management and conservation of shark species requires an understanding of all major sources of mortality (Bensley et al., 2010)

1.6 Shark fishing in the Great Barrier Reef World Heritage Area

The Great Barrier Reef (GBR) is considered one of the least degraded reef systems in the world (Pandolfi et al., 2003) and is home to around 133 species of sharks, rays, skates and chimeras (Chin et al., 2010). They are very diverse in size, appearance and lifestyle, ranging from small cryptic to large migratory species and can be found in a wide range of habitats (from inshore soft bottom habitats to coral reefs and the upper slope). Several species found in the GBRWHA are considered threatened; e.g. grey nurse shark *Carcharias taurus* and all species of sawfish (Chin, 2005).

The main pressure on shark populations in the GBRWHA is fishing (GBRMPA, 2009a, Lynch et al., 2010) as well as habitat degradation and climate change (Chin et al., 2010). The East Coast Inshore Finfish Fishery (ECIFF) is QLD's largest and most diverse fishery comprising commercial, recreational, charter and indigenous sectors. This is a very complex fishery involving multiple species and a variety of gears (DEEDI, 2011). In the GBRWHA, 90% of the reported commercial harvest of sharks is taken within the ECIFF gill-net fishery while the remaining 10% is taken within the reef line and trawl fisheries (Chin, 2005). According to Fisheries Queensland, the total gross value of production derived from sharks taken commercially from the GBRWHA was AU$ 4.4 million in 2005. The four most abundant species in the GBRWHA commercial catch of sharks are *C. tilstoni*, *C. limbatus*, *C. sorrah* and scalloped hammerhead shark *Sphyrna lewini* (DEEDI, 2011, Harry et al., 2011b).

Many studies have addressed the potential effects of fishing on shark populations (e.g. Walker, 1998, Stevens et al., 2000, Campana et al., 2009, Lynch et al., 2010), but few studies have focused on the GBRWHA. Robbins et al. (2006) raised concerns regarding the decline of populations of two species of reef shark in the GBRWHA due to overfishing even though these species are not targeted in commercial fisheries. The study suggested that fishing was a major cause of population decline, and highlighted concern for fishing in the GBRWHA. Heupel et al. (2009) when studying the effects of fishing on tropical reef associated sharks in the GBRWHA using three different data sources (fisheries logbooks data, fisheries observer data and fisheries-independent data) concluded that while there were declines on fished reefs, reef shark populations in the GBRWHA were not depleted as severely as suggested by Robbins et. al. (2006). The differences in the findings of these studies highlight the uncertainty in the status of many shark species and the need for further research on the effects of fishing on sharks in the GBRWHA. There are currently no stock assessments for any of the GBRWHA target shark species due to limitations in data availability such as species biology and total catches. A few studies have focused on life history traits of target species (e.g. Harry et al., 2011a) but such data have not yet been translated into formal assessments or management measures (DEEDI, 2011).

Recreational fishing is a very popular activity in the GBRWHA with approximately 180,000 active recreational fishers living adjacent to the marine park (McInnes, 2006), yet very little is known about the shark catch of the recreational sector (Lynch et al., 2010). Until recently, there were no restrictions for the recreational catch of sharks in QLD, but in July 2009 Fisheries Queensland introduced a bag limit of one shark and a maximum size limit of 1.5 m total length. The introduction of these regulations was designed to address concerns about the level of shark catch in general and to preserve the breeding stock by protecting larger growing, less productive species considered most at risk (Simpfendorfer, 1999, Prince, 2005). There are also no-take species including the threatened species such as the speartooth shark *Glyphis glyphis* (QPI&F, 2009).

Although individual recreational fishers may have limited effect on populations of sharks, recreational fishing can have a large cumulative effect due to the large number of people who participate in the fishery. The latest estimate of recreational fishing catch and effort in QLD was conducted by Fisheries Queensland in 2005* using a series of telephone and diary surveys. The survey estimated that a total of 182,000 sharks were caught by recreational fishers state-wide. Within this total, 29,000 were harvested and 153,000 released (release rate = 84%) (McInnes, 2008). In fact, QDPI&F (2008) estimated the recreational catch of sharks (including harvested and released individuals) to be higher than the state's commercial catch (Figure 1.1). However, these recreational fishing surveys provide very little information on the species composition of the shark catches. Given the diversity of sharks in the GBRWHA understanding the species composition is imperative for proper management.

Lynch et al. (2010) undertook the first dedicated study on recreational fishing of sharks in the GBRWHA. The study interviewed 309 recreational fishers in the Townsville region (QLD) aiming to determine recreational fishing harvest and release rates of sharks and rays and explore recreational fishers handling behaviour and attitudes towards them. The study found that recreational fishers do not usually target sharks and most sharks caught are released, which was consistent with results from the broader state-wide survey (Figures 1.2 and 1.3). The high release rates suggest that post-release mortality has great potential to affect shark populations of the GBRWHA if sharks are not surviving after release. Lynch et al. (2010) concluded that there is a need for improved recreational catch data for sharks to species level and more importantly it is necessary to determine post-release mortality rates and methods for

**The latest survey was conducted in 2010-11 but results were not available at the time of writing. Results of the 2010 survey can be found at http://www.daff.qld.gov.au/28_18273.htm* improving post-release survival. It is imperative that estimates of impacts of recreational fishing on sharks take into consideration potential post-release mortality as a result of capture and handling.

Improved management of sharks in the GBRWHA will require improvement in information of shark catch and related fishing effort (Chin, 2005). Incomplete catch statistics, particularly at the species level, make it difficult for managers and researchers to analyse the status of shark species (Holmes et al., 2009). The Great Barrier Reef Marine Park Authority (GBRMPA) has identified in its research priority list, and Outlook report, high priority for research on the risks to sharks and rays taken in commercial and recreational fisheries including species and quantities taken (GBRMPA, 2009b). Species composition, post-release mortality and catch effort studies will provide data for future assessments in shark fisheries and enhance their accuracy culminating in improved management.

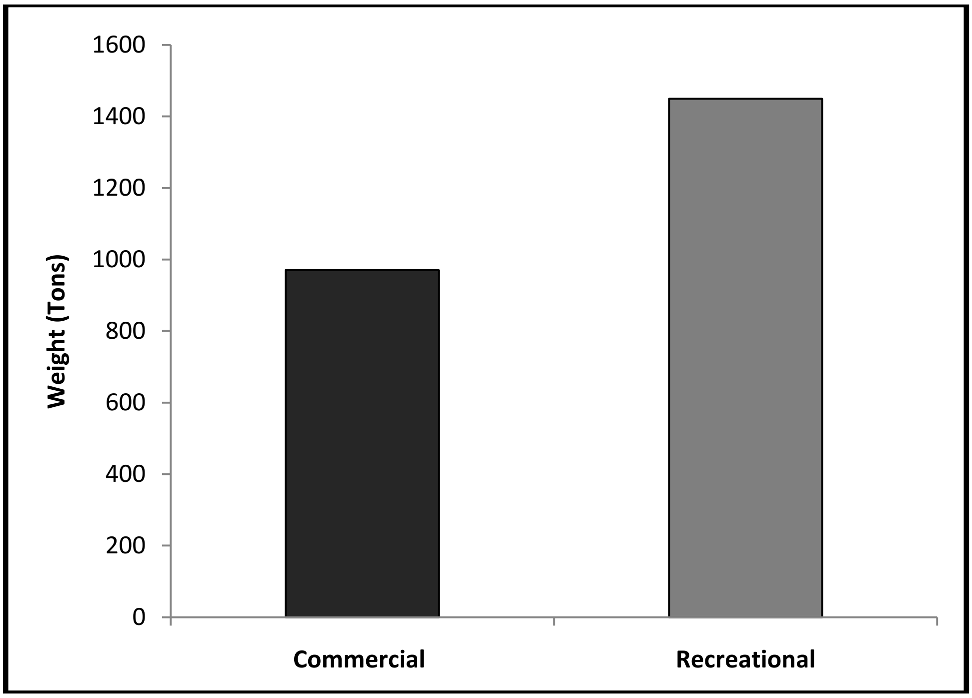

Figure 1.1 Total catch of sharks and rays by commercial and recreational fishing in QLD in 2005 (Data from DPI&F, 2008). Commercial production is generally reported in terms of weight and recreational harvest is usually reported in numbers and thus to permit comparisons between sectors for species that are

caught by both it is necessary to estimate the recreational harvest of some species as weights (Henry and Lyle, 2003).

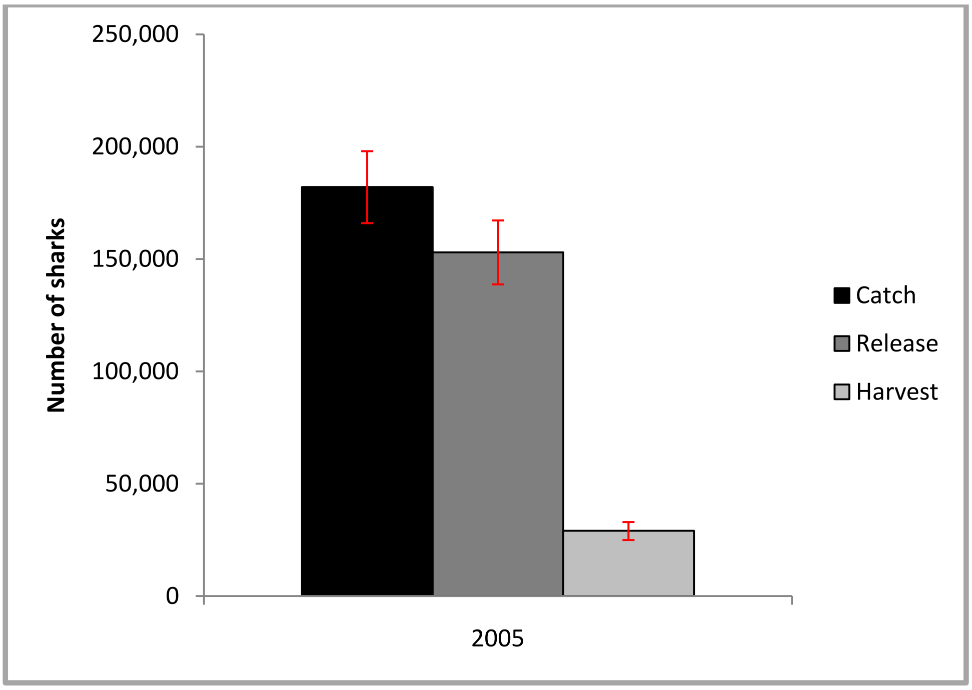

Figure 1.2 Estimated QLD state-wide catch, harvest and release of sharks from the 2005 RFISH diary rounds (Data from McInnes, 2008).

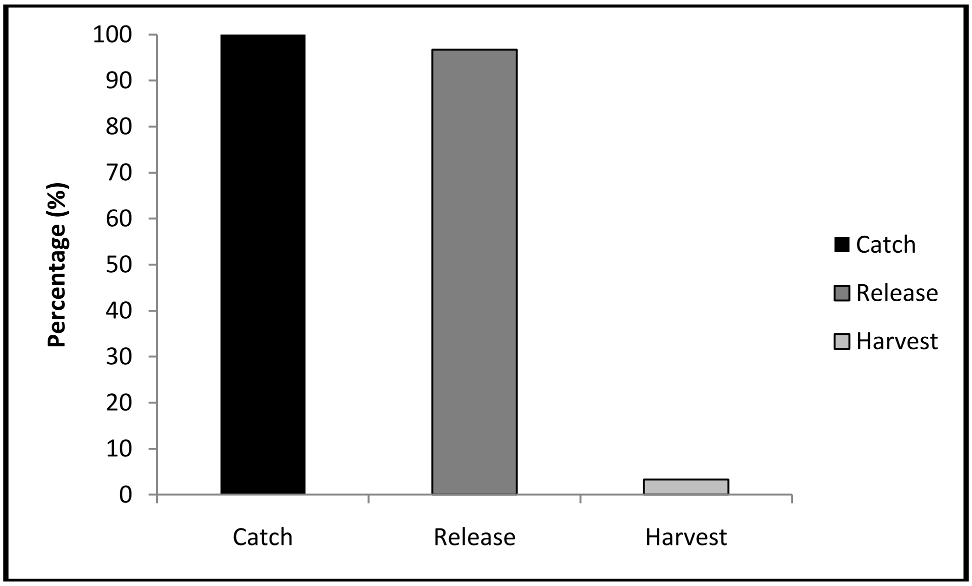

Figure 1.3 Percentage of catch, release and harvest sharks from boat ramp surveys in the GBR (Data from Lynch et al, 2010).

1.7 The need to involve recreational fishing communities in research

In recent years there has been a growing recognition that the fishing community has to become more actively involved in fisheries management in order to improve management effectiveness and legitimacy (Nielsen and Vedsmand, 1997). Scientific knowledge plays an important role in fisheries management (Jentoft and McCay, 1995) however understanding fishers' concerns and developing methods to actively involve them will have positive impacts on management and conservation efforts (Granek et al., 2008).

Recreational fishers constitute a social group that has the potential to be an important conservation force because of their interest in the resource and in the leisure activity itself (Granek et al., 2008). Giving recreational fishers responsibility for helping to solve management problems requires them to become more knowledgeable about the different species and their habitats, culminating in benefits to the fishery. Local knowledge and experience contributed by fishers will facilitate the understanding and monitoring of the fishery (Granek et al., 2008). If given a high degree of stewardship through personal experiences or effective education programs recreational fishers are more likely to actively engage in conservation.

There are many ways that recreational fishers can be engaged in research, management and conservation such as in monitoring, data collection, enforcement and management design. Opportunities for engagement with recreational fishers can be increased by focusing initiatives on representative groups such as fishing clubs (Granek et al., 2008). Previous research has found that GBRWHA recreational fishers have positive attitudes towards shark conservation and are willing to learn new handling and release practices to minimize their impacts on shark populations (Lynch et al., 2010)

1.8 Objectives of the project

Although recreational fishers in the GBRWHA are not targeting sharks specifically, they may still be having a negative effect on shark populations due to the large number of participants and cumulative effects with other sources of mortality. Because of the high release rates, post-release mortality may be the largest effect of recreational fishing on shark populations if incidentally caught and released sharks do not survive after release. To determine the impacts of recreational fishing on sharks of the GBRWHA it is crucial to improve recreational catch data to species level and identification of species most susceptible depending on their life history characteristics, conservation status and mortality caused by other sources. In addition, it is important to determine post-release mortality rates as well as improve understanding of how recreational fishers' current catch and handling practises may influence post-release survival.

The aim of this thesis was to involve the recreational fishing community of the GBRWHA to describe their current catch and handling practices and the potential impacts of such practices in the post-release survival of incidentally caught and released sharks. Data collected during this project will contribute in improving the assessment of shark populations in the GBRWHA and assist with the management of recreational fisheries in the area. To achieve this aim, the specific objectives were:

1. To develop test and evaluate a method for involving the recreational fishing community in field data collection.

2. To determine the species composition of the recreational catch of sharks in the GBRWHA.

3. To measure stress caused by capture and handling and determine consequent post-release mortality rates.

1.9 Study Area

The study area falls within the boundaries of the Great Barrier Reef Marine Park (GBRMP) and GBRWHA. The GBR is the world's largest heritage area covering an area of 350,000 km². The study area was the section of the GBRWHA extending from Mackay in the south (21° 8'31.66"S 149°11'11.46"E) to Port Douglas in the north (16°29'10.95"S 145°28'9.94"E) (Figure 1.4).

