THE STATUS AND PROGNOSIS OF THE SMOOTHHOUND SHARK (*MUSTELUS MUSTELUS*) FISHERY IN THE SOUTHEASTERN AND SOUTHWESTERN CAPE COASTS, SOUTH AFRICA

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ABSTRACT

Global trends in commercially valuable teleost fisheries point to substantial deterioration in population size, offering limited potential for increased harvests. Consequently a shift in focus towards alternative fisheries has increased fishing effort towards targeting chondrichthyans as a possible solution to meet global demands. The life-history traits of chondrichthyans make them poor candidates for resolving economic and nutritional security as these make them particularly vulnerable to anthromorphic influences.

Current fisheries management approaches based on centralized government intervention have proved inadequate. This failure of current management approaches is often linked with poor co-operation by industry with government when collecting fishery-dependent data. As management decisions are based on quantitative estimates from fishery assessment modes data collected are often of poor quality. Co-management with its implied power-sharing arrangement between government and fishing communities has been proposed as a more realistic alternative. The motivation within industry to collect high quality data can only be created with a feeling of ownership.

The decline in linefish species in South Africa has led to increased exploitation of demersal sharks such as *Mustelus mustelus*. Their status as one of the target and by-catch species of South Africa's shark fisheries necessitated resource assessment.

Age, growth, maturity and mortality calculations for *M. mustelus* were made from data collected from 1983-2006. The maximum observed age for *M. mustelus* was 25 years. Estimated von Bertalanffy growth parameters from observed length-at-age for combined sexes, females and males were L_∞ = 1946.16 mm TL, K = 0.08 year^{-1}, t_0 =–3.63 year^{-1}; L_∞ = 2202.21mm, K = 0.05 year^{-1}, t_0 = 4.67 years; and L_∞ = 1713.19 mm TL, K = 0.08 year^{-1} and t_0 = –4.36 years, respectively. Instantaneous total mortality (Z) was estimated at 0.16 yr^{-1}, whilst natural mortality (M) for *M. mustelus* was estimated at 0.05 yr^{-1}. The age and length at 50% maturity was determined for combined sexes, females and males at

1216 mm TL corresponding to an age of 9.93 years, 1234 mm (TL) and 10.75 years, and 1106 mm TL and 9.1 years respectively.

The smoothhound shark resource off the south-eastern and south-western Cape coast was assessed by three dynamic pool models; yield per recruit, spawner biomass per recruit and an extended yield and spawner biomass per recruit. Due to the longevity of elasmobranches the per-recruit model was extended over a 20 year time-frame to simulate resource responses to management options. $F_{0.1}$ was estimated as 0.034 year^{-1} and F_{MAX} was estimated as 0.045 year^{-1}. F_{SB50} was estimated as 0.031. The extended per-recruit model tested the outcome of different management scenarios, *Size and effort control* showed the least probability of pristine biomass falling below 20% of current levels in 20 years (where selectivity was set at 3 years). The replacement yield model showed that the average catches over the past decade are 2.5 times higher than the replacement yield is on the South Coast and 1.30 on the West Coast. A more realistic level optimising yield would be at 0.05 with a selection pattern at 3 years, where the probability of the biomass falling to below 20% of pristine pre-exploited levels in twenty years becomes negligible. A comparison of the models showed that current catches need to be halved for exploitation of smoothhound sharks to be sustainable.

The results of this study indicate a need for a management intervention for *M. mustelus* in South Africa with regards to potential overexploitation and collection of quality data for further assessments. A demersal identification key was developed as part of this study, which should aid monitoring officials in accurately identifying shark logs for collecting data.

This study showed how adopting a management plan with the inclusion of co-management concepts would improve the quality of data collected and increase monitoring of fishing activities. The inclusion of co-management is possible due to the unique bottle neck created by few demersal shark processing facilities actively exporting shark. A fishery management plan was compiled proposing several management options including size and effort controls.

TABLE OF CONTENTS

ABSTRACT...ii

DEDICATION..vii

ACKNOWLEDGEMENTS..viiii

CHAPTER 1: GENERAL INTRODUCTION

1.1 Fisheries management and sustainability 1

1.2 Public awareness..5

1.3 Fishing for demersal sharks...6

1.4 The demersal shark fishery of South Africa...................................7

1.5 Smoothhound sharks...9

1.6 Biology of *Mustelus mustelus*..10

1.7 Thesis outline..11

CHAPTER 2: STUDY AREA AND GENERAL SAMPLING METHODS

2.1 The study area..13

2.2 Sources of data...14

2.3 Dressed demersal shark identification key......................................18

CHAPTER 3: CATCH TRENDS AND SOCIO-ECONOMIC ISSUES

3.1 Introduction...22

3.2 Materials and Methods...34

3.3 Results..43

3.4 Data analysis...44

3.5 Discussion..53

CHAPTER 4: ASPECTS OF THE BIOLOGY OF THE SMOOTHHOUND SHARK, *MUSTELUS MUSTELUS*, IN SOUTH AFRICA

4.1 Introduction..57
4.2 Materials and Methods...58
4.3 Results...64
4.4 Discussion...73

CHAPTER 5: STOCK ASSESENT OF THE SMOOTHHOUND SHARK (*MUSTELUS MUSTELUS*) POPULATION OF SOUTH AFRICA

5.1 Introduction..77
5.2 Materials and Methods...79
5.3 Results...89
5.4 Discussion...94

CHAPTER 6: TOWARDS THE DEVELOPMENT OF A PRECAUTIONARY APPROACH TO THE MANAGEMENT OF SOUTH AFRICAN SHARK RESOURCES: AN EXAMPLE OF THE *MUSTELUS MUSTELUS* RESOURCE

....101

CHAPTER 7: GENERAL DISCUSSION

7.1 Introduction..108
7.2 Overview of findings..109
7.3 Conclusions..111

REFERENCES..114

APPENDIX 1..132

APPENDIX 2..137

DEDICATION

This thesis is dedicated to my father, thank you so much for your support

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Fisheries management and sustainability

The rapid increase in the global human population has placed additional strain on food security, which has resulted in nutritional and economic focus being placed on marine resources. World fisheries are reported to be facing a crisis with worldwide catches increasing from 14 million t to 71 million t over the past five decades (FAO, 2004). Commensurate with these increased catches in high-value teleosts, and their resultant stock declines, has been a deliberate shift to targeting of chondrichthyans as an alternative food resource. Global statistics report an increase in catches from 53 to 142 thousand tons over the past six decades (FAO, 2004).

The realisation that resources are dynamic has led to the belief that they cannot be managed by centralised management strategies (Nielsen *et al.*, 2004). The FAO *Committee on Fisheries* expressed the need for responsible international fisheries management (FAO, 2003). The *Code of Conduct for Responsible Fisheries* (COFI) was adopted by the FAO in 1995. Its objectives include the establishment of principles for responsible fishing and fishing activities, promoting conservation, ensuring resource sustainability, and promoting the need for nutritional security (FAO, 1995).

The *Precautionary Approach to Fisheries* (FAO, 1995) was developed for the purpose of enabling management bodies to cope with uncertainty in the face of increasing marine resource usage. The primary aim of this approach is to reduce the risk to fisheries through caution when faced with data-poor situations, and by taking socio-economic and environmental implications into account when making management decisions.

Unfortunately, the implementation of this management approach is difficult to achieve particularly when confronted with multi-species fisheries or with fisheries where little data on catches, effort, and biology are available. Chondrichthyans fall into this category. They are often caught as a suite of species in the absence of high-value teleosts (Musick, 2004) and they exhibit complex migratory patterns and life-history characteristics. Further complications arise due to its status as a "difficult" research organism. As a result, little data concerning their biology are available. These factors in conjunction with poor fishery data and limited identification abilities of dressed animals have resulted in poor management. It is also widely accepted that elasmobranch fisheries are unsustainable (Holden, 1973), despite Walker (1998) demonstrating that sustainability is theoretically possible under an active management regime. As a result, scientists have highlighted the need to develop management strategies for chondrichthyans based on the implementation of the FAO's *Precautionary Approach to Fisheries*.

Conventional views of fisheries management strategies often refer to the term "sustainable exploitation". A brief overview of the world's most valuable fisheries clearly demonstrates that this objective is not being met. Most of these fisheries, such as the patagonian toothfish fishery (Laptikhovsky & Brickle, 2005) and cod fishery in the North Sea (Walters & Maguire, 1996; Myers *et al.*, 1997) are on the brink of collapse or have collapsed. These fisheries cannot be considered 'sustainable'. Over recent years, the serial depletion of various species has been masked by improved technology (such as better acoustic technology to detect population aggregations), geographic expansion of fishing (fishers spending more time at sea and fishing further from land), and shifting exploitation patterns to previously underutilised resources (Pauly *et al.*, 2002).

Although sustainability has been the principal objective of fisheries management since the 1980's, these objectives for sustainability have still not been met (Levin, 1993). All participants involved in global fisheries management acknowledge that the concept of sustainability rests on a universally accepted worldview, and with it, a specific value judgment. In the past it was presumed that future generations were guaranteed the natural resources that current generations had enjoyed. The worldview that presumes that natural resources are unlimited no longer holds sway. The value judgment associated with this worldview implies that people are intrinsically concerned about the environmental inheritance of future generations (Lele & Norgaard, 1996). Brooks (1992) highlights a crucial dilemma concerning sustainability. The concept of "sustainability" requires measurable, objective, value-neutral criteria for effective action. However, worldviews and values are essential to the concept of sustainability, and there is a high plurality of these values across individuals and communities (Lele & Norgaard, 1996). In order to overcome this plurality, sustainability needs to be defined in scientific terms. This will ensure value-neutrality when fisheries issues are being resolved across global scales. It is essential to have value-neutrality, because, by using mutual shared meanings with reference to world views and value-judgments, conflicts may be resolved (Jasanoff, 1992). Hillborn & Ludwig (1993) have sought to reconcile this differing societal partiality, by suggesting the notion of rational decision-making that balances the risks and benefits of an assortment of probable outcomes. Lele & Norgaard (1996) attempted to reconcile the problems inherent to value judgments by making them clear to both the affected communities prior to undertaking research and to all potential users of scientific results stemming from the research. The term "sustainable development", at its most optimistic, calls for development such that poverty is reduced. In developing countries where fisheries development is aimed at reducing poverty, communities affected need to be considered. The socio-economic implications of particular fisheries need to be examined and considered for the successful implementation of a sustainable management strategy.

Fisheries management where practiced in the 1990s was based on centralized, top-down, government-implemented regulations. These regulations prescribed compliance-control procedures with stakeholder involvement concerning access and utilization rights (Nielsen *et al.*, 2004). The unsustainable use of resources has reduced them in most instances to a point that local communities are feeling the effect. This has resulted in increased conflict with governments. Conflict between fishing communities and government has increased with increasing international competition for local resources (Nielsen *et al.*, 2004). Local communities often lose access and control of resources to more affluent foreign users. This is pertinent in South Africa where sustainable development of fisheries has been a recognized goal towards poverty alleviation.

Although resources are being lost to foreign involvement, economic benefits are not reaching previously disadvantaged individuals. Previously advantaged individuals still use and control resources.

The *Code of Conduct for Responsible Fisheries* has led to the formulation of the fisheries co-management concept and the ecosystem approach to fisheries. Co-management is defined as a combined understanding between government, user groups and stakeholders for successful management of a given resource (Kearney, 2002). This approach attempts the development and management of fisheries by addressing the diversity of the needs and wishes of society (FAO, 2004). This goal is completed without jeopardizing the options for future generations (Kearney, 2002).

Co-management provides an alternative solution to the "tragedy of the commons", (Hardin, 1968), which states that territorial waters are treated as national commons with few restrictions. The law of supply works adequately where fish stocks are plentiful, but as the demand of a desirable stock increases it exceeds the capacity of these stocks to replenish themselves (Keen, 1991). Harvesting of a fishery resource under a common property framework becomes wasteful once the tragedy point in resource exploitation has been reached. The co-management paradigm tries to resolve this problem by providing the fishing community and stakeholders with incentives to protect the resource through ownership (Keen, 1991). Co-management processes use the same model of planning, implementation and evaluation of fisheries with a more classical fisheries management paradigm (Kearney, 2002).

Co-management has had both documented successes (Harte, 2000; 2001; Metzener *et al.*, 2003) and failures (Metzener *et al.*, 2003). For co-management to be successful, the fishing public needs to understand several important concepts. These include the election of responsible representatives, the collection of scientific-based information about the resource, accurate government and scientific support, and general public awareness through the media. Several problems are associated with the implementation of the co-management concept. First, there lies a problem with the general lack of knowledge of the socio-economic dynamics governing the use of the resource. Second, co-management relies heavily on the fishery infrastructure (monitoring and accurate scientific knowledge). Third, it relies heavily on the development of a transparent governing policy with considerable weight placed on public awareness and media coverage. Lastly, it assumes that users have a thorough knowledge in concepts of management that would engender a feeling of willingness and make them able to contribute to the development of the practice.

1.2 Public awareness

Papson (1992) discussed the development of public awareness of sharks generated by the media. Public awareness of sharks in the last decade started with negative media perceptions generated by Spielberg's "*Jaws*" (1975) to more positive natural history programmes. In recent years, natural history programmes have undergone dramatic changes in development both in form and representation of organisms (Cottle, 2004). This includes chondrichthyans. Kawashima (2005) explored the process by which whales have been mythologised as giant sacrosanct creatures. His ideas were based on the principle that the differences between images and reality are beginning to disappear. This is especially pertinent to whales perceived in the 18^{th} and 19^{th} century as oil producing fish with "as much aesthetic appeal as gigantic pigs" (Kawashima, 2005, pg 2) to graceful leviathans of the oceans. This has resulted in mass outcry by the public against whaling, and its subsequent banning in many countries. Arguably, public perceptions of whales are further developed than those of chondrichthyans. However, the recent public outcry against the practice of shark finning, in particular, highlights the brewing change in public perception. This initiation of increased awareness of chondrichthyans has launched a platform from which chondrichthyans can be adequately protected under almost any management paradigm. From this historically unique position, co-management of chondrichthyan fisheries could therefore be possible.

Following this change of awareness, there is a desperate need to restructure the methods by which the general public, fishers and fishery stakeholders are informed about changing policies. Fishery stakeholders often feel overlooked. This prompts the need for the co-management regime to address issues of ownership and inclusively. Effective communication of scientific information to the general public is therefore of fundamental importance to the development of a successful, sustainable management plan (Funtowicz, *et al.*, 1998). Prior to successfully distributing scientific information to the general public, fishers and fishery stakeholders, an awareness of the significance of the species in question needs to be repeatedly emphasised. There can only be success in co-management procedures by implementing transparent management policies which can be interrogated and propagated by the media.

1.3 Fishing for demersal sharks

Elasmobranchs, the subclass of chondrichthyans including the sharks, skates and rays, are generally apex predators with a low biomass relative to that of teleosts (Musick, 2004). Elasmobranch fishes are also inherently more vulnerable to anthropogenic influences due to their life-history characteristics. These characteristics include slow growth, late sexual maturation, and low fecundity. In addition, there is often segregation by sex and age, and diverse migration patterns. It is a widely accepted that the removal of apex predators through anthropogenic influences have negative impacts on ecosystems (Begon, *et al.*, 1996). Direct effects associated with removal of apex predators include density-dependent changes in size and age structure within a population, or worse, local or global extinctions (Friedlander *et al.*, 2004). Indirect effects include the removal of competitors, or species removals, and resultant changing community structures (Estes, 1996). The removal of apex predators results in fundamental changes through top-down cascading. This implies that this removal can affect the whole ecosystem, as species are tightly connected through this process (Paine, 1966).

Although elasmobranch fisheries predate recorded history, commercial exploitation of elasmobranchs began in response to vitamin A supplement shortages after World War II (Vannuccini, 1999). More than 100 species of sharks are now landed by directed fisheries and as incidental bycatch worldwide (Vannuccini, 1999). Increasing exploitation has now led to growing international concern about their long-term sustainability.

Traditionally sharks were caught in an attempt to defray fishing costs in poor fishing conditions. With the rise of global awareness regarding the price of shark fins and increased marketing of sharks as a food source, elasmobranchs are now increasingly targeted (Simpfendorfer & Donohue, 1998). In developing countries, such as South Africa, where some communities are dependent on shark fisheries for the maintenance of socio-economic livelihoods, the development of management plans have been slow.

Historically disadvantaged persons exploit these resources by illegal shark fishing, finning activities off small vessels or by-catch from other industries (e.g. purse-seine vessels). These activities will be compounded by the growing demands for elasmobranch products from developed countries. The globalization of fishery practices and product demands heightens the knowledge of the value associated with various elasmobranchs. This will ultimately result in elasmobranch trade becoming increasingly illegal.

1.4 The demersal shark fishery of South Africa

Globally, shark catches are divided into directed and bycatch fisheries. A similar situation occurs in South Africa. Table 1.1 summarises the different fisheries that impact on demersal elasmobranchs in South Africa. Both the commercial linefish and demersal longline target smoothhound sharks *(Mustelus mustelus, Mustelus palumbes)*, soupfin shark (*Galeorhinus galeus*), bronze whaler shark (*Carcharhinus. brachyurus*), dusky shark (*Carcharhinus obscurus*), hammerhead species (*Sphyrna* spp.), gully sharks (*Triakis megalopterus*), cow sharks (*Notorhynchus cepedianus*) and St Josephs

(*Callorhinchus capensis*). The offshore and inshore trawl fisheries catch similar species. The gillnet fishery mainly target demersal species such as smoothhound, soupfin and cow sharks.

There are six fisheries in South Africa in which sharks are either directly targeted or caught as by-catch. These are the longline fisheries, the inshore trawl fisheries, gillnet and beach-seine fisheries, the recreational fisheries, and commercial line fisheries. The line and gill net fisheries target sharks, while trawling and longlining fisheries land sharks as by-catch. The main landing site for targeted shark fishing on the south-western Coast is Gans Bay, but sharks are landed at practically all western ports.

Table 1.1. All existing known fisheries for demersal shark in South Africa (modified from McCord, 2005) with description of their fisheries, region of operation and exploitation levels.

Fishery	*Target/Bycatch*	*Region*	*Exploitation level*
Commercial line and handline fishery	Target	Eastern Cape coast	High
		Southern Cape coast	High
		West Coast	Low
Demersal shark longline	Target	Unknown	Low (very few active)
Inshore trawl	Bycatch although some targeting have been reported	Southern and Eastern Cape coast	Unknown
Offshore trawl	Bycatch	Western and Southern Cape coast	Low
Hake longline	Bycatch although targeted to defray costs	Western and Southern Cape coast	Unknown
Recreational line	Bycatch although are targeted in competitions	Western, Southern and Eastern Cape coast	Low (handling damage unknown)
Gillnet (illegal and legal)	Bycatch	Western Cape coast	Low
Aquarium Trade	Target	Eastern Cape coast	Low

1.5 Smoothhound sharks

Triakid sharks of the genus *Mustelus* are common over the continental shelves in tropical and temperate waters worldwide (Compagno, 1984). They are abundant in enclosed bays with soft substrate where they may have a large impact on their benthic prey species (Smale & Compagno, 1997). They are slender, strong-swimming benthic feeders with flattened ventral surfaces on the head and body (Heemstra & Heemstra 2004) and have small cusped teeth in multi-serial rows that are adapted for preying on crustaceans and other invertebrates. Other prey includes gastropods, bivalves, cephalopods, echiurids, sipunculids, annelid worms, tunicates, various species of teleosts, and offal (Compagno, 1984).

The genus is represented by three species in South Africa. These are *Mustelus mustelus, M. palumbes* and *M. mosis*. These species together with the spotted gullyshark *Triakis megalopterus* are often confused with one another despite Heemstra's (1973) revision of the genus. *Mustelus* spp. There is substantial overlap in the Southern African distribution between *M. mustelus* and *M. palumbes*. Both species occur from Namibia to KwaZulu-Natal (Compagno, 1984). *M. mustelus* also occurs in the Mediterranean, whilst *M. palumbes* is endemic to Southern Africa. The hardnose smoothhound, *M. mosis*, is a Western Indian Ocean species. Its southernmost distribution is KwaZulu Natal (Smale & Compagno, 1997).

Compagno *et al.* (1991) investigated the distribution of offshore benthic chondrichthyans from the West Coast of Southern Africa using data collected from research surveys. Catches were dominated by *M. palumbes*, with few *M. mustelus*. *Mustelus palumbes* were mostly caught between 100-299 m, and has therefore are classified as an inshore overlap species whilst *M. mustelus* was classified as an inshore species as it is found from the surface to 100 m.

Smoothhound sharks are commonly caught off Southern African waters by commercial trawlers, long-lining operations, line-fishing boats, shore based anglers and recreational fishermen (Smale & Compagno, 1997). Until the 1980's, *Mustelus* spp. were not considered suitable for human consumption. They are now targeted in the Western Cape predominantly in the absence of high value teleosts. Commercial trawlers catch *Mustelus* spp. as by-catch. These are often discarded in favour of more valuable fish. However, as most of the sharks suffer high mortality rates when caught they are still affected by fishing pressure. Intensive fishing for sharks occurs in Struis Bay, Saldanha Bay and St Helena Bay (Smale & Compagno, 1997). Smoothhounds and many other sharks are also commonly caught in amateur angling and light tackle boat competitions. Many of these competitions have, since 1986, been based on tag-and-release systems. Although mortality rates of released sharks are unknown, the impact from these fisheries is considerably less than that from other fisheries.

1.6 Biology of *Mustelus mustelus*

M. mustelus is a shallow coastal species. Although there is considerable overlap in depth preference between sex and age classes, mature and pregnant females are caught at shallower depths than immature females and males. The size at maturity of smoothhounds is gender specific with females attaining maturity at a larger size (1250-1400 mm TL) than males (950-1050 mm TL) (Smale & Compagno, 1997).

Data collected by Smale & Compagno (1997) suggest a broad reproductive season. They state that mating frequency peaks at the beginning of the year, and ovulation is broadly seasonal. Subsequent to ovulation, the egg is covered by an egg case. Large yolked eggs that are not passed into the uterus may be resorbed in the ovary after ovulation. During embryonic development the egg case of smoothhounds amalgamates with the uterine wall. Gestation period of *M. mustelus* is about 9-11 months. Larger females have significantly larger litters, with the average litter size found to be 11.54 (Smale & Compagno, 1997).

Smale & Compagno (1997) suggest, from interviews with trawl net and line fishermen, that sporadic aggregation of *M. mustelus* and sexual segregation and aggregation may occasionally occur. Individual *M. mustelus* swim close to the substrate hunting for prey. Further findings of this study propose that *M. mustelus* change diet with increasing size. Prey selected shifts in importance from crustaceans and polychaetes moving to cephalopods, squid, and small fish with growth. Other shifts noticed include the transfer of importance of small carid shrimps and polychaetes to larger crustaceans such as rock lobster with growth. Smale & Compagno (1997) noted that scavenging might explain the teleost component of the diet. Linked with the dietary shift with weight, another dietary shift occurs with depth due to availability of species. Inshore shallower-water prey includes the swimming crab *Ovalipes punctata*, Cape rock crab *Plagusia chabrus* and chokka squid *Loligo vulgaris reynaudii* (Smale & Compagno, 1997). At depths between 50-100 m crustaceans become the dominant prey component, while at depths exceeding 100 m octopods dominate although crustaceans are also important.

1.7 Thesis outline

For the implementation of a successful precautionary approach to shark co-management in South Africa, an understanding of the fishery dynamics and biology of all species is necessary.

Few restrictions are currently in place with regards to the exploitation of sharks. Those restrictions in place involve bans on catching several species, bag limits of several species and permit and license requirements for some species. Therefore, the shark fishery in South Africa is largely unregulated. Due to the unique socio-economic conditions created in 1994 and associated high poverty levels, regular management may not be a successful endeavor. Co-management may be the most successful management approach due to the unique management bottleneck created by the existence of only three demersal shark-processing facilities.

For a co-management approach to management to be developed, using *M. mustelus* as a candidate species, several aspects need to be considered. These include understanding fishing patterns and quantifying catches and catch rates, investigating biological aspects such as reproductive seasonality, maturity, growth, and conducting a resource assessment to investigate the species' current status.

The thesis is structured as follows. Chapter 2 introduces the study area and the various fisheries dependent and fisheries independent data used in the various analyses. The demersal dressed shark identification key developed as a part of this study is presented along with various suggested measurements to be taken.

General catch trends, catch rates, the general processing and dressing procedures and additional socio-economic aspects of the demersal shark fishery are presented in Chapter 3.

Biological aspects of *M. mustelus* are investigated in Chapter 4. In this chapter, age is determined and growth parameters estimated using the von Bertalanffy growth equation. Length at maturity is estimated together with fishing mortality.

Chapter 5 uses different stock assessment approaches to estimate the stock status of two *M. mustelus* stocks. These results are then used as targets to determine the most suitable method of management. All information gathered from Chapters 2, 3, 4 and 5 are discussed in Chapter 7 and used to develop the management plan for *M. mustelus* demersal species (Appendix 2).

CHAPTER 2

STUDY AREA AND GENERAL SAMPLING METHODS

2.1 The study area

The distribution of the demersal shark fishery in the south-eastern and south-western Cape coast of South Africa is illustrated in Figure 2.1. The area of operation extends from Port Elizabeth to Saldanha Bay. Effort is concentrated off Port Elizabeth, Mossel Bay, Stil Bay, Struis Bay and Gans Bay.

The area in this study along the South African coast (Fig. 2.1) was divided into the Eastern Cape coast (Kei river to Breede river), the Southern Cape coast (Breede river to Melkbos), and Western Cape coast (Melkbos to Orange river). Where the Western Cape and Southern Cape coast are combined, this is referred to as the south-western Cape coast, south-eastern Cape coast refers to the area between Port Elizabeth and Breede river. The Southern Cape coast is also mentioned in most instances instead of the south-western Cape as most shark fisheries do not operate as far as the West Coast. Shark processing facilities are situated in Port Elizabeth (Fishermen Fresh), Strand (Sharkex) and Mitchell's Plain (Selecta) (Fig 2.1). The area of operation for each shark processing facility is also illustrated.