The GBRMP is a multiple use area that is divided into different zones. Each zone has different rules for the activities that are allowed, prohibited, restricted or require a permit. The fishing carried out during the study was undertaken in Conservation park zones (line fishing restricted to one line and one hook per person) and General use zones (no restrictions for line fishing).

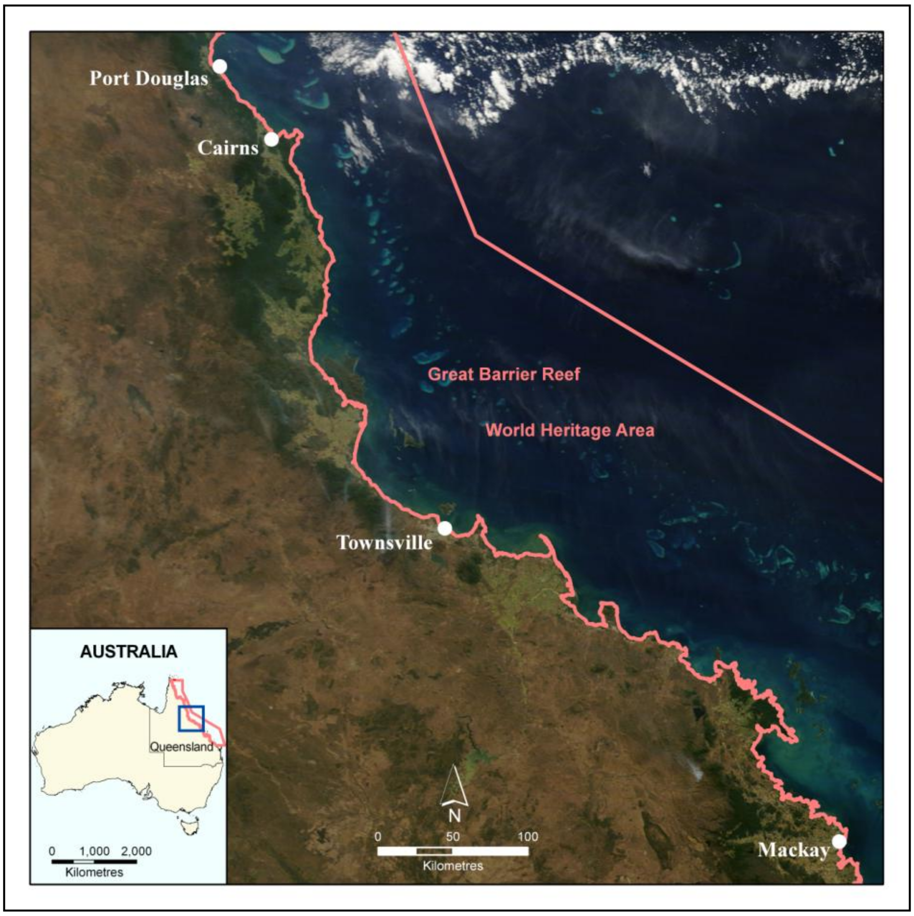

Figure 1.4 Map showing study area. Pink line is the GBRWHA boundaries. Main towns in the study area are labelled in white.

2.0 Thesis Outline

Chapter 2 The importance of involving recreational fishing communities in data collection for shark research - argues the importance of involving the recreational fishing community in research then shows the methods used in this study to involve the recreational fishing community of the GBRWHA in data collection. Individual recreational fishers and charter operators of the study area were recruited to collect photos and fin clips of any sharks they caught and charter operators were also asked to take the researcher on board their fishing trips. Data collected by the individual fishers and charter operators and by the researcher on board charter vessels were used in Chapters 3 and 4.

Chapter 3 Recreational catch composition of sharks in the Great Barrier Reef World Heritage Area – uses information collected from a combination of fisheries-dependent and independent sampling to provide the first description of the species composition of the recreational catch of sharks within the GBRWHA. This chapter then discusses some of the issues faced by fishery managers and the importance of including the recreational catch in stock and risk assessments.

Chapter 4 Understanding the effects of incidental recreational capture on juvenile sharks – measures the physiological stress experienced by incidentally caught and released sharks in recreational fisheries by using fisheries-independent experiments reproducing recreational fishers techniques. It examines the effects of angling and air exposure durations on physiological stress measured by whole blood lactate concentrations then gives recommendations to fishers and managers to minimise capture stress to guarantee post-release survival of sharks.

Chapter 5 General conclusions, recommendations for future research and implications for recreational fishers and the management of shark fisheries in the Great Barrier Reef World Heritage Area - concludes this thesis by discussing the fishery implications of this research, identifies the knowledge gaps and provides advice for future research.

Chapter 2. The importance of involving recreational fishing communities in data collection for shark research

Plate 2. Recreational charter fishers

2.1 Introduction

The recognition of the need for active involvement of non-academics in environmental conservation and management has increased but the mechanisms of stakeholder engagement and their effects have suffered from limited appreciation in past research (Phillipson et al., 2011). Successful uptake of research in environmental policy or practice must be built upon a foundation of active exchange and stakeholders' engagement during the process. Intensifying community participation can improve management effectiveness while enhancing research capacity and data delivery (Almany et al., 2010). Such partnerships can result in benefits for both scientists and stakeholders and, more importantly, culminate in effective management. If the management process includes stakeholders in the decision-making process, it is more likely that the response may be a higher degree of acceptability and compliance with resulting regulation (Nielsen and Vedsmand, 1997). Natural resource scientists and managers should be developing active cooperation with local communities because it can result in greater ownership over environmental conservation and management measures and in consequence increase compliance and decrease conflict.

The extent to which stakeholders are brought into the management process and the ways they are employed will influence knowledge, compliance and socio-economic impacts (Jentoft and McCay, 1995). Environmental scientific knowledge production is dependent upon non-scientific sources of expertise, and the boundaries between producers and users of knowledge must be permeable. Moreover, such partnerships can provide an invaluable source of both skilled field assistance and site-specific local knowledge providing a cost effective way of increasing research capacity, enhancing sampling efficiency and expanding the research scale. Furthermore, such partnerships can improve scientists' ability to identify and address research questions relevant to the community (Almany et al., 2010). The knowledge required for effective management of natural resources must involve biological data supplemented with socio-economic data

(Jentoft and McCay, 1995). Social and economic research can identify management strategies that will have less social and/or economic dislocation and be best received by all stakeholders. The combination of these insights with biological and ecological information can results in more effective management (Clay and McGoodwin, 1995).

As discussed in Chapter 1 fisheries stakeholders can be instrumental in successful fisheries management through meaningful participation. Recreational fishers of the Great Barrier Reef World Heritage Area (GBRWHA) are inclined to become involved in the monitoring and managing of fisheries resources and participate in education programs (Sawynok et al., 2009, Lynch et al., 2010). For instance, in 2004 the GBRWHA recreational fishing community felt their lack of knowledge about local fisheries resources inhibited their ability to meaningfully engage in management decision such as the rezoning of the Great Barrier Reef Marine Park. As a result CapReef was created in 2005. CapReef is a community-based monitoring program initiated in central QLD to collect information on local fisheries resources and recreational fisheries. It is a partnership program involving managers, researchers and the recreational fishing community (Sawynok et al., 2009). Recreational fishers participate in the program because they believe it can improve fisheries management, enhance their recreational fishing practice and because it allows them to express their values towards fisheries conservation (Cheong, 2010). The interaction of researchers and government agencies with those involved in CapReef and the local fishing community has helped develop trust between government, science and the community (Sawynok et al., 2009). More relevant to the current study, Lynch et al. (2010) explored GBRWHA recreational fishers' attitudes and practices towards sharks and rays and also found that recreational fishers of the GBRWHA are willing to be engaged and are prepared to improve their catch and handling techniques to minimise their impacts.

A recent study (Li et al., 2010) investigated recreational fishers' attitudes towards and desire for scientific information about fisheries resources in the GBRWHA. The study found that recreational fishers are interested in scientific information and believe that scientific research outcomes can be useful. However they concluded that communication of scientific information and education aimed at recreational fishers should also consider increasing fishers' understanding of the process by which information is collected, interpreted and used. Therefore, this project may help improve communication of scientific information to recreational fishers by engaging them directly in the research process resulting in improved success of management measures and data accuracy.

In the GBRWHA, recreational fishers are not required to report their catch. At the time of this study, the current recreational catch data that were available had been collected through telephone surveys and diary programs conducted by Fisheries Queensland in the Queensland region in 2002 (McInnes, 2006) and 2005 (McInnes, 2008) and by boat ramp surveys conducted by Lynch et al. (2010) in the GBRWHA. The survey methods employed by Fisheries Queensland rely solely on the fishers' commitment and ability to record data and identify their catch. However Lynch et al. (2010) found that recreational fishers in the GBRWHA could not correctly identify most shark species.

The present study looked at the potential effects of recreational fishers practices on post-release survival of incidentally caught and released sharks in the GBRWHA. To describe the species composition of the recreational catch and accurately reproduce recreational fishers' catch and handling practices when dealing with sharks it was crucial to involve recreational fishers in the data collection process for three reasons. Firstly, because recreational fishers have first-hand knowledge about the techniques that they use, their handling and release practices and their shark catch. By engaging recreational fishers their knowledge is directly brought into the research and can make a meaningful contribution to the decision making process (Li et al., 2010). Secondly, because there are a large number of recreational fishers in the GBRWHA and including them in data collection maximises the sampling area and access to shark populations.

And finally, uptake by the recreational fishing community of potential management and conservation measures resulting from the study would more likely be successful if recreational fishers were involved in the research. By getting involved, recreational fishers could prove that they not only say they understand the importance of sharks, but they are also actively involved in shark research. In this way, recreational fishers can be seen as part of the solution rather than part of the problem.

To address the need to involve the recreational fishing community in shark research and to collect reliable and accurate data this chapter aimed to: (1) discuss the approach used in this study to involve the recreational fishing community of the GBRWHA in shark research, and (2) discuss the difficulties encountered and suggestions for future studies.

2.2 Methods and Results

To collect species composition and capture and handling stress data for this project it was decided that collecting information directly and together with the recreational fishing community would provide more accurate data covering a larger area. Initially, data were collected directly from individual fishers. However because there was a low return of data by individual fishers and because most fished only inshore, it was decided that contacting charter operators would help increase data collection due to the larger number of people fishing on each trip. In addition, it would help expand the sampling area to different habitats because most of the contacted charter operators fished around offshore reefs.

2.2.1 Individual recreational fishers

A search for the fishing clubs in the study area was undertaken and all fishing clubs found in the study area (Figure 1.4) were contacted to determine if they would help promote the project by hosting a talk by the researcher. The talk presented the project and invited recreational fishers to collaborate in the research. The talk aimed to introduce the project, its objectives and its methodology, highlighting the importance of involving the recreational fishing community to maximise data collection and guarantee data accuracy. Using fishing clubs as the first point of contact to individual recreational fishers allowed for reaching a greater audience in an attempt to recruit as many fishers as possible to help in the project.

Five fishing clubs agreed and hosted a talk during one of their monthly club meetings. The remaining seven clubs also showed interest initially but did not respond when contacted later to arrange a date. Over 100 people attended the talks and 25 recreational fishers signed up to help by collecting data whenever they caught a shark.

Given the inability of recreational fishers to identify shark species accurately (Lynch et al., 2010), in the present study it was important to confirm the species identification by recreational fishers by using photos and genetic samples. Each participating fisher received a data collection kit and was asked to collect fin clips and photos of any sharks they caught. Volunteer fishers were contacted every three months for 12 months to see how they were progressing and if they had collected any samples.

During the study period, six fishers returned photos of one shark each while a seventh fisher returned photos of three sharks. No fin clips were returned. The remaining 19 fishers reported not having been fishing during the data collection period or not catching any sharks for those who did fish. The resulting data contributed to the description of the species composition of the recreational catch of sharks in the GBRWHA provided in Chapter 3.

2.2.2 Charter operators

A search for charter operators in the study area was conducted and 14 operators were contacted. During the initial contact, charter operators were asked information about their trips such as number of fishers on board, target species and fishing location so it was possible to establish the operations more likely to catch sharks (e.g. charters operating in estuaries were less likely to encounter sharks).

Five charter operators agreed to assist with the project by allowing the researcher to go on board and collect data on any sharks caught. A total of four one-day trips off Cairns, seven one-day trips off Port Douglas and one three-day trip and one seven-day trip off Mackay (Figure 1.4) were completed with the researcher on board. These trips would have cost a total of $7000 and were provided by the charter operators free of charge for the researcher. On average, each trip had 12 fishers on board. A total of 80 sharks were caught in the presence of the researcher. The majority (n=78) were caught on the extended trips (i.e. three days and seven days fishing on a live aboard vessel off Mackay) while one was caught on a day trip off Cairns and another one on a day trip off Port Douglas.

In addition to the on board data collection by the researcher, three one-day trip charter operators were supplied with a data collection kit to collect photos and tissue samples of sharks caught in the absence of the researcher. One charter operator from Port Douglas returned fin clips and photos from 10 sharks while one from Cairns returned photos and samples from three sharks. The other charter operators reported not catching any sharks during the data collection period. These data also contributed to the species composition component of the project provided in Chapter 3 and assisted in designing the fisheries-independent experiments to measure capture and handling stress in Chapter 4.

2.3 Discussion

Fisheries are social-ecological systems that involve marine organisms, the physical environment and the people who utilize and manage these resources. Collaboration and communication between all interested parties is crucial for the effective management of such resources (Clay and McGoodwin, 1995). Recreational fishers can be instrumental in successful fisheries conservation and management through active involvement in research and management (Granek et al., 2008). Recreational fishers do not uptake and use information the same way researchers and managers do; therefore understanding how they perceive and react to scientific information will become more important as their level of participation increases (Li et al., 2010).

The present study involved part of the GBRWHA recreational fishing community in data collection to accurately measure potential impacts of recreational fishers practices on post-release survival of sharks and to describe the species composition of the recreational catch of sharks. Both groups (i.e. Individual recreational fishers and recreational fishing charter operators) initially seemed interested in becoming involved but their level of engagement differed. Most charter operators contacted participated in the project and provided a number of samples. They were very open to taking the researcher on board and did not charge for the trips. In contrast, only a few individual recreational fishers volunteered to help, and from those who volunteered and seemed interested, most did not provide any samples.