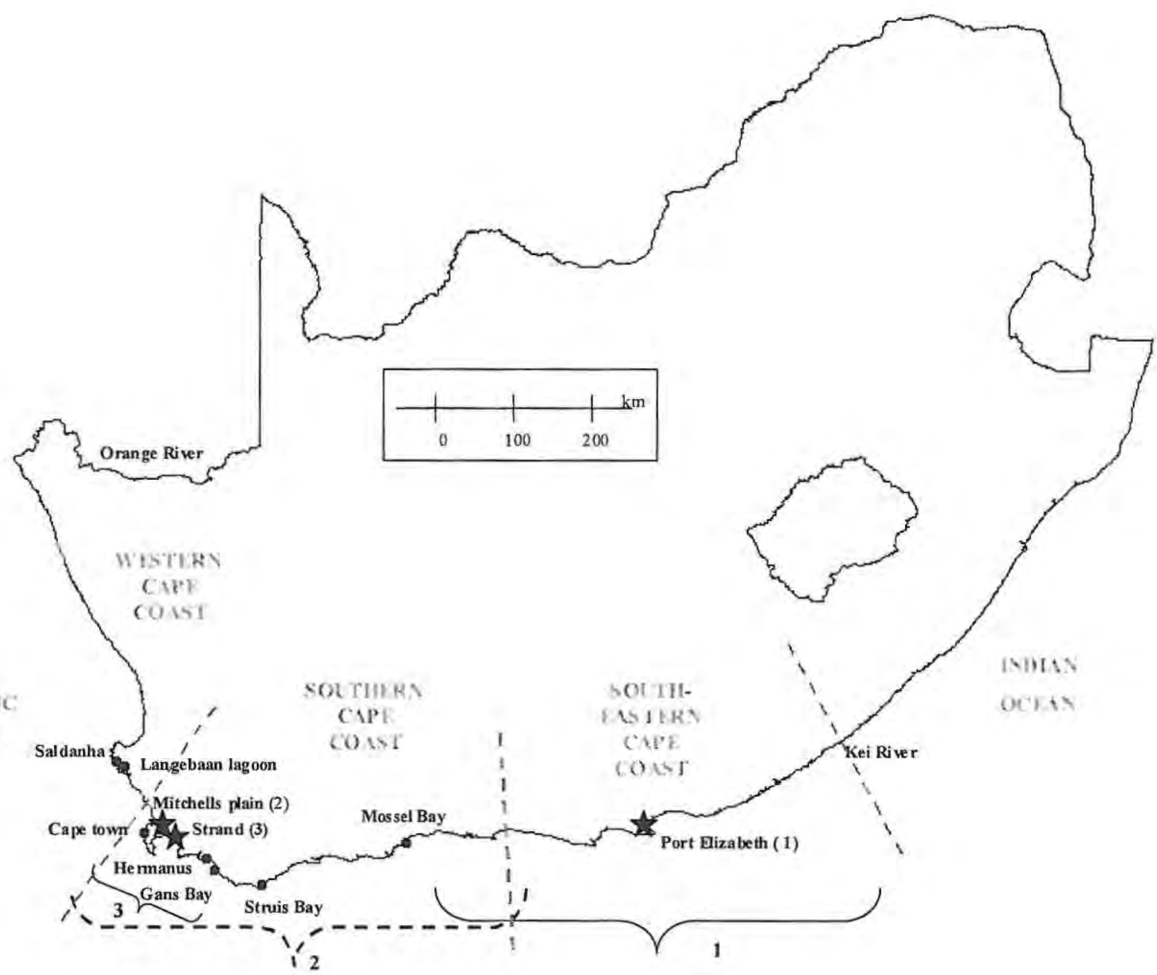


Fig 2.1 Map of South Africa showing the distribution of the demersal shark fishery around the 3 factories, areas that process sharks are illustrated with stars and corresponding numbers refer to areas of operation

2.2 Sources of data

Table 2.1 and 2.2 summarises the data used for this study. Data used from Marine and Coastal Management included all years where sharks were identified to species level (poor records of shark catches in the various fisheries for earlier years). The offshore trawl data was not included due to confusion between *M. mustelus* and the deeper water *M. palumbes*.

Table 2.1 Fishery-independent and fishery-dependent data with their location and year of collection of capture used within this study

	Type of data	Location	Source	Year
Fishery independent data	*Africana* biomass survey cruises	Cape Town to Saldanha Bay and Hout bay to Mossel Bay	MCM	1992-2003
Fishery dependent data	National linefish database	Kei River to Orange River	MCM	1985-2006 (up to Sept)
	Trawl data	Inshore trawl; Port Elizabeth to Mossel Bay	MCM	2000-2006
	Longline data	Southern Africa	MCM	2000-2006
	Catch data	Saldanha Bay - gillnet (factory data)	Factory purchase forms	2003-2005
	Catch data	Selecta (False Bay)	Return forms	2005
	Catch data	Provided by *TRAFFIC*	*TRAFFIC*	2006

Fishery-dependent data were collected from catch-return data sheets collected by MCM for the linefish, and longline fisheries. Fishery-independent data was collected on the research vessel *Africana* as part of yearly survey biomass indices completed for various different commercially important stocks.

Table 2.2 Types of data used in this study along with location of data, and collector

Type of data	Location	Data source
Vertebral samples	Port Elizabeth	M.J. Smale
Vertebral samples	Port Elizabeth and Strand	Part of this study
Biological and life-history parameters from previous studies	Eastern Cape	M.J. Smale, R.J. Bennett, A. Goosen
Random factory samples	Port Elizabeth, Strand and Mitchell's Plain (area of operations shown in Fig 1)	Part of this study

Fishery-independent data were collected from research surveys conducted between 1992 and 2006 for spring and autumn samples by Marine and Coastal Management (MCM). During these research surveys, smoothhound sharks were collected by trawl nets between Saldanha Bay (33°01'0 S, 17°56'60 E) and Gans Bay (34°34'60 S, 19°21'0 E) for West Coast samples and between Hout Bay (34°02'0 S, 18°21'0 E) and Mossel Bay. (34°11'0 S, 22°08'0 E).

Biological data from previous studies together with samples collected as part of this study were used in Chapters 4 and 5.

A random monthly processing day per factory was selected for sampling based on availability (monthly in the Eastern Cape and quarterly in the Southern Cape). All animals processed during that day were identified, sexed, and measured (measurements shown in the identification key in section 2.3) and maturity of males assessed by clasper calcification. Vertebral samples and measurements were taken from the three processing facilities and used in conjunction to raw data obtained from Bennett (2004). Due to the unavailability of whole sharks, Bennett's (2004) raw data was used to determine life-history parameters, whilst data collected during this study were used for comparative purposes.

Due to the dressed state of the sharks, all lengths were taken from the dorsal origin to the caudal tip (DOCL). Twelve whole animals were weighed and the following measurements were taken; total length (TL), standard length (SL), dorsal origin to caudal tip (DOCL) and dorsal origin to precaudal pit (DOPCP). These animals were used to convert DOCL to total lengths by fitting a least squares regression. The relationship is shown by $TL = 1.37DOCL + 13.071$ with a fit of R^2 = 0.97. The relationship between length and weight was estimated by fitting a least squares regression and is shown by $weight = 0.1662TL - 12.15$ (Figure 2.2), with a fit of R^2 = 0.94. This relationship considered appropriate because of the small sample size. Although the sample size for the both conversions was small, the converted data (2005-2006 set) was compared to data collected by Goosen & Smale (1997) and reanalyzed by Bennet (2004) by using a likelihood ratio test. This test showed no statistical difference between datasets, therefore the conversions from the twelve animals were used. This may be problematic as the second dataset was also used to estimate the difference in growth between smoothhound sharks from the south-eastern and south-western Cape coast (as the majority of animals were collected from False Bay).

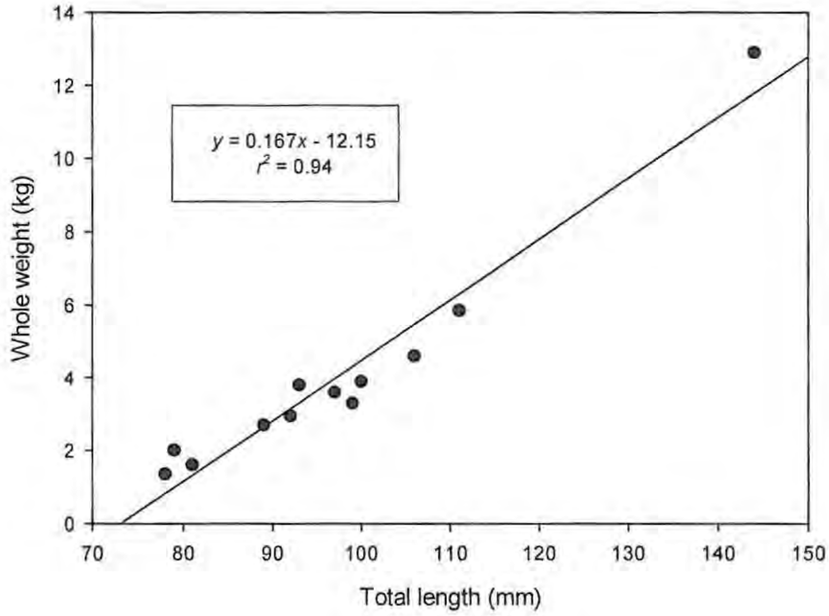


Fig 2.2 Length-weight relationship of *M. mustelus* (n = 12) from the Southern Cape coast of South Africa

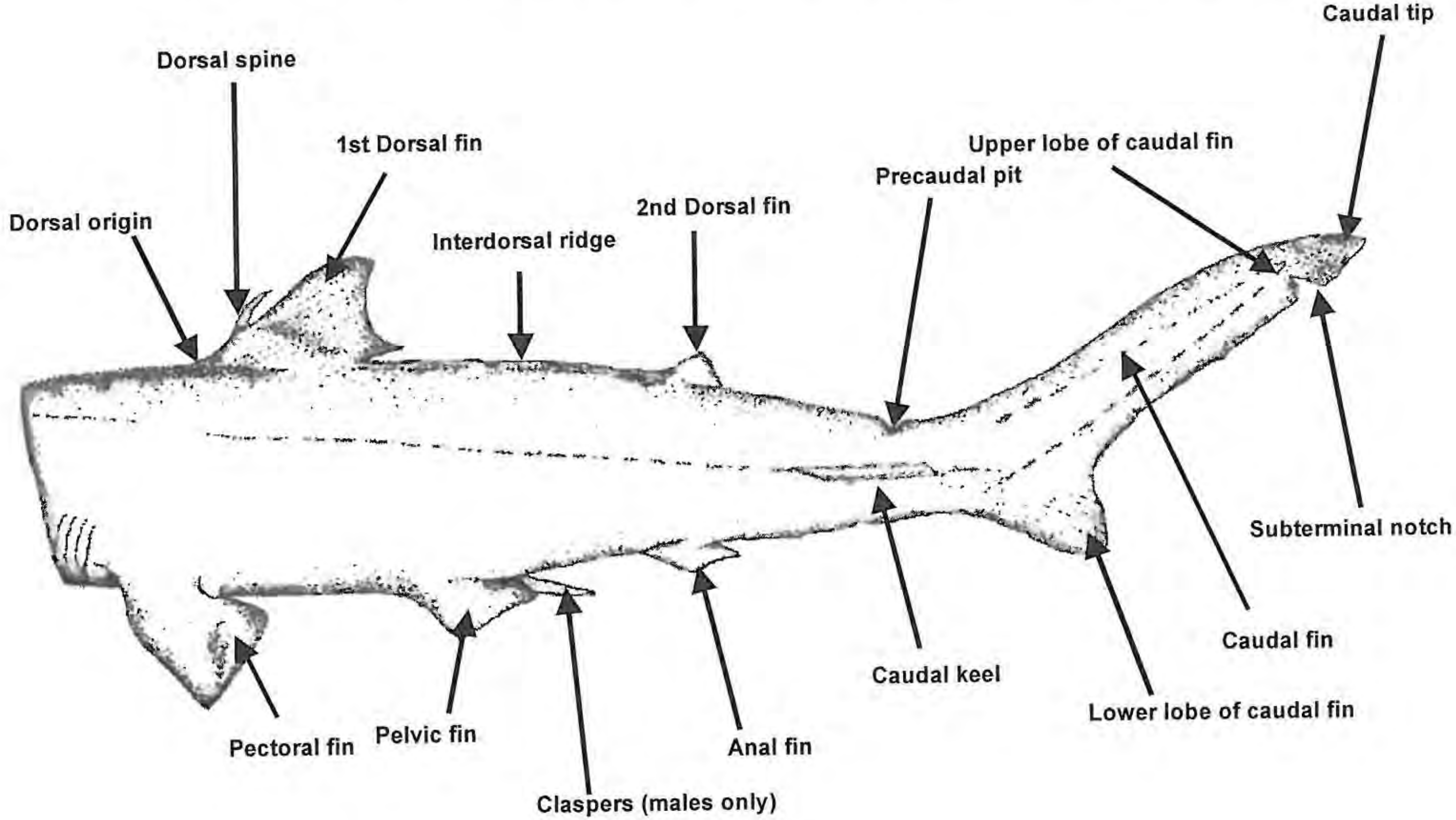
2.3 Dressed demersal shark identification key

Demersal shark identification key for commonly caught demersal species

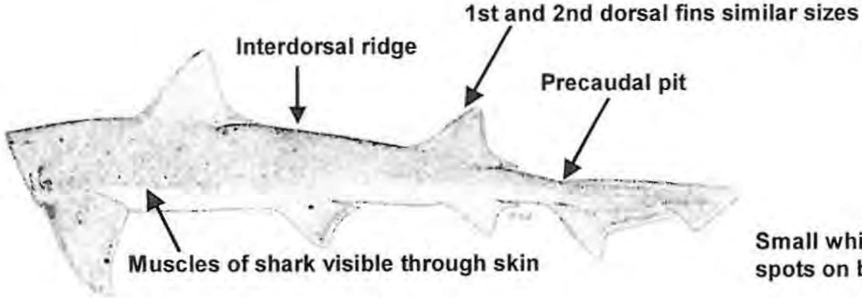
1.1	One dorsal fin; 7 gill slits: anal fin present	***Notorynchus cepedianus***
1.2	Two dorsal fins; 5 gill slits; anal fin present or absent	**2**
2.1	Spine on first dorsal fin, anal fin absent	***Squalus* spp.**
2.2	No spine on first dorsal fin, anal fin present	**3**
3.1	First dorsal fin above or behind pelvic fins, body usually with distinct body patterning	***Scyliorhinidae***
3.2	First dorsal fin in front of the pelvic fins, body without distinct uniform patterning	**4**
4.1	Interdorsal ridge present	**5**
4.2	Interdorsal ridge absent	**8**
5.1	Interdorsal ridge and precaudal pit	**6**
5.2	Interdorsal ridge and no precaudal pit	***Triakis megalopterus***
6.1	First and second dorsal fin similar size	**7**
6.2	First dorsal fin much larger than second dorsal fin	***Carcharhinus obscurus***
7.1	Small white spots on body	***Mustelus palumbes***
7.2	No spots/ Black spots on body	***Mustelus mustelus***
8.1	No interdorsal ridge but with precaudal pit	**9**
8.2	No interdorsal ridge nor precaudal pit	***Galeorhinus galeus***
9.1	First dorsal fin upright and longer than pectoral fins	***Sphyrna* spp.**
9.2	First dorsal fin not longer than pectoral fins	**10**
10.1	Black tips on dorsal surfaces of fins	***Carcharhinus limbatus***
10.2	Black tips on ventral surfaces of fins	***Carcharhinus brachyurus***

Inaccuracies in various shark data sources were noted with regards to identification. Identification characters of sharks are normally based on head and teeth morphology. As dressing of the sharks remove these primary identification features, this has resulted in a difficulty in identifying species. It was therefore necessary to develop a dressed demersal identification key.

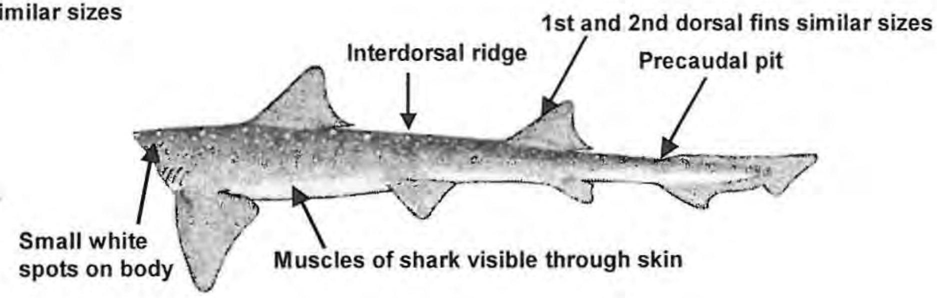
ANATOMY OF A GENERALIZED SHARK WITH TRUNK MEASUREMENTS TO BE TAKEN



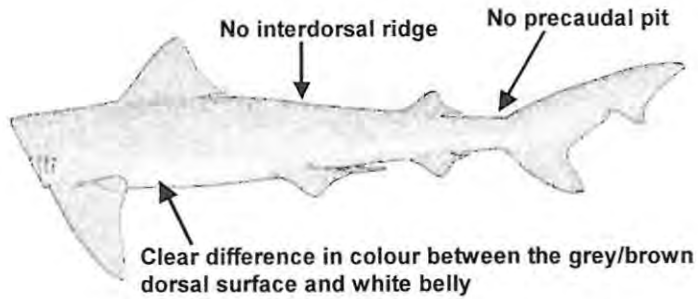
<u>Measurements to be taken</u>
L1 = Dorsal origin to caudal tip
L2 = Dorsal origin to precaudal tip



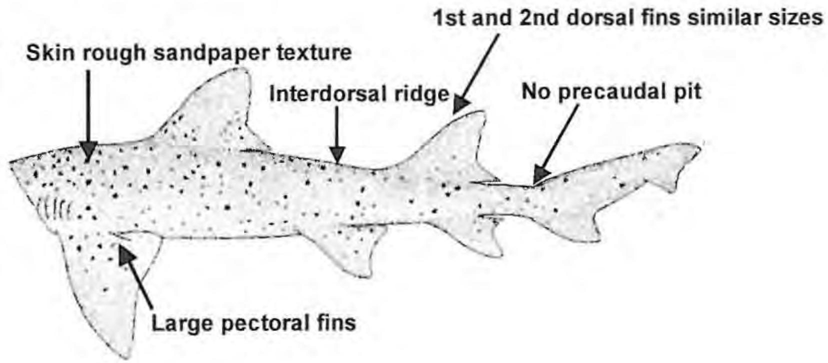
Mustelus mustelus (Smoothhound shark)
Medium sized shark up to 1.7 m, common inshore. Uniform grey or brown colour with white belly, some have black spots (Smith & Heemstra, 2003)



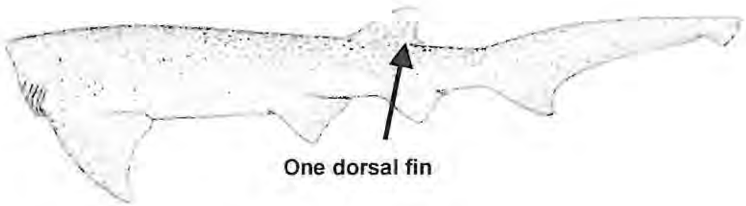
Mustelus palumbes (White spotted smoothhound shark)
Small shark up to 1.2 m. Light to dark grey with numerous white spots (Smith & Heemstra, 2003).



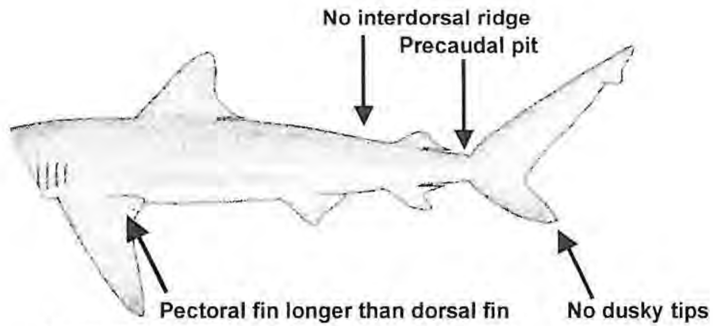
Galeorhinus galeus (Soupfin shark)
Medium sized shark up to 1.9 m, commonly caught inshore, uniform grey with white belly (Smith & Heemstra, 2003).



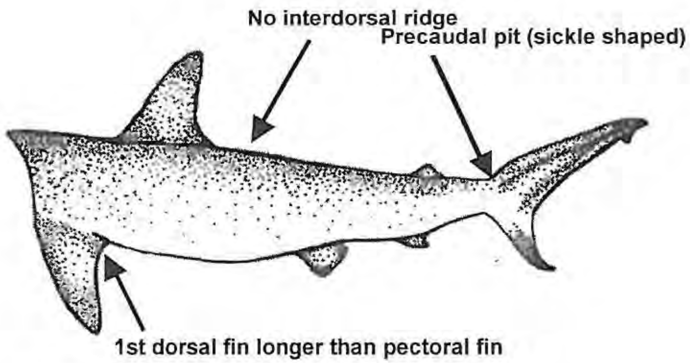
Triakis megalopterus (Gully shark)
Medium sized shark, up to 1.7 m, commonly found inshore, grey/brown/ bronze above with numerous small black spots, stocky body, large fins (Smith & Heemstra, 2003).



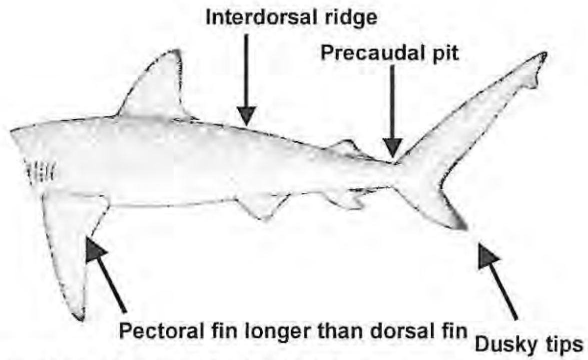
Notorhynchus cepedianus (Six gill cow shark)
Large shark > 3 m, commonly found close inshore, colour ranges from silvery grey to dark grey, also reddish brown to olive grey, often covered in white spots (Smith & Heemstra, 2003).



Carcharhinus brachyurus (Bronze whaler shark)
Medium to large shark (up to 2.9 m), shiny light bronze to rich copper, however colour fades to grey / brown after capture (Smith & Heemstra, 2003).



Sphyrna zygaena (Smooth hammerhead shark)
Medium sized shark up to 1.8 m, most frequent hammerhead shark seen in the Eastern and Southern Cape coast.
Crescent shaped precaudal pit. Caudal fin has a hooked lower tip.
Denticles fall off with handling leaving green blotches.
(Smith & Heemstra, 2003).



Carcharhinus obscurus (Dusky shark)
Large shark (up to 4 m), common close inshore, dark grey, with dusky tips on dorsal and ventral surfaces of fins (Smith & Heemstra, 2003).

[1] All diagrams except *S. zygaena* are modified with permission from Smith's Sea Fishes, 2003 – *Struik Publishes*, Smith M. M., & P.C. Heemstra, pictures by Bass, A. J. Western Australian Museum, and Heemstra, E.outh African Institute of Aquatic Biodiversity (SAIAB).

CHAPTER 3

CATCH TRENDS AND SOCIO-ECONOMIC ISSUES

3.1 Introduction

Uncertainty regarding the accuracy of data can severely limit the results of a stock assessment, which in turn provides information on resource status and is used as important information within the development of a management plan. Reliable fishery-dependent and fishery-independent data are therefore a requisite for the development of a fisheries management plan whose objective is to ensure resource sustainability.

Fishery-dependent data not only provides catch estimates for target and bycatch species but also provides information regarding the amount of effort allocated to a particular fishery over a given period of time (Morgan & Burgess, 2004). This information provides estimates used to model changes in population abundance against effort attributed to the fishery, and used to allocate fishing permits. Fishery-independent data can be used to test general trends by highlighting similarities and differences between trends in scientific data obtained from research surveys and fishery-dependent data.

Rosenberg *et al.* (1993 pg 828) stated that the sustainable use of resources "meets the needs of the present without compromising the ability of future generations to meet their own needs." The constraints involved in fisheries development are influenced by unique resource characteristics. These characteristics include the biological renewability of fish stocks, the uncertainty of scientific data regarding the state of fish stocks, and the absence of property rights governing access to stocks (Baily & Jentoft, 1990). The high level of uncertainty regarding the state of fish stocks is further compromised by several factors including the difficulty in finding reliable fishery-dependent data. Other factors include misidentification of species due to the dressing of carcasses (referred to as logs) by fishers, and underreporting of total catches on data sheets.

In South Africa, the national fisheries authority, Marine and Coastal Management (MCM), collects commercial catches of elasmobranchs from fishers who record monthly catches in logbooks. Fishery records in the national linefish and longline database include vessel names, registration codes, date, and depth, hook number, soak time, species caught (weight and numbers), and number of crew per vessel. Monitoring of landings occur in the Eastern, Western and Northern Cape Provinces by Fisheries Control Officers falling under the Department of Environmental Affairs and Tourism: Branch Marine and Coastal Management (DEAT: MCM), as well as monitors under contract to MCM (Da Silva & Bürgener, 2007). The latter have no enforcement powers. The majority of officials in all provinces lack the species identification skills to correctly identify demersal sharks to the species level. Species identification is especially difficult for demersal sharks as they are normally landed, after having been headed and eviscerated at sea.

Morgan & Burgess (2004) highlighted the caution with which fishery-dependent data need to be considered. Since fishermen record the data in the absence of monitors, in most cases, high underreporting numbers and misidentification of species is common. The lack of funding for monitoring landings and validation of commercial shark data in South Africa has further contributed to the low data reliability. As exploitation of elasmobranch species in South Africa is increasing, it is therefore necessary to estimate catch trends.

This chapter provides an overview of the fisheries targeting or catching sharks as by-catch, and gives a general background to the demersal shark fishery targeting smoothhound sharks, as this has previously been unknown. Following this, the general catch trends and CPUE trends will be examined and preliminary findings of the status of *M. mustelus* presented. The socio-economic aspects governing the fishery will also be examined in an attempt to elucidate catch trends. Combined, these catch trends and socio-economic factors will provide an indication as to the initial status of the stock by highlighting problems and data inconsistencies. These data, combined with stock assessment-related management quantities estimated in Chapter 5, will provide the platform from which smoothhound sharks can be sustainably harvested.

Fisheries targeting sharks or catching sharks as by-catch

Trawl fisheries

Bottom-trawl inshore hake-directed fisheries are potentially the greatest threat to some species of demersal elasmobranchs (Sauer *et al.*, 2003). The focus of the trawl component of the demersal shark fishery will be the inshore trawl fishery as they catch large quantities of demersal shark species, including *M. mustelus,* as by-catch. The inshore hake trawl fishery is concentrated mainly in Mossel Bay and Port Elizabeth and consists of 17 operators (in 2006) with vessels ranging in length between 14-31 m (Sauer *et al.*, 2003). These vessels operate between Cape Agulhas in the west and the Great Kei River in the east, and may extend seawards past the 110m contour (area in which the deep-sea trawlers are excluded by permit) (Sauer *et al.*, 2003). This fishery is classified as a "dual quota mixed species fishery" with effort directed mainly at shallow-water hake (*Merluccius capensis*) (Although the TAC of 10 000t is for *Merluccius capensis* and *Merlucius paradoxus*), and Agulhas sole (*Austroglossus pectoralis*).

Chondrichthyan species landed on trawlers include biscuit skate (*Raja straeleni*), smoothhound sharks, soupfin shark and St Joseph shark (*Callorhinchus capensis*). The most common shark caught in trawl fisheries on the Agulhas Bank is the shortspine dogshark (*Squalus megalops*). Whilst dogsharks have high biomass, they are considered too small for processing (Sauer *et al.*, 2003), although *Squalus megalops* and *S. mitsikurii* are sometimes landed.

Between 1979 and 1991, sharks comprised 0.3 % of South Africa's total commercial landings by mass (Crawford *et al.*, 1993). The annual shark catches in 1990 was estimated at 606 t (Crawford *et al.*, 1993). Owing to high level of discarding and nonreporting the actual number of chondrichthyans caught in the trawl fisheries is difficult to quantify. The incentives for trawlers to target chondrichthyans have increased with increasing market value of sharks. A worrying observation is that a high proportion of sharks seen at factories are said to originate from the trawl fisheries that operated from mostly inshore areas.

Traditional line-fisheries

Commercial line fisheries

Commercial line fisheries are the oldest fisheries to have specifically caught sharks in South Africa. This fishery is divided into two portions: the Cape region and the KwaZulu Natal region. The focus of this study was on the Cape region. This fishery is responsible for 95% of the South African linefish catch, consisting of about 25 000 vessels (3-15 m long) operating on the continental shelf (5-130 m depth) between the Orange River and the Kei River (Sauer *et al.*, 2003). This range of coastline is about 2 500 km in length. Fishers from this fishing sector mostly use handlines although some use rod-and-reel (Sauer *et al.*, 2003).

Although the Dutch colonised the Cape in 1652 the fishery was slow to develop (Sauer *et al.*, 2003), only thriving in the mid-1800s with row and sailboats (Sauer, *et al* 2003). Prior to the introduction of the towable outboard motor-powered ski-boats (1970), the dominant vessel boat was the deck-boat locally known as *chukkie* (Sauer *et al.*, 2003). *Chukkies* are still commonly used in small fishing towns such as Vlees Bay, Klein Bay, Saldanha Bay, and Gans Bay.

Shark catches by the traditional commercial line fishery have fluctuated dramatically in response to the availability of higher priced species and market forces. Since 1991, however, there has been a steady increase in catches with decrease in valuable linefish species (Sauer *et al.*, 2003). Species targeted include the soupfin sharks, houndsharks, dusky sharks, copper sharks, spotted gully sharks, thresher sharks, dogfish, catsharks and skates.