The take home message from this study is that there is more to community engagement than simply asking for their help and careful consideration should be given when designing studies that aim to involve the community in data collection. Studies such as McInnes (2008) and Lynch et al. (2010) were very successful in collecting data directly from recreational fishers however the level of engagement required to answer phone surveys and boat ramp questionnaires is much lower than the level required by this study (i.e. field data collection). It is unknown why most individual fishers did not participate and why only very few provided samples. This low return of samples could be because they may have not caught any sharks during the study period or because they may have forgotten to take samples. In addition, the present study did not provide any incentives to recreational fishers who participated. Incentives, especially material ones, are often perceived as tangible rewards used to induce individuals or groups to behave in a desired manner (Tang, 2005). Appropriate incentives such as compensation, prizes for fishing performance and opportunities to fish in closed areas could be useful tools to engage recreational fishers. Furthermore, many recreational fishers may mistrust science and how it is used. Trust plays an important role in engaging recreational fishers in fisheries research and management therefore trust issues represent constraints but also opportunities for improvement. Possible reasons for this mistrust are lack of credibility, flexibility and stakeholder engagement as well as poor communication (Glenn et al., 2012). The approach used in this study may not have been communicated adequately with recreational fishers. Inadequate communication of scientific information to recreational fishers can create a barrier to engaging the recreational fishing community in conservation and management initiatives (Arlinghaus, 2006).

To better communicate and engage with the recreational fishing community, more research is necessary to understand fishers' motivations and constraints and their perceptions of the costs and benefits regarding participating in scientific research. This study did not measure the costs or benefits recreational fishers may or may not have perceived from becoming involved in the research. Moreover, identifying and addressing questions that are of interest to both scientists and community are crucial for the success of these partnerships (Almany et al., 2010). Studies that are driven by scientists but have an applied nature and direct benefits to the fishing community are likely to be more successful (e.g. CapReef 2005).

The present study involved the recreational fishing community in data collection but did not involve them in the design of the project when the research questions and aims of the project were set. Research programmes and projects must engage the community in the early processes of designing the research to generate mutual benefit (Phillipson et al., 2011). Early engagement generates familiarity and trust that are key elements in developing a successful partnership (Almany et al., 2010).

When fishers are protecting a valued resource from threats external to recreational fishing (e.g. commercial fishing) they are more likely to be involved because recreational fishers do not perceive their own activity as a threat to the environment (Lynch et al., 2010). In addition, recreational fishers of the GBRWHA recognise overfishing by commercial fishers as a larger threat when compared to recreational fishing (Sutton, 2008). It is important to highlight that species that are not of recreational interest (e.g. sharks) may still be affected by recreational fishing and therefore need to be studied and managed within a total source of mortality context.

The low participation by individual recreational fishers showed that more work is needed to better understand how to efficiently engage them in research and management. Engaging the recreational fishing community is important for success of conservation and management measures concerning the sector. To develop appropriate engagement programs it is important to first understand fishers' motivations for participating in research and the benefits they see from such participation. In addition, early engagement, recreational fisher's interest in the subject, improved communication and active involvement are crucial for the success of any research engaging with the recreational fishing community. Data collected through the engagement of charter operators and few individual fishers formed an integral part of this study and could not have been collected without their support. There was not only biological data collected from them but also important information regarding recreational fishers' catch and handling practices when dealing with sharks. These data were crucial to describe the species composition of the recreational catch in the GBRWHA (Chapter 3) and for the design of the fisheries-independent experiments to accurately reproduce recreational fisher’s practices to measure post-release survival and (Chapter 4).

Chapter 3. Recreational catch composition of sharks within the Great Barrier Reef World Heritage Area

Plate 3. Grey reef shark *Carcharhinus amblyrhynchos* caught by a recreational fisher

3.1 Introduction

Sharks, rays and chimeras comprise the Class Chondrichthyes (Last and Stevens, 2009) and are one of the two major taxonomic groups of contemporary fishes. There are more than 1200 species of chondrichthyans worldwide including about 500 species of sharks. In Australia there are an estimated 322 species of Chondrichthyes, including 182 species of sharks (Last and Stevens, 2009). In the Great Barrier Reef World Heritage Area (GBRWHA) specifically, there are 133 species of Chondrichthyes, including approximately 84 species of sharks (Chin et al., 2010).

The Great Barrier Reef Marine Park Authority (GBRMPA) has identified research on the risks to elasmobranchs (i.e. sharks and rays) taken in commercial and recreational fisheries (including species and quantities taken) as high priority. They consider the issue to be critical and that it needs to be addressed urgently (GBRMPA, 2009a, GBRMPA, 2009b). Shark catch composition studies in the GBRWHA to date have focused on commercial fishing (e.g. Harry et al., 2011b) and there is no literature concerning the species composition of the recreational catch. However, recreational fishing effects on sharks are a significant challenge for marine resource managers in the GBRWHA (Lynch et al., 2010) and species composition studies will help inform future stock assessments and fisheries management measures. In addition, these species composition studies may also highlight species that are more susceptible to recreational fishing and require urgent attention depending on their life history characteristics and conservation status.

According to (2008) it is difficult to collect and aggregate catch data relating to the recreational fishing sector because, in the majority of cases, recreational fishers are not required to report their activities to a management agency. The latest estimate of recreational fishing catch and effort in QLD was made by Fisheries Queensland in 2005 using a series of telephone and diary surveys. However, this type of survey relies primarily on recreational fishers' commitment to recording the data and ability to identify their catch. Lynch et al. (2010) highlighted the inability of recreational fishers from the GBRWHA to identify shark species correctly. For instance, some of the species reportedly caught by fishers in the Townsville area are not known to occur in the area (e.g. bronze whalers, *Carcharhinus brachyurus*), and some of the species commonly found in the area and likely caught frequently by recreational fishers were not reported. As a result, in order to collect meaningful and accurate data on the species composition of the recreational catch of sharks it is not possible to rely solely on recreational fishers' knowledge.

This inability of recreational fishers to identify shark species accurately highlights the need to develop a methodology to reliably identify the recreational catch of sharks taking into consideration the nature of such activities and the difficulties of collecting the data. Furthermore, there is a need for education programs to help fishers improve their shark species knowledge. However, in order to do that, it is first necessary to gather more information about what they are catching and how good their identification skills are. Identifying the recreational catch of sharks in the GBRWHA is crucial for the effective management and conservation planning of shark fisheries as well as sustainable fishing practices. Incomplete catch statistics make it difficult for managers and researchers to determine the status of shark populations (Holmes et al., 2009). The diversity of shark species and the fact that many are similar in appearance make it difficult in many situations for non-professionals to correctly identify them.

The most important features for identifying the different species of sharks are colour, body shape, fin size and position, and tooth shape and number. However, many of the species are very similar and identification can be difficult because identifying features are often subtle (Last and Stevens, 2009). Moreover, the taxonomy for some species has not been adequately studied (Chin, 2005). Different methodologies have been used to identify shark species ranging from simple photo identification used to identify individuals of the same species (Graham and Roberts, 2007) to complex genetic analysis used to precisely identify species and genomic variations (Kawakoshi et al., 2007, Magnussen et al., 2007, Holmes et al., 2009, Shivji et al., 2009, Wynen et al., 2009). Tissue samples are used for DNA barcoding. The results of the DNA analysis are then compared to a library of known species that have already had their barcode gene mapped. Many of the species found in the GBRWHA have already been mapped and are in the Fisheries Queensland's Molecular Fisheries Laboratory library, therefore the identification using tissue samples can be very reliable.

To address the need for improved information on the identity of the shark species captured by recreational fishers in the GBRWHA this chapter aimed to: (1) describe the species composition of the recreational catch and (2) evaluate recreational fishers' ability to identify the species.

3.2 Methods

To maximise the collection of accurate data, individual recreational fishers and charter operators were invited to become involved in the project by collecting photos and tissue samples of any sharks they caught. The photos and tissue samples were used to identify the sharks to species level. All charter operators fished the reef and/or the edge of the continental shelf while individual recreational fishers fished inshore areas. There was a low return of samples from individual fishers therefore fisheries-independent sampling reproducing recreational fishers' techniques was used to enrich the data for inshore areas.

3.2.1 Data collection - Individual recreational fishers

As described in detail in Chapter 2 Section 2.2.1 volunteer recreational fishers were recruited through a series of presentations given to fishing clubs located from the study area. Recreational fishers were asked to record information about the sharks they caught. Each participating fisher received a data collection kit containing a waterproof disposal camera, scissors (for tissue sampling), plastic tubes (for storage of frozen tissue), pencils and datasheets. All fishers were briefed about what they were expected to do and were provided with written instructions in their kits. The fishers were asked to take a photograph and take a fin clip (if it was safe) of every shark they caught and record relevant data (i.e. species name, sex, total length (mm), angling duration, air exposure duration, release condition, fishing gear used, fishing location and target species). Fishers were not provided with an identification guide. Fishers were contacted every three months for 12 months for retrieval of datasheets and tissue samples.

3.2.2 Data collection - Charter operators

As described in detail in Chapter 2 Section 2.2.2 the researcher went on board five different charter vessels operating in the study area to record shark species, sex and total length (mm) and number of sharks caught by recreational charter fishers. Charter operators who participated in the study were also given data collection kits (same as individual fishers) and were asked to take photos and collect fin clips as well as record relevant data on any sharks caught in the absence of the researcher.

3.2.3 Data collection – Fisheries-independent

As discussed in Chapter 2, fisheries-independent sampling was needed to supplement the fisheries-dependent sampling. Therefore, a method was designed to replicate recreational fishers techniques. This method was based on observations made during the fisheries-dependent sampling.

There were 24 fishing trips on board a research vessel and each trip had a field team of three fishers. Fishing trips were conducted during daylight hours lasting for an average of six hours. Fishing locations were initially chosen randomly then locations where sharks were caught frequently were revisited at subsequent trips. All fishing was conducted in inshore waters of Cleveland Bay, North Queensland, Australia (19° 13' 36.10"S/146° 55' 51.46"E) using rod and reel with monofilament fishing line with a barbless circle hook (Mustad 7/0). The fishing lines were fitted with 80lbs breaking strength wire traces to ensure that sharks could be landed. Frozen squid and pilchards were used as bait. All sampling took place during summer/wet season between the months of November 2010 and March 2011. The average water temperature was 28 °C and the average salinity was 27 ppt.

All sharks caught during the study were identified to species and had their sex determined by the presence or absence of claspers. The total length (mm) of each shark was measured using a measuring tape then all sharks were externally tagged with a roto-tag on their first dorsal fin and then released. The roto-tags had an individual identification number and a phone number to facilitate the reporting of recaptured animals by fishers.

3.2.4 Data analysis – Species identification

Photos and tissue samples were used to identify the shark species because they can, in most cases, be easily and safely taken by the recreational fishers. The photos were analysed by shark researchers from the Centre for Sustainable Tropical Fisheries and Aquaculture (James Cook University, Townsville, Australia) and most species were identified to species level using external morphology and the species identification key from Last and Stevens (2009). In addition, fin clips of 16 individuals that could not be identified from the photos were sent to the Fisheries Queensland's Molecular Fisheries

Laboratory in Brisbane for DNA barcoding. Identification to species level was conducted as follows.

The NADH dehydrogenase subunit 4 (ND4), region of mtDNA was amplified and sequenced using primers ND4 (CAC CTA TGA CTA CCA AAA GCT CAT GTA GAA GC) (Arevalo *et al*., 1994) and H12293-LEU (TTG CAC CAA GAG TTT TTG GTT CCT AAG ACC) (Inoue *et al*., 2001). For species not in the Ovenden ND4 shark DNA library (*Carcharhinus amblyrhynchos*) the cytochrome oxidase subunit I (COI) gene was also sequenced between primers SharkCO1F (ACC TGT GGC AAT TAA TCG TTG A) and SharkCO1R (GGC CAA TTG CTA TTA TTG CTC) (Ovenden unpublished). PCR amplification reactions were carried out in 20 μL volumes and contained 0.5 μM of each primer, combined with 10-100 ng of template DNA, 10x Taq buffer (containing 15 mM MgCl2), 0.8 mM dNTP's, and 0.6 units of Taq DNA polymerase (Qiagen, Valencia, CA, USA). Thermal cycling conditions consisted of an initial denaturation (94°C for 3 min) followed by 35 cycles of 94°C for 15 seconds, 56°C (COI) or 60°C (ND4) for 30 seconds and 72°C for 1 min, with a final extension step of 72°C for 10 minutes. Cycling was performed in either a PTC200 DNA Engine (MJ Research, USA) or PerkinElmer 9600 & 9700 series thermocyclers (PerkinElmer Australia, Melbourne, VIC). PCR products were viewed on a 1.5% agarose TAE gel stained with GelRed (Biotium, USA). Approximately 20 ng of DNA was used in standard ABI Dye Terminator sequencing reactions using Big Dye Vers 3.1 technology (Applied Biosystems, California) and were run on an Applied Biosystems 3130xl Genetic Analyser. Shark identity was confirmed by alignment to species in the Ovenden ND4 shark DNA library or by Blast similarity in Genbank (NCBI). For the blacktip species *C. tilstoni* and *C. limbatus* hybrid status was determined by mtDNA ND4 sequencing followed by nuclear DNA typing at CT06 and CS08 loci (J.A.T Morgan, pers comm. Methods currently unpublished).

3.2.5 Data analysis – Sex ratio

Sex ratio (females : males) of the total catch was calculated and where there were at least five individuals from each sex, Chi-square tests (X^2) were used to determine any significant differences in sex ratio within species.

3.2.6 Data analysis - Fishers' ability to identify the different shark species

To determine recreational fisher's ability to identify the different shark species, charter fishers who caught a shark in the presence of the researcher were asked if they could identify the species. These species were noted together with the species identified by the researcher. In addition, the species recorded on the datasheets by the individual fishers and charter operators was compared to results from photo identification and/or DNA analysis.

3.3 Results

Over the course of the study period (May 2010 – March 2011) a total of 209 sharks were caught including fisheries-dependent and fisheries-independent sampling. The catch consisted of 17 species representing two orders and four families (Table 3.1). The family Carcharhinidae was the most diverse family (12 species) and the largest component of the catch (86.8%). The other families represented in the study were Sphyrnidae, Hemigaleidae and Ginglymostomatidae (Table 3.1). *Carcharhinus tilstoni* and *Carcharhinus limbatus* are two species that are very similar in appearance and there are no known external morphological features for distinguishing between them (Last and Stevens, 2009). As such, they are usually identified using genetic methods or by counting the number of pre-caudal vertebrae, which differs between species. The length at birth is also different in both species allowing the identification of neonates without the need for genetics or vertebrae counts (Harry et al., 2012). These two species were grouped together in this chapter and were the overall most abundant species of the catch (33.1%). No sharks were reported harvested by recreational fishers and charter fishers during the study.

There was a low return of data from individual fishers with only seven fishers having caught nine sharks of seven different species (i.e. *C. amboinensis, C. limbatus/tilstoni, C. sorrah, G. cuvier, N. acutidens, R. taylori and S. mokarran)* belonging to two families (Table 3.2).

Five charter operators from the study area agreed to take the researcher on board during charter fishing trips. There was a total of 14 days of charter fishing in the Mackay, Cairns and Port Douglas regions. Two charter operators also recorded data in the absence of the researcher providing photos and tissue samples from 13 sharks. A total of 82 sharks including 12 species from four different families were recorded from charter fishing trips. The most abundant species was *C. amblyrhynchos* followed by *T. obesus* and *N. ferrugineus* (Table 3.2).

Table 3.1 Total catch of sharks (n=209) by recreational fishers, charter operators and recreational fisheries-independent sampling within the Great Barrier World Heritage Area.

Family	Species		% of the catch
Carcharhinidae			**86.8**
	Carcharhinus amblyrhynchos	Grey reef shark	23.4
	Carcharhinus albimarginatus	Silvertip shark	1.0
	Carcharhinus amboinensis	Pigeye shark	4.4
	Carcharhinus coatesi	Whitecheek shark	1.9
	Carcharhinus fitzroyensis	Creek whaler	3.4
	Carcharhinus limbatus/tilstoni	Blacktip shark	33.1
	Carcharhinus sorrah	Spot-tail shark	2.9
	Galeocerdo cuvier	Tiger shark	1.5
	Negaprion acutidens	Lemon shark	0.5
	Rhizoprionodon acutus	Milk shark	7.8
	Rhizoprionodon taylori	Australian sharpnose shark	1.0
	Triaenodon obesus	Whitetip shark	6.3
Hemigaleidae			**1.0**
	Hemigaleus australiensis	Australian weasel shark	0.5
	Hemipristis elongata	Fossil shark	0.5
Sphyrnidae			**7.8**
	Sphyrna lewini	Scalloped hammerhead	6.8
	Sphyrna mokarran	Great hammerhead	1.0
Ginglymostomatidae			**4.4**
	Nebrius ferrugineus	Tawny nurse shark	4.4

3.3.1 Catch composition

Diversity of shark species in the two habitats (i.e. reef/edge of continental shelf and inshore) was the same with 12 species recorded inshore and 12 on the reef. Seven of the 12 species were recorded in both habitats (Table 3.2). *Carcharhinus tilstoni* and *C.*

limbatus accounted for 55.3% of all sharks caught inshore followed by *R. acutus* and *S. lewini*. *Carcharhinus amblyrhynchos* was the most abundant species (58.5%) on the reef followed by *T. obesus and N. ferrugineus* (Table 3.2).

The total length was measured in 192 sharks during the study. Overall lengths ranged from 420 mm for *R. acutus* caught inshore to 2200 mm for *N. ferrugineus* caught on the reef (Figure 3.1). Reef catch ranged from 600 mm for *C. amblyrhynchos* to 2200 mm for *N. ferrugineus* (Figure 3.2) while inshore catch ranged from 420 mm for *R. acutus* to 1700 mm for *S. mokarran* (Figure 3.3).

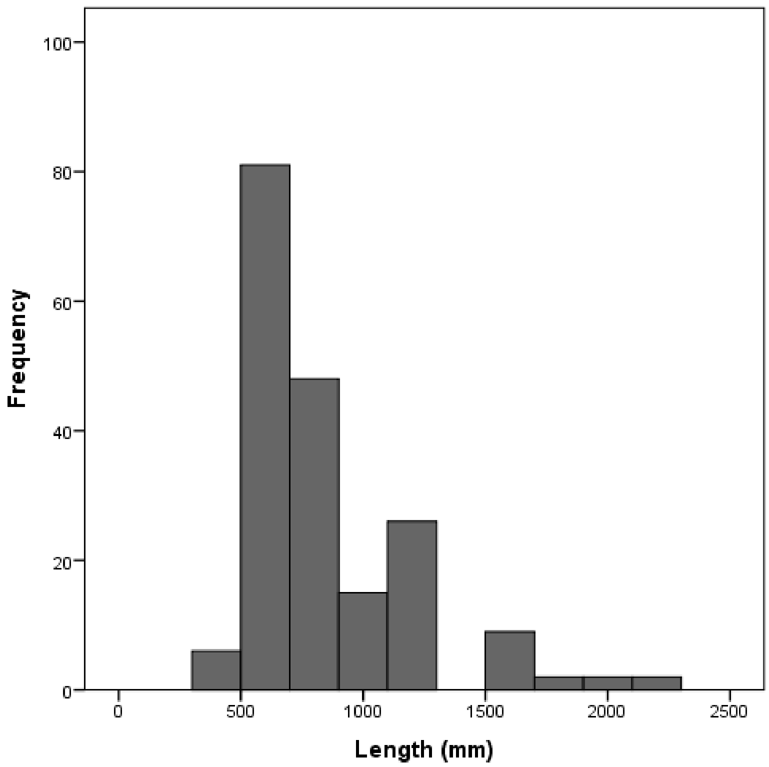

Figure 3.1 Length frequency of the overall recreationally sampled shark catch (N=192) in the GBRWHA.

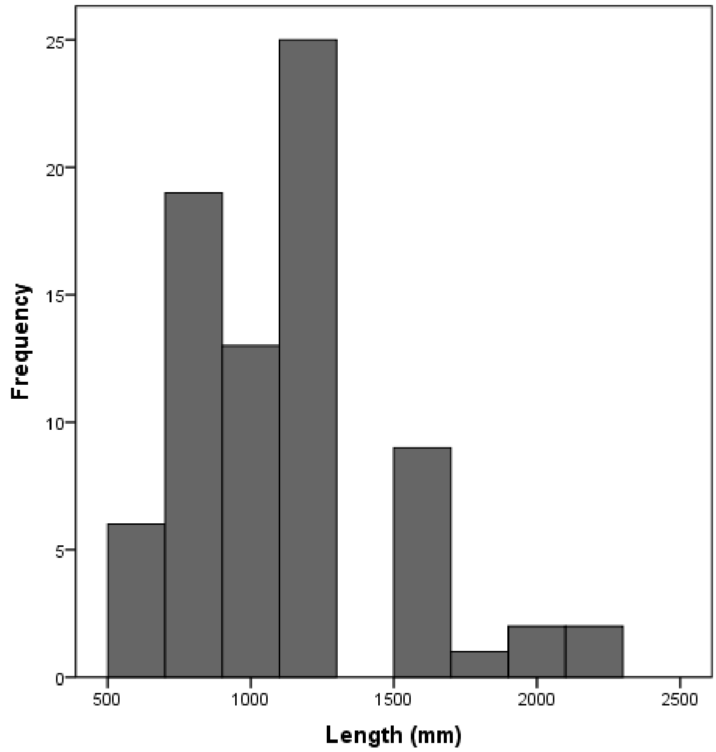

Figure 3.2 Length frequency distributions of sharks (N=78) caught on the reef by recreational charter fisher of the GBRWHA.

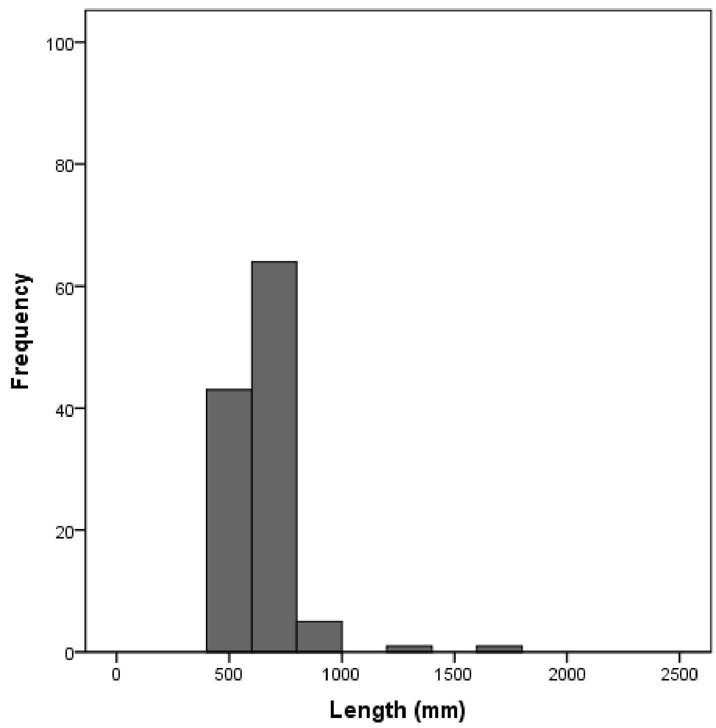

Figure 3.3 Length frequency distributions of sharks (N=114) caught inshore by individual recreational fishers and fisheries-independent sampling within the GBRWHA.

The sex of 160 sharks was determined during the study. The overall sex ratio of the total catch was not significantly different from 1:1 (χ^2 test, P = 0.35). In addition, all species tested also did not display a significant difference in sex ratio: *C. amblyrhynchos* (χ^2 test, P = 0.46), *R. acutus* (χ^2 test, P = 0.32), *S. lewini* (χ^2 test, P = 0.38) and *C.limbatus/tilstoni* (χ^2 test, P = 0.34). The other species were not assessed due to the small sample size (n<5).

Table 3.2 Catch composition of sharks caught by recreational fishers, recreational charter operators and fisheries-independent sampling within the Great Barrier Reef World Heritage Area. Species are grouped by family, sorted alphabetically and presence (P) or absence (A) is noted in two habitat types (i.e. reef and inshore).

Family	Scientific name	Individual Fishers	Charter operators	Fisheries-Independent	P/A Reef	P/A Inshore
Carcharhinidae						
	Carcharhinus amblyrhynchos	0	48	0	**P**	**A**
	Carcharhinus albimarginatus	0	2	0	**P**	**A**
	Carcharhinus amboinensis	2	0	7	**A**	**P**
	Carcharhinus coatesi	0	1	3	**P**	**P**
	Carcharhinus fitzroyensis	0	0	7	**A**	**P**
	Carcharhinus limbatus/tilstoni	1	2	65	**P**	**P**
	Carcharhinus sorrah	2	1	3	**P**	**P**
	Galeocerdo cuvier	1	2	0	**P**	**P**
	Negaprion acutidens	1	0	0	**A**	**P**
	Rhizoprionodon acutus	0	1	14	**P**	**P**
	Rhizoprionodon taylori	1	0	2	**A**	**P**
	Triaenodon obesus	0	13	0	**P**	**A**
Hemigaleidae						
	Hemigaleus australiensis	0	0	1	**A**	**P**
	Hemipristis elongata	0	1	0	**P**	**A**
Sphyrnidae						
	Sphyrna lewini	0	1	13	**P**	**P**
	Sphyrna mokarran	1	1	0	**P**	**P**
Ginglymostomatidae						
	Nebrius ferrugineus	0	9	0	**P**	**A**
Total		**9**	**82**	**115**		

3.3.2 Fishers' ability to identify sharks

Most recreational fishers could identify their shark catch to family level if the shark belonged to the family Carcharhinidae - referring to them as whaler sharks. However, one *C. amblyrhynchos* was reported as bronze whaler *Carcharhinus brachyurus* (Figure 3.4), one *C. sorrah* was reported as blacktip reef shark *Carcharhinus melanopterus* and two *C. albimarginatus* were reported as *T. obesus*. In addition, one *N. ferrugineus* was reported as a wobbegong shark *Orectolobus* spp. and another as a zebra shark *Stegostoma fasciatum*.

Two species with distinctive external morphologies were always correctly identified by the fishers (i.e. *T. obesus* and *G. cuvier*). In addition, *Sphyrna* spp. were always identified correctly to genus level, being reported as hammerheads (Figure 3.5). However, fishers seemed to be unaware that there is more than one species of hammerhead shark in the GBRWHA.

Figure 3.4 *C. amblyrhynchos* caught by a charter fisher. Species reported as *C. brachyurus*.

Figure 3.5 a) *S. mokarran* caught by an individual recreational fisher and reported simply as hammerhead and not great hammerhead. b) *G. cuvier* caught by an individual recreational fisher and reported accurately as tiger shark.

3.4 Discussion

To describe the recreational shark catch composition it was important to use a methodology that did not rely on recreational fishers' ability to identify sharks. In light of this, instead of using diary and interviews (McInnes, 2006, McInnes, 2008) or boat ramp surveys (Lynch et al., 2010), the present study asked individual fishers and charter operators to collect photos and fin clips of any sharks they caught. The collection of photos and tissues samples, followed by analysis by shark researchers, allowed the accurate identification to species level.

The most abundant family of sharks recorded in this study was the Carcharhinidae (86.8%) with *C. limbatus/tilstoni* being the most numerous (33.1%). This result was expected because 31 of the 54 species of Carcharhinidae found worldwide are found in Australia, mainly in tropical and warm temperate waters (Last and Stevens, 2009). Accordingly, Harry et al. (2011b) described the catch composition of elasmobranchs to species level in commercial inshore gill-net fisheries of the East Coast Inshore Finfish Fishery within the GBRWHA, where sharks are actually targeted. That study identified 5593 sharks consisting of 27 species from four families and two orders. Consistent with the present study, the family Carcharhinidae was the most abundant (86%) with *C. limbatus/tilstoni* also being the most numerous (23.5%).

Two species recorded in the present study were not recorded in the gill-net study (i.e. *C. albimarginatus* and *N. ferrugineus)*. Both species do not have an important commercial value in Australia and therefore are not targeted by commercial fishers. Although both may occur inshore they are more common near coral reefs (Last and Stevens, 2009) which may explain their absence in the inshore gill-net fishery (which does not operate in coral reef areas). Moreover, *N. ferrugineus* are benthic, spending most of their time near the bottom, which minimises their chances of being caught on gill-nets. In addition, twelve species caught in the gill-net study were not caught in the present study. This difference could be a consequence of the area size and different habitats fished by both studies (e.g. *Colclough's* shark *Brachaelurus coleloughi* – do not occur in the study area and bull sharks *Carcharhinus leucas* – are mainly found in rivers and estuaries). The present study covered a smaller area extending from Mackay to Port Douglas mainly inshore and out on the reef while the gill-net study covered from Cape York to Bundaberg mainly in rivers, intertidal and inshore areas. In spite of these differences, 80% of the catch recorded in the present study was comprised by the same species recorded in the gill-net fishery study being 15 of the 17 species (Figure 3.6). A number of the species caught in the GBRWHA in commercial and recreational fisheries are also caught in other states. For instance, the primary component of gill-net catches in the Northern Kimberly (WA) are *C. limbatus/tilstoni* and *C. sorrah* (Bensley et al., 2010). Although the latter species was not abundant in the present study’s catch it is the second most important species in the GBRWHA inshore gill-net shark fisheries (Harry et al., 2011b). In addition, these same three species are the primary target shark species in the Northern Territory gillnet and longline fishery (Bensley et al., 2010).

The similarities between the species caught by commercial and recreational fishing in the GBRWHA and other State fisheries highlight the importance of identifying the recreational catch of sharks accurately so that any estimates and assessments involving species caught in both fisheries (i.e. commercial and recreational) can include potential effects caused by recreational fishing. Moreover, these overlap of shark species means that both sectors need to be involved in the assessment and management of these species.