Recreational fisheries

The recreational linefishery includes shore anglers, boat fishers, estuarine fishers (all of which use rod and line) and spearfishermen. Sharks are not generally targeted, except during competitions when edible fish are scarce, as sharks score higher points due to larger size (1 point per kg for sharks and 2 points per kg for edible teleosts). The commonly targeted sharks are *M. mustelus*, *G. galeus*, *C. brachyurus*, *C. obscurus* and *Caracharias taurus.*

Shore angling is a rapidly expanding recreational pursuit in South Africa. Clarke & Buxton (1989) completed an examination of the recreational rock-angling fishery at Port Elizabeth. He found that between 1985 and 1986 at least 76 600 *M. mustelus* individuals were caught. These sharks ranged in length between 790 and 1610 mm TL. Another study completed by Hanekom *et al.* (1997) on the shore angling catches in the Tsitsikamma National Park, showed that 11.2% of the total annual catch from 1991 to 1995 was *Mustelus* spp.

M. mustelus is caught on sandy beaches and rocky shores, and is mainly exploited by the subsistence fishermen, the recreational fishers, and commercial fishers. The exploitation gear technology is advanced (rod and reel), with medium levels of exploitation in South Africa.

The shark longline fishery

Initially the shark longline fishery was composed of both demersal and pelagic longline vessels. This was later divided into the distinct demersal and pelagic longline fisheries.

The pelagic longline is being incorporated into the large pelagic longline fishery with pelagic sharks caught as by-catch. Generally shark longline vessels are < 30m in length and deploy bottom longlines with up to 3 000 hooks per set in water depths from 50-450m (Sauer *et al.*, 2003). All vessels hold more than one permit and are generally 12-23 m that are predominantly wooden construction (Sauer *et al.*, 2003). Traditionally, "Japanese" single line multi-stranded lines were used. These have now been replaced by the expensive nylon monofilament Lindgren Pitman spool system (Sauer *et al.*, 2003 pg 192).

The directed shark longline fishery has two distinct fleets. The first longline fleet target pelagic sharks using offshore pelagic drifting gear. The second fleet target demersal shark using bottom-set gear in inshore environments (shallower than 100 m) (Sauer *et al.*, 2003).

The domestic pelagic longline fishery originally only targeted tuna and swordfish although shark bycatch was also recorded. Foreign pelagic tuna-directed fisheries are mostly comprised of Japanese and Chinese vessels targeting offshore oceanic species such as mako sharks (*Isurus oxyrhincus*), blue sharks (*Prionace glauca*), carcharhinid sharks such as silky sharks (*Carcharhinus falciformes*) oceanic whitetip sharks (*C. longimanus*), and porbeagle sharks (*Lamna nasus*) (Sauer *et al.*, 2003). The foreign pelagic tuna-directed and the pelagic shark fisheries mainly target sharks for the fin trade, and is mostly illegal, inshore species such as houndsharks and soupfin sharks are excluded (Sauer *et al.*, 2003). Pelagic sharks are also caught as by-catch by the large pelagic longline sector.

The demersal long-line fishery occurs in the Southern and West Coast based in Mossel Bay (Britz *et al.*, 2001), Port Elizabeth, Gans Bay and Hout Bay targeting smoothhound sharks and soupfin sharks. The majority of the permits issued for this fishery are not used, and those used do not necessarily operate on a weekly basis. The area of operation of the demersal longline vessels is restricted to coastal waters. Demersal shark species such as smoothhound sharks are also caught as by-catch by the hake longline sector.

Longline permits for the directed catching of sharks were first issued in 1991 (Crawford *et al*., 1993). Vessels utilize both a pelagic (to target oceanic species) and a demersal longline to target soupfin and houndsharks. Crawford *et al*. (1993) suggests that the initial incentive to gain these permits was to exploit loopholes in the regulations to catch hake by longline, which had been banned in 1990. After large quantities of hake exceeding the 1991 Total allowable Catch, for hake had been caught by this method, the loophole in the law was closed. Boats in possession of shark long-line permits were given hake and kingklip bag limits. Most of the vessels in possession of shark long-line permits either have tuna or linefish permits and will, whenever possible, catch these preferred species.

Prior to 1998, over 30 permits were issued to target shark. Due to poor fishery performance these were reduced to 23 permits. In 2004, for the same reasons, the shark permits were further decreased to 11. The demersal longline vessels targeting houndsharks and soupfin sharks are generally smaller than those targeting pelagic species. The DEAT stipulated in the draft policy for the allocation and management of commercial fishing rights in 2005 and as of 2006 there will no longer be a pelagic shark longlining fishery. As many permit holders hold permits in many fishing sectors, the shark fishery is generally active when the vessels are not engaged in other sectors. There has been an annual fluctuation in the number of active vessels from 14 in 1999 to 5 active in 2003.

A stock assessment completed between 2001 and 2002 indicated that, although only three longliners were operational in 2001 and two in 2002, that the principal component of the industry *G. galeus* was overexploited (Anon, 2005a). The new policy aims to decrease the effort of the fishery to a maximum of six fishing rights authorising a maximum of six fishing vessels. The fishery will be managed in accordance with the ecosystem approach to fisheries (Anon, 2005a). The current by-catches limits of hake and kingklip will be retained, and by-catch limitations will be introduced for both blue and mako sharks (Anon, 2005a). The allocation of long-term rights will also be given by performance.

Those not using actively using the permits or caught breaching restrictions would not be given permits. Observer programs will also be initiated.

Gill and beach seine net fisheries

On the South African West Coast, gill net and beach seine net fisheries have operated traditionally since 1652 (Lamberth, 2006). In 1980, a directed gill-net fishery for St Joseph sharks (*C. capensis*) was initiated. Gill nets catch elasmobranchs such as soupfin sharks, houndsharks and sandsharks (*Rhinobatus annulatus*). Beach seine nets primarily target teleosts, but considerable quantities of elasmobranchs are also caught, comprising on average 70% skates and rays including sandshark, bull rays (*Myliobatis aquilla*), and blue rays (*Dasyatus chrysonata*) (Sauer *et al.*, 2003).

As early as 1947, a shark advisory committee expressed concerned about the high catches of undersized soupfins, and introduced a minimum mesh size of 22.9 cm for gillnets (Crawford *et al.*, 1993). In 1948, a quota of 250 000 t shark was set, as concern increased about the escalating number of gravid females caught. The fishery fluctuated heavily from 1950-1975 with the low price of shark liver oil, after the production of synthesized vitamin A. Later due to the worldwide scare of bioaccumulated mercury further affected prices. Between 1987 and 1991 around 104 t of soupfin sharks and 42 t of other sharks were caught in the gillnet fishery (Crawford *et al.*, 1993).

A driftnet shark directed fishery was established in the early 1980's to harvest St. Joseph sharks in St Helena Bay. Prior to 1982, beach-seine, set net and drift nets were permitted for the capture of haarders (*Lisa richardsonii*) and other species. In 1982, all permits for set nets were cancelled and replaced by drift net permits. Catches between 1985 and 1991averaged 389 t of St Joseph sharks, 4 t of soupfin sharks, 10 t of skates and 24 t of unspecified sharks, mostly comprising of *Mustelus* spp. The amount of effort was dependent on the availability of haarder as an alternative and more lucrative species. The overall catch in the nets was, and still is, almost entirely cartilaginous, with up to 80% of the catch comprising of St Joseph shark (Crawford *et al.*, 1993). In 1990, 208 t sharks were landed in the net fishery.

The gillnet fishery is restricted to Yzerfontein northwards, whilst the beach-seine fishery is restricted to the west of Gordons Bay. As part of a proposed management strategy, the coast will be subdivided into beach-seine and gillnet areas. Effort will be limited by gear restrictions and fishing by means of nets will be prohibited in Marine Protected Areas. The estuarine gillnet fishery (operating out of Olifants Estuary) will be phased out over a 5 to 10 year period. Preceeding the 2001 medium-term allocation process, approximately 6000 t of fish was landed per annum, of which only 1 400 t were reported. Less than 8% of the permit-holders were full-time netfishers, acquiring more 50% of their income from the fishery. The primary target species, the haarder is currently over-exploited and the export market for the secondary target species, St Joseph shark, has collapsed (MCM : DEAT, 2005b).

A substantial illegal gillnet fishery exists directed at high value species throughout the West, South and East Coast. The illegal gillnetting on the West Coast is directed at galjoen (*Dichistius capensis*) and smoothhound sharks amongst others. Illegal gillnet fisheries on the south and east coast is mainly confined to estuaries.

Lamberth (2006) examined the sharks and rays caught in 11400 beach-seine hauls in False Bay. *M. mustelus* represented 12.5% of overall shark catch with an average of 4 smoothhounds per haul. Although smoothhound shark catches represented only 0.2 % of overall catch, the gillnets used on the Western Cape coast have a larger mesh-size than average (de Goede *pers comm.*, MCM : DEAT), therefore their potential for catching sharks are increased. High numbers of gill-nets in Langebaan Lagoon may considerably threaten the smoothhound shark stock if Langebaan Lagoon is a nursery area as suspected.

Prior the allocation of rights in 2001, the fishery consisted of 147 beach-seine and 293 gillnet permits between Port Nolloth and Nature's Valley. The total allowable effort

(TAE) was accordingly set to 58 beach-seine rights and 162 gillnets. The main goal 2005 the draft policy for the allocation and management of the fishery is to manage the fishery to ensure the long-term sustainability of the main target species. The existence of the illegal gillnet fishery is further substantiated with the fact that little shark from the Western Cape coast enters the two processing factories in Western Cape Province. A gillnet shark processing factory is reported to occur in Elands Bay (Sauer, *pers comm.*, Rhodes University, 2007; Brandt, *pers comm.*, Selecta Fishing, Shark buyer, 2007). Some sharks are also processed in a factory in Saldanha Bay.

General background to the shark fishery

There is a distinct difference between the south-eastern and south-western Cape fisheries, and the West Coast. Sharks are landed in Port Elizabeth, Mossel Bay, Vlees Bay, Struis Bay, Gans Bay, Hout Bay and False Bay. The fishery on the south-eastern Cape coast focuses on edible species such as the two smoothhound species (*Mustelus mustelus* and *M. palumbes*), soupfin sharks (*Galeorhinus galeus*), bronze whalers (*Carcharhinus brachyurus*), dusky sharks (*C. obscurus*), and hammerheads (*Sphyrna zygaena* but occasionally be *S. lewini*). Bronze whalers and dusky sharks are both referred to as bronzies and are combined as *Carcharhinus* spp. As few sharks are caught past Hout Bay, the Western Cape coast was not be covered in this chapter, except for the gillnet fishery.

Spotted gully sharks (*T. megalopterus*), if of small size, and both the smoothhound species mentioned above are processed as gummy sharks (*Mustelus* spp.). Bronze whalers (*C. brachyurus*), duskies (*C. obscurus*) and black tip sharks (*C. limbatus*) are all processed and sold under bronzies. Blue sharks (*Prionace glauca*), and mako sharks (*Isurus oxyrhincus*) make up a small percentage of sharks processed.

Sharks bought from fishermen fall into three general categories, "good", "bad" and "big". "Good" sharks are smoothhound sharks, bronze whalers and soupfin sharks and are named because of their high value flesh. "Bad" sharks are those whose flesh have a lower value and are larger spotted gully sharks, hammerhead sharks and blue sharks. The term "bad shark" is also used with regards to quality, in which three different quality grades are given. Many different factors influence the quality of the animals. These factors are mainly concerned with initial cleaning of the animals. For quality produce sharks should immediately (or within two to three days if refrigerated and or small size) be headed, eviscerated and exsanguinated after capture. This product, the dressed carcass, is referred to as a "log". Following this, logs should be kept in a freezer or on ice. "Big sharks" refers mainly to the mercury content from different species of sharks. Some species have smaller mercury content at a larger size than others. These are bought at larger sizes. Soupfin sharks and bronze whaler sharks are bought from 1.5 to 12 kg. The mercury content in animals above 12kg is too high to be edible. Smoothhound sharks however get a higher price for animals below 12 kg, although animals above 12 kg are also bought at lower prices. The problem with large smoothhound sharks (+12kg) however is with regards to the fillet. The flesh from large smoothhounds shrinks when filleted and portioned, and flake when defrosted. This immediately lowers the quality to grade two or three. Most factories on the south-eastern Cape coast act as holding facilities. Sharks are sent or collected by the companies that process and export the sharks.

Handling of the carcass after capture is of primary importance. Sharks should not be picked up by their tails as this tends to tear the abdominal musculature. This damage immediately lowers the quality of the meat. Smoothhounds often fall into this category because according to the shark processors, the meat is almost as delicate as hake, and rough treatment causes the flesh to become flaky. A major problem with the capture of smoothhounds is that when they are caught over rocky areas the gall bladder frequently bursts and spoils the meat. They are than sold as second grade meat. This problem has not been observed for smoothhounds caught over sandy areas.

Although other companies may on occasion export sharks, three companies are responsible for the processing and export of sharks. These are Fishermen Fresh based in Port Elizabeth and Sharkex Viking, which are based in Cape Town.

The fishery on the south-western Cape coast concentrates mainly on blue sharks and mako sharks. Some teleosts are also processed. These blue and mako sharks are caught at larger sizes and are mainly used for their fins, which unlike the small edibles are sold as sets and reach high prices on Asian markets. In an interview with one of the shark exporters, it was confirmed that on average 14-day trip four to five tons of pelagic shark are caught. Although little processing of smoothhounds occur, interest has been shown by some of the factories to expand into this market, i.e., the Indo-Atlantic group is interested in starting a fish sticks and dried fish patty factory in Hout Bay. Pelagic shark species are used in the manufacture of fish biltong (dried fish sticks) (DeepBlue fish biltong) (R240-R300 per kg). The flesh of these pelagic species is exported especially to Asian markets where they are sold as *sokomoro* (mako sharks) and *moro* (blue shark).

Processing factories and regulation issues

The *Marine Living Resources Act 18 of 1998* regulates all fisheries in South Africa, including aspects of processing, sale and trade of almost all marine resources (Da Silva & Bürgener, 2007). Sharks may not in terms of this *Act* be landed, transported, transhipped or disposed with their fins removed without the authority of a permit (Da Silva & Bürgener, 2007). Within the terms of this *Act*, no person may operate a fish-processing establishment without authorisation (Da Silva & Bürgener, 2007). The *Act* defines fish processing establishments as "… any vehicle, vessel, premises or place where any substance or article is produced from fish by any method including the work of cutting up, dismembering, separating parts of, cleaning, sorting, lining and preserving of fish, or where fish are canned, packed, dried, gutted, salted, iced, chilled, frozen or otherwise processed for sale in or outside the territory of the Republic" (*Marine Living Resource Act 18 of* 1998, pg 9.). In terms of the *Act*, a holder of a commercial fishing permit may not deliver any fish or part thereof to any person for processing purposes without authorisation, and a commercial rights holder is prohibited from marketing any fish or any part thereof, unless packed in accordance with the approved stipulations of the South African Bureau of Standards (SABS) (Da Silva & Bürgener, 2007).

In terms of this study, a processing facility was defined as any premise where shark logs are filleted, and fins are removed for export purposes. Shark processing factories given above are divided into three sections; the pre-processing section, filleting section and packing section in which an average of 10 people work. Logs entering the facility are weighed and taken to the pre-processing section where animals are sorted according to species and sometimes size. At this stage, dorsal, pectoral and caudal fins are removed and placed into separate bins according to both quality and quality (carcharhinid shark fins are more valuable than triakids). Belly flaps are removed for domestic sale by factory workers. Sharks are then moved to the second section where anal fins, skin, vertebrae and fillets are removed. These fillets are moved to the third section where fillets are cut according to the "Gummy", "Bronzy", and "Vaalhaai" categories mentioned above according to the sizes small, medium, and large.

3.2 Materials and Methods

General sampling at shark processing factories

Fish factories and processing units were visited and contacted in 2005 to determine which process sharks and to distinguish between those that serve as holding facilities and those that continually process and export sharks. Factories that were willing to participate in vertebrae and data collection were identified. As all other Eastern Cape factories were identified as holding facilities for Fishermen Fresh, monthly samples from them were not required.

During the period from October 2005 to September 2006 monthly samples were taken from Fishermen Fresh (Port Elizabeth), Sharkex (Strand) and Selecta (Mitchell's Plain). In total, 2019 different sharks were measured, sexed and maturity determined whenever possible (1424 from Port Elizabeth, and 595 from the Southern Cape factories). Demersal shark processing factories process sharks on average one to two days a week. One day a month was selected, based on shark availability. All sharks processed during that day were identified, sexed, and all were measured. Maturity of males was assessed by clasper state, which was assigned a score of 1-3 based on length and clasper calcification; 1) juvenile sharks with soft claspers shorter than the pelvic fins, 2) maturing sharks with soft claspers longer than pelvic fins, and 3) mature males with calcified clasper fins longer than pelvic fins. As all sharks are eviscerated immediately after capture, female maturity could not be assessed. Sampling during some months was not possible due to bad weather conditions, broken vessels and conflict with fishermen.

Sampling was severely constrained by various factors, these initial reluctance of factories to give access, spontaneous nature of day selection for shark processing (staff rarely know a day in advance what will be processed the next day), poor communication from processing staff, distance and sea state. Species identification is significantly compromised for fisheries compliance officials because of the dressing of carcasses. A demersal shark log identification kit (see Chapter 2) was developed for commonly caught demersal sharks. These included *C. obscurus*, *C. limbatus*, *C. brachyurus*, *G. galeus*, *T. megalopterus*, *M. mustelus*, *M. palumbes*, *S. zygaena*, and *N. cepedianus*. This identification toolkit has the potential to greatly facilitate species identification of dressed sharks. Data for sharks collected in 2005 from Selecta in Mitchell's Plain was analysed to determine monthly trends in species composition of the whole fishery

Fishery validation

Estimating the reporting rate of the fisheries targeting smoothhound sharks and other demersal species is crucial for stock assessment. In general, catches reported by fishers are significantly lower than actual catches. Catches, therefore, need to be scaled up accordingly. Reporting rate was estimated by validation of linefish and trawl data, and by using samples taken at factories. Lack of data precluded longline validation from this study.

Linefish validation

Vessel specific linefish data collected from MCM was used to compare against purchase forms from a factory located in Gans Bay. Of the five vessels selected, one did not report catches from three months between 2005 and 2006. All others reported more than what was seen from purchase forms. This over-reporting rate could be explained by two scenarios. The first scenario is that the vessel moved from Gans Bay to other areas during this month. As catches were low for these vessels (< 500 kg) in this area this scenario is likely. The second scenario would be that the vessels are over-reporting in fear that if the government regulatory authorities believe that few sharks are being caught. Loopholes in existing permits allowing for the targeting of sharks would be removed. This is not likely as the reverse sentiment from fishers was experienced. Fishers did not want the exact extent of shark exploitation known for fear of restrictions from government regulatory authorities. It was therefore not possible to validate the linefish fishery because of this inconsistency in the data.

Trawl fishery validation

Similar data was collected from the industry for comparison with MCM data collected from logbooks. Of the 29 inshore trawl operators seven vessels were selected that catch a large proportion of smoothhound sharks as by-catch > 0.1 % of overall catch. All seven operators were either directly or indirectly owned by two of the demersal shark processing factories. Cumulatively the average percentage of smoothhound sharks caught as by-catch ranged from 0.64 % to 12.9%, ($\bar{x} = 3.9, \sigma = 3.0$). Although the average ($\bar{x} = 2.2, \sigma = 2.4$) of those operating on the Southern and south-western Cape coast (five vessels) was lower than those operating on the south-eastern Cape Coast (two vessels) ($\bar{x} = 5.7, \sigma = 2.5$). This high proportion of smoothhound sharks as by-catch suggests targeting of sharks. The ownership of trawl-vessels catching smoothhound sharks by shark processing factories severely restricted data integrity (no data inconsistencies could be found between MCM data and purchase sheets). As with linefish validation, data validation could not be completed for trawl data.

Reporting rate for combined fisheries using factory data

Demersal sharks are processed on average at factories once a week, which calculates 104 shark-processing days a year. A total number of 13 samples were taken at all processing facilities between mid 2005- mid 2006. Inverse variance weighted averages were calculated using the samples taken. This took into account the considerable uncertainty of factory data with regards to small numbers of samples. These inverse variance weighted averages were multiplied by the average number of smoothhounds observed per factory visit. This final figure was compared to catch estimates obtained from MCM: DEAT, to acquire reporting rates. This figure was used to estimate sharks processed in 2005. Although half the samples were taken in 2006, it was assumed that catches in 2005 and 2006 were similar.

Current actual catch was estimated at 1326.2 t, which was significantly higher than the 284.9 t reported by the line fish, longline and trawl fisheries for 2005. It is important to note that shark catches have increased exponentially from 1985-2003 with the increased importance associated with sharks. The reporting rate was therefore estimated at 21.48%.

Trawl extrapolation

The trawl fishery only reported smoothhound shark catches from 2004 to 2006. The proportion of smoothhound sharks as a fraction of total shark catches was calculated, and averaged out. This average was used to calculate smoothhound catches from 2000-2003. The average catch (t) from 2000 to 2002 was used for stock assessment in Chapter 5

Fishery-dependent and fishery–independent data

General catch trends

Fishery-dependent catch information was obtained from the commercial longline, inshore trawl and linefish databases at MCM. Fishery-dependent data for the gillnet fishery was obtained from the South Africa Bureau of Standards forms obtained from a factory in Saldanha bay that buy from this sector. Trends in weight of smoothhound sharks caught over time were determined by calculating the total weight of shark caught according to year. These catch trends were examined using scatterplots for the commercial linefish, demersal longline, trawl and gillnet for the years 1986-2006, 1992-2005, 2000-2006 and 2003-2005, respectively. Fishery-independent biomass indices were collected from the *RV Africana* by MCM from 1986-2003.

Catch per unit effort (CPUE)

According to Morgan & Burgess (2004), catch per unit effort (CPUE) is commonly used to assess temporal and regional tends in fish stock abundance. Catch was estimated by calculating the total weight of shark caught per year (t). Effort was calculated as man hours for line fishers, and number of hooks for longline fishers, and total fishing trips per vessel for trawlers. Effort data for the gillnet fishery could not be obtained. Trends in the weight of smoothhound sharks caught over time as a function of effort were determined by calculating the total weight (t) of shark caught per year for the total effort allocated per year. CPUE for the linefish fishery was calculated as the average total weight (kg) of "shark" caught as a ratio of total effort (man hours) for 1986-2006. CPUE for the longline fishery was calculated as the average total weight (kg) of "houndsharks" as a ratio of average effort (number of hooks) caught for the years 1992-2005. CPUE for the trawl fishery was calculated as the average total weight (kg) of smoothhound sharks per number of fishing days per vessel for the years 2000-2006.

A regression was fitted to the CPUE of the linefishery, the demersal longline fishery, and the trawl fishery. The slope was divided by the average value in the series to denote the percentage change over the years in question.

Socio-economic aspects governing the demersal shark fishery

General socio-economic aspects

A questionnaire (Appendix 1) was modified from Smith (2005) to include aspects of socio-economic contribution of sharks to South-African linefisheries. Data collected included, but was not limited to, information on vessels sizes, crew descriptions, ownership, employee descriptions and value of catch. A discrete descriptive economic analysis was completed to identify the role of shark fisheries in South Africa in terms of socio-economic importance.

Breakeven price

The breakeven price is calculated as $bp = \frac{\sum FishingCosts}{CPUE \times Effort}$. No fixed costs such as depreciation of vessels and gear were included. The break-even price was only used to provide a snapshot of the economic incentive relative to the ease at which an animal is captured in the linefishery, longline fishery and trawl fishery.

3.3 Results

General sampling at shark processing factories

A total of 2019 sharks were identified, measured, sexed and maturity assessed (seven samples in Port Elizabeth (1424) and seven samples in the south-western Cape factories (595)). Demersal shark species commonly observed in the Eastern Cape processing factories were *M. mustelus*, *G. galeus*, *C. obscurus*, *M. palumbes*, *C. brachyurus* and *S. zygaena.* These were caught in percentages of 49 %, 16 %, 12 %, 10 %, 8 %, and 5 %, respectively. Demersal shark species commonly observed in south-western Cape factories were *M. mustelus*, *G. galeus*, *C. brachyurus*, *C. obscurus*, *P. glauca*, *M. palumbes* and *N. cepedianus*. Percentages observed were 45 %, 23 %, 9 %, 9 %, 7 %, 6%, and 1%, respectively (Table. 3.1). There was no significant difference with regards to numbers, proportions, percentage males, length of females and males of *M. mustelus* between areas (for all $p > 0.05$). There was, however, a significant difference ($p < 0.05$) between catches (as observed in factories) of all demersal shark species between the Eastern and south-western Cape coasts.

Smoothhounds overall contributed to the majority of demersal sharks exported to Australia (Brandt, *pers comm.,* Selecta Fishing, Shark buyer). Market demands for "flake" (shark fillets) will increase targeting of smoothhound sharks and other demersal shark species caught. Results obtained from monthly sampling at processors show that smoothhound sharks are caught throughout the year (Table 3.2 and Fig 3.1).

Table 3.1 Percentages and standard deviations of demersal sharks commonly caught in the Eastern and Southern Cape coast from daily factory sampling trips split into species to highlight the importance of *M. mustelus* to the demersal shark fishery.

Species	Eastern Cape	Standard deviation	Southern Cape coast	Standard deviation
M.mustelus	0.48	0.25	0.44	0.50
C. brachyurus	0.08	0.07	0.09	0.30
C.obscurus	0.12	0.10	0.07	0.30
G.galeus	0.16	0.12	0.23	0.42
M. palumbes	0.10	0.09	0.06	0.24
S.zygaena	0.04	0.04	0.01	0.07
T.megalopterus	0.01	0.01	<0.01	0.04
C.limbatus	0.01	< 0.01	0	0
P.glauca	0	0	0.07	0.26
I.oxyrinchus	< 0.01	< 0.01	0	0
C.taurus	<0.01	< 0.01	0	0
N. cepedianus	0	0	0.01	0.04
A. vulpinus	0	0	<0.01	0.12

Table 3.2 shows *M. mustelus* processed daily in the Eastern and south-western Cape coast factories. Of the smoothhounds observed, 42 % were males, of which, 36% were sexually mature.