In addition to the direct impact of fishing pressure the effects of fishing may be coupled with other effects on shark populations. For instance, Chin et al. (2010) assessed the vulnerability of sharks and rays of the GBRWHA to climate change. The authors assigned each species to an ecological group defined by habitat types and associated biological and physical processes. Six ecological groups were identified: freshwater/estuarine, coastal/inshore, reef, shelf, pelagic and bathyal. The coastal/inshore group contained 44 species from which 11 were also recorded in the present study. Additionally, the present study recorded eight of the 19 reef species and four of the 26 shelf species. Chin et al. (2010) concluded that freshwater/estuarine, coastal/inshore and reef associated sharks and rays of the GBRWHA are at the highest risk from climate change and synergistic effects of fishing and habitat loss. In addition, the coastal/inshore sharks are the most exploited by commercial fisheries in the GBRWHA and are likely to be affected in a range of different ways due to the wide variety of life history characteristics (Harry et al., 2011b). Moreover, in the present study, the majority of the catch occurred inshore within the GBRWHA where many of the inshore areas are considered nursery areas for many shark species (Simpfendorfer and Milward, 1993). Even though many of these nursery areas are protected from commercial fishing, regulated recreational fishing is allowed. Sharks of the GBRWHA are subjected to a range of potential threats and recreational fishing is just one of them. Risk assessments should take into consideration cumulative impacts of all potential sources of mortality.

Most recreational fishers in the study area do not target sharks because they consider them inedible (Lynch et al., 2010) and therefore only a portion of the total catch is harvested (McInnes, 2006, McInnes, 2008, Lynch et al., 2010). However, the majority of the present study's catch was smaller than the maximum legal size (1500 mm) for the recreational catch of sharks in QLD (QPI&F, 2009). This means that if the recreational fishers' perception towards sharks' edibility changes and they start targeting and retaining sharks, most of their catch would be legal size and the primary control on harvest would then be the bag limit which is currently one shark per person per day (QPI&F, 2009). Even though it is unlikely that recreational fishing alone will be responsible for population collapse it has the potential to contribute to both local and more widespread declines of species also targeted by commercial fishing (Cooke and Cowx, 2006). The diversity of species harvested within the GBRWHA coupled with the complexity of fishery participants and their motivations provide a major challenge for managers in monitoring, assessing and managing the GBRWHA fisheries (Tobin et al., 2010).

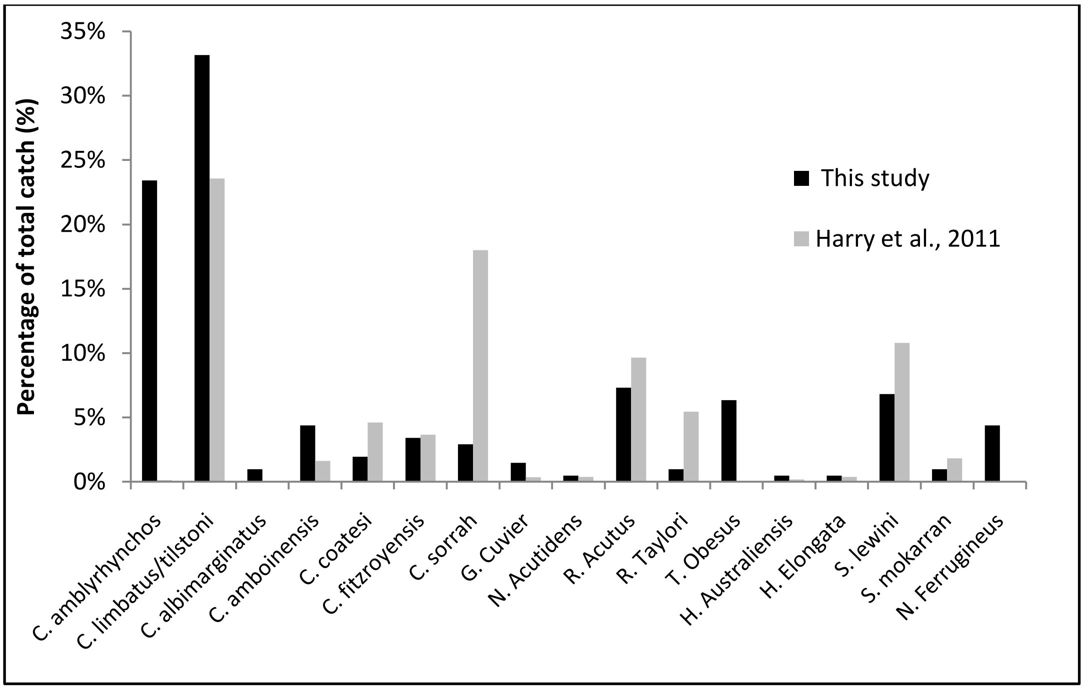

Figure 3.6 Proportion of 17 species of sharks of the total recreational catch (this study) and the total commercial inshore gill-net shark catch (Harry et al., 2011) in the GBRWHA.

The results suggest that, in most cases, recreational fishers' ability to identify their shark catch to species level is low. Similarly, Lynch et al. (2010) interviewed 309 recreational fishers in the Townsville area and concluded that most fishers could not identify sharks correctly. Recreational fishers in the GBRWHA do not target sharks and are not required to report their catch to authorities, and therefore may have no interest or need to learn how to distinguish between species. In addition, many shark species in the study region look very similar and are difficult to identify in the field by non professionals. This inability of recreational fishers to identify sharks means that any species-specific shark catch estimates derived solely from recreational fisher's self reporting will most likely be inaccurate.

3.5 Conclusions

The present study provided the first description of the species composition of the recreational catch of sharks in the GBRWHA. A total of 206 individuals from 17 species were recorded varying in habitat, size, life stage and sex. The results showed that the species composition of the recreational catch of the GBRWHA is very similar to the species composition of the GBRWHA commercial inshore gill-net fishery where sharks are targeted (Harry et al., 2011b). These overlap of the species composition highlight potential for cumulative effects on species caught in both fisheries. In addition, the species recorded in this study inhabit coastal and reef areas therefore are at higher risk to climate change (Chin et al., 2010). Recreational fishers may not have a direct impact on shark populations because they are not harvesting sharks. However, when coupled with climate change, commercial fishing and habitat degradation, recreational fishing may be affecting sharks indirectly through synergistic effects, especially if post-release mortality is high in recreational fisheries. It is important to measure capture stress and potential post-release mortality when estimating impacts of recreational fishing on sharks.

Chapter 4. Understanding the effects of incidental recreational capture on juvenile sharks

Plate 4. Juvenile blacktip shark *Carcharhinus limbatus/tilstoni* being released

4.1 Introduction

Recreational fishers in the Great Barrier Reef World Heritage Area (GBRWHA) do not usually target sharks and incidentally caught sharks are often released (McInnes, 2006, McInnes, 2008, Lynch et al., 2010). Currently, there is very little information on the number of sharks caught by GBRWHA recreational fishers or on the fate of released animals. This lack of information complicates efforts to estimate fishing mortality (Frick et al., 2010b, Heberer et al., 2010) and design effective management strategies for sharks in the GBRWHA. Importantly, high post-release mortality rates of sharks can lead to possible population declines, changes in size and age structures, altered community composition, reduced biomass and as a consequence altered productivity and structure of marine ecosystems (Coleman et al., 2004). Consequently, capture stress and subsequent mortality may be the greatest effect of recreational fishing on sharks of the GBRWHA (Lynch et al., 2010).

Incidentally caught and released sharks are exposed to a range of capture stressors such as angling exhaustion, hooking injury, air exposure and handling (Manire et al., 2001, Skomal, 2007, Mandelman and Skomal, 2009). For instance, air exposure and handling usually occur upon capture when fishers are trying to remove hooks, weigh or take photographs of their catch (Cooke and Suski, 2005). The magnitude of these stressors as well as the species in question will determine the extent of the physiological response. Captured sharks are exposed to varying degrees of physiological stress regardless of the fishing gear used (Skomal, 2007)
.

Stress is manifested as primary, secondary and in some cases tertiary responses. The primary stress response involves the release of catecholamine and stress hormones. This primary response triggers the sequential secondary response that includes production of lactate and glucose and pH reduction. Ultimately, these responses can cascade to tertiary stress responses which include reduced growth rates, decrease reproductive capacity, altered behaviour and ultimately lower survival (Wood et al., 1983, Wells et al., 1986). These physiological stresses derived from capture can cause profound disruptions in concentrations of all major plasma electrolytes (e.g. Cliff and Thurman, 1984), stress hormones (e.g. Manire et al., 2007) as well as plasma metabolites (e.g. Hoffmayer and Parsons, 2001) and leukocytes (e.g. Van Rijn and Reina, 2010). The measurement of these physiological indicators can provide quantitative information about the magnitude of physiological stress (Wells et al., 1986, Skomal, 2007) and can be used to predict the fate of a shark after it has been caught and released (Frick and Reina, 2009) especially if combine with release condition, reflex responses and post release monitoring..

Even though many studies have measured physiological indicators to assess capture stress in sharks there have been no studies directly relevant to understanding the potential for post-release mortality in sharks caught in recreational fisheries, or more specifically in the GBRWHA. Most studies were for example conducted in captivity with one or two species using commercial fishing techniques (Frick and Reina, 2009, Frick et al., 2010a, Frick et al., 2010b, Van Rijn and Reina, 2010), in the wild using commercial fishing techniques (Mandelman et al, 2009), or in the wild with a single species using hook and line (Hoffmayer and Parsons, 2001).

The aim of this chapter was to determine whether common practices resulting from incidental capture and release of sharks in recreational fisheries have any impact on post-release survival of sharks in the GBRWHA. This was accomplished by using whole blood lactate concentrations as an indicator of physiological stress measured against angling duration and air exposure. In addition, differences in capture stress response between species and sexes were tested.

Angling duration and air exposure were chosen because they are the major stressors associated with catch and release (Cooke and Suski, 2005) and these practices are known to cause an increase in whole blood lactate in sharks (Hoffmayer and Parsons, 2001, Awruch et al., 2011). During angling capture, the energy demands are mainly supported by anaerobic glycolysis within the white muscle cells (Hoffmayer and Parsons, 2001). Glycolysis causes accumulation of lactic acid which dissociates into lactate and metabolic protons. Some of the protons may be released into the blood stream reducing muscle and blood pH. The pH reduction is also increased by respiratory acidosis which often accompanies the metabolic acidosis (Kieffer, 2000). Similarly, air exposure is known to cause metabolic and anatomical changes as a result of gill damage. Physiological changes include extracellular acidosis (Ferguson and Tufts, 1992) and accumulation of metabolites such as lactate (Suski, 2004). The cellular acidosis caused by reduced pH is likely the lethal response and not the accumulation of blood lactate *per se* (Wood et al., 1983). Nevertheless there is a strong correlation between blood lactate and pH and because lactate can be easily measured in the field (Awruch et al., 2011) it can be a good indicator of immediate stress derived from capture.

Whole blood lactate concentrations may not reach peak levels until well after the initial stress (Frick and Reina, 2009) however it is a good starting indicator of anaerobic stress caused by exhaustive exercise and/or hypoxia associated with capture.When long-term monitoring of plasma constituents is not possible, other methods such as post-release monitoring can be used to estimate survival of released animals. In light of this, this study combined post-release monitoring methods to determine if released animals survived. Physiological indicators, when coupled with post-release monitoring and mortality estimates, can provide good insights into mortality causative factors and possible mitigation measures (Mandelman and Skomal, 2009).

4.2 Methods

4.2.1 Data collection – Charter fishing

This study aimed to look at the direct effects of recreational fishing on post-release survival of sharks; therefore, it was important that it was conducted with animals in the wild and that the methodology used was consistent with recreational fishing practices. The common practices of recreational charter fishers when dealing with sharks were observed on board charter vessels (See Chapter 2 Section 2.2.2). The time the sharks were kept on the line and the time sharks were kept out of the water (if brought on board) were recorded as well as the species, the total length (mm) and the sex.

Collecting samples for lactate measurement and performing post-release monitoring on board charter vessels with minimal disturbance to the fishing activities was not possible. Therefore, to investigate the influence of handling practices on lactate levels, fisheries-independent experiments were designed in which the data regarding handling practices collected on board charter vessels were used to reproduce recreational fisher's practices.

Data from 82 sharks collected on board the charter boats showed that angling time varied from 90 seconds to a maximum of 10 minutes (i.e. until recreational fishers could retrieve their gear or cut the line as close to the animal as possible before releasing them). The majority (86%) of the sharks caught were not exposed to air;

those that were exposed were kept out of the water from 30 seconds to a maximum of four minutes.

4.2.2 Data collection - Fisheries-Independent sampling

Sharks were caught using rod and reel with the purpose of replicating recreational fishers' techniques (See chapter 3 Section 3.2.3 for fishing details). Species, total length (mm) and sex were recorded and all sharks were roto-tagged on their first dorsal fin and released. The release condition was noted based on a scale from Hueter et al., (2006) (Table 4.1).

Table 4.1 Description of condition categories for released sharks. Adapted from Hueter et al. (2006)

Condition	Criteria
1 (Very Good)	No revival required. Rapid swimming away on release
2 (Good)	No revival required. Slow but strong swimming away on release
3 (Fair)	Revival of up to 30 seconds required
4 (Poor)	Revival of more than 30 seconds required
5 (Dead)	Dead on removal from gear or moribund and unable to revive

4.2.3 Blood sampling and whole blood lactate analysis

As discussed previously, whole blood lactate concentrations are good indicators of physiological stress derived from capture. To measure whole blood lactate levels, a small blood sample (1 mL) was drawn by caudal venipuncture using a syringe fitted with a 22G needle. Immediately after obtaining the blood sample, a drop of whole blood (10 µL) was placed on a handheld Lactate Pro^{TM} test strip and whole blood lactate concentrations were displayed on the screen after 60 seconds.

Most stress studies comparing blood chemistry parameters used standard laboratory assays after sampling (Cliff and Thurman, 1984, Wells et al., 1984, Hoffmayer and Parsons, 2001, Mandelman and Farrington, 2007, Brill et al., 2008, Arlinghaus et al., 2009). However, portable glucose and blood lactate analysers have recently been used and produce results that are comparable to laboratory analysers (Beecham et al., 2006, Skomal, 2007, White et al., 2008, Awruch et al., 2011). The Lactate Pro™ handheld analyser was used in this study because of its portability, accuracy and ability to provide quick results. It was also very useful when relative rather than absolute values can be applied to evaluate stress responses.

Lactate Pro™ only measures values in the range of 0.8 mmol/l to 23.3 mmol/L otherwise displaying the words “LO” or “HI” for values lower or higher than the detection range. In this study, all LO values were replaced by the value immediately below the detection range (i.e. 0.7 mmol/L). There were a total of 17 LO values. There were no HI values recorded.

4.2.4 Baseline lactate concentrations

One of the issues when dealing with capture stress is obtaining baseline data (pre-stress levels) of physiological indicators. Any attempt to sample sharks will require handling to some degree and may influence the level of stress and indicators that are manifested rapidly (Mandelman and Skomal, 2009). Despite this issue, blood samples that are obtained within 3 minutes after disturbance can be considered estimates of resting levels (Hoffmayer and Parsons, 2001). Lactate is slowly diffused from the white muscle cells to the blood stream making it relatively easy to obtain baseline level from minimally stress animals. In this study, it was assumed that the whole blood lactate concentrations of the initial blood samples taken in this study were very close to baseline values in the wild. These samples were taken with minimal handling and, because all sharks were small neonates or juveniles, it was possible to bring them to the side of the boat within 30 seconds of capture.

To measure baseline whole blood lactate levels, sharks caught as part of the fisheries-independent experiments were brought to the side of the boat then positioned ventral side up with head and gills submerged for blood sampling. These samples were used to establish baseline whole blood lactate concentrations for minimally stressed sharks. After the baseline sample, each shark was subjected to one of two treatments (i.e. angling duration or air exposure). The treatments were done sequentially starting with angling duration. Thus when there were enough samples for the angling duration treatment, subsequent sharks were subjected to the air exposure experiments.

4.2.5 Effects of angling duration and air exposure

Data collected on board the charter vessels showed that recreational fishers kept the sharks on the line for a maximum of 10 minutes. Based on these results, to test for effects of angling duration on whole blood lactate concentrations, captured sharks were released back into the water (after the baseline sample) still hooked and were kept swimming while fighting the tension on the line for 10 minutes. Two subsequent blood samples were taken after five and 10 minutes of angling.

In addition, data collected on board the charter vessels also showed that most sharks were not exposed to air; those that were exposed were kept out of the water for a maximum of four minutes. Based on these results, to test for effects of air exposure duration on whole blood lactate concentrations, captured sharks were placed in a dip net and kept out of the water on the side of the boat for four minutes (after the baseline sample was obtained). A second and third blood samples were taken after two and four minutes of air exposure. The effects of air exposure were tested independently to the effects of angling duration (i.e. using a separate sample of animals).

4.2.6 Effects of handling

The sampling procedure itself can cause some degree of stress on the sharks and, as a consequence, it can interfere with results (Frick et al., 2009). To test for possible changes in whole blood lactate concentrations due to sampling handling, a separate sample of sharks was subjected to 10 minutes of angling as described in section 4.2.4; however, with this sample group only the baseline and the 10 minute samples were taken (i.e. no five minute sample was taken). By removing the middle sample and comparing the whole blood lactate concentrations observed after 10 minutes of angling it is possible to determine whether the extra handling of the middle sample caused additional stress.

4.2.7 Post-release monitoring

4.2.7.1 Tag and Recapture

Prior to release, a roto-tag was externally attached to the dorsal fin of all sharks caught (See Chapter 3 Section 3.2.3 for tagging details). Recaptured animals were used to confirm the survival of individuals after release.

4.2.7.2 Post release enclosure

Although tagging is a useful way of monitoring post-release survival, the low probability of any single animal being recaptured and reported means that the fate of most tagged animals remains unknown. In an attempt to overcome this limitation, the use of an enclosure for post-release monitoring was trialled. An enclosure (4 m diameter and 1.2 m depth) was built following consultation with Reef HQ aquarium staff (Townsville, QLD). The bottom and sides were made of 20 mm plastic mesh with PVC pipes to maintain a rigid structure. Four cylindrical foam floats of 1100mm in length and 100mm in diameter were attached to the top to provide floatation. The size of the enclosure was thought to be ideal considering the small size of the animals being caught, and was designed to allow recapture without causing excessive stress (Figure 4.1.a).

Sharks were caught and subjected to the baseline and 10 minute angling samples. The hook was then quickly removed and the sharks were released in the enclosure that was attached to the side of the boat (Figure 4.1.b). The sharks were left swimming freely in the enclosure for one hour when they were quickly caught using a dip net to obtain the last blood sample before being released into the wild. The purpose of this treatment was to allow the animals to recover and to determine the changes in whole blood lactate concentrations one hour after release.

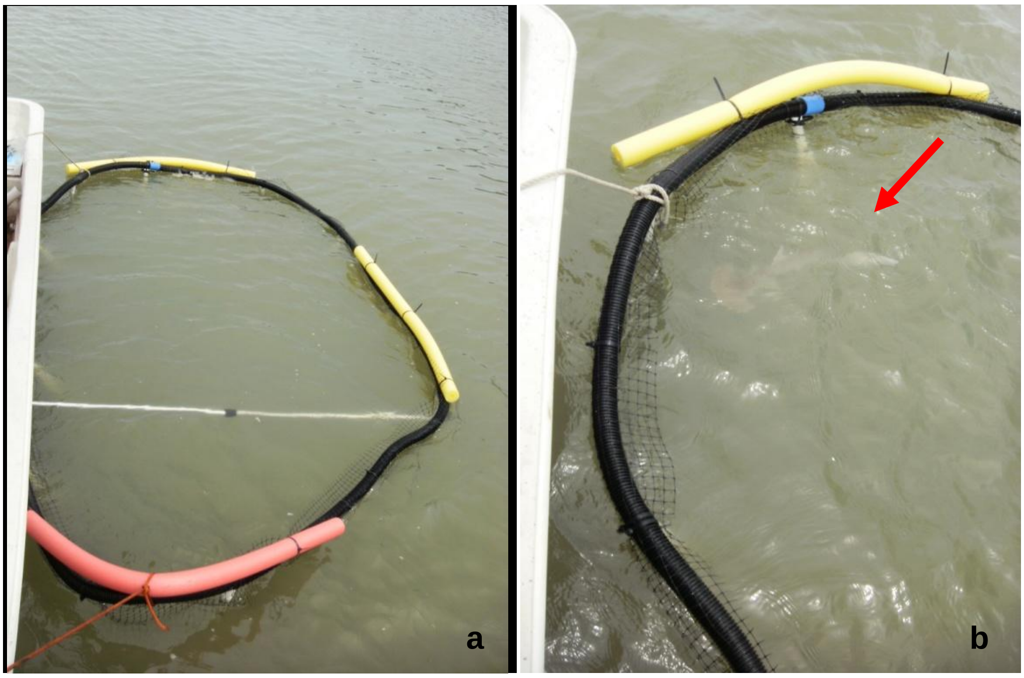

Figure 4.1. a) Post-release enclosure; b) *S. lewini* swimming in the enclosure

4.2.7.3 Passive acoustic tracking

While the current study was taking place, a second study monitoring the movements of sharks in the local area was being conducted. In this second study sharks were caught using recreational fishing techniques (i.e. using rod and reel) and were surgically inserted with an acoustic transmitter in their body cavity. Movements of acoustically tagged animals was then monitored by an array of acoustic receivers spread around Cleveland Bay (Knip et al., 2011) (Figure 4.2). To make use of this array for monitoring post-release survival, sharks were fitted with an acoustic transmitter and their movements were tracked after release to confirm post-release survival. A blood sample was taken before release (following capture and surgery) and the whole blood lactate concentration was measured. The presence and movements of these tagged animals within the array following release was used to determine survival.

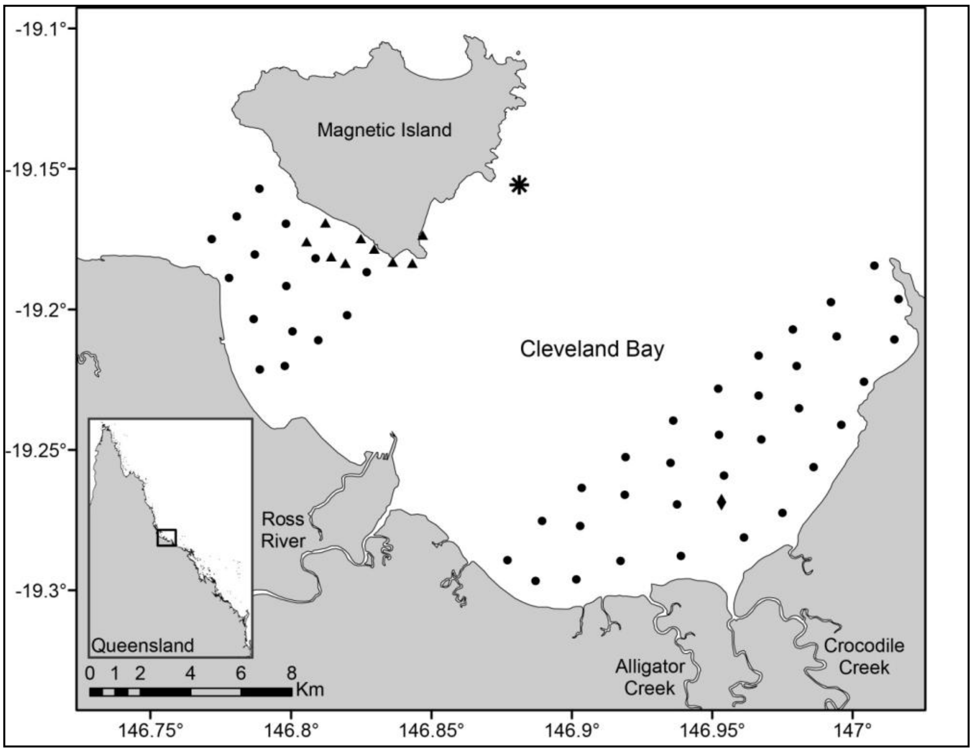

Figure 4.2 Map showing the distribution of acoustic receivers in Cleveland Bay, Townsville, Queensland.

4.2.8 Comparing different fishing techniques

To establish whether the level of stress observed in the experiments conducted in this study were higher or lower than stress levels caused by other fishing techniques, whole blood lactate concentrations were measured in sharks caught in concurrent research studies using gill-nets and longlines.

The research gill-net fishing was typically done using a monofilament gill-net with a stretch mesh of 45 mm, a height of 2.8 m and a length of 200 m. The net had a bottom lead line and a top float line and was anchored on one side by a sand anchor and attached to the boat on the other side. In most deployments, the net was soaked for 20 to 30 minutes. The research longline was composed of a main line approximately 600 m in length with about fifty 4 m gangions on. Each gangion was attached to the main line by a shark clip and had a wire trace and a baited circle hook. Different hook sizes were used depending on the targeted species ranging from 12/0 to 16/0. Each line was anchored at both ends and soaked for 60 to 90 minutes.

4.2.9 Statistical analysis

All whole blood lactate concentrations were log-transformed prior to statistical analysis to meet assumptions of normality unless specified otherwise. Unequal variances were assumed for t-tests which applied a correction to the degrees of freedom (df). Statistical data analyses were performed in SPSS Statistics 17.0.

4.2.9.1 Effects of handling

To establish if there was a significant difference in whole blood lactate concentrations after 10 minutes of angling between animals subjected to two or three samples a two tailed independent samples t-test was used. The test compared changes of mean whole blood lactate concentrations between the baseline and the 10 minute samples for each treatment group (i.e. two blood samples vs. three blood samples). The change in whole blood lactate concentration was the difference between the lactate concentration after 10 minutes of angling and the baseline concentration.

4.2.9.2 Effects of angling duration and air exposure

To establish the relationship between angling duration and whole blood lactate concentrations a one tailed paired samples t-test was used to compare baseline concentrations and whole blood lactate concentrations after 10 minutes of angling. The same approach was used for air exposure, comparing baseline concentrations and whole blood lactate concentrations after four minutes of air exposure.

4.2.9.3 Variations within and between species

To analyse whether individuals of the same species responded to the stressor in a similar way the coefficient of variation (CV) was calculated for each species with at least five individuals. The results indicated the level of variation in whole blood lactate concentrations between individuals within each species. The CVs of each species were then compared to establish if there was any variation between species.

4.2.9.4 Differences between sexes

To establish if stress response was sex dependent a two tailed independent t-test was used to compare changes in mean whole blood lactate concentrations in males and females of the same species.

4.3 Results

4.3.1 Fisheries-independent catch

A total of 115 individuals of 11 species were caught during the fisheries-independent experiments (Table 4.2). All captured individuals were neonates or juveniles. All sharks survived the experiment and were released in very good (1) or good (2) conditions (See Table 4.1).

The most common species caught in the fisheries-independent experiments were the two species of blacktip shark common blacktip shark *Carcharhinus limbatus* and the Australian blacktip shark *Carcharhinus tilstoni*. They constituted more than 50% of the catch followed by the scalloped hammerhead *Sphyrna lewini* and the milk shark *Rhizoprionodon acutus* (Table 4.2). The species with a sample size of at least five individuals were used in the analysis resulting in five species representing the families Carcharhinidae, Hemigaleidae and Sphyrnidae.

Table 4.2 Fisheries-independent experiments catch

Scientific name	Common name	Total	Component of catch (%)
Carcharhinus amboinensis	Pigeye shark	7	6.09
Carcharhinus coatesi	Whitecheek shark	3	2.61
Carcharhinus fitzroyensis	Creek whaler	7	6.09
Carcharhinus limbatus	Common blacktip shark	4	3.48
C. limbatus/tilstoni	Unidentified blacktip shark	17	14.78
Carcharhinus sorrah	Spot-tail shark	3	2.61
Carcharhinus tilstoni	Australian blacktip shark	44	38.26
Hemigaleus australiensis	Australian weasel shark	1	0.87
Rhizoprionodon taylori	Australian sharpnose shark	2	1.74
Rhizoprionodon acutus	Milk shark	14	12.17
Sphyrna lewini	Scalloped hammerhead	13	11.30
Total		**115**	

As discussed in Chapter 3, *C. limbatus* and *C. tilstoni* are morphologically identical. In this chapter, most individuals were identified by their size and the presence or absence of an umbilical scar. The ones not identified were grouped as unidentified blacktip sharks *C. limbatus/tilstoni*. On average, *C. tilstoni* showed slightly lower mean changes in whole blood lactate concentrations (1.82 mmol/L, SE=0.11) than *C. limbatus/tilstoni* (1.83 mmol/L, SE=0.096). This difference was not significant (independent t-test: t = -0.48, d.f. = 17.4, P = 0.96) and as a result both groups were combined in all analysis. The small sample size of *C. limbatus* (mean changes in whole blood lactate concentrations = 5.1 mmol/L) did not allow comparison to the other two groups. Although both species of blacktip sharks may differ in many aspects of their biology it was assumed that there was no significant difference in mean changes in whole blood lactate concentrations and thus the three blacktip shark groups (i.e. Australian blacktip, common blacktip and unidentified blacktip) were combined and referred to them as *C. limbatus/tilstoni*.

Rhizoprionodon taylori and *R. acutus* presented the same mean baseline concentration (1.18 mmol/L, SE=0.00; 1.18 mmol/L, SE=0.26) and similar mean whole blood lactate concentrations after 10 minutes of angling (5.1 mmol/L, SE=0.45; 6.4 mmol/L, SE=0.61) and therefore were combined and referred to as *Rhizoprionodon.*

4.3.2 Effects of angling duration and air exposure

Rhizoprionodon (n=8), *C. fitzroyensis* (n=6), *C. amboinensis* (n=5), *S. lewini* (n=5) and *C. limbatus/tilstoni* (n=25) were subjected to 10 minutes of angling. All species displayed a significant increase in whole blood lactate concentrations after 10 minutes of angling relative to the baseline levels, suggesting an increase in lactate when angling time is extended (Table 4.3). For all species, mean whole blood lactate concentrations never reached values higher than 8 mmol/L after 10 minutes of angling (Figure 4.3).