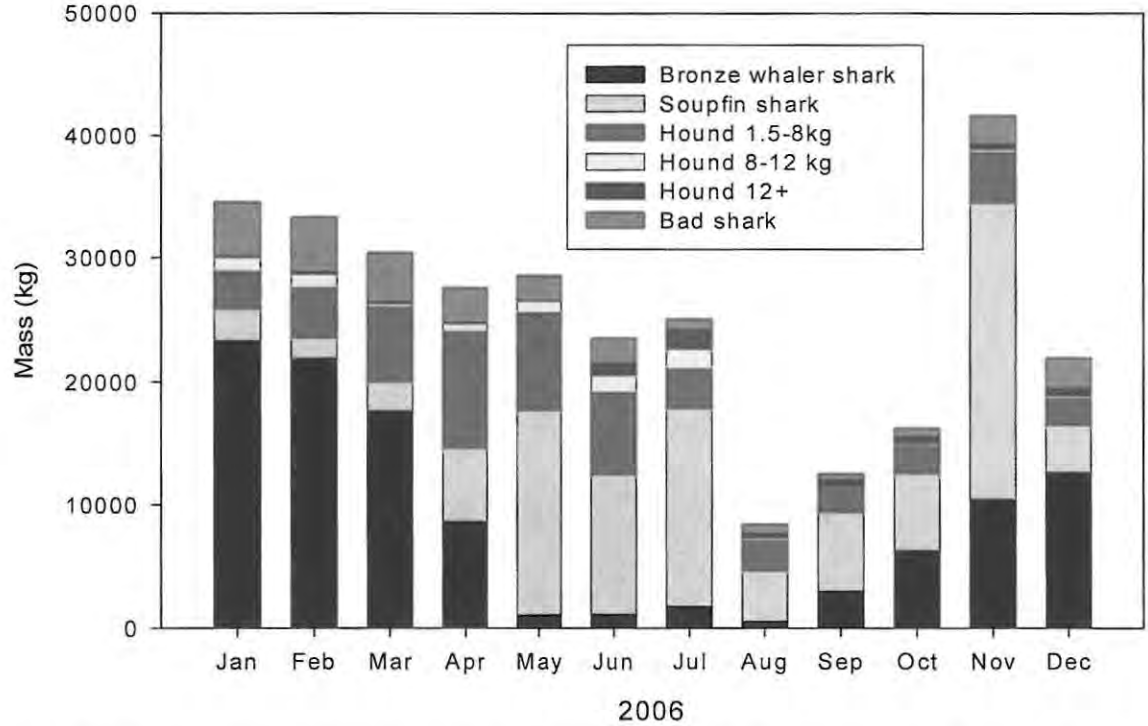


Figure 3.1 Processed shark from Selecta (Viking) based for 2006, for the categories bronze whaler (*C. limbatus, C. obscurus* and *C. brachyurus*), hound shark (*M. mustelus* and *M. palumbes*), Soupfin shark (*G. galeus*), and bad shark (*Sphyrna spp., I. oxyrinchus*, and *P. glauca*)

Table. 3.2 Summarized *M. mustelus* processed daily in the Eastern and south-western Cape coasts. Due to dressing, log lengths are taken from dorsal origin to caudal tip, standard deviations shown in parentheses

		Nr. *M. mustelus* processed	Average proportions of total sharks processed	Average proportion male maturity	Average length of females (mm) (DOCL)	Average length of males (mm) (DOCL)	Proportion males
Eastern Cape coast	Summer	422 (48.2)	0.56 (54.3)	0.61 (31.8)	76 (8.0)	80 (5.4)	0.60 (13.8)
	Winter	257 (75.2)	0.47 (20.1)	0.51 (14.1)	71 (5.3)	76 (7.0)	0.46 (20.8)
south-west Cape coast	Summer	9 (3.6)	0.8 (2.9)	0 (0)	75 (3.9)	36 (50.5)	0.08 (50.5)
	Winter	246 (84.1)	0.23 (3.5)	0 (0)	70 (10.7)	62 (3.9)	0.54 (22.9)

3.4 Data analysis

Testing for database accuracy with the use of factory samples

According to Wilke (MCM, *pers comm.*, 2005), inaccuracies exist within the commercial linefish and demersal longline fisheries. These are similar those found by McCord (2005) with regards to the South Africa soupfin fishing industry. These inaccuracies make data analysis and associated stock assessment difficult.

An investigation into data integrity was conducted prior to the data analysis. This investigation included an examination of catch records to determine possible inaccuracies between various data. Little data were available for *M. mustelus* in the linefish database and catches reported per year were often less than a 1 t, which is extremely low for smoothhound catches per year. Samples taken at factories (Table 3.1) show that *M. mustelus* are caught in higher concentrations than any other demersal shark species for all years and within years. All other commonly caught demersal shark species were listed in adequate proportions except for the record "sharks". Accuracy testing was completed by paired t-tests of proportions (after arcsin transformation of the data) of "sharks" from the linefish database and proportions of smoothhounds seen in various factories. The commercial linefish database was adjusted and the record "sharks" was taken as smoothhound sharks. The record "houndshark" was not used, nor incorporated in "sharks".

According to both Brand (*pers comm.,* Selecta fishing; shark buyer, 2006), and Kroese *et al.* (1995), when catches of high value teleosts decline effort is shifted towards demersal sharks. Therefore a negative relationship should be observed between weight of linefish caught per boat and weight of high value teleosts. The existence of a negative relationship between "sharks" as smoothhound sharks and high value teleosts (snoek, kob and geelbek) was tested by looking statistically assessing their correlation coefficients.

No significant differences ($p < 0.05$) were found between "sharks" as smoothhound sharks and proportions of smoothhounds observed in factories between all years. But when the test was completed for years independently, the years 1989-1996 were similar. Correlation coefficients between high value teleosts and smoothhound sharks showed no significant relationships ($p > 0.05$).

Suspect data such as the "houndshark" (due to low occurrence when compared to factory data) record in the commercial linefish database was not used and the record "sharks" was used to represent smoothhound sharks instead.

Data analysis was completed for the commercial linefish and demersal longline fisheries described above and in detail in Chapters 3, 4 and 6. Analyses of these data were based on the vessel-based commercial linefish and demersal longline fisheries, and were used to calculate yearly and overall catch trends. Analysis of the fishery-independent survey data were based on biological and catch information gathered aboard survey biomass estimate trawls aboard the *RV Africana*. These data were used to calculate yearly catch trends and for estimating biological parameters of *M. mustelus*. Analysis of these data was described in detail in Chapters 3, 4, 5 and 6.

General catch trends

Catch trends for smoothhound sharks in the commercial line, and demersal shark longline fisheries the years 1986-2006 and 1992-2004, respectively, are shown in Figure 3.2. for Catch trends for *M. mustelus* in the inshore trawl and gillnet are shown in Fig 3.3. Catch trends for the research surveys are shown in Fig. 3.4.

Table 3.2 illustrates that the recorded catches in the commercial line fisheries where the highest in 1994 at 1313 t and lowest in 1986 at 262.8 t. From 1986 to 2006 (end of September) catches of *M. mustelus* have increased from 262.8 to 387.0 t (Fig 3.2). Recorded catches in the demersal shark longline fishery were highest in 2000 at 248 t, lowest in 1997 at 0.09 t and not recorded in 1992, 1993, 2003 or 2005 (Fig 3.2). Catch trends observed in the gillnet fishery during the period 2003-2005 were highest beginning of 2005, and lowest before 2004 (Fig 3.3). Two peaks were observed in November 2004 (36.2 t) and June 2005 (53.5 t). Recorded catches in the trawl fishery were lowest in 2000 (113.8 t), peaked in 2005 (269.4 t), and decreased rapidly in 2006 as data was only collected up to September (154 t) (Fig 3.3).

Table 3.3 Catch trends shown by the linefishery, demersal longline fishery, gillnet data and inshore trawl fishery from 1986 to 2006, records represented by a dash denote that data were unavailable. Catches were adjusted by assuming a reporting rate of 21.8%.

Year	Line fishery (t)	Longline fishery (t)	Gillnet fishery (t)	Inshore trawl fishery (t)
1986	262.82	-	-	-
1987	274.01	-	-	-
1988	366.28	-	-	-
1989	362.55	-	-	-
1990	393.78	-	-	-
1991	741.41	-	-	-
1992	980.00	-	-	-
1993	1079.00	-	-	-
1994	1313.19	0.37	-	-
1995	704.13	5.31	-	-
1996	667.78	0.16	-	-
1997	1138.44	0.09	-	-
1998	1120.73	32.94	-	-
1999	1141.23	126.34	-	-
2000	976.74	248.81	-	113.75
2001	591.70	22.01	-	107.15
2002	608.58	7.00	-	173.83
2003	693.38	-	1.2	221.40
2004	1059.10	24.28	45.16	253.57
2005	702.36	-	68.07	269.36
2006	386.97	-	-	154.45

Relative survey biomass indices for the fishery independent research surveys were taken along the Western and Southern Cape coast between 1986 and 2003 (Fig 3.4). Indices based on trawl catches were lower on the West Coast than on the Southern Cape coast (Fig 3.4). Indices on the West Coast were highest in 1999 at 3 357 kg and lowest in 1990 at 1 259 kg and not recorded in 1998 and between 2000 and 2001. On the South Coast, the highest survey biomass indices were seen in 1990 at 24 374 t and lowest in 1997 at 3 124 t. Indices for the South Coast were not estimated in 1998 or between 2000 and 2003, as vessels were not operational due to lack of funding or repairs. Survey biomass indices for the South Coast showed a clear decline in trend from 1986 to 2003. The survey biomass indices for *Mustelus* spp increased from 1984 to 1994 and decreased to levels similar to indices observed prior to 1994.

Catch per unit effort

CPUE for the commercial line, demersal longline fisheries for the years 1986-2006 (until September) and 1992-2004, respectively, are shown in Figure 3.2. CPUE for the commercial line fishery was highest in 1994 at 0.79 kg .man hour^{-1} and lowest in 1987 at 0.017 kg.man hour^{-1}. From 1986 –2006 (September) CPUE increased from 0.019 kg.man hour^{-1} to 0.053 kg.man hour^{-1} showing a change of 4.00 %. CPUE for the demersal shark longline fishery was highest in 2000 at 0.163 kg.hook hour^{-1} and not recorded in 1992, 1993, 2003 and 2005. A general increase in CPUE is seen from 1996-2005 with a change estimated at 6.00 %. CPUE for the trawl fishery increased dramatically from 2000 to 2006 showing a change of 12.75%. CPUE was significantly higher in 2006 than 2005. Data from 2006 were only collected up to September, *Mustelus* spp are predominantly caught in the colder months as shown in Fig 3.3, therefore, the increase of CPUE in 2006 is an artifact of bias in sampling. This resulted in a higher CPUE in 2006 than 2005.

Socio-economic aspects governing the demersal shark fishery

Thirty-one different fishermen in three towns known for shark fishing completed the questionnaire modified from Smith (2005) and one fisher was questioned twice. The majority of the boats interviewed had commercial permits (61%), followed by recreational fishing permits (36%), than charter companies with associated permits (3%). Vessel types commonly used listed from most to least common were deckboats (*chukkies*) (61%), skiboats (33%) and inflateable boats (6%). The level of monitoring per catch estimated by the fishers was fairly high at 67%. This was not surprising as monitoring officials where based near slipways at two of the three towns sampled. The employment characteristics of the fishing boats interviewed showed 78% of the fishermen depended on fishing for 100% of their income. In total, 28% of the skipper's monthly salary ranged between R5 001.00 and R10 000.00 or were pensioners, 11% received salaries between R15 001.00 and R25 000.00, and lastly 6% received monthly salaries over R25 000.00 and between R 2 001.00 and R 5 000.00.

Table 3.4 shows a breakdown of the average expenses experienced by individual fishers/vessels participating in each fishery. These were used to calculate the breakeven price at R2.30, R 5.1 and <R1.00 for the line, trawl and longline fisheries, respectively.

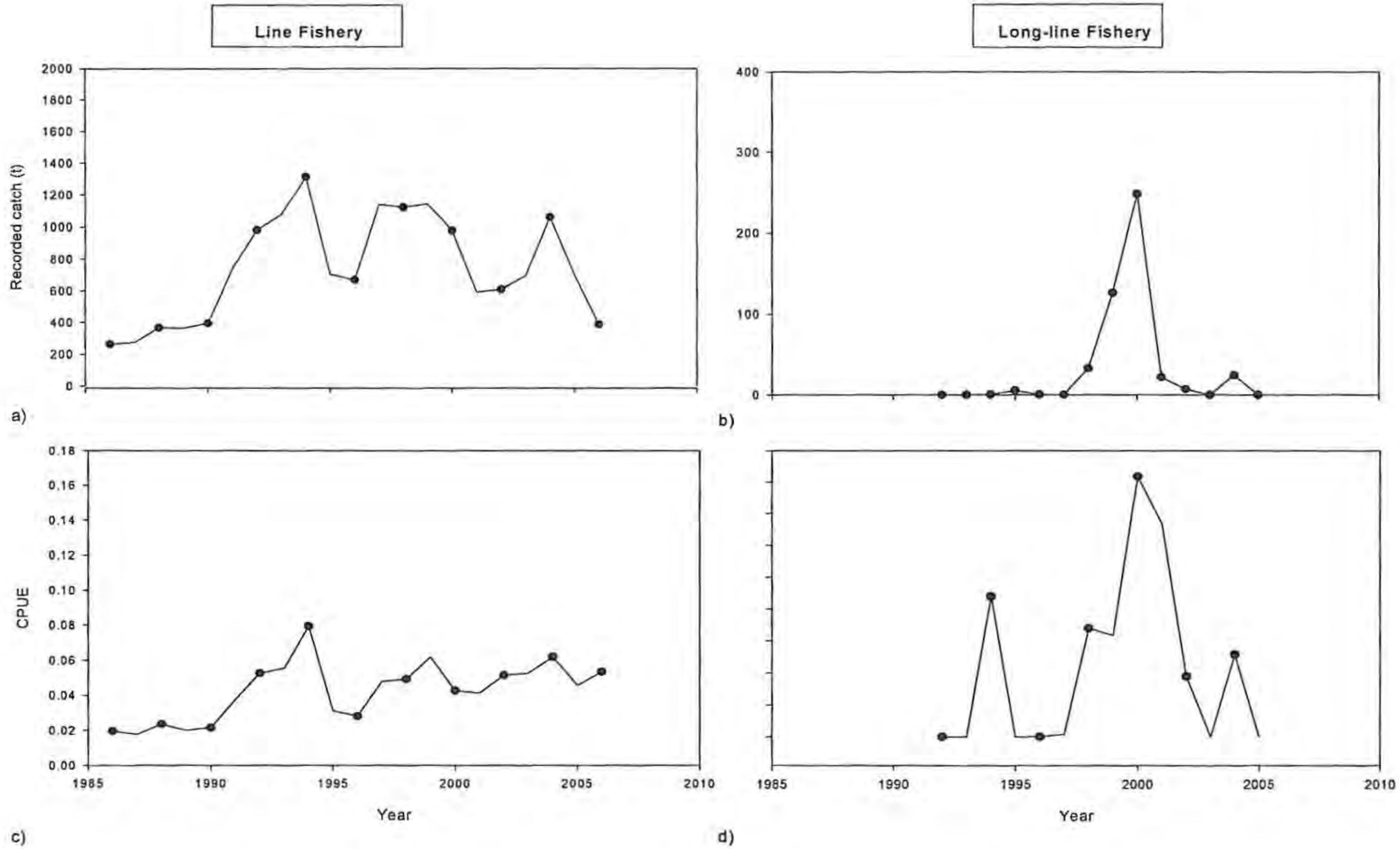


Fig 3.2 Trends in recorded catches (kg) of smoothhound sharks (*Mustelus* spp) for the a) line fishery (1986-2006), b) demersal longline fishery (1992-2003), CPUE trends of smoothhound sharks for the c) line fishery (1986-2006), d) demersal longline fishery (1992-2003). CPUE is calculated as the average catch (kg) per man hour^{-1} for the line fishery and average catch (kg) per hook hour^{-1}

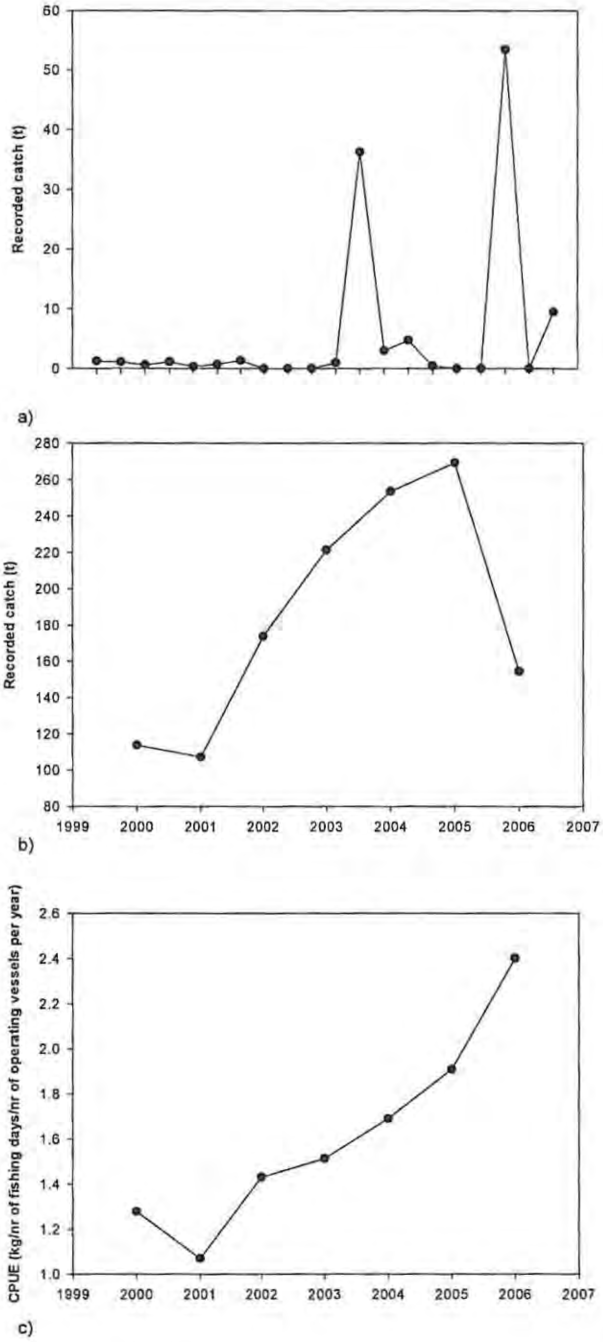


Fig 3.3 Trends in recorded catches (t) of smoothhound sharks (*Mustelus* spp) for the a) gillnet fishery (end 2003-mid 2005), b) inshore trawl fishery (2000-2006), CPUE trends of smoothhound sharks for the c) trawl fishery (2000-2006), CPUE is calculated as the average catch (kg) per number of fishing days per number of vessels operating per year

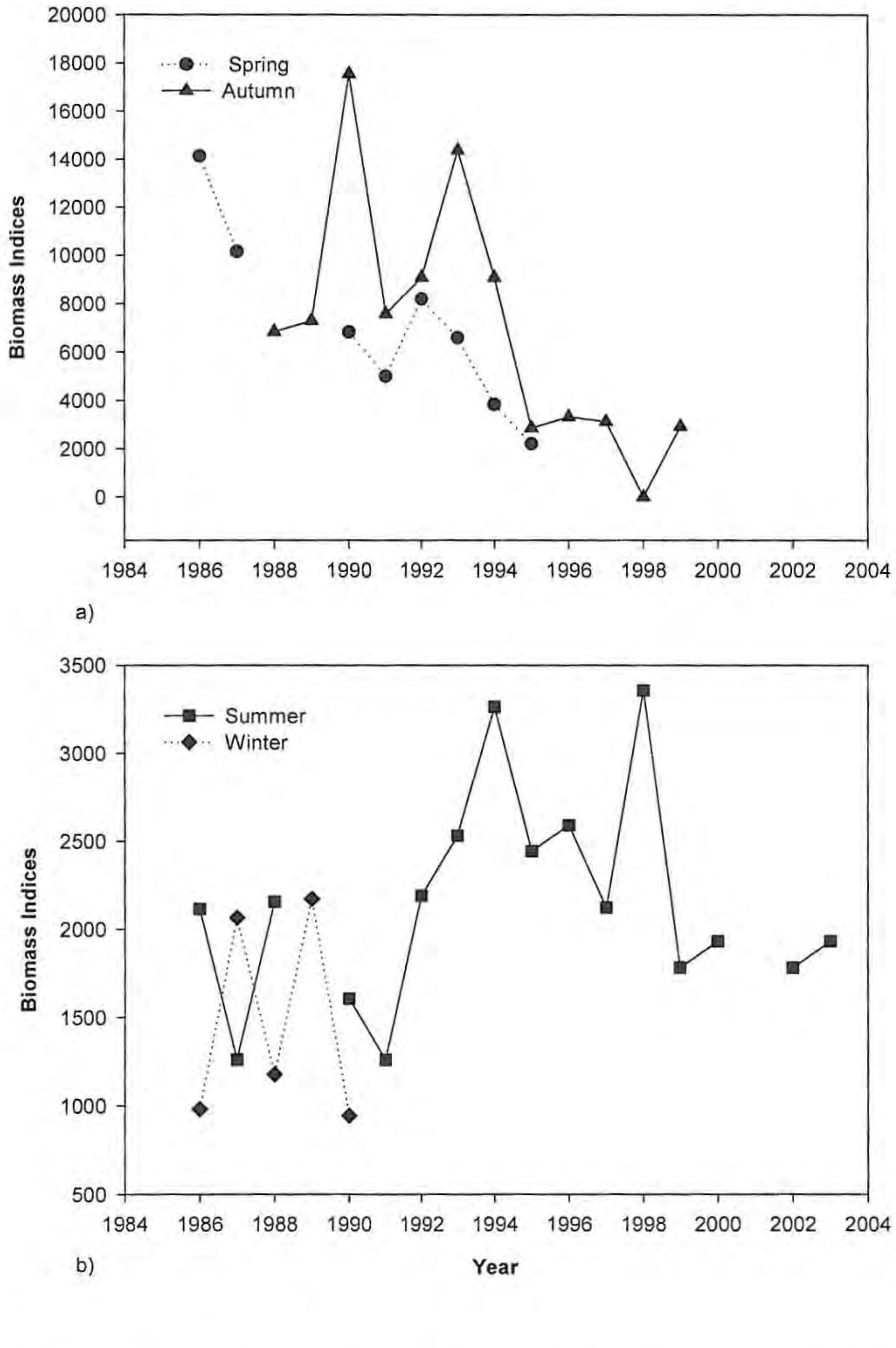


Fig 3.4 Resarch survey relative biomass indices of *Mustelus* spp from the a) South and b) West Coasts of South Africa

Table 3.4 Common yearly expenses experienced by line fishers (as determined by 33 fishers) (socio-economic questionnaires), the trawl fishery (as determined by 31 vessels) (Sauer *et al.*, 2003), and the longline fishery (as determined by 12 fishers) (Sauer *et al.*, 2003). No data for standard deviation is available for the trawl and longline fishery.

Linefishery	
Expenses	Average Yearly Costs
Fuel and lubricant costs	R 62 486 (σ = 50,573.4)
Statutory costs	R 3 834 (σ = 5,472.8)
Provisions and store costs	R 187 (σ = 681.0)
Insurance costs	R 3 976 (σ = 5,317.0)
Repair / Maintenance costs	R 15 449, (σ = 19,366.0)
Gear replacement costs	R 3 384 (σ = 9079))
Bait costs	R 32 959 (σ = 34, 028.0)
Trawlfishery	
Expenses	Average Yearly Costs
Fuel and lubricant costs	R 1 427 073
Harbour fees/ Charges	R 28 809
Insurance costs	R 433 419
License fees	R 1 851
Taxes levies	R 223 559
Repair / Maintenance costs	R 466 421
Biannual slipping/ refit costs	R 539 993
Gear replacement costs	R 315 453
Provisions and store costs	R 189 291
Wages	R 1 605 524
Longline fishery	
Expenses	Average Yearly Costs
Fuel and lubricant costs	R 209 998
Harbour fees/ Charges	R 3 599
Insurance costs	R 67 382
Licence fees	R 1 326
Taxes levies	R 27 595
Repair / Maintenance costs	R 130 002
Communications	R 14 207
Gear replacement costs	R 244 507
Provisions and store costs	R 164 503
Wages	R 899 332

Average beach prices in relation to demersal shark species are shown in Fig 3.5. Carcharhinids command higher prices on average than other demersal species followed by *M. mustelus*, *G. galeus*, *T. megalopterus*, *N. cepedianus* and *Sphyrna* spp. These beach prices however fluctuate with location, with Mossel Bay paying considerably higher for high-value elasmobranchs than Gans Bay and St. Francis Bay (Table 3.5). This higher price is due to Selecta being a subsidiary factory of Viking Fishing based in Mossel Bay. Of the 33 fishers interviewed elasmobranchs accounted for 23% of their yearly income, *M. mustelus* accounted for 8 %. As a percentage of shark catches, *G. galeus* comprised 41%, followed by *M. mustelus* (36%), *C. brachyurus* (20%), *N. cepedianus* (1%), *Sphyrna* spp. (1%). There was high variability. The first 18 socio-economic questionnaires showed *M. mustelus* as contributing 57% of the catch, closely followed by *C. brachyurus* (47%) then *G. galeus* (1%).

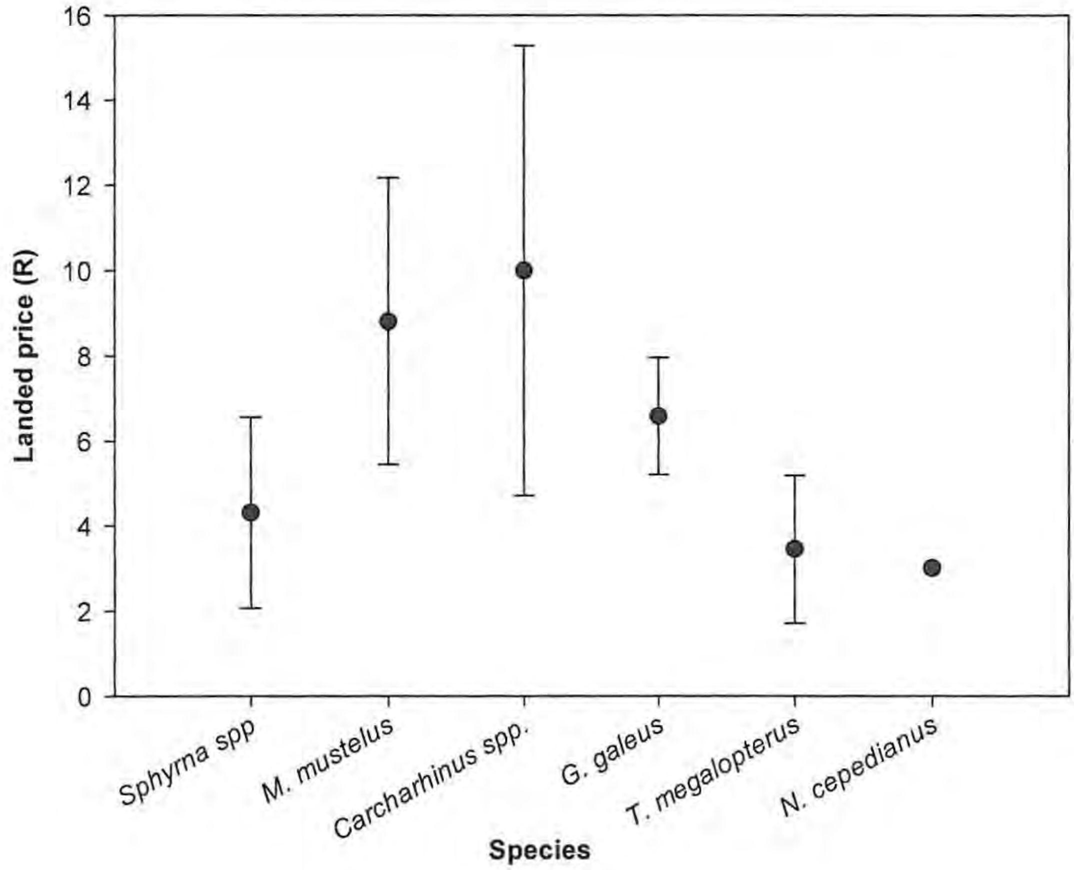


Fig 3.5 Landed price of various commercially important demersal species (logs)

Table 3.5 Landed price of demersal shark logs (and standard deviation) paid to fishermen per species in Gans Bay, Mossel Bay and St Francis Bay.

Price per town Species	Gans Bay	Mossel Bay	St Francis Bay
G.galeus	R 6.00 (-)	R.6.60 (1.54)	R 6.80 (1.62)
M.mustelus	R 6.00 (-)	R 11.00 (3.00)	R 6.50 (1.74)
Carcharhinus	R 6.00 (-)	R 11.00 (4.82)	R 6.5 (1.72)
T.megalopterus	R 6.00 (-)	R 2.00 (0)	R 3.70 (1.51)
Sphyrna spp.	R 6.00 (-)	R 2.20 (0.31)	R 5.30 (2.51)
C. limbatus	R 6.00 (-)	R 2.00 (0)	R 5.00 (0)

3.5 Discussion

Catch trends provide a useful tool for scientists and fisheries managers as it allows for the analysis of population abundance over time. Catch trends measured by CPUE may, however, be misleading as a measure of abundance, especially if catch composition is affected by market forces (through targeting and discarding). CPUE information is nevertheless important in multi-species fisheries where little other accurate data are available (Morgan & Burgess 2004). Catch trends enable the facilitation of decisions regarding catch quotas and permit allocations where more complex statistical analysis may not be possible (Morgan & Burgess, 2004).

Whilst a decline in CPUE over time is usually indicative of a declining stock, the reverse is not necessarily true, as an increase in CPUE may not indicate an increase in stock abundance but show increased targeting.