Carcharhinus limbatus/tilstoni (n=23) were subjected to four minutes of air exposure. On average, baseline concentrations (0.96 mmol/L, SE=0.06) were lower than whole blood lactate concentrations after four minutes of air exposure (1.63 mmol/L, SE=0.04). Like the angling duration, the air exposure also caused a significant increase in whole blood lactate concentrations (Paired t-test: $t = -15.12$, $df = 22.0$, $P < 0.0001$) over time. For all species, mean whole blood lactate concentrations never reached values higher than 5 mmol/L after 4 minutes of air exposure (Figure 4.3).

4.3.3 Effects of handling

Carcharhinus fitzroyensis (n=3) and *C. limbatus/tilstoni* (n=4) were subjected to two blood samples (baseline and 10 minutes) and *C. fitzroyensis* (n=3) and *C. limbatus/tilstoni* (n=21) were subjected to three blood samples (baseline, five and 10 minutes). On average, *C. fitzroyensis* subjected to three samples showed a mean whole blood lactate concentration after 10 minutes of angling of 1.7 mmol/L, (SE=0.23) while *C. fitzroyensis* subjected to two samples showed a mean whole blood lactate concentration of 1.5 mmol/L (SE=0.15). The extra handling of the middle sample taken at five minutes did not cause a significant increase in mean whole blood lactate concentrations after 10 minutes of angling (independent t-test: $t = -0.73$, d.f. = 3.5, $P = 0.50$). *C. limbatus/tilstoni* subjected to two samples displayed, on average, whole blood lactate concentrations of 1.9 mmol/L, (SE=0.13) while the ones subjected to three samples displayed a whole blood lactate concentration of 1.7 mmol/L (SE=0.96). This difference was also not significant (independent t-test: $t = 0.50$, $df = 6.5$, $P = 0.50$). These results indicated that the sampling and handling did not interfere with the whole blood lactate concentration results.

Table 4.3 Paired t-test results comparing baseline concentrations and whole blood lactate concentrations after 10 minute of angling for five different species.

Species	t	df	P
Rhizoprionodon	-12.24	7.0	<0.0001
C. fitzroyensis	-8.20	5.0	<0.0001
C. limbatus/tilstoni	-15.35	24.0	<0.0001
S. lewini	-12.72	4.0	<0.0001
C. amboinensis	-3.92	4.0	0.0085

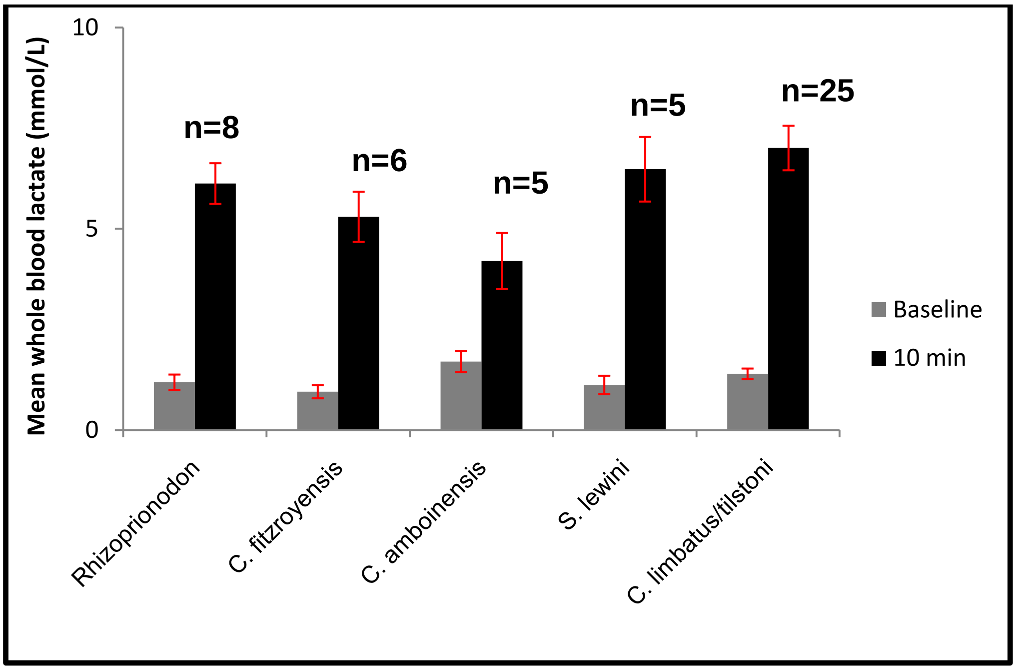

Figure 4.3 Effects of 10 minutes of angling on the mean (± SE) whole blood lactate concentrations of five species of sharks. Whole blood lactate values showed here were not log transformed.

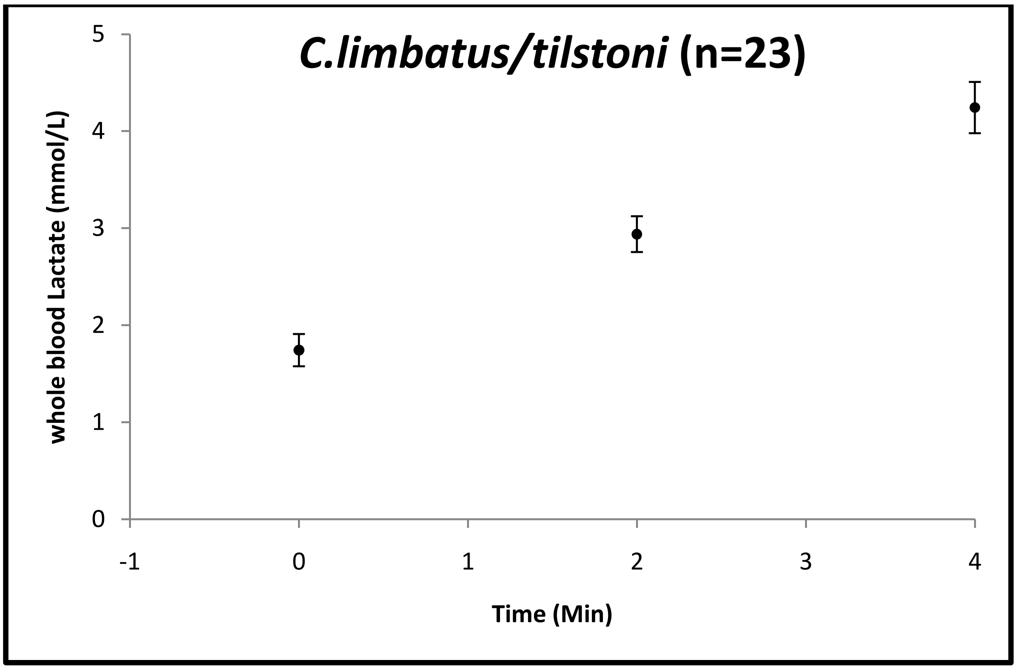

Figure 4.4 Effects of four minutes of air exposure on the mean (± SE) whole blood lactate concentrations of *C. limbatus/tilstoni*. Whole blood lactate values showed here were not log transformed.

4.3.4 Comparison to other fishing techniques

Whole blood lactate concentrations from animals caught by line fishing in this study were compared to those obtained from sharks caught by other fishing methods (Table 4.4). All maximum whole blood lactate concentrations observed during the study were lower than values obtained for the same species caught in other fisheries.

Table 4.4 Range of whole blood lactate concentrations (mmol/L) of 5 species of sharks measured in sharks caught by three different fishing techniques. Values showed in this table were not log transformed. Values below the detection range of the Lactate Pro® are shown as < 0.8 and values over the detection range are shown as > 23.3.

Species	Research Gill-net	Research Longline	Rod and Reel
Rhizoprionodon	1.8 - >22.3 (n=51)	6.8 - > 23.3 (n=11)	< 0.8 - 9.4 (n=8)
C. amboinensis	1.3 - 9.4 (n=5)	1.3 - 18.1 (n=10)	< 0.8 - 6.7 (n=5)
C. limbatus/tilstoni	1 - 16.4 (n=19)	7 - 22.9 (n=6)	< 0.8 - 10.4 (n=48)
S. lewini	13.6	> 23.3	< 0.8 - 8.6

	(n=1)	(n=6)	(n=5)
C. fitzroyensis	N/A	3.2 - > 23.3 (n=7)	< 0.8 - 7.8 (n=7)

4.3.5 Variance of whole blood lactate concentrations within and between species

The highest variation in whole blood lactate concentrations between individuals was shown by *C. amboinensis* (coefficient of variation (CV) = 62%), followed by *C. limbatus/tilstoni* (CV = 45%) and *C. fitzroyensis* (CV = 38%). *S. lewini* (CV = 30%) and *Rhizoprionodon* (CV = 31%) presented very similar and the lowest variation within species.

4.3.6 Differences between sexes

Mean changes in whole blood lactate concentrations in *Rhizoprionodon* (female=4; male=4), *C. fitzroyensis* (female=3; male=3) and *C. limbatus/tilstoni* (female=11 and male=14) subjected to 10 minutes of angling showed that there was no significant difference in stress response between sexes in any of these species (Table 4.5). Similarly, *C. limbatus/tilstoni* (female = 13; male = 10) that were subjected to 4 minutes of air exposure also did not display a significant difference in stress response between males and females (independent t-test: t = -0.92, df = 19.9, P= 0.37)

Table 4.5 Independent t-test results comparing mean whole blood lactate concentrations between males and females of 3 different species.

Species	Female mean lactate (mmol/L)	Male mean lactate (mmol/L)	t	df	P
Rhizoprionodon	1.70	1.80	-0.62	3.4	0.569
C. fitzroyensis	1.86	1.40	2.50	3.5	0.740
C. limbatus/tilstoni	1.84	1.78	0.36	22.7	0.718

4.3.7 Post-release monitoring – Tag and recapture

Of the total of 115 sharks tagged and released, six (5.2 %) were recaptured during the study. One *C. limbatus/tilstoni* was recaptured by a recreational fisher five weeks after release. This *C. limbatus/tilstoni* was initially released with a whole blood lactate concentration of 5.3 mmol/L and release condition 2 (Good: No revival required. Slow but strong swimming away on release; Table 4.1). One *C. amboinensis* was recaptured by a recreational fisher eight months after release. This same *C. amboinensis* was then recaptured by a commercial fisher two weeks after it was released by the recreational fisher. These recaptures show that the individual survived 8 months after the initial capture and then survived for two weeks before being captured (and harvested) in the commercial fishery. This *C. amboinensis* was initially released with a whole blood lactate concentration of 3.1 mmol/L and release condition 2. Both recreational fishers reported the sharks as being in a very good condition on recapture and release. In addition, one *C. fitzroyensis* was recaptured during the fisheries-independent experiments two weeks after release. This *C. fitzroyensis* was initially released with a whole blood lactate concentration of 5.0 mmol/L and release condition 2. Likewise, the recaptured animal was subsequently released in very good condition by the researcher.

Another two sharks were recaptured by a commercial fisher but unfortunately the fisher could not provide an accurate date of recapture therefore it is not known how much time had elapsed since they were first released. Nevertheless, these results do confirm at least short-term survival of these animals. The *C. limbatus/tilstoni* was initially released with a whole blood lactate concentration of 3.6 mmol/L and release condition 2. The *Rhizoprionodon* was initially released with a whole blood lactate concentration of 5.6 mmol/L and release condition 1. All sharks caught by the commercial fisher were harvested.

4.3.8 Post-release monitoring - Post-release enclosure

Three *S. lewini* and one *C. fitzroyensis* were separately released in the enclosure. All animals showed signs of stress immediately after release in the enclosure i.e. swimming frantically and repeatedly hitting the sides of the enclosure. Therefore blood samples were taken at 15 and 30 minutes instead of 60 minutes. Two *S. lewini* displayed high lactate concentrations after 15 minutes in the enclosure (11.9 mmol/L and 15.9 mmol/L). Similarly, one *C. fitzroyensis* and one *S. lewini* also displayed high lactate concentrations after 30 minutes in the enclosure (23.1 mmol/L and 16.7 mmol/L). These values were much higher than the maximum values observed after the angling and air exposure experiments. It is not known if these high values were a result of the extra stress caused by the enclosure or a function of the initial capture experience. Nevertheless, it was clear that the 60 minutes in the enclosure was not providing a recovery period, and therefore its use was discontinued and the results excluded from the analysis.

4.3.9 Post-release monitoring – Passive acoustic tracking

Two *S. lewini* were fitted with an acoustic transmitter and their movements were tracked after release to confirm post-release survival. Both sharks displayed baseline whole blood lactate values lower than the detection range (i.e. lower than 0.8 mmol/L), release condition 1 and survived after release. One shark swam within the array for five days after release and the other for approximately one month. After these periods of tracking both sharks were considered to have swum out of the tracking array based on the fact that their last detections were on the seaward-edge of the array (Figure 4.2).

4.4 Discussion

Recreational fishers in the GBRWHA do not target sharks (Lynch et al., 2010) and consequently sharks incidentally caught are rarely keept on the line for very long. Nevertheless, this study showed that this short angling duration caused a significant increase in whole blood lactate concentrations with time of exposure to the stressor. The increase in whole blood lactate concentrations as a result of angling duration is well documented in teleosts (Haux et al., 1985, Meka and McCormick, 2005, Beecham et al., 2006, White et al., 2008, Arlinghaus et al., 2009, O'Toole et al., 2010) and in elasmobranchs (Cliff and Thurman, 1984, Frick and Reina, 2009, Mandelman and Skomal, 2009, Frick et al., 2010a, Frick et al., 2010b, Awruch et al., 2011). The increase in whole blood lactate concentration observed in this study was expected because whole blood lactate is produced when the aerobic metabolism cannot meet the energy demand (Hoffmayer and Parsons, 2001) and the fighting on the line requires extra energy.

In the present study, the maximum whole blood lactate concentrations observed after 10 minutes of recreational angling were relatively low compared to results using commercial fishing techniques. Similarly, Hoffmayer and Parsons (2001) described the physiological changes that occurred in the *Rhizoprionodon terraenovae* during hook and line capture. The study found that after 15 minutes of capture the mean maximum whole blood lactate concentration was around 12 mmol/L which was in accordance with results found in the present study for *Rhizoprionodon*. Despite the short angling time and low whole blood lactate concentrations, sharks caught incidentally by recreational fishers undergo some level of stress.

Sharks in the present study were also subjected to four minutes air exposure simulating fisher's practices of removing the hook or taking photos. All individuals displayed a statistically significant increase in whole blood lactate concentrations but the maximum concentrations observed were relatively low compared to results from other studies and also compared to the results from the post-release enclosure experiment. In the current study, most sharks remained relatively still during the experiment and showed a significant increase in whole blood lactate even though they were not exercising. This increase may possibly be a result of the initial capture and not the air exposure *per se*. Similarly, Frick et al. (2010b) found that there was a significant increase in blood lactate concentrations in gummy sharks *Mustelus antarcticus* following trawl capture and air exposure but this result was not statistically different from animals subjected to the capture alone.