Hillborn & Walters (1992) attributes this uncertainty to the relationship between CPUE and abundance, which can have at least two other forms than a linear form; either hyperdepletion or hyperstability. Hyperdepletion occurs when the stock abundance decreases at a much slower rate than the CPUE, consequently the CPUE indicator designate that stock abundance is low when it is still high. Hyperstability occurs when stock abundance falls more rapidly than the CPUE index and stock abundance is shown as high when it is in fact heavily overexploited (Morgan & Burgess, 2004). These states may be attributed to technological advances in fishing gear, fishery shift towards areas of greater productivity and advancement in fishing efficiency of crew (Morgan & Burgess, 2004).

Fishery-dependent data should always be interpreted with a degree of caution. The analysis of the catch trends and CPUE data both indicate that the catch data for smoothhound sharks is inadequate mainly due to missing data for several years and species misidentification. The inadequacy of data is attributed to several factors. First the lack of validation of fisheries data encompass all unidentified errors in catch records such as under-reporting as fishery-dependent data is provided by fishermen via catch sheets. Actual rates of reporting were estimated for the demersal shark fishery was estimated as 21.48% , although it is suspected that linefishers report a larger portion of catches and that reporting rate is dragged down due to addition of linefish data with that of the trawl fishery. Second, the absence of compliance and monitoring in the linefish and demersal longline fishery may facilitate underreporting, discards of unwanted catches, deliberate misidentification of valuable but banned species, and unreporting catches (especially in the demersal longline fishery). Third, the inability to accurately identify dressed sharks forces fishery managers to use aggregated shark data for analyses. Fourth, the lack of historical data in the demersal longline fishery means that long-term trends in catches can not be calculated.

Analysis of the linefish fishery from 1986 to 2006 indicates that both the catch and CPUE are increasing. The deterioration of high value teleost stocks (Griffiths, 1997; Hutton *et al.*, 2001) has led to an increased popularity of sharks as an economically viable alternative. This has resulted in higher numbers of sharks caught. Smoothhound are abundant and easily caught and comprise the bulk of these numbers. The increase in CPUE is attributed to the increased economic value associated with shark fillets, as more fishers are now actively targeting elasmobranchs due to their increased market value (Fouché, *pers comm.*, Sharkex: Factory owner, 2005.). This has resulted in an increase in fishing pressure not an increase in smoothhound shark stocks. The collapse of the Australian soupfin shark in 1991 (McGregor, 1991) led to increased levels of import from New Zealand to sustain high consumer demand for shark fillets. As the New Zealand shark fisheries (which were in a state of collapsing) are struggling to keep up with demand pressure for larger numbers of *G. galeus* and *Mustelus* spp. from South Africa is increasing. This increased demand explains the explosion of the catch trends observed in Fig 3.1 after 1991.

The demersal shark longline fishery is still in its infancy. It has been in a developmental phase since its introduction as a viable shark fishing method. Every couple of years misidentification of export species have resulted in complete shutting down of the industry. Catches are low, with a peak in 2000, catches increased from zero in 1997 to 53 t in 2000. The history of the fishery is punctuated with confrontations between South African processing units and major shark buyers in Australia. Initially low process quality was caused by the misidentification of dressed sharks (due to pre-processing of sharks on-board by fishermen and the inability of fishers/factory owners to identify sharks). Fillets were consequently mislabeled according to species by shark processing facilities in South Africa and poor quality fillets due to mishandling were exported. These factors resulted in Australian buyers refusing to purchase demersal sharks including smoothhounds from South Africa. Recently, however, identification of logs and quality control of fillets have improved significantly. Intensive training by processing factory shark buyers has led to increased trust regarding identification in shark fillets originating from South African processing facilities. This combined with increased economical value for sharks will improve catches. CPUE in the demersal shark fishery has increased from 1992 to 2005.

The trawl fishery catches from 2000 to 2006 have increased. After 2005 catches decreased, whilst CPUE increased. The majority of the smoothhound discards originate from this sector, although difficult to quantify undersize sharks are often caught (Fouché, *pers* comm., Sharkex, Factory owner, 2007). Fouché (*pers comm*, 2007) reported undersized sharks from a trawling vessel in March 2007 where 29% of the overall catch were undersized and were discarded. He further reported that this was a common occurrence within the industry. Discards are not a common phenomenon in the line fishery (as unwanted sharks are released live), and impossible to quantify on the longline vessels.

The socio-economic questionnaires showed that elasmobranchs contribute a significant economic benefit to fishers. Smoothhound sharks and soupfin sharks contribute the largest portion of the shark catch. The breakeven price for the linefishery, trawl fishery, and longline fishery was R2.30, R5.10, and R 0.86, respectively. All of these were lower than average beach prices (R5 - R8). This indicates that given the ease at which smoothhound sharks are caught. This breakeven price is lower than for teleosts, and shows the incentives for fishermen to increasingly target sharks with decreasing teleost catches. There are few restrictions in place with regard to the shark fishery. Only restrictions in place are with regards to certain species that are not permitted (*C. carcharius*, *C. taurus*, and various scyliorhinid catsharks), and finning (fins landed with trunks). Fishing effort is difficult to estimate in multi-species fisheries such as the shark fishery as sharks are primarily targeted in absence of high value teleosts (Morgan, 2004). Several recommendations were made by McCord (2005) regarding the development of the shark fishery in South Africa. Her first recommendation was for the development of a dedicated chondrichthyan database at MCM that houses all fishery-dependent and fishery-independent catch and effort data. She then recommended that validation should be completed through observer coverage monitored and funded by MCM. Lastly, she recommendation that there be dedicated fishery-independent sampling with regards to sharks allowing for comparison with fishery-dependent data thereby increasing data reliability.

CHAPTER 4

ASPECTS OF THE BIOLOGY OF THE SMOOTHHOUND SHARK, *MUSTELUS MUSTELUS*, IN SOUTH AFRICA

4.1 Introduction

Biological studies that include the estimation of growth, maturity, reproductive seasonality and natural mortality provide important management information. The ability to accurately determine age, and hence calculate growth, is of particular importance as it lays the foundation for management based quantitative stock assessment methods (Kanyerere *et al.*, 2005). In effect, the accurate determination of age allows for the estimation of various time-based rates such as growth, maturation and mortality rates (Beamish & Fournier, 1981). Similarly, estimates of maturity and mortality are vital as they provide estimates of whether animals are caught before they have had the time to reproduce, this is especially important for longer lived animals. These life history parameters have also been used to estimate rebound potential of exploited stock of elasmobranches (Smith *et al.* 1998)

Age in elasmobranchs is usually determined by examining vertebrae. Growth studies assume that vertebral bands are of an accurate indicator of age, and few have validated the temporal periodicity of band deposition and validated the absolute age. Growth can be categorized into the terms validation and verification and the distinction between the two is important. The validation of absolute age must prove the consistency of the marks formed per year, proving the accuracy of age estimates with determinate methods. Verification confirms age estimates by comparison with other indeterminate methods (Branstetter, 1987; Cailliet *et al.*, 1983; Cailliet, 1990; Campana *et al.*, 2002; Natanson *et al.*, 2002).

This study investigates aspects of the biology of the smoothhound shark including age and growth using sectioned vertebrae, sexual maturity, lengths at capture, and mortality, on the south-eastern and south-western Cape coasts of South Africa. This data will be used to elucidate stock structure for the development of a preliminary management plan.

4.2 Materials and Methods

General sampling

Two sources of vertebrae were used for age and growth determination. The first sample of vertebrae (n = 223) were pre-collected by Goosen & Smale (1997) and re-analysed by Bennet (2004) from Mossel Bay to Port Elizabeth, South Africa between December 1983 to July 1991. The second sample (n = 500) were collected as part of this study, which ranged between the south-western Cape coast factory situated in Strand (Sharkex) with sharks predominantly caught in False Bay (2006).

Due to dressed state of sharks, lengths differed between the two samples; precaudal and total lengths for first sample, and dorsal origin to caudal tip and dorsal origin to precaudal pit for the second sample. It was not possible to sex or assess maturity for the 2005-2006 samples as these were collected from smoothhound sharks in various stages of processing. As a result, total length for the second sample was estimated using weight length regression (Fig 2.2). Sex and maturity could not be assessed for sharks collected from the second data set. The first sample have been pre-aged (Bennett 2004) and used for comparison against the second sample.

Age and growth

Preparation, cleaning and sectioning of vertebrae

Approximately five of the largest vertebrae were excised from the vertebral column below the first dorsal fin. Two methods were used to section the vertebrae

The first method, suggested by Goldman (2005), was initially used for cleaning the vertebrae where the muscle tissue was removed from thawed vertebrae. As recommended, the neural and haemal arches were removed from half of the vertebral sample for each animal. The vertebrae with the neural arches attached together with a subsample of fully cleaned (whole) vertebrae were then refrozen. Where manual cleaning was not sufficient when removing of surrounding tissue, vertebrae were soaked in a 5% sodium hyperchlorite solution. Soak times ranged from five minutes to one hour depending on the size of the vertebrae. This was followed by soaking in distilled water for 30 to 45 minutes (Johnson, 1979). This method also assisted in the removal of the vertebral fascia between centra. Centra where then stored in 70-95% ethyl alcohol or 95% isopropyl alcohol. Centra where then resin-embedded and sectioned.

A central section at the widest diameter of each vertebra was cut sagittally, with a double-bladed saw to a thickness of approximately 200µm. Sagittally-sectioned centra were used as transversally-sectioned centra bands become increasingly tightly grouped toward the outer edge of the vertebrae. This has been shown to result in the age underestimates in older animals (Cailliet *et al.,* 1983; Branstetter, 1987). Unfortunately this method proved to be time-consuming and laborious.

The second method involved freezing the removed vertebral column section and sectioning the frozen vertebrae. This method proved to be better as it removed the cleaning and resining steps and repeated attempts could be made if centra were not cut centrally.

Sections from both methods were mounted on glass slides with DPX and viewed at a constant magnification (10 X) using transmitted light. Assigned age equaled the number of growth zones, with each zone consisting of one translucent and one opaque bland.

Age interpretation

Age estimates by Goosen & Smale (1997) and Bennet (2004) from the south-eastern Cape coast (i.e. old dataset) were compared to the new readings of the same set of vertebrae by using a Likelihood Ratio Test. These were then compared with the updated age estimates. Using linear regression, the null hypothesis that the slope between the assigned ages of two readers was unity, was tested. Sex-specific growth curves were only estimated using the historical datasets as the new data were unsexed (collected from smoothhound logs).

Growth patterns

Growth curves were fitted to observed data using a von Bertalanffy growth function. Total length as a function of age t is defined as

$$L_t = L_\infty\left(1 - e^{-k(t-t_0)}\right)$$

where L_∞ is the maximum theoretical length, k is the rate at which L_∞ is reached, and t_o the theoretical age at zero length. Parameter estimates were obtained using non-linear minimisation of a negated log-likelihood of the form

$$-\ln L = \frac{n}{2}\ln\left(\frac{\sum_{i=1}^{n}\left(L_i - \hat{L}_i\right)^2}{n}\right) + \frac{n}{2}$$

where L_t and $\hat{L}_t$ are the observed and model predicted lengths at age, and n the sample size.

Parameter variability calculated using parametric bootstrapping with 1000 replicates (Patterson *et al.*, 2001). A Likelihood Ratio Test was used to test the null hypothesis that there is no difference in growth between *M. mustelus* from the south-eastern Cape coast and those from the south-western Cape coast (Cerrato, 1990). Another Likelihood Ratio Test was completed to determine whether there is a difference in growth between sexes.

Precision Analysis

The vertebral characteristics of the same species often change with age and growth zone interpretation is vulnerable to subjectivity. These factors often lead to inaccurate readings. Cailliet *et al.* (1983) standardized procedures for counting bands in centra to ensure consistent and objective evaluation of various techniques. For confident interpretations of band counts, Cailliet *et al.*'s (1983) standardized counting method was used. One researcher made independent randomized blind counts of the broad and narrow bands in centra, two weeks apart. Count reproducibility was then assessed using the Average Percentage Error (APE) approach described by Beamish & Fournier (1981) as

$$APE = 100 \times \frac{1}{R} \times \sum_{i=1}^{R} \frac{\left|X_{ij} - X_j\right|}{X_j}$$

where X_{ij} represented the i^{th} count for the j^{th} fish, X_j was the average count for the j^{th} fish, and R was the number of counts for each fish.

This method provides error estimates for individual fish whilst considering the lifespan of the species in question by considering increased error with larger sizes. An APE of 20%, as used by Wintner (1995) for each was set. Samples exceeding this limit were discarded. The final reading excluded discarded samples. For the samples within the limit, the average of the counts was used as an age estimate.

The index of average percentage error (APE index) was calculated for the sample, according to the following:

$$IAPE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\times\sum_{i=j}^{R}\frac{|X_{ij}-X_j|}{X_j}\right]$$

where N is the number of vertebrae with acceptable readability scores.

Validation of growth zone periodicity

It is imperative that the growth zone periodicity is validated to ensure unbiased age estimates (Calliet, 1983). It is generally assumed that the growth bands in teleost hard parts are of an annual (one band pair) nature, but has not been adequately validated for bands in elasmobranch centra which may in fact have two band pairs per year.

Marginal increment analysis (MIA), Marginal zone analysis (MZA) and flourochrome marking are the most common methods used. A total of 103 smoothhound sharks were tagged and injected in Langebaan Lagoon, and four additional animals were injected in the Jeffreys Bay shark aquarium. Because no recaptures were made during this study of wild sharks, and the negligence in the aquarium (study animals died due to electricity failure), validation using this method was not possible. Validation by MIA and MZA was not possible either as centrum edges were difficult to delineate which affected the accuracy of measurements.

Mortality

Natural mortality (*M*) was estimated using three empirical methods.

Pauly's method (1980), assuming a mean annual sea temperature of $T = 15°C$, iss

$$\ln(M) = -0.0066 - 0.279\log(L_{\infty}) + 0.6543\log(K) + 0.4634\log(T).$$

Jensen's method (1996) is $M = 1.6K$, and Hoenig's method (1983) used the maximum age of the shark ($t_{\max}$), such that $\ln M = 1.46 - 1.01\ln(t_{\max})$

Total mortality was estimated using catch curve analysis where the total mortality (Z) is equal to the slope of the negative natural logarithm of the age frequency for each age class. Fishing mortality (*F*) was calculated via subtraction as $Z = M + F$.

Estimation of maturity

Female and male maturity was ascertained using the approach by Goosen & Smale (1997). Maturity (as a function of age or length) was modelled by a logistic function of the form

$$P_l = \left(1 + e^{-(l - l_{50})/\delta}\right)^{-1}$$

where P_l is the proportion of fish mature at length (or age) l, l_{50} is the length (or age) at which 50% of the animals are mature, and δ is the inverse rate at which animals mature.

Ogive parameters were estimated by non-linear minimization of a negated Binomial likelihood of the form

$$-\ln L = -\left(\sum_{m} y_i \ln\left(\frac{\hat{p}_i}{1-\hat{p}_i}\right) + m_i \ln(1-\hat{p}_i) + \ln\binom{m_i}{y_i}\right)$$

where m_i is the number of fish sampled in length class i, y_i is the number of mature fish in size class i , and $\hat{p}_i$ the logistic model predicted proportion of fish mature in size class i. A Likelihood Ratio Test was conducted to test the null hypothesis that there is no difference between maturity of females and males.

4.3 Results

Size structure

Figure 4.1 illustrates the population structure, in terms of length, of smoothhound sharks as sampled in the south-eastern and south-western Cape coast factories. Approximately 83% and 92% of all smoothhound sharks were caught between 800 and 1400 mm (TL) along the Eastern and Southern Cape coasts. Half of the female sharks caught were between 1000-1300 mm (TL), and between 900-1100 mm (TL) along both the Eastern and Southern Cape coasts, respectively. The largest numbers of males were caught in the Eastern Cape with lengths of 1400 mm (TL) length class (30) and 1000 mm (TL) length class (21) in the Southern Cape. Half of the male *M. mustelus* were caught between 1300-1400 mm (TL), and 1100-1300 mm (TL) in the Eastern and Southern Cape coasts, respectively.

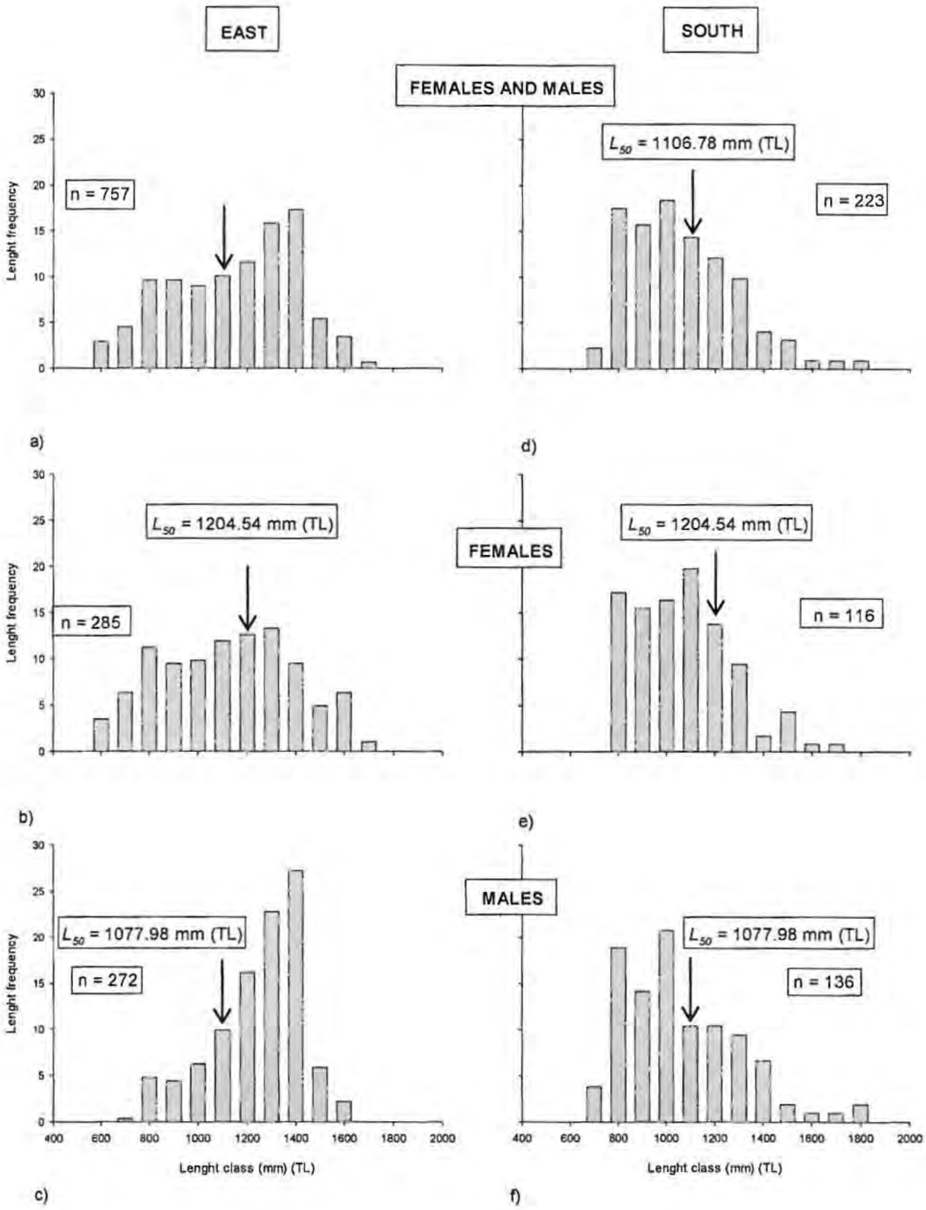


Figure 4.1 Length frequency histograms of combined sex, and sex-specific *Mustelus mustelus* sampled between 2005 and 2006 caught on the Eastern Cape coast (left panels) and Southern Cape coast (right hand panels). Arrows represent the length at maturity

Age and growth

Suitability of vertebrae

All of the vertebral samples processed by Bennett (2004) and Goosen & Smale (1997) from the south-eastern Cape coast were used (n= 322). Of the 500 vertebrae collected from the south-western Cape coast 377 were successfully sectioned. A total of 305 sectioned vertebrae met the criteria for ageing reliability (81%). Seventy-two vertebrae were classified as unreadable.

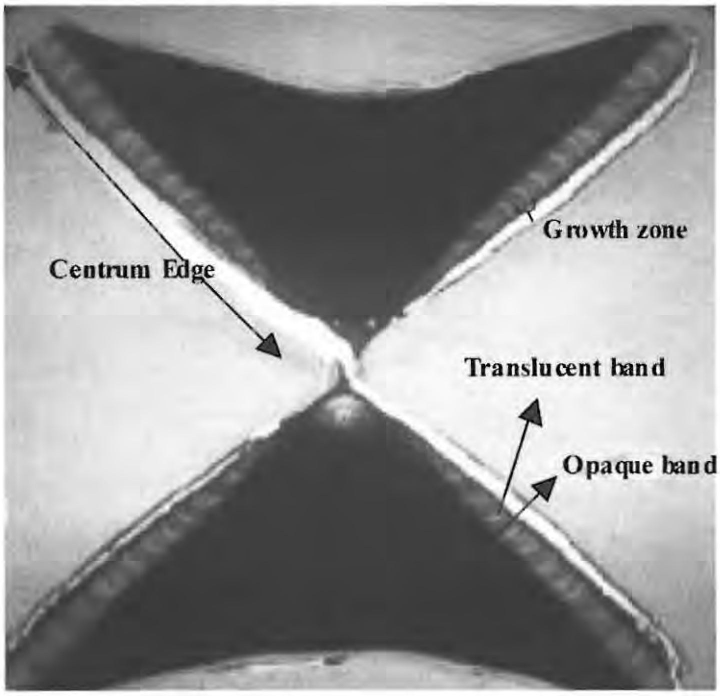


Fig 4.2 Vertebra from *M. mustelus* stained with Alizarin red for enhanced quality (Bennett, 2004)

Ageing precision

The age estimates between both readers were strongly correlated (r =0.86) (Fig 4.3). The slope of the regression was not significantly different from unity (P >0.05). It is therefore assumed that both readers interpreted the vertebrae similarly.

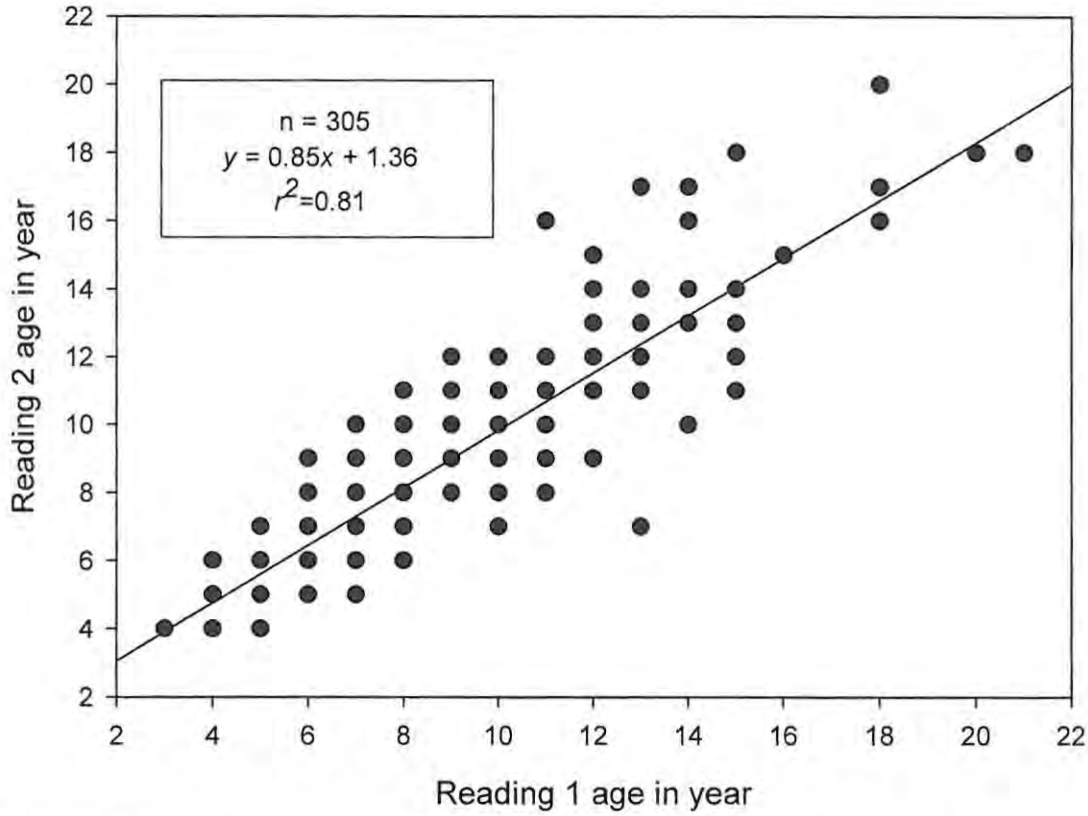


Fig 4.3 Correlation between two readers interpreting the same vertebrae. The plot shows good agreement and limited bias between readings

Validation

Due to negligence at the aquarium where the four oxytetracycline injected animals were kept, no sharks survived the experimental year. Centrum edge analysis and marginal increment analysis was not completed as centrum edges where difficult to delineate and vertebrae collected for this study where collected over a three month period.

Although growth of *M. mustelus* was not validated in this study, annual deposition have been found in five species of *Mustelus* (Tanaka & Mizue, 1979;Wang & Chen, 1982; Taniuchi *et al.*, 1983; Moulton *et al.*, 1992; Yamaguchi *et al.*, 1998; Francis & Maolagàin, 2000), including *M.mustelus* (Goosen & Smale., 1997), where data suggested annual deposition of rings.

Estimation of growth parameters

The von Bertalanffy growth parameters are summarized in Table 4.1. The sex specific and combined growth curves are shown in Fig 4.4 and Fig 4.5 respectively. The growth parameters for the combined sexes, and unsexed data for *M. mustelus* illustrate that a maximum asymptotic total length (L_∞) of 1946.16 mm TL, with a Brody's growth coefficient (K) of 0.08 year^{-1}, and an age at zero length (t_0) of –3.63 year^{-1}(n= 528). Female *M. mustelus* attain an L_∞ of 2202.21mm TL, with a K of 0.05 year^{-1}, and a t_0 of -4.67 years (n=109). Male *M. mustelus* acquire a L_∞ of 1713.19 mm TL, a K of 0.08 year^{-1} and a t_0 of –4.36 years.

The length at age von Bertalanffy growth curves for female and male *M. mustelus* are shown in Figure 4.4. Although growth for earlier data (processed by Goosen & Smale (1997) and Bennet (2004)) appears faster than current growth rates (Fig 4.5), growth was not significantly different for smoothhound sharks caught in the south-eastern (earlier Goosen & Smale (1997) and Bennet (2004) data) and south-western Cape coasts (2005-2006 dataset). This apparent change in growth is a sampling bias as later samples were collected from processing facilities (data collected as part of this study), and these select against larger individuals. Significant differences in growth were estimated between female and male fish ($p < 0.05$). As mentioned above sex was not determined for the second data set (2005-2006 dataset) as samples were collected from individuals in different stages of processing. Actual measurements of maximum sizes were smaller than estimated L_∞ .

Table 4.1. Von Bertalanffy growth model parameter point estimates and associated standard errors (SE) and 95% confidence intervals (CI). Results have been presented for combined sex data, and male- and female-specific data. The combined sex data includes all sharks sampled irrespective of sex.. Parameters that are significantly different from one another ($p < 0.05$) share a common superscript

Parameter	Point estimate	SE	95% CI Range
Combined sexes (n = 528)			
L_∞ (mm TL)	1946.17	145.21	(1712.18,2161.53)
K (year^{-1})	0.08	0.01	(0.05,0.1)
t_0 (years)	-3.63	0.57	(-4.84,-2.89)
Males (n = 114)			
L_∞ (mm TL)	1767.7[a]	369.88	(1437.12,2160.44)
K (year^{-1})	0.08	0.02	(0.04,0.11)
t_0 (years)	-4.36	0.83	(-6.38,-3.36)
Females (n = 109)			
L_∞ (mm TL)	2252.87 [a]	283.49	(1879.03,2651.86)
K (year^{-1})	0.05	0.01	(0.03,0.07)
t_0 (years)	-4.72	0.72	(-6.19,-3.82)

Mortality

Instantaneous total mortality (Z) was estimated at 0.16 yr^{-1} . Natural mortality (M) for *M. mustelus* was estimated using Pauly's (1980), Jensen's (1996) and Hoenig's (1983) methods at 0.05 yr^{-1}, 0.08 yr^{-1}, and 0.16 yr^{-1}, respectively (Fig 4.6). The median value of 0.08 yr^{-1} was used for further assessment. By subtraction, fishing mortality was estimated at $F = 0.1$ yr^{-1} (Fig 4.6).

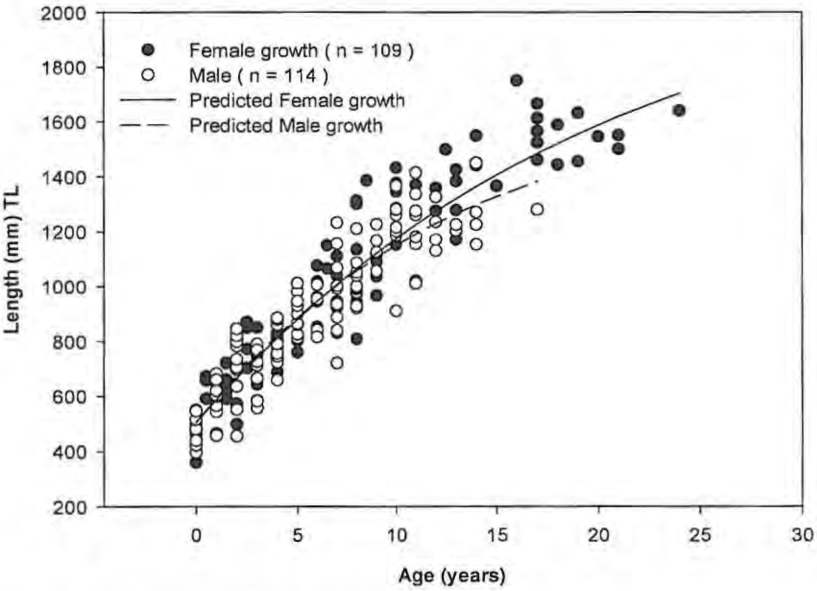


Fig 4.4 Sex-specific growth curves of *M. mustelus*.

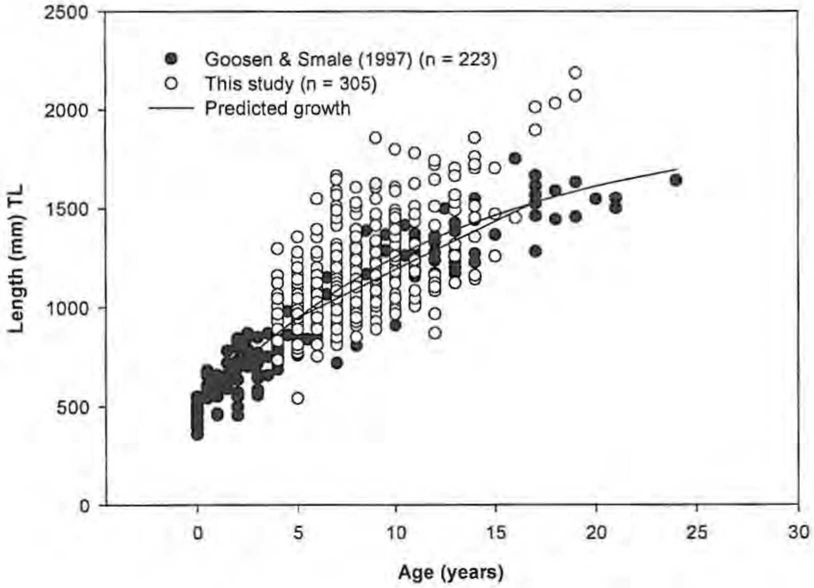


Fig 4.5 The growth curve of *Mustelus mustelus* from two samples of vertebrae.

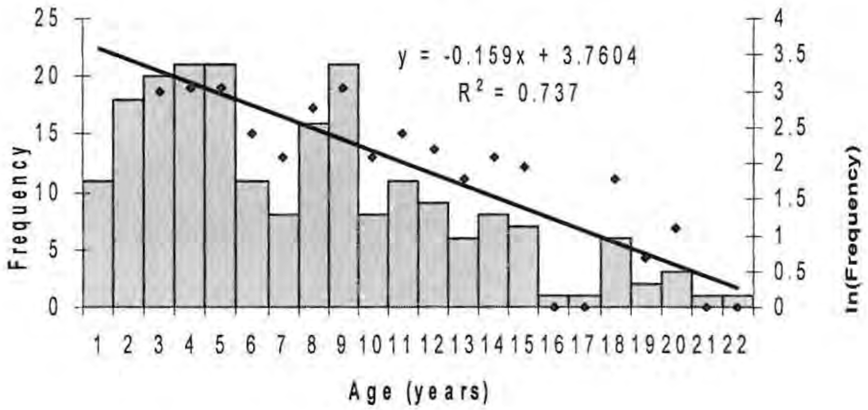


Figure 4.6 *Mustelus mustelus* frequency (histogram) and its natural logarithm equivalent (dots) plotted against age. Instantaneous total mortality was estimated for all ages 9-21 using linear regression. The slope of the regression line indicates the rate of instantaneous total mortality at $Z = 0.16$ yr^{1}.

Maturity

Length and age at 50% maturity are illustrated in Figure 4.7. The A_{50} of the combined sexes was 9.93 years, corresponding to a length of 1216.43 mm (TL). A_{50} of the females was 10.75 years, corresponding to a length of 1234.33 mm (TL), whilst A_{50} of the males was 9.1 corresponding to a length of 1106.78 mm (TL). L_{50} of the combined sexes, females and males was 1078.11 mm (age 7), 1204.54 mm (age 9) and 1077.98 (age 7) respectively.

Females matured at 1234 mm (TL) and 10.75 years, while males mature at 1106 mm TL and 9.1 years. The likelihood ratio tests showed significant differences in maturity rates between females and males (Fig 4.7).

Using combined sex data, *M. mustelus* matured at 1216 mm TL and 9.13 years, respectively.

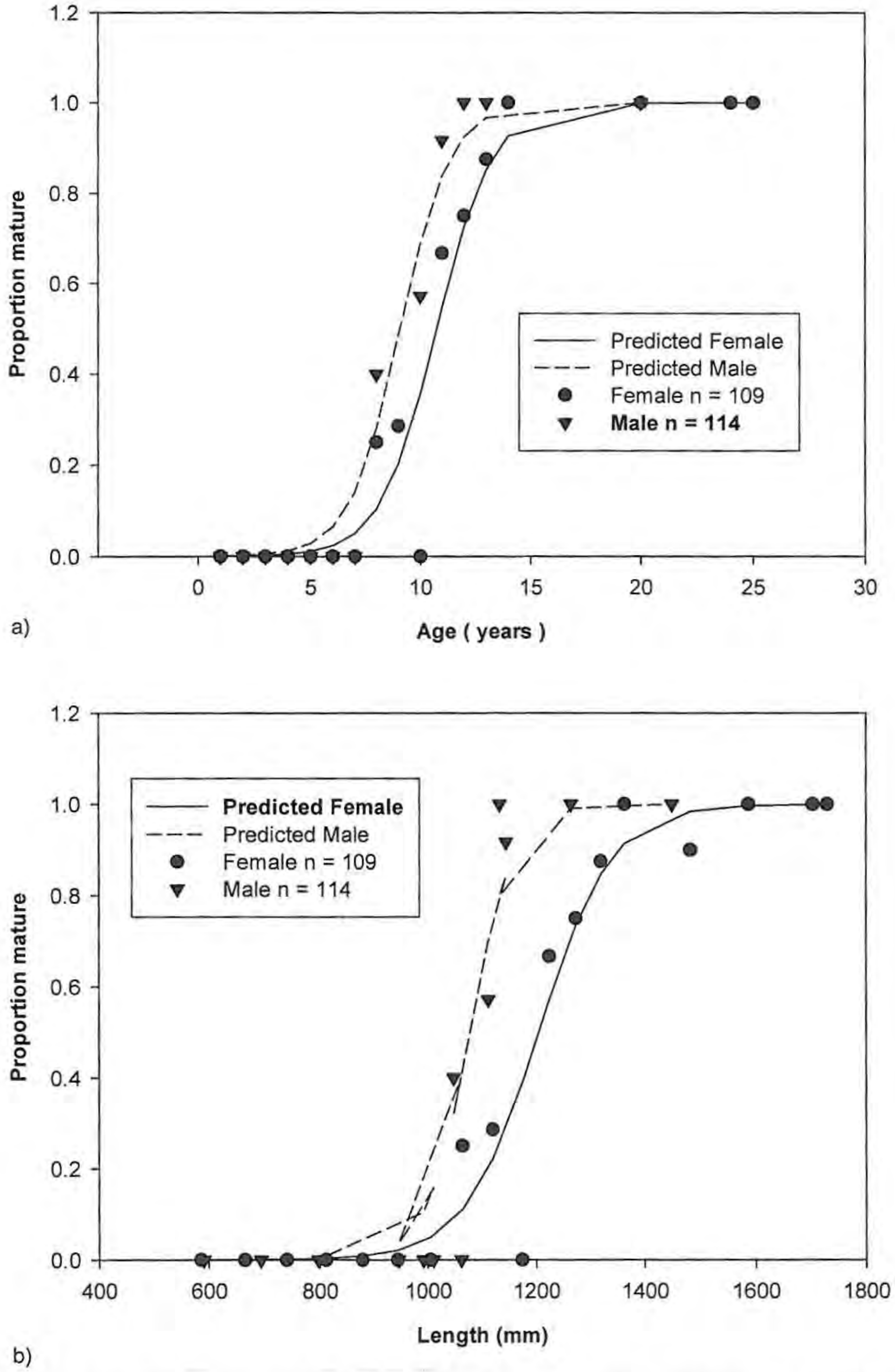


Fig 4.7 Age and length at 50% maturity for *M. mustelus* a) age at 50% maturity (n = 223), b) length at 50% maturity (n = 223).

4.4 Discussion

The size and age composition of the catches provides valuable information which proportion of the population is frequently targeted (Bonfil, 2004). The size composition data showed that the highest frequency of smoothhound sharks caught in the Eastern Cape coast are significantly larger at 1400 mm (TL) than those caught on the Southern Cape coast 1000 mm (TL) ($p < 0.05$). Size composition of catches off the Eastern Cape coast ranged from 600-1700 mm (TL), whilst those in the Southern Cape coast ranged from 700-1800 mm (TL). Size composition of females range from 600-1700 mm (TL) along the Eastern Cape coast and 800-1700 mm (TL) along the Western Cape coast.

Females matured at 1204 mm (TL) corresponding to an age of 9.1 yrs. However, they only begin to get targeted at 800 mm (TL) in the Southern Cape, whilst 600 mm (TL) size classes are being targeted in the Eastern Cape. The majority of females are therefore targeted at a size well below that of 50% maturity on both coasts. This is was not the case for male smoothhounds. Males are caught from 700-1600 mm (TL) in the Eastern Cape and between 700-1800 in the Southern Cape coast. The majority of males are caught at lengths above 50% maturity in the Eastern Cape and below 50 % maturity in the Southern Cape coast.

Only the lengths 800-1450 mm (TL) fall within the ranges of acceptable weights for processing; that is between 1.5 and 12 kg (Chapter 3). Sharks under 800 mm (TL) and over 1450 mm (TL) have little commercial value due to their mercury content (Chapter 3). Numbers of animals between 1210 mm (TL) to 1450 have a lower value than 800-1210 mm (TL). Catches observed in the Southern Cape coast factories fall closer within these ranges than those from the Eastern Cape coast. Southern Cape catches also tends to drop after 1210 mm (DOCL) as the value of smoothhound sharks over this range is low. Finning earns the most profit from sharks. Therefore, it appears from the size composition data that more *M. mustelus* are caught for fins in the Eastern Cape than in the Southern Cape coast.

Modeled length at age revealed the *M. mustelus* grow rapidly. *M. mustelus* as a whole reach an asymptotic length of 2252.1 mm (TL), and a maximum age of 25 was observed. Of interest is that maximum recorded ages for *Mustelus* are seldom over 13 years. Moulton *et al.*, (1992) showed that female *Mustelus antarcticus* reach a maximum age at 16+ years, which is older than *M. manazo* (9+) (Tanaka & Mizue., 1979) and *M. californicus* (9+) (Yuden *et al.*, 1990).

Differences in growth rate was observed between the males and females. Females reach a larger asymptotic length than males at 2202 mm (TL) and 1713 mm (TL), with males attaining their asymptotic length faster than females. A difference in growth rates between female and male sharks has been demonstrated for other *Mustelus* species (Moulton *et al.*, 1992). Species from the genus *Mustelus* that exhibit this differential growth rate include *M. antarcticus* (Moulton *et al., 1992*), *M. manazo* (Taniuchi *et al.*, 1983; Cailliet *et al.*, 1992), *M. californicus* (Yudin & Cailliet, 1990). Differential growth patterns between sexes in other genera include *C. tilstoni*, *C. sorrah* (Davenport & Stevens, 1988), *C. limbatus* (Killam & Parsons, 1989) and *G. galeus* (Ferreira & Vooren, 1991; McCord., 2005).

Age and length at 50% maturity was estimated at 9 years and 1078 mm TL. Values found in this study are relatively high when compared to maturity data for other *Mustelus* species (Francis & Mace, 1980; Francis, 1989; Francis & Maolagáin, 2000). Low estimates of age at 50% maturity can be explained by sampling bias, location of capture (sexual and size segregation), underestimation of ages, and high levels of fishing pressure resulting in a decrease in age at maturity. Fishermen and shark processing facility owners developing the fishery have previously ignored areas that historically have shown catches of larger size sharks (i.e Western Cape coast). Coupled with this lack of development and interest shown by fishermen in these areas, known nursery areas where large females are distributed are often closed to fishermen as marine protected areas such as St Croix island in Algoa Bay and Langebaan Lagoon). Although this is widely suspected, few studies regarding shark composition in these areas have been conducted.

A long-term illegal gill net fishery is suspected to exist in Langebaan Lagoon (Smale, *pers comm.*., BayWorld, 2007). As the majority of smoothhound sharks caught in gill-nets are juveniles (Lamberth, 2006), and considering the possibility of Langebaan lagoon being a nursery area, further research is required.

It is a well-documented phenomenon that high levels of fishing pressure may lead to a decrease in age at 50% maturity (Buxton, 1993; Barot *et al.*, 2003; Engelhard & Heino, 2004). This has been shown in *M. antarcticus* (Walker *et al.*, 1998). This change is present in fisheries where larger fish are selected over smaller, younger fish. This results in a shift in life-history characteristics compensating for over-fishing the reproductively active component of the population. Although this phenomenon is not likely for smoothhound sharks targeted in South Africa, as relatively small sharks are targeted, accurate historical data are not available. Therefore, it is unlikely that the *M. mustelus* population has been exploited at levels that show density-dependent responses to stock reduction.

Both natural and fishing mortality were estimated at 0.08 yr^{-1}. This estimate was accepted as within an acceptable range for *M. mustelus* as they have relatively long life spans. McCord (2005) found natural mortality estimates of 0.13 $year^{-1}$ to be appropriate for *G.galeus* caught in South Africa. Natural mortality rates are not available for *M. mustelus* caught in other regions, but have been estimated for other species in the genus (*M. californicus* and *M. henlei* at 0.37 $year^{-1}$ and 0.29 $year^{-1}$ respectively (Moulton *et al.*, 1992; Cailliet *et al.*, 1990). Natural mortality for other demersal sharks; *C. falciformis*, *C. obscurus*, and *C. Taurus,* were estimated at 0.18 $year^{-1}$, 0.11 $year^{-1}$, and 0.26 $year^{-1}$ respectively (Bonfil, 1990; Bonfil, *et al.*, 1993; Simpfendorfer *et al.*, 2002; Branstetter & Musick, 1994).

Accurate estimates of natural mortally are vital indicators of population dynamics and allow for sensible estimates of rates of sustainable exploitation (Simpfendorfer *et al.*, 2004). It has been shown that many sharks including *G. galeus* exhibit age-independent natural mortality after a certain age (Punt & Walker, 1998). Prince (2005) showed that restricting fishing to a few juvenile age-classes proves to be a robust management strategy for elasmobranches. This is highly effective if older adults are protected from fishing mortality. He emphasized that this management strategy is more effective with species exhibiting low productivity and higher longevity. The restrictions of the fishery regarding mercury bans and consequently economic value also limit the fishery

In conclusion, this chapter has estimated age and growth parameters, and estimates ages at maturity and mortality rates. Estimates of age and growth parameters indicate that *M. mustelus* as with all sharks are long-lived sharks maturing at late ages and demonstrating a susceptibility to exploitation. Comparisons with other studies on life-history of sharks from the genus *Mustelus* have shown that estimates are reasonable although some are slightly higher than expected. These estimates need to be improved with dedicated sampling of smoothhound sharks at more varied length classes and in higher numbers. More important is the need to validate age estimates. This is especially pertinent in the South and West Cape of South Africa where demersal sharks are being increasingly targeted.

CHAPTER 4

ASPECTS OF THE BIOLOGY OF THE SMOOTHHOUND SHARK, *MUSTELUS MUSTELUS*, IN SOUTH AFRICA

4.1 Introduction

Biological studies that include the estimation of growth, maturity, reproductive seasonality and natural mortality provide important management information. The ability to accurately determine age, and hence calculate growth, is of particular importance as it lays the foundation for management based quantitative stock assessment methods (Kanyerere *et al.*, 2005). In effect, the accurate determination of age allows for the estimation of various time-based rates such as growth, maturation and mortality rates (Beamish & Fournier, 1981). Similarly, estimates of maturity and mortality are vital as they provide estimates of whether animals are caught before they have had the time to reproduce, this is especially important for longer lived animals. These life history parameters have also been used to estimate rebound potential of exploited stock of elasmobranches (Smith *et al.* 1998)

Age in elasmobranchs is usually determined by examining vertebrae. Growth studies assume that vertebral bands are of an accurate indicator of age, and few have validated the temporal periodicity of band deposition and validated the absolute age. Growth can be categorized into the terms validation and verification and the distinction between the two is important. The validation of absolute age must prove the consistency of the marks formed per year, proving the accuracy of age estimates with determinate methods. Verification confirms age estimates by comparison with other indeterminate methods (Branstetter, 1987; Cailliet *et al.*, 1983; Cailliet, 1990; Campana *et al.*, 2002; Natanson *et al.*, 2002).

This study investigates aspects of the biology of the smoothhound shark including age and growth using sectioned vertebrae, sexual maturity, lengths at capture, and mortality, on the south-eastern and south-western Cape coasts of South Africa. This data will be used to elucidate stock structure for the development of a preliminary management plan.

4.2 Materials and Methods

General sampling

Two sources of vertebrae were used for age and growth determination. The first sample of vertebrae (n = 223) were pre-collected by Goosen & Smale (1997) and re-analysed by Bennet (2004) from Mossel Bay to Port Elizabeth, South Africa between December 1983 to July 1991. The second sample (n = 500) were collected as part of this study, which ranged between the south-western Cape coast factory situated in Strand (Sharkex) with sharks predominantly caught in False Bay (2006).

Due to dressed state of sharks, lengths differed between the two samples; precaudal and total lengths for first sample, and dorsal origin to caudal tip and dorsal origin to precaudal pit for the second sample. It was not possible to sex or assess maturity for the 2005-2006 samples as these were collected from smoothhound sharks in various stages of processing. As a result, total length for the second sample was estimated using weight length regression (Fig 2.2). Sex and maturity could not be assessed for sharks collected from the second data set. The first sample have been pre-aged (Bennett 2004) and used for comparison against the second sample.

Age and growth

Preparation, cleaning and sectioning of vertebrae

Approximately five of the largest vertebrae were excised from the vertebral column below the first dorsal fin. Two methods were used to section the vertebrae

The first method, suggested by Goldman (2005), was initially used for cleaning the vertebrae where the muscle tissue was removed from thawed vertebrae. As recommended, the neural and haemal arches were removed from half of the vertebral sample for each animal. The vertebrae with the neural arches attached together with a subsample of fully cleaned (whole) vertebrae were then refrozen. Where manual cleaning was not sufficient when removing of surrounding tissue, vertebrae were soaked in a 5% sodium hyperchlorite solution. Soak times ranged from five minutes to one hour depending on the size of the vertebrae. This was followed by soaking in distilled water for 30 to 45 minutes (Johnson, 1979). This method also assisted in the removal of the vertebral fascia between centra. Centra where then stored in 70-95% ethyl alcohol or 95% isopropyl alcohol. Centra where then resin-embedded and sectioned.

A central section at the widest diameter of each vertebra was cut sagittally, with a double-bladed saw to a thickness of approximately 200μm. Sagittally-sectioned centra were used as transversally-sectioned centra bands become increasingly tightly grouped toward the outer edge of the vertebrae. This has been shown to result in the age underestimates in older animals (Cailliet *et al.*, 1983; Branstetter, 1987). Unfortunately this method proved to be time-consuming and laborious.

The second method involved freezing the removed vertebral column section and sectioning the frozen vertebrae. This method proved to be better as it removed the cleaning and resining steps and repeated attempts could be made if centra were not cut centrally.

Sections from both methods were mounted on glass slides with DPX and viewed at a constant magnification (10 X) using transmitted light. Assigned age equaled the number of growth zones, with each zone consisting of one translucent and one opaque bland.

Age interpretation

Age estimates by Goosen & Smale (1997) and Bennet (2004) from the south-eastern Cape coast (i.e. old dataset) were compared to the new readings of the same set of vertebrae by using a Likelihood Ratio Test. These were then compared with the updated age estimates. Using linear regression, the null hypothesis that the slope between the assigned ages of two readers was unity, was tested. Sex-specific growth curves were only estimated using the historical datasets as the new data were unsexed (collected from smoothhound logs).

Growth patterns

Growth curves were fitted to observed data using a von Bertalanffy growth function. Total length as a function of age t is defined as

$$L_t = L_\infty\left(1 - e^{-k(t-t_0)}\right)$$

where L_∞ is the maximum theoretical length, k is the rate at which L_∞ is reached, and t_o the theoretical age at zero length. Parameter estimates were obtained using non-linear minimisation of a negated log-likelihood of the form

$$-\ln L = \frac{n}{2}\ln\left(\frac{\sum_{i=1}^{n}\left(L_i - \hat{L}_i\right)^2}{n}\right) + \frac{n}{2}$$

where L_t and $\hat{L}_t$ are the observed and model predicted lengths at age, and n the sample size.

Parameter variability calculated using parametric bootstrapping with 1000 replicates (Patterson *et al.*, 2001). A Likelihood Ratio Test was used to test the null hypothesis that there is no difference in growth between *M. mustelus* from the south-eastern Cape coast and those from the south-western Cape coast (Cerrato, 1990). Another Likelihood Ratio Test was completed to determine whether there is a difference in growth between sexes.

Precision Analysis

The vertebral characteristics of the same species often change with age and growth zone interpretation is vulnerable to subjectivity. These factors often lead to inaccurate readings. Cailliet *et al.* (1983) standardized procedures for counting bands in centra to ensure consistent and objective evaluation of various techniques. For confident interpretations of band counts, Cailliet *et al.*'s (1983) standardized counting method was used. One researcher made independent randomized blind counts of the broad and narrow bands in centra, two weeks apart. Count reproducibility was then assessed using the Average Percentage Error (APE) approach described by Beamish & Fournier (1981) as

$$APE = 100 \times \frac{1}{R} \times \sum_{i=1}^{R} \frac{|X_{ij} - X_j|}{X_j}$$

where X_{ij} represented the i^{th} count for the j^{th} fish, X_j was the average count for the j^{th} fish, and R was the number of counts for each fish.

This method provides error estimates for individual fish whilst considering the lifespan of the species in question by considering increased error with larger sizes. An APE of 20%, as used by Wintner (1995) for each was set. Samples exceeding this limit were discarded. The final reading excluded discarded samples. For the samples within the limit, the average of the counts was used as an age estimate.

The index of average percentage error (APE index) was calculated for the sample, according to the following:

$$IAPE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\times\sum_{i=j}^{R}\frac{|X_{ij}-X_j|}{X_j}\right]$$

where N is the number of vertebrae with acceptable readability scores.

Validation of growth zone periodicity

It is imperative that the growth zone periodicity is validated to ensure unbiased age estimates (Calliet, 1983). It is generally assumed that the growth bands in teleost hard parts are of an annual (one band pair) nature, but has not been adequately validated for bands in elasmobranch centra which may in fact have two band pairs per year.

Marginal increment analysis (MIA), Marginal zone analysis (MZA) and flourochrome marking are the most common methods used. A total of 103 smoothhound sharks were tagged and injected in Langebaan Lagoon, and four additional animals were injected in the Jeffreys Bay shark aquarium. Because no recaptures were made during this study of wild sharks, and the negligence in the aquarium (study animals died due to electricity failure), validation using this method was not possible. Validation by MIA and MZA was not possible either as centrum edges were difficult to delineate which affected the accuracy of measurements.

Mortality

Natural mortality (*M*) was estimated using three empirical methods.

Pauly's method (1980), assuming a mean annual sea temperature of $T = 15°C$, iss

$$\ln(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T).$$

Jensen's method (1996) is $M = 1.6K$, and Hoenig's method (1983) used the maximum age of the shark ($t_{\max}$), such that $\ln M = 1.46 - 1.01\ln(t_{\max})$

Total mortality was estimated using catch curve analysis where the total mortality (Z) is equal to the slope of the negative natural logarithm of the age frequency for each age class. Fishing mortality (*F*) was calculated via subtraction as $Z = M + F$.

Estimation of maturity

Female and male maturity was ascertained using the approach by Goosen & Smale (1997). Maturity (as a function of age or length) was modelled by a logistic function of the form

$$P_l = \left(1 + e^{-(l - l_{50})/\delta}\right)^{-1}$$

where P_l is the proportion of fish mature at length (or age) l, l_{50} is the length (or age) at which 50% of the animals are mature, and δ is the inverse rate at which animals mature.

Ogive parameters were estimated by non-linear minimization of a negated Binomial likelihood of the form

$$-\ln L = -\left(\sum_{m} y_i \ln\left(\frac{\hat{p}_i}{1-\hat{p}_i}\right) + m_i \ln(1-\hat{p}_i) + \ln\binom{m_i}{y_i}\right)$$

where m_i is the number of fish sampled in length class i, y_i is the number of mature fish in size class i , and $\hat{p}_i$ the logistic model predicted proportion of fish mature in size class i. A Likelihood Ratio Test was conducted to test the null hypothesis that there is no difference between maturity of females and males.

4.3 Results

Size structure

Figure 4.1 illustrates the population structure, in terms of length, of smoothhound sharks as sampled in the south-eastern and south-western Cape coast factories. Approximately 83% and 92% of all smoothhound sharks were caught between 800 and 1400 mm (TL) along the Eastern and Southern Cape coasts. Half of the female sharks caught were between 1000-1300 mm (TL), and between 900-1100 mm (TL) along both the Eastern and Southern Cape coasts, respectively. The largest numbers of males were caught in the Eastern Cape with lengths of 1400 mm (TL) length class (30) and 1000 mm (TL) length class (21) in the Southern Cape. Half of the male *M. mustelus* were caught between 1300-1400 mm (TL), and 1100-1300 mm (TL) in the Eastern and Southern Cape coasts, respectively.

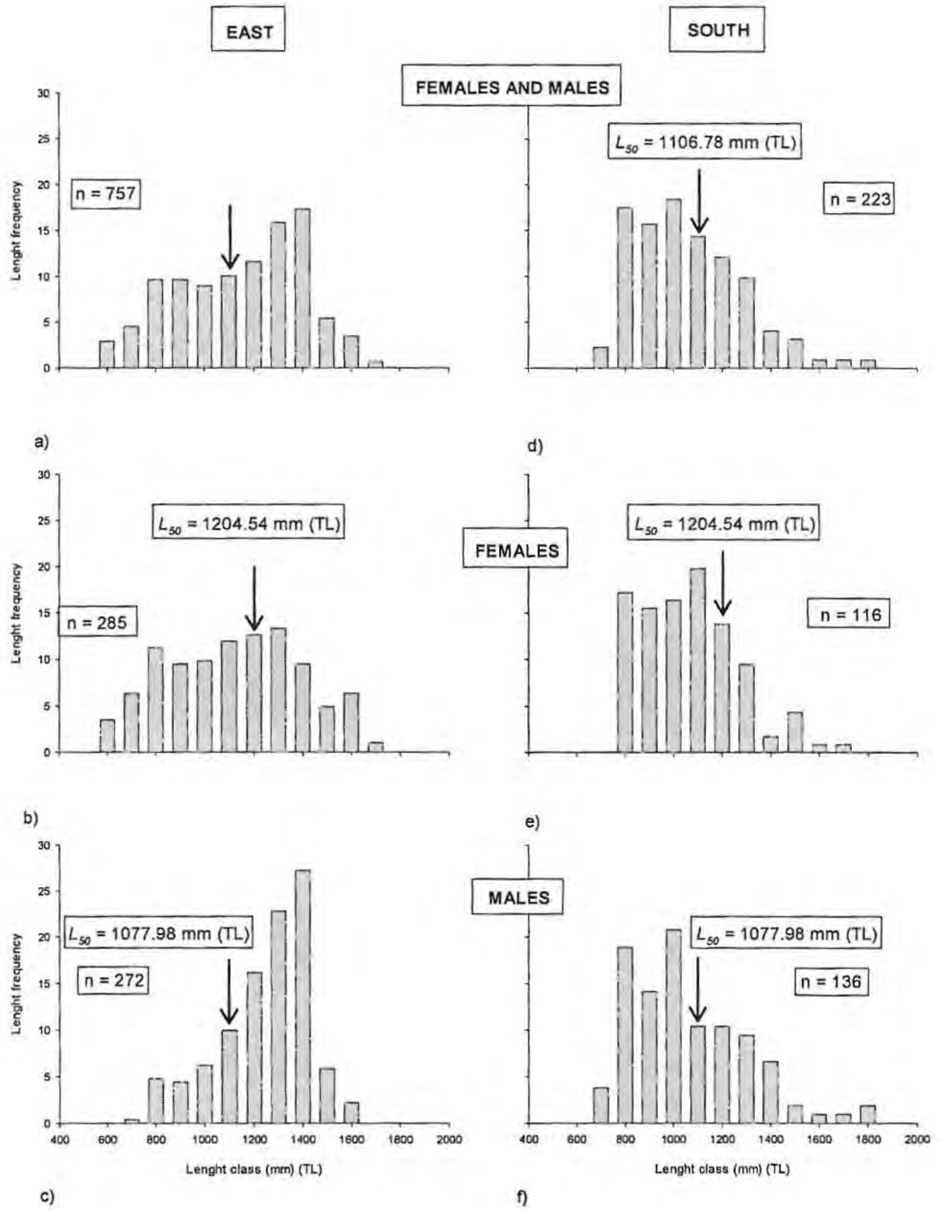


Figure 4.1 Length frequency histograms of combined sex, and sex-specific *Mustelus mustelus* sampled between 2005 and 2006 caught on the Eastern Cape coast (left panels) and Southern Cape coast (right hand panels). Arrows represent the length at maturity

Age and growth

Suitability of vertebrae

All of the vertebral samples processed by Bennett (2004) and Goosen & Smale (1997) from the south-eastern Cape coast were used (n= 322). Of the 500 vertebrae collected from the south-western Cape coast 377 were successfully sectioned. A total of 305 sectioned vertebrae met the criteria for ageing reliability (81%). Seventy-two vertebrae were classified as unreadable.

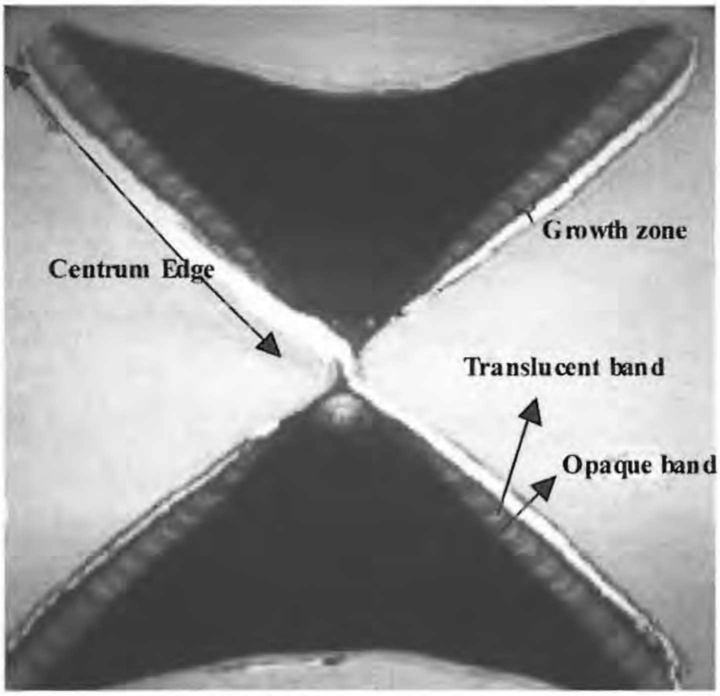


Fig 4.2 Vertebra from *M. mustelus* stained with Alizarin red for enhanced quality (Bennett, 2004)

Ageing precision

The age estimates between both readers were strongly correlated (r =0.86) (Fig 4.3). The slope of the regression was not significantly different from unity (P >0.05). It is therefore assumed that both readers interpreted the vertebrae similarly.

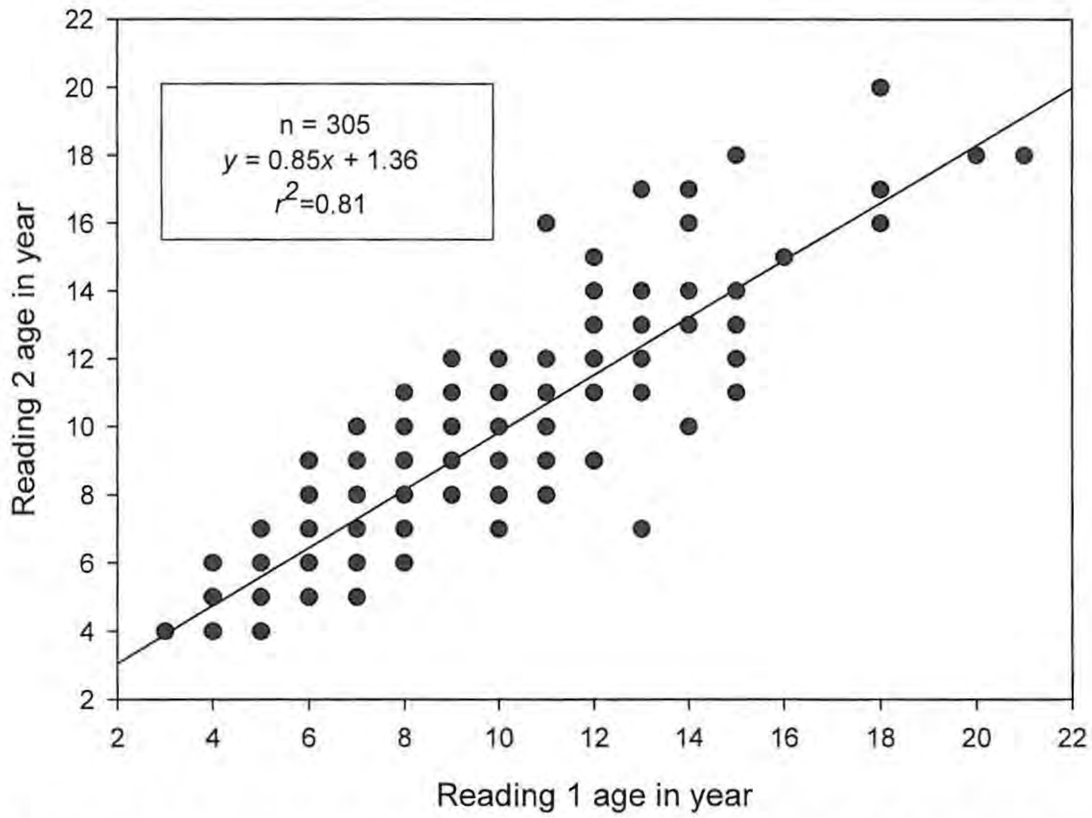


Fig 4.3 Correlation between two readers interpreting the same vertebrae. The plot shows good agreement and limited bias between readings

Validation

Due to negligence at the aquarium where the four oxytetracycline injected animals were kept, no sharks survived the experimental year. Centrum edge analysis and marginal increment analysis was not completed as centrum edges where difficult to delineate and vertebrae collected for this study where collected over a three month period.

Although growth of *M. mustelus* was not validated in this study, annual deposition have been found in five species of *Mustelus* (Tanaka & Mizue, 1979;Wang & Chen, 1982; Taniuchi *et al.*, 1983; Moulton *et al.*, 1992; Yamaguchi *et al.*, 1998; Francis & Maolagâin, 2000), including *M.mustelus* (Goosen & Smale., 1997), where data suggested annual deposition of rings.

Estimation of growth parameters

The von Bertalanffy growth parameters are summarized in Table 4.1. The sex specific and combined growth curves are shown in Fig 4.4 and Fig 4.5 respectively. The growth parameters for the combined sexes, and unsexed data for *M. mustelus* illustrate that a maximum asymptotic total length (L_∞) of 1946.16 mm TL, with a Brody's growth coefficient (K) of 0.08 year^{-1}, and an age at zero length (t_0) of –3.63 year^{-1}(n= 528). Female *M. mustelus* attain an L_∞ of 2202.21mm TL, with a K of 0.05 year^{-1}, and a t_0 of -4.67 years (n=109). Male *M. mustelus* acquire a L_∞ of 1713.19 mm TL, a K of 0.08 year^{-1} and a t_0 of –4.36 years.

The length at age von Bertalanffy growth curves for female and male *M. mustelus* are shown in Figure 4.4. Although growth for earlier data (processed by Goosen & Smale (1997) and Bennet (2004)) appears faster than current growth rates (Fig 4.5), growth was not significantly different for smoothhound sharks caught in the south-eastern (earlier Goosen & Smale (1997) and Bennet (2004) data) and south-western Cape coasts (2005-2006 dataset). This apparent change in growth is a sampling bias as later samples were collected from processing facilities (data collected as part of this study), and these select against larger individuals. Significant differences in growth were estimated between female and male fish ($p < 0.05$). As mentioned above sex was not determined for the second data set (2005-2006 dataset) as samples were collected from individuals in different stages of processing. Actual measurements of maximum sizes were smaller than estimated L_∞.

Table 4.1. Von Bertalanffy growth model parameter point estimates and associated standard errors (SE) and 95% confidence intervals (CI). Results have been presented for combined sex data, and male- and female-specific data. The combined sex data includes all sharks sampled irrespective of sex.. Parameters that are significantly different from one another ($p < 0.05$) share a common superscript

Parameter	Point estimate	SE	95% CI Range
Combined sexes (n = 528)			
L_∞ (mm TL)	1946.17	145.21	(1712.18,2161.53)
K (year^{-1})	0.08	0.01	(0.05,0.1)
t_0 (years)	-3.63	0.57	(-4.84,-2.89)
Males (n = 114)			
L_∞ (mm TL)	1767.7^a	369.88	(1437.12,2160.44)
K (year^{-1})	0.08	0.02	(0.04,0.11)
t_0 (years)	-4.36	0.83	(-6.38,-3.36)
Females (n = 109)			
L_∞ (mm TL)	2252.87^a	283.49	(1879.03,2651.86)
K (year^{-1})	0.05	0.01	(0.03,0.07)
t_0 (years)	-4.72	0.72	(-6.19,-3.82)

Mortality

Instantaneous total mortality (Z) was estimated at 0.16 yr^{-1} . Natural mortality (M) for *M. mustelus* was estimated using Pauly's (1980), Jensen's (1996) and Hoenig's (1983) methods at 0.05 yr^{-1}, 0.08 yr^{-1}, and 0.16 yr^{-1}, respectively (Fig 4.6). The median value of 0.08 yr^{-1} was used for further assessment. By subtraction, fishing mortality was estimated at $F = 0.1$ yr^{-1} (Fig 4.6).

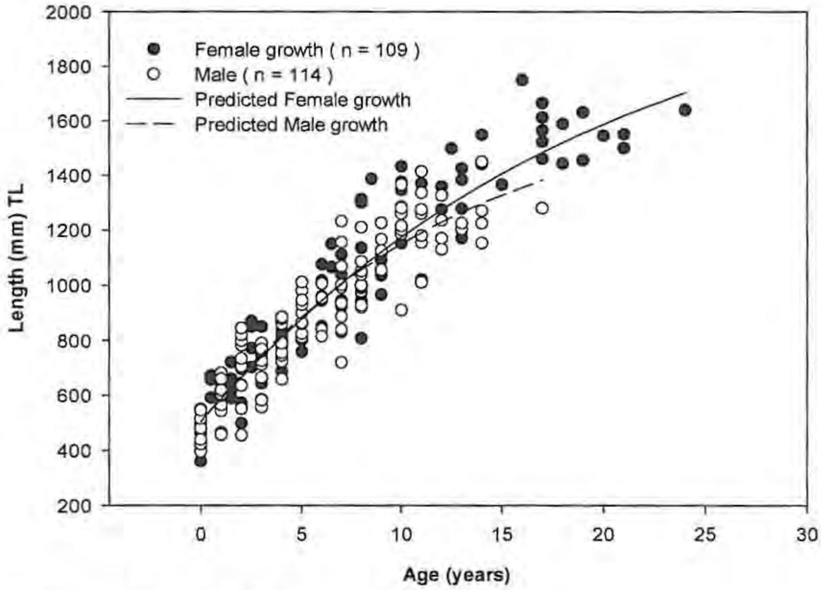


Fig 4.4 Sex-specific growth curves of *M. mustelus*.

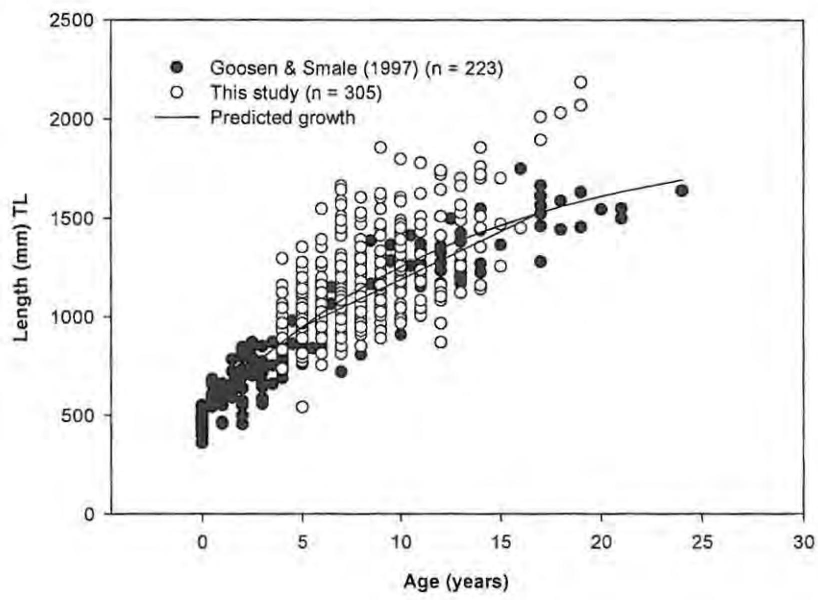


Fig 4.5 The growth curve of *Mustelus mustelus* from two samples of vertebrae.

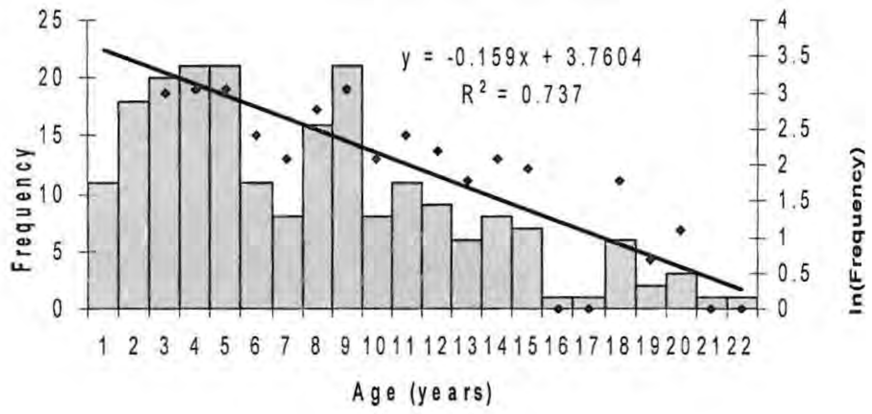


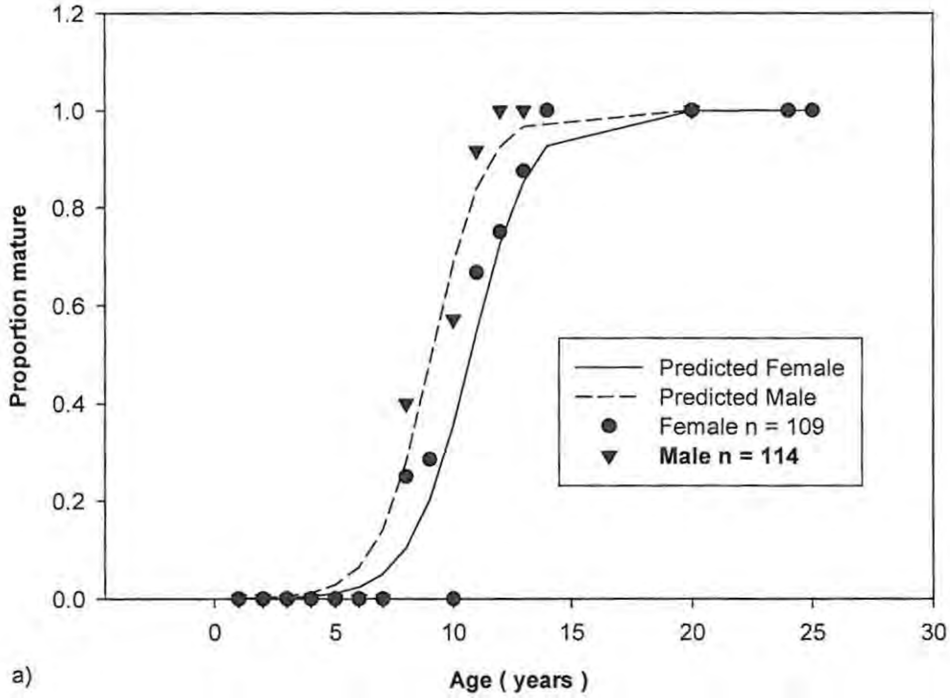
Figure 4.6 *Mustelus mustelus* frequency (histogram) and its natural logarithm equivalent (dots) plotted against age. Instantaneous total mortality was estimated for all ages 9-21 using linear regression. The slope of the regression line indicates the rate of instantaneous total mortality at $Z = 0.16\ yr^{1}$.

Maturity

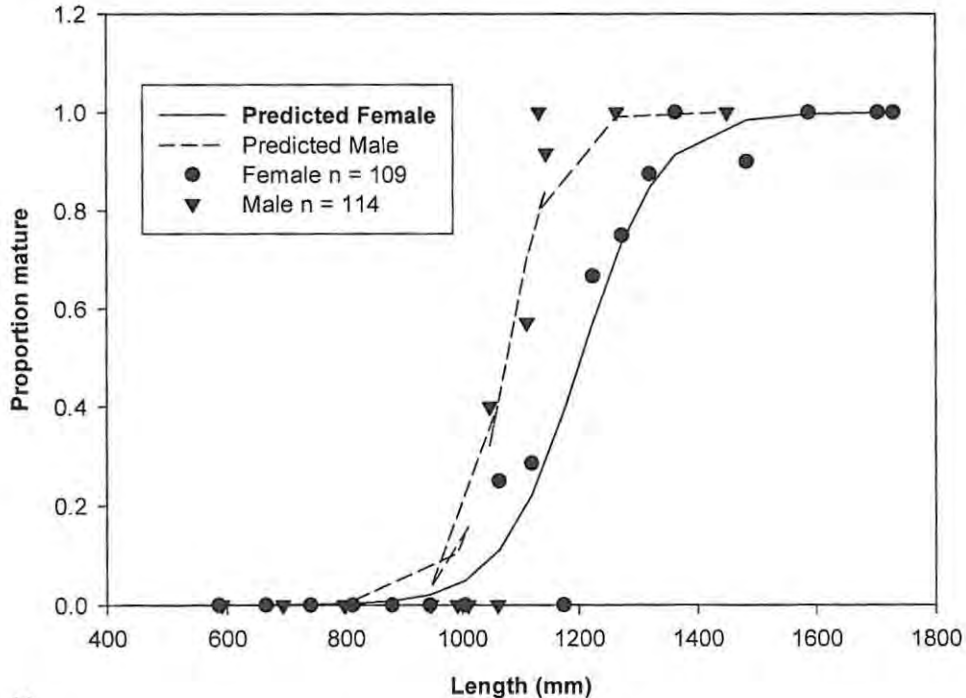
Length and age at 50% maturity are illustrated in Figure 4.7. The A_{50} of the combined sexes was 9.93 years, corresponding to a length of 1216.43 mm (TL). A_{50} of the females was 10.75 years, corresponding to a length of 1234.33 mm (TL), whilst A_{50} of the males was 9.1 corresponding to a length of 1106.78 mm (TL). L_{50} of the combined sexes, females and males was 1078.11 mm (age 7), 1204.54 mm (age 9) and 1077.98 (age 7) respectively.

Females matured at 1234 mm (TL) and 10.75 years, while males mature at 1106 mm TL and 9.1 years. The likelihood ratio tests showed significant differences in maturity rates between females and males (Fig 4.7).

Using combined sex data, *M. mustelus* matured at 1216 mm TL and 9.13 years, respectively.



a)



b)

Fig 4.7 Age and length at 50% maturity for *M. mustelus* a) age at 50% maturity (n = 223), b) length at 50% maturity (n = 223).

4.4 Discussion

The size and age composition of the catches provides valuable information which proportion of the population is frequently targeted (Bonfil, 2004). The size composition data showed that the highest frequency of smoothhound sharks caught in the Eastern Cape coast are significantly larger at 1400 mm (TL) than those caught on the Southern Cape coast 1000 mm (TL) ($p < 0.05$). Size composition of catches off the Eastern Cape coast ranged from 600-1700 mm (TL), whilst those in the Southern Cape coast ranged from 700-1800 mm (TL). Size composition of females range from 600-1700 mm (TL) along the Eastern Cape coast and 800-1700 mm (TL) along the Western Cape coast.

Females matured at 1204 mm (TL) corresponding to an age of 9.1 yrs. However, they only begin to get targeted at 800 mm (TL) in the Southern Cape, whilst 600 mm (TL) size classes are being targeted in the Eastern Cape. The majority of females are therefore targeted at a size well below that of 50% maturity on both coasts. This is was not the case for male smoothhounds. Males are caught from 700-1600 mm (TL) in the Eastern Cape and between 700-1800 in the Southern Cape coast. The majority of males are caught at lengths above 50% maturity in the Eastern Cape and below 50 % maturity in the Southern Cape coast.

Only the lengths 800-1450 mm (TL) fall within the ranges of acceptable weights for processing; that is between 1.5 and 12 kg (Chapter 3). Sharks under 800 mm (TL) and over 1450 mm (TL) have little commercial value due to their mercury content (Chapter 3). Numbers of animals between 1210 mm (TL) to 1450 have a lower value than 800-1210 mm (TL). Catches observed in the Southern Cape coast factories fall closer within these ranges than those from the Eastern Cape coast. Southern Cape catches also tends to drop after 1210 mm (DOCL) as the value of smoothhound sharks over this range is low. Finning earns the most profit from sharks. Therefore, it appears from the size composition data that more *M. mustelus* are caught for fins in the Eastern Cape than in the Southern Cape coast.

Modeled length at age revealed the *M. mustelus* grow rapidly. *M. mustelus* as a whole reach an asymptotic length of 2252.1 mm (TL), and a maximum age of 25 was observed. Of interest is that maximum recorded ages for *Mustelus* are seldom over 13 years. Moulton *et al.*, (1992) showed that female *Mustelus antarcticus* reach a maximum age at 16+ years, which is older than *M. manazo* (9+) (Tanaka & Mizue., 1979) and *M. californicus* (9+) (Yuden *et al.*, 1990).

Differences in growth rate was observed between the males and females. Females reach a larger asymptotic length than males at 2202 mm (TL) and 1713 mm (TL), with males attaining their asymptotic length faster than females. A difference in growth rates between female and male sharks has been demonstrated for other *Mustelus* species (Moulton *et al.*, 1992). Species from the genus *Mustelus* that exhibit this differential growth rate include *M. antarcticus* (Moulton *et al., 1992*), *M. manazo* (Taniuchi *et al.*, 1983; Cailliet *et al.*, 1992), *M. californicus* (Yudin & Cailliet, 1990). Differential growth patterns between sexes in other genera include *C. tilstoni*, *C. sorrah* (Davenport & Stevens, 1988), *C. limbatus* (Killam & Parsons, 1989) and *G. galeus* (Ferreira & Vooren, 1991; McCord., 2005).

Age and length at 50% maturity was estimated at 9 years and 1078 mm TL. Values found in this study are relatively high when compared to maturity data for other *Mustelus* species (Francis & Mace, 1980; Francis, 1989; Francis & Maolagáin, 2000). Low estimates of age at 50% maturity can be explained by sampling bias, location of capture (sexual and size segregation), underestimation of ages, and high levels of fishing pressure resulting in a decrease in age at maturity. Fishermen and shark processing facility owners developing the fishery have previously ignored areas that historically have shown catches of larger size sharks (i.e Western Cape coast). Coupled with this lack of development and interest shown by fishermen in these areas, known nursery areas where large females are distributed are often closed to fishermen as marine protected areas such as St Croix island in Algoa Bay and Langebaan Lagoon). Although this is widely suspected, few studies regarding shark composition in these areas have been conducted.

A long-term illegal gill net fishery is suspected to exist in Langebaan Lagoon (Smale, *pers comm..*, BayWorld, 2007). As the majority of smoothhound sharks caught in gill-nets are juveniles (Lamberth, 2006), and considering the possibility of Langebaan lagoon being a nursery area, further research is required.

It is a well-documented phenomenon that high levels of fishing pressure may lead to a decrease in age at 50% maturity (Buxton, 1993; Barot *et al.*, 2003; Engelhard & Heino, 2004). This has been shown in *M. antarcticus* (Walker *et al.*, 1998). This change is present in fisheries where larger fish are selected over smaller, younger fish. This results in a shift in life-history characteristics compensating for over-fishing the reproductively active component of the population. Although this phenomenon is not likely for smoothhound sharks targeted in South Africa, as relatively small sharks are targeted, accurate historical data are not available. Therefore, it is unlikely that the *M. mustelus* population has been exploited at levels that show density-dependent responses to stock reduction.

Both natural and fishing mortality were estimated at 0.08 yr^{-1}. This estimate was accepted as within an acceptable range for *M. mustelus* as they have relatively long life spans. McCord (2005) found natural mortality estimates of 0.13 $year^{-1}$ to be appropriate for *G.galeus* caught in South Africa. Natural mortality rates are not available for *M. mustelus* caught in other regions, but have been estimated for other species in the genus (*M. californicus* and *M. henlei* at 0.37 $year^{-1}$ and 0.29 $year^{-1}$ respectively (Moulton *et al.*, 1992; Cailliet *et al.*, 1990). Natural mortality for other demersal sharks; *C. falciformis*, *C. obscurus*, and *C. Taurus,* were estimated at 0.18 $year^{-1}$, 0.11 $year^{-1}$, and 0.26 $year^{-1}$ respectively (Bonfil, 1990; Bonfil, *et al.*, 1993; Simpfendorfer *et al.*, 2002; Branstetter & Musick, 1994).

Accurate estimates of natural mortally are vital indicators of population dynamics and allow for sensible estimates of rates of sustainable exploitation (Simpfendorfer *et al.*, 2004). It has been shown that many sharks including *G. galeus* exhibit age-independent natural mortality after a certain age (Punt & Walker, 1998). Prince (2005) showed that restricting fishing to a few juvenile age-classes proves to be a robust management strategy for elasmobranches. This is highly effective if older adults are protected from fishing mortality. He emphasized that this management strategy is more effective with species exhibiting low productivity and higher longevity. The restrictions of the fishery regarding mercury bans and consequently economic value also limit the fishery

In conclusion, this chapter has estimated age and growth parameters, and estimates ages at maturity and mortality rates. Estimates of age and growth parameters indicate that *M. mustelus* as with all sharks are long-lived sharks maturing at late ages and demonstrating a susceptibility to exploitation. Comparisons with other studies on life-history of sharks from the genus *Mustelus* have shown that estimates are reasonable although some are slightly higher than expected. These estimates need to be improved with dedicated sampling of smoothhound sharks at more varied length classes and in higher numbers. More important is the need to validate age estimates. This is especially pertinent in the South and West Cape of South Africa where demersal sharks are being increasingly targeted.

CHAPTER 5

STOCK ASSESSENT OF THE SMOOTHHOUND SHARK (*MUSTELUS MUSTELUS*) POPULATION OF SOUTH AFRICA

5.1 Introduction

Stock assessment encompasses the use of various mathematical and statistical methods to make quantitative predictions about the response of a fish population to alternative management choices (Hillborn & Walters, 1992). To conduct a stock assessment certain data inputs are required.

General inputs required for stock assessment methods include both fishery-independent and fishery-dependent data on catches, biological data (such as growth, maturity, selectivity and mortality), and in some instances environmental data. General outputs include status of the resource, estimates of long-term sustainable yield and optimal harvesting and effort levels. One of the most important outputs from a stock assessment are biological reference points (BRPs) as they are commonly used as a guide for management decisions. These are values representing the state of a resource and are believed to be useful for management of a stock through providing information of its status relative to a chosen acceptable value or range (Booth, 2004).

Stock assessments have frequently been utilized for teleosts but have been neglected for elasmobranch populations. The few attempts at assessing elasmobranch resources of shark stocks have produced ambiguous results owing to insufficient data or the use of models integrating invalid assumptions (Anderson, 1990; Cortés, 2002). Examples of various elasmobranch stock assessment approaches, adapted from Bonfil (2004a), are summarised in Table 5.1.

Table 5.1. A referenced selection of various shark fisheries, the species targeted, the assessment methods in use, and current resource status (Bonfil, 2004b)

Fishery	Species	Catch level	Management System	Stock Assessment method	Status	Main References
Southern Australian shark fishery	*Galeorhinus galeus*, *Mustelus antarcticus* and others	2 800 t/y	Controls on amount of gear (licences)	Surplus Production, Delay-difference and Age-structured models	Overexploited, under severe recovering regulations	Walker (1999) Xiao (1995) Punt & Walker (1998) Walker (1992)
Canadian Porbeagle fishery	*Lamna nasus*	850 t/y	TAC (250 t). Fishing licenses plus fishing restrictions	Catch curves, catch rate trends, age-structured model	Overexploited, under severe recovering regulations	Campana *et al.* (2001)
New Zealand shark fisheries	*Galeorhinus galeus*, *Squalus acanthias*, *Callorhinchus milli*, *Mustelus lenticulatus*, *Raja spp*. *Hydrolagus spp*. and other 15 species.	17 000t/y	ITQs and TACs	None, quotas established through ad hoc methods (proportions of past catches)	Recovered after overexploitation or unknown	Francis & Shallard (1999)
East coast of US shark fishery	39 species mostly *Carcharhinus*	3 500t/y	TAC	Bayesian Surplus Production Models	Overexploited, under recovering regulations	McAllister & Pikitch (1998a,b) Branstetter (1999)
Gulf of Mexico shark fisheries	35 species mostly *Carcharhinus*	12 000t/y	5 prohibited species and other simple regulations	None	Unknown, likely heavily overexploited	Bonfil (1997) Castillo *et al.* (1998)
Argentinean shark fisheries	*Mustelus schmitti*, *Galeorhinus galeus*, *Carcharhinus brachyurus* and other 10 spp	30 000t/y	None	None	Unknown, likely heavily overexploited	Chiaramonte (1998)
U.S Atlantic, and Gulf of Mexico	9 species of small and large coastal sharks	12 85 mg /y	TAC	Surplus production, Lagged recruitment survival and growth model, Schaefer,	Unknown, likely overexploited	Cortés (2002) Cortês *et al.* (2002)
South Africa	*G. galeus*	Actual levels unknown	None	Yield per recruit	Overexploited	McCord (2005)

There is a trend towards using data-intensive age-structured models for stock assessment (Quinn & Deriso, 1999). Stock assessment approaches involving long-lived slow growing organisms in particular, are moving towards employing these methods in an attempt to include an explicit age-structured component which was only implicit within the surplus production and delay-difference models that were used previously (Punt, 1991; Polachek *et al.,* 1993; Prager *et al.*, 1994; Babcock & Pikitch, 2001).

One shark stock assessment has been completed in South African. This was for the soupfin shark, *G. galeus* resource (McCord, 2005). Her per-recruit analysis suggested that the stock was overexploited.

In South Africa there has also been move towards using age-structured assessment approaches. Unfortunately, due to the lack of infrastructure within government institutions that collect primary data on catch and effort, and the general difficulty collecting elasmobranch data, the data collected are considered poor and therefore fully age-structured models are out of reach. There is, therefore, a need to find a compromise solution to provide interim results using those data which are available. This chapter presents a stock assessment attempts to find this compromise and presents a stock assessment of the smoothhound shark fishery based on per-recruit and replacement yield approaches

5.2 Materials and Methods

The modeling framework

Bonfil (2004a) encourages the use of a suite of models, including simple and complex models, to describe the state of an elasmobranch resource. The determining factor for any assessment however, is the data available. The type of output, i.e. BRPs and catch limits, is also limited to certain models.

The types of data available for this study were limited. They consist of some fishery-dependent catches, some fishery-independent estimates of abundance from research biomass surveys, and some biological data. These are summarised in Tables 2.1, 2.2 and 5.2.

The possible stock assessment options for the *M. mustelus* resource are therefore restricted to a combination of Dynamic Pool and Surplus Production Models. The dynamic pool models require no catch data as an input but can provide fishing mortality-based BRPs as outputs. The surplus production model requires catches and estimates of relative abundance as its inputs with catch and effort limits and BRPs as outputs.

Three dynamic pool models were used for the purpose of this study; yield per recruit, spawner biomass per recruit, and an extended yield and spawner biomass per recruit. The former two are steady-state approaches. Given the longevity of elasmobranches, this per-recruit model was extended over a 20 year time-frame to simulate resource responses to management options. The surplus production method chosen was the replacement yield model. This is a simplified biomass dynamic modeling approach that estimate that harvest level required to maintain current exploitable biomass at medium-term levels.

Model descriptions

Per-recruit analysis

Yield (YPR) and Spawner biomass per recruit (SPR) were calculated as:

$$YPR = \sum_{a=0}^{\max} W_{a+\frac{1}{2}} \tilde{N}_a \frac{S_a F}{M + S_a F}\left(1 - e^{-M - S_a F}\right)h_a$$

$$SPR = \sum_{a=0}^{\max} W_a \tilde{N}_a \psi_a$$

where W_a is weight at age a, $\widetilde{N}_a$ is the relative numbers at age a, M is the age-invariant natural mortality rate, S_a selectivity at age a, F the fully-selected age-invariant fishing mortality rate, Ψ_a maturity at age a, and *max* the oldest aged fish in the population.

Numbers at age

Relative numbers, $\widetilde{N}_a$, at age were estimated by the recursive equation:

$$\widetilde{N}_a = \begin{cases} R_0 & \text{if } a = 0 \\ \widetilde{N}_{a-1} e^{-M - S_{a-1}F} & \text{if } 0 < a < \max \\ \dfrac{\widetilde{N}_{\max-1} e^{-M - S_{\max-1}F}}{1 - e^{-M - S_{\max-1}F}} & \text{if } a = \max \end{cases}$$

where R_o is the number of age-0 recruits.

Length and weight

Length at age was estimated with the standard von Bertalanffy growth model as

$$L_a = L_\infty \left(1 - e^{-K(a - t_0)} \right)$$

and weight-at-age as

$$W_a = \varphi L_a^{\xi}.$$

were φ and ξ are the length-weight regression coefficients.

Age-specific selectivity

Age-specific selectivity was estimated using length-converted ages, and was modeled using a logistic ogive (Butterworth *et al.*, 1989) as:

$$S_a = \left(1 + \exp\left(-\left(a - a_{50}\right)/\delta\right)\right)^{-1}$$

where a_{50} is the age at 50% selectivity, and δ is the parameter that describes the inverse of selectivity rate. As δ approaches zero, this function approaches knife-edged selection (Butterworth *et al.*, 1989).

Inclusion of a stock-recruitment relationship

Traditional per-recruit approaches do not include a stock-recruit relationship. Therefore, irrespective of extant spawner biomass levels and fishing mortality rate, there will always be constant recruitment. In this scenario, $R_0 = 1$. To include some biological realism into the assessment framework, a Beverton-Holt (1957) stock recruitment relationship was included such that

$$R = \frac{SB}{\alpha + \beta SB}$$

where α and β are the parameters that define the stock recruitment curve.

The Beverton and Holt stock-recruitment relationship can be reparameterized in terms of a single "steepness" parameter h which represents that proportion of pristine recruitment when spawner biomass is reduced to 20% of pristine levels.

Therefore, in terms of R_0,

SB_0 and h, $\alpha = \dfrac{SB_0(1-h)}{4hR_0}$ and $\beta = \dfrac{5h-1}{4hR_0}$.

The model is based on a per-recruit basis such that recruitment as a function of fishing mortality is therefore calculated as $R(F) = \dfrac{SPR(F) \times R(F)}{\alpha + \beta SPR(F) \times R(F)}$, which reduces to $R(F) = \dfrac{SPR(F) - \alpha}{\beta SPR(F)}$ and the stock-recruitment parameters are adjusted to $\alpha = \dfrac{SPR_0(1-h)}{4h}$ and $\beta = \dfrac{5h-1}{4h}$.

Age-structured extended per-recruit model

The steady-state per-recruit model was extended to assess the relative effects of a variety of management interventions on the current status of the smoothhound shark resource over the long-term. This was justified because *M. mu*stelus is a long-lived species. This longevity affects management decisions, which on their own are long-processes.

The model was considered to be fully age-structured and was initiated in 2004 to have the same age-structure as the per-recruit model. The model was extended for an additional 20 years and included both stochastic recruitment and fishing mortality.

Numbers at age

Initial age-structure was calculated as in the standard per-recruit analysis, while subsequent years was calculated as

$$N_{y+1,a} = \begin{cases} R_{y+1} & \text{if } a = 0 \\ N_{y,a-1}e^{-M-S_{a-1}F_y} & \text{if } 0 < a < \max \\ N_{y,\max-1}e^{-M-S_{\max-1}F_y} + N_{y,\max}e^{-M-S_{\max}F_y} & \text{if } a = \max \end{cases}$$

Stock-recruitment relationship and fishing mortality

Recruitment as a function of the previous year's spawner biomass per recruit was assumed to log-normally distributed such that

$$R_y = \left(\frac{SPR_{y-1} - \alpha}{\beta SPR_{y-1}}\right)e^{\varepsilon-\sigma^2/2} \text{with } \varepsilon \sim N(0,\sigma^2)$$

Fishing mortality was also considered to be log-normally distributed as $F_y = F_y e^{\varepsilon-\frac{\sigma^2}{2}}$ with $\varepsilon \sim N(0,\sigma^2)$. A coefficient of variation of 20%, such that $\sigma = 0.2$, was considered appropriate to the analysis as it added an aspect of stochasticity into the deterministic model.

Replacement yield

Many elasmobranch resources have been assessed using dynamic surplus production models (Walker, 1999; Xiao, 1995; Punt & Walker, 1998; McAllister & Pikitch 1998a; McAllister & Pikitch, 1998b; Branstetter, 1999 ; Cortés, 2002; Cortés *et al*., 2002). Given known catches (C_y) and one or more estimates of relative abundance (I_y), the biomass of the resource can be modeled as $B_y = B_{y-1} + g(B_{y-1} \mid \theta) - C_{y-1}$, where $g(B_y - 1 \mid \theta)$ is the net growth function based on the pervious years biomass with a parameter vector θ.

Examples include Schaefer's (1957), Fox's (1970) and Pella &Tomlinson's (1969) parameterizations.

The parameter vector θ is estimated by minimising a negative log-Normal likelihood of the form

$-\ln L = \sum_i \left[\frac{n_i}{2} \ln \sigma_i^2 + \frac{n_i}{2} \right]$ where the variance for each biomass index i over years y is given as $\sigma_i^2 = \frac{1}{n_i} \sum_y \left(\ln B_y - \ln qI_y \right)^2$ and n_i the number of observations in each biomass index i.

An alternative approach is to assume that the net growth function can be replaced by its temporally invariant replacement yield. Therefore, for population biomass to remain in equilibrium, then the catches should equal the replacement yield. Replacement yield (RY) and the exploitable biomass in 1986, B_{1986}, are then treated as estimable parameters, such that:

$$B_y = B_{y-1} + RY - C_{y-1}.$$

In this approach, the maximum likelihood solution is obtained by minimising the negated log-likelihood.

Model execution and data used within each analysis

Per-recruit and extended per-recruit analyses

The data used in the per-recruit and extended per-recruit analyses are summarised in Table 5.2.

Table 5.2 Summary of the input parameters used in the yield-per-recruit analysis for *M. mustelus* in South Africa.

Parameter	Definition	Estimate	Source
k	Brody growth coefficient (rate at which maximum theoretical length is reached)	0.08 yr^{-1}	Chapter 4
L_{∞}	Maximum theoretical length	1946.2 mm (TL)	Chapter 4
t_0	Theoretical age at zero length	-3.6	Chapter 4
M	Age-invariant natural mortality	0.08 yr^{-1}	Chapter 4
Z	Instantaneous rate of total mortality	0.16 yr^{-1}	Chapter 4
F	Fishing mortality	0.08 yr^{-1}	Chapter 4
φ	Length-weight regression coefficient	0.062	Dulcic & Kraljevic (1996)
ξ	Length-weight regression coefficient	2.758	Dulcic & Kraljevic (1996)
A_{50}	Age at which 50% of animals are mature	9.93 yr	Chapter 4
δ_m	Inverse rate at which animals mature	0.44	Chapter 4
S_a	Selectivity	1.4 yr	Chapter 5
δ	Inverse rate at which animals re selected	0.02	Chapter 5
max	Maximum age	25	Chapter 4
h	Steepness parameter	0.8	This chapter

In the per-recruit model, three BRP's were estimated; F_{MAX} (the fishing mortality that maximizes the YPR curve), F_{SB40} (the fishing mortality at which SPR is reduced to 40% or pristine levels) and $F_{0.1}$ (the fishing mortality at which the slope of the YPR curve is 10% that of the origin).

These BRPs were then included as possible harvesting levels in the age-structured model where the resource was fished for a total of 20 years. Three different harvesting scenarios were considered. These were a *Status quo* situation, second was *Size control* (only sharks over 3 years were harvested), third was *Effort control* from F=0.08 yr^{-1} to F=0.04 yr^{-1} over 10 years and F=0.04 yr^{-1} thereafter, *Size and effort control* (combining the first two), and last was *Fishery closure* (no fishing effort) (Table 5.3)

Table 5.3 Summary of five different management scenarios used to harvest *Mustelus mustelus* within and extended per-recruit analysis model.

Scenario	Fishing mortality	Selectivity
Status quo	F = 0.08 yr^{-1} for all years	Retain current age at selectivity (a_{50}) at 1 year of age
Size control	F = 0.08 yr^{-1} for all years	Increase age at selectivity from 1 to 3 years of age immediately
Effort control	Decrease from F = 0.08 yr^{-1} to F = 0.04 yr^{-1} over the first 10 years, and for the second 10 years, F = 0.04 yr^{-1}	Retain current age at selectivity at 1 year of age
Size and effort control	Decrease from F = 0.08 yr^{-1} to F = 0.04 yr^{-1} over the first 10 years, and for the second 10 years, F = 0.04 yr^{-1}	Increase age at selectivity from 1 to 3 years of age immediately
Fishery closure	Zero fishing mortality.	Retain current age at selectivity at 1 year of age

For each year, within each scenario, yield and spawner biomass, average yield over the period, and minimum spawner biomass, increase in spawner biomass in relative to the first assessment year, the average spawner biomass, and the probability of spawner biomass dropping below 80% of current levels were calculated.

A total of 500 Monte-Carlo projections were conducted per scenario.

Replacement yield model

Data used for the replacement yield model was obtained from the research survey biomass indices, demersal longline and line fishery catches.

The first assumption of this model is that the research vessel, in the case the *Africana*, catches 75% of what is in front of the net. Although the otter boards of the trawling net would herd fish into the net, sharks have the ability to sense the disturbance in the water and evade the net (especially larger sized sharks) (Cortéz & Parsons, 1996). Therefore $q = 0.75$.

The second assumption was that the *RV Africana* biomass indices for *Mustelus* spp. accurately represent the biomass of *Mustelus mustelus*. The *RV Africana* shows biomass indices for *Mustelus* spp. which combines *Mustelus mustelus* and *Mustelus palumbes*. *M. palumbes* is more commonly caught in research survey catches.

The key uncertainties associated with this model are the exact level of reporting rate, the accuracy of the catches and whether the term 'sharks' is in fact smoothhound sharks (investigated in Chapter 2). As repeated trends were observed with the data a retrospective analysis was completed on the length of the Western and South Coast data set, to determine whether observed repeated trends over were coincidental or as result of time series repetition. Reporting rate of the linefish, longline, and trawl fisheries was estimated at 21.48 %

Replacement yield (*RY*) was statistically estimated, and the average observed catch higher than *RY* calculated. Parameter variability was estimated by bootstrapping the replacement yield data 1000 times for both the West and South Cape coasts. Retrospective analysis was conduced on an annual basis. This analysis allowed for the estimation of uncertainty regarding the estimated biomass relative to the magnitude of errors (measurement, identification etc) regarding the year of data collection. It also provided an estimate of a maximum time period necessary for change to be observed relative to the catch data.

5.3 Results

Per-recruit analysis

Maximum yield per recruit fluctuated with changes in natural mortality (Figure 5.1) with the highest YPR attained at the lowest level of natural mortality (0.05 year^{-1}). $F_{0.1}$ and F_{MAX} increased with increasing natural mortality. $F_{0.1}$ ranged from 0.03-0.08 year^{-1} and F_{MAX} ranged from 0.05 - 0.1 year^{-1}. This indicates that productivity increases with increasing natural mortality.

Fishing mortality ranged from 0.05-0.16 year^{-1} using the different empirical methods. Fishing mortality (F = 0.08 yr^{-1}) is higher than $F_{0.1}$. This suggests that the current exploitation level is above optimal levels. Typical per-recruit effects can be noticed with relative yield-per-recruit increasing quicker if sharks are harvested prior to sexual maturity. SPR was not significantly affected by increasing mortality (Fig 5.1) although SPR slightly decreased with decreasing natural mortality, with the highest levels attained with Pauly's (1980) method (M = 0.16 year^{-1}). F_{SB50} ranged between 0.03 - 0.06 year^{-1}.

As a percentage of the pristine pre-exploitation level, current SPR is at 21%. Spawner biomass-per recruit, decreases rapidly with small increases in fishing mortality and with selection before sexual maturity. This indicates that spawner biomass is lower than the optimal level as a percentage of the pristine unfished condition. These different estimates of spawner biomass suggest that an increase in fishing pressure will result in drastic recruitment over-fishing. The $F_{0.1}$ and F_{SB50} BRP's were similar for sharks fished at current selection levels and when selection was increased to 3 years.

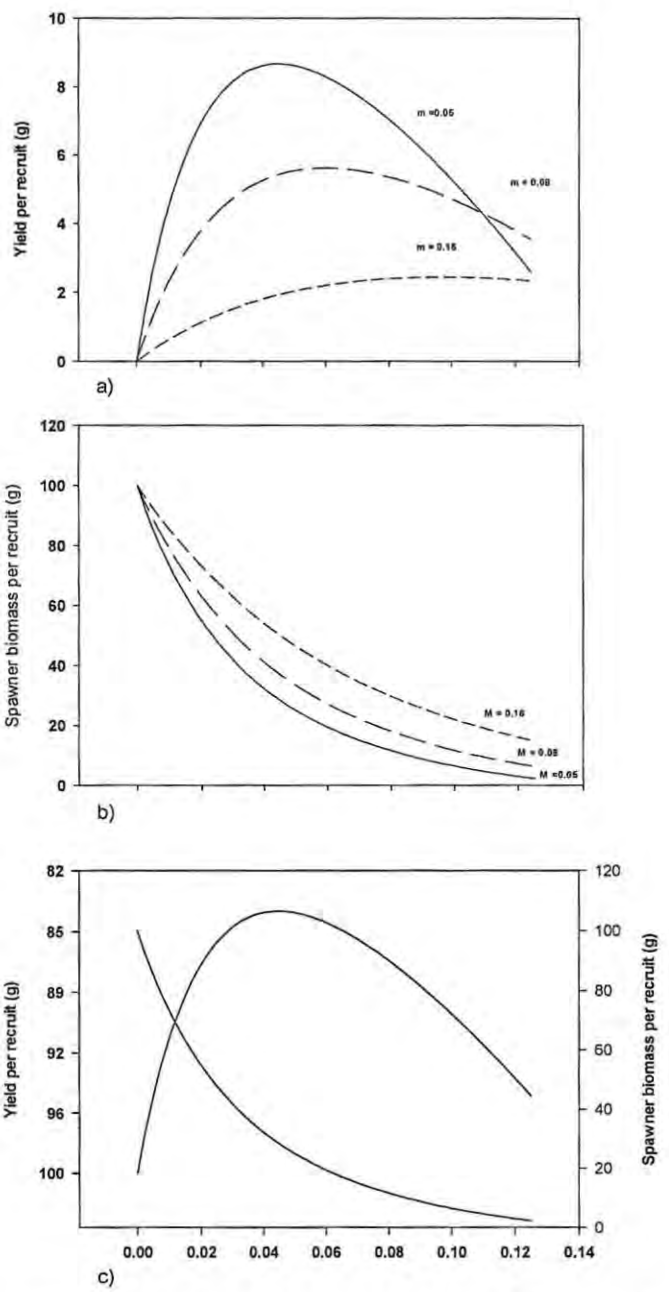


Fig 5.1. Yield-per-recruit (Y/R) and spawner biomass per-recruit (SB/R) as functions of fishing mortality for *M. mustelus* at current age at first capture (t_c = 1.4 years) a), b) and c) (t_c = 3 years). Natural mortality (*M*) was estimated at different levels (0.05 y^{-1}, 0.08 y^{-1} and 0.16 y^{-1}) a) and b), with c) at 0.05 y^{-1}

The extended per-recruit analysis

The per-recruit analysis suggested that the current exploitation level ($F = 0.08$) was at optimal levels.

Different scenarios shown in Table 5.3 was used to quantify potential long-term trade-offs between maximum yield whilst limiting the risk of possible reproductive failure within twenty years (Table 5.4, Fig 5.2).

The *Status quo* management intervention signifies the fisheries state at current fishing levels with no management intervention. The probability of spawner biomass dropping below 80% of current levels was 0.71±0.02. The probabilities mentioned above relative to management intervention ranged from highest to lowest are as follows (0.4, 0.3, 0.2 and 0) as *Effort control*, *Size control*, *Size and effort control*, and *Closure*. The minimum potential change in spawner biomass at *Status quo* is at 0.58±0.3. This risk ranges from 0.58-1.00. The lowest potential depletion levels in spawner biomass relative to management intervention is 0.58, 0.78, 0.83, 0.91 and 1 as *Status quo*, *Effort control*, *Size Control*, *Size and effort control* and *Closure*. The standard deviation which denotes the uncertainty regarding change in spawner biomass relative to 2006 decreases from *Status quo*, *Effort control*, *Size control*, *Size and effort control*, and *Closure*. Average yield in 20 years is highest with *Size control* as a management intervention. This is followed by *Size and effort control*, *Status quo*, *Effort control* and *Closure*. The average change in spawner biomass increases significantly from *Status quo*, *Size control*, *Effort control*, *Size and effort control* and *Closure*.

Table 5.4 Results of the age-structured per-recruit model from Monte Carlo projections at various management interventions; *Status quo*, *Size control*, *Effort control*, *Size and effort control*, and *Closure*. Results presented are the mean, standard deviation and 95% confidence intervals after 500 Monte Carlo simulations.

Management intervention	Mean	Standard deviation	95% CI
Probability of spawner biomass dropping below 80% of current levels in 20 years			
Status quo	0.72	0.02	0.04
Size control	0.33	0.02	0.04
Effort control	0.43	0.02	0.04
Size and effort control	0.18	0.02	0.03
Closure	0.00	0.00	0.00
Lowest potential depletion levels			
Status quo	0.58	0.30	0.59
Size control	0.83	0.23	0.45
Effort control	0.78	0.26	0.5
Size and effort control	0.91	0.18	0.34
Closure	1.00	0.00	0.00
Average yield in 20 years			
Status quo	915.72	158.07	309.8
Size control	1155.71	85.55	167.77
Effort control	866.75	100.60	197.20
Size and effort control	979.24	88.42	173.30
Closure	0.00	0.00	0.00
Relative change in spawner biomass over 20 years			
Status quo	-0.00	0.03	0.05
Size control	0.02	0.03	0.06
Effort control	0.07	0.05	0.09
Size and effort control	0.09	0.05	0.10
Closure	0.19	0.09	0.18

Replacement yield

The replacement yield model estimated for *M. mustelus* caught in the shark fisheries is illustrated in Fig. 5.3 (South and West Coast). The 95% confidence intervals associated with both with both trend are wide, which is expected, as the data series for both models are short. The coefficient of variation on the South Coast for the biomass starting 1986 was estimated at 20% with a 29% CV associated with the replacement yield value. The CV associated with the model for the West Coast was estimated for the biomass starting in 1986 and the replacement yield as 14% and 41%, respectively. The replacement yield in the South Coast and West Coast was estimated at 387.26 and 68.64 t, respectively; the Southern Cape replacement yield is 17.7% higher than on the West Coast (Table 5.5).

Fig. 5.3b and 5.3d illustrate the 95% confidence intervals associated with the data from the South and West Coast respectively. Greater variance on the South Coast is greater in earlier years (prior to 1990), variance is greater prior to 1990 and after 1998 for data collected from the West Coast.

Table 5.5. Replacement yield model parameter point estimates, mean, associated standard errors (SE), coefficient of variation (CV), and upper and lower 95% confidence intervals (LCI & UCI). Results have been presented for the replacement yield models in the South and West Coast.

	Point estimates	Mean	SE	CV	95% Confidence Intervals
South Coast					
B_{1986}	6118.52	6144.43	1240.94	20 %	(3994.24-8746.14)
RY	387.26	392.55	113.71	29&	(158.17-604.10)
West Coast					
B_{1986}	2188.13	2201.58	309.76	14 %	(1694.32-3785.67)
RY	69.50	69.35	28.51	41 %	(15.91-123.32)

The average catches over the past decade are 2.5 times higher than the replacement yield