As well as the effects on whole blood lactate concentrations, air exposure may cause irreversible damage to gill lamellae, reducing the ability to exchange gases (Casselman S.J., 2005). Furthermore, air exposure can also cause behaviour and orientation impairment and its effects can be cumulative with other stressors (Davis and Parker, 2004). Maximum whole blood lactate concentrations observed in the present study were also much lower than values obtained from sharks caught by research gill-nets and longlines (e.g. *Rhizoprionodon* caught in gill-nets and longlines displayed whole blood lactate concentrations about four times higher than the ones caught recreationally). This difference can possibly be due to the different fishing gears used or because of the different durations of exposure to the stressor because angling duration is a critical factor in capture stress response (Cooke and Suski, 2005, Heberer et al., 2010). Frick et al. (2010a) also found that effects on physiology and survival of sharks after capture is highly gear dependent and species specific. For instance, gill-net capture led to higher concentrations of lactate and higher mortality in *M. antarcticus* than longline, while Port Jackson sharks *Heterodontus portusjacksoni* suffered minor effects and no mortality in either gear. One explanation could be that sharks caught in gill-nets undergo more stress because they cannot swim and therefore cannot ventilate. *Heterodontus portusjacksoni* are not ram ventilators which means that they have a mechanism to pump water through their gills and can therefore respire while caught on the net. In the present study the exact time the animals were in the gill-nets and or on longlines before sampling were not measured. Nevertheless, values obtained through these fishing methods are good indicators of how high whole blood lactate concentrations can get in each species.

Recreational fishing caused some degree of stress to sharks however lactate levels (and thus stress levels) do get much higher (as observed in other fisheries). This suggests that recreational fisher's current practices have less effect on the physiology and consequent post-release survival of sharks than other fishing techniques.

Studies using commercial fishing techniques (e.g. Frick and Reina, 2009, Mandelman and Skomal, 2009, Frick et al., 2010b) also found that response to stress varies between species and highlighted the importance of species-specific and fishery-specific assessments of physiological response to capture stress. For example, Mandelman and Skomal (2009) reported significant differences in how five species of carcharhinids reacted to acute stress caused by commercial demersal longline catch and concluded that the magnitude of the stress response in each species was linked to their metabolic scope. Similarly, although the present study did not statically test differences between species, the CV showed differences between species even though all sharks caught, except for the *S. lewini*, belong to the family Carcharhinidae. For instance, *C. amboinensis* displayed a high CV between individuals while *Rhizoprionodon*, *C. fitzroyensis* and *S. lewini* displayed similar lower CVs which were about half that observed in *C. amboinensis*. One possible explanation is that the fitness of the different individuals at the time of capture played an important role in the animals capability of reversing physiological disturbance following capture (Frick et al., 2010b). In addition, the short capture duration applied in this study may not have caused sufficient stress to allow a different response by each species. Despite that, because the focus of the study was recreational fisheries, and because recreational fishers in the GBRWHA do not usually target sharks, there was no need to subject animals to a longer capture.

Response to stress may also vary between life stages and sexes. For instance, Brill et al. (2008) studied the effects of anaerobic exercise during catch and release fishing on sandbar sharks *Carcharhinus plumbeus* and found that it has less impact on juveniles. Like teleosts, these juvenile sharks have mechanisms to minimise disruption of blood oxygen during anaerobic exercise such as buffering pH decrease by haemoglobin and organic phosphates. All sharks used in the present study were neonates or juveniles; therefore, the low whole blood lactate concentrations observed could be a result of similar mechanisms to *C. plumbeus* and teleosts.

The present study also examined whether response to stress is sex dependent and did not find a significant effect. This may mean that different sexes respond similarly to stress or that juvenile sharks of different sexes respond similarly. It would be expected that adults of the different sexes in different reproductive stages would respond differently (Frick et al., 2010b). There is currently no literature comparing stress response between sharks of different sexes. However, corticosterone levels were found to be different between sexes of three deepwater shark species subjected to stress (C. Awruch, pers. comm.)

When studying effects of capture stress in sharks it is important to consider many factors that may affect response such as species (e.g. Mandelman and Skomal, 2009), life stage (e.g. Brill et al., 2008) , stress duration (e.g. Cooke and Suski, 2005), fishing gear used (Frick et al., 2010b) and cumulative effects (e.g Davis and Parker, 2004).

4.5 Conclusion

The present study provided the first measure of capture and handling stress in incidentally caught and release sharks in recreational fisheries in the GBRWHA. The results showed that angling and air exposure durations caused a significant increase in whole blood lactate concentration in all five species of shark examined. However, the maximum whole blood lactate concentrations measured in line-caught sharks were significantly lower than in individuals of the same species caught by other fisheries. The study also found that there was some degree of individual variation in response to stressors within each species but there was not much variation between species and between sexes.

All sharks caught in the study most likely survived after release which was confirmed by post-release monitoring, good release conditions and low whole blood lactate concentrations. Consequently, it can be concluded that the stress caused only by angling duration and air exposure does not likely have a large direct impact on individual sharks, or on shark populations due to this high post-release survival provided that angling duration is short.

Chapter 5. General conclusions, recommendations for future research and implications for recreational fishers and the management of shark fisheries in the Great Barrier Reef World Heritage Area

Plate 5. Cape Cleveland, Cleveland Bay, Townsville, Queensland

5.1 The recreational catch of sharks in the GBRWHA

When this research was conceived, little was known about the potential impacts of recreational fishing on sharks in the Great Barrier Reef World Heritage Area (GBRWHA). Although some limited catch data were available (McInnes, 2006, McInnes, 2008, Lynch et al., 2010), they did not provide catch composition and specific catch numbers. Further, while the data showed recreational catches of sharks were significant, it also showed that recreational fishers in QLD and in the GBRWHA release most of the sharks they catch. In addition, prior research also suggested that engagement of the recreational fishing community in shark research, management and conservation efforts would be important for their success (Lynch et al., 2010). Given these findings, the present study aimed to understand the potential effects of recreational fishing on sharks of the GBRWHA by involving recreational fishers in data collection to describe the species composition and measure capture and handling physiological stress (i.e. whole blood lactate levels) to predict post-release survival.

The data reported in Chapter 2 accords with other studies that suggested that recreational fishers in the study area in general do not target sharks. However, even though the recreational harvest of sharks is low, it must be assessed against productivity of harvested populations and within the context of total fishing mortality and cumulative impacts (Bensley et al., 2010). In fact, the species composition of the recreational catch of sharks in the study area has an 80% overlap with the composition of the commercial inshore gill-net catch. The family Carcharhinidae is the most abundant with *Carcharhinus limbatus* and *Carcharhinus tilstoni* being the most numerous species in both the commercial and the recreational catch (Chapter 3). There are currently no stock assessments for these species in the GBRWHA but an ecological risk assessment (ERA) has highlighted that although both species are numerically dominant in catches they are not considered at high risk. However outputs of the ERA should be considered indicative, not definite, and mitigation measures should be put in place until a stock assessment is completed (Tobin et al., 2010). *C. limbatus* and *C. tilstoni* are classified as near threatened and least concern respectively in the IUCN Red List.

In addition, because of the high release rates in recreational fisheries, assessments of the impacts of recreational fishing on sharks must also take into account post-release survival rates (Lynch et al., 2010). Sharks incidentally caught and released by recreational fishers in the GBRWHA in this study displayed low whole blood lactate concentrations and good release conditions which suggests high survival rates (Chapter 4).

5.2 Can recreational fishing cause declines of shark populations in the GBRWHA?

As discussed in Chapter 1, a previous study argued that because of the high release rates in recreational fisheries there were concerns that post-release mortality could be the greatest impact of recreational fishing on sharks in the GBRWHA, and possibly in QLD (Lynch et al., 2010). Conversely, the results of this study have demonstrated that if incidentally caught and released sharks are kept on the line for relatively short periods (up to 10 minutes) and are exposed to air also for short periods (up to 4 minutes) there is a low impact on their physiological stress and consequent survival (Chapter 4). This means that if recreational fishers continue to not target sharks for harvest they most likely will not be solely negatively impacting on shark populations.

Nevertheless, most fishers reported not targeting sharks because they consider them inedible (Lynch et al., 2010). If their perception towards edibility changes and they start targeting sharks the impacts of recreational fishing on sharks could also change. Current regulations regarding the recreational catch of sharks in QLD prohibits fishers from keeping sharks that are larger than 1.5 m, however most of the sharks caught during the study were of legal size and therefore could be harvested by recreational fishers (Chapter 3). Recreational fishers in the GBRWHA are also subject to a bag limit of one shark per person per day. These present regulations in place in QLD are not currently affecting the recreational catch of sharks in the GBRWHA because most fishers in the area are not targeting or harvesting sharks. Nevertheless, it is important to highlight that there is a large number of recreational fishers in the area therefore if each individual fisher kept their legally permitted catch of sharks they could have an impact on local shark populations. In addition, there would also be cumulative effects derived from the overlap of the species composition of the GBRWHA commercial and recreational catches of sharks (Chapter 3). Moreover, inshore species are also affected by environmental changes (Knip et al., 2010), habitat degradation (Walker, 1998), shark control programs (Bensley et al., 2010) and potentially by climate change (Chin et al., 2010). In light of this, any assessments on the current status of shark populations in the GBRWHA will have to consider the potential cumulative effects of all these sources of mortality, including recreational fishing.

5.3 Implications for recreational fishers and managers in the GBRWHA

Future stock and risk assessments of shark species in the GBRWHA should take into consideration both the commercial and the recreational catch which will require estimates of species composition and total catch of sharks by both sectors. More importantly, the challenge for managers of the Great Barrier Reef Marine Park and the East Coast Inshore Finfish Fishery is to work with the local recreational fishing community to ensure that recreational fishers have positive attitudes towards post release survival of sharks. Moreover, any negative attitudes should be taken into account in management and education of recreational fishers.

Many teleosts species studies have shown that recreational fishers can impact on local populations (e.g. Coleman et al., 2004, Erisman et al., 2011) but only very few shark species assessments have included the recreational catch (e.g. McAllister et al., 2001, Hayes et al., 2009). Studies like the present provide a useful starting point describing the species composition of the recreational catch but also highlighting the urgent need to engage the community so they can contribute with catch and effort and species composition data for future stock and risk assessments. Recreational fishers may not have an interest or direct effect on sharks but they can still contribute to research with valuable local knowledge, fishing experience and data collection

Lynch et al. (2010) found that most recreational fishers from the GBRWHA area have a positive attitude towards sharks placing high importance in their conservation. Similarly, Chapter 2 also found that recreational fishers and charter operators of the study area were interested in getting involved in shark conservation research. Managers should take advantage of these positive attitudes of recreational fishers and engage them in the collection of data and in education programs. For this engagement to be successful it is important that involvement happens early in the process and that recreational fishers' interests are taken into account (Granek et al., 2008).

Chapter 3 confirmed findings by Lynch et al. (2010) that recreational fishers of the GBRWHA cannot identify shark species correctly. Because of the importance of identifying the species being caught by recreational fishers it is essential that education programs be undertaken to educate recreational fishers about identifying the different shark species. If the collection of adequate information on the species composition of the recreational catch of sharks will continue to rely on data provided by individual volunteer fishers through surveys, it is important that coverage is representative of the fisheries, data are accurate and there is strong community support given the large number of people who participate in the fishery.

On the basis of the results of this research there are several things that recreational fishers can do to minimize the effects of incidental catch and release. The angling duration and air exposure trials support the advice of the Queensland Department of Environment and Natural Resources to avoid long play times, and only bring the animal out of the water if required, releasing it as soon as possible to minimize air exposure (Queensland Department of Environment and Natural Resources, 2007). Based on the common recreational practices observed in this study most fishers follow these guidelines, and thus are releasing sharks in a relatively healthy condition. Similarly, Lynch et al. (2010) showed that fishers reported that their handling and release behaviour is consistent with the best practice guidelines. Managers should closely monitor recreational fishers' behaviour towards sharks as this will be the key to detecting any changes in the likely impact. In addition, It is important to ensure that best practice guidelines are widely disseminated and recreational fishers of the GBRWHA continue to follow them.

5.4 Recommendations for future research

The present study was undertaken together with few recreational fishers and charter operators from the GBRWHA. It is important that similar studies are undertaken with the participation of a larger number of individual recreational fishers and charter operators to improve management effectiveness while maximizing sample size and accuracy of data. Higher degree of community involvement means higher degree of acceptability and compliance (Nielsen and Vedsmand, 1997). In order to do that, it is important to have a better understanding of recreational fishers' reasons for participating or not in research. Understanding the recreational fishers' interests will help researchers and managers to enhance community participation.

Given the present study focused on the effects of two practices (i.e. air exposure and angling durations) there are a number of other practices and sub lethal effects that should be taken into consideration such as gill damage (e.g. Casselman S.J., 2005), hooking injury (e.g. Mapleston et al., 2008), effects of not removing hooks (e.g. Fobert et al., 2009) and post-release predation (e.g. Danylchuk et al., 2007). Moreover, this study looked at effects of angling and air exposure separately, but further studies combining multiple factors are required because this combination can result in cumulative effects (Davis and Parker, 2004).

The use of whole blood lactate and post-release monitoring proved to be very appropriate for measuring capture stress and post-release survival. These methodologies can potentially be used in other catch and release situations such as in commercial fishing (e.g. when sharks are released because they are bycatch, exceed bag limits or are no-take species), game fishing, shark control programs and fisheries-independent research. However this study used a single physiological indicator (i.e. whole blood lactate) but there are several other indicators that can potentially be used such as glucose (e.g. Hoffmayer and Parsons, 2001, Moyes et al., 2006, Frick et al., 2010b), electrolytes (e.g. Cliff and Thurman, 1984, Mandelman and Farrington, 2007), leukocytes (e.g. Van Rijn and Reina, 2010), urea (e.g. Moyes et al., 2006, Frick et al., 2010a) and blood pH (e.g. Hoffmayer and Parsons, 2001, Mandelman and Skomal, 2009). Moreover, post-release monitoring is crucial for determination of post-release survival so studies using appropriate post-release enclosures and a larger number of tracked animals (passive and/or active) and tagged animals (increasing chances of recapture) would be beneficial to further understanding capture stress and post-release mortality.

This study was undertaken with juvenile sharks and focused in a small area of the GBRWHA where recreational fishers do not usually target sharks. It will be very important that similar studies are undertaken on a broader scale including different species in different life stages and habitats. In addition, effects of fishing which target sharks are likely very different to the effects on incidentally caught sharks. Most recreational fishers in the study area are not targeting sharks specifically, and their capture and handling practices are having a minimal effect on the post-release survival of sharks. However there are other states (e.g. VIC) (Pepperell, 1992) and other countries (e.g. USA) where game fishers target sharks for harvest or catch and release. Therefore research involving game fishers to measure impacts of fishing on targeted shark species is crucial. For example, pelagic game fishers are known to target sharks. They have been engaged in recording catch and in catch and release tagging programs (McLoughlin and Eliason, 2008). However, while catch and release is a valuable tool for conservation of fisheries resources, it is only effective if it is done correctly guaranteeing high post-release survival (Cooke and Suski, 2005). Therefore research is required into tagging and handling techniques, measuring post release survival as well as educating game fishers (Bensley et al., 2010).

Until the recreational catch of sharks is properly identified and quantified and included in stock and risk assessments together with other sources of mortality it is not possible to conclusively affirm that recreational fishing is not impacting on shark populations.

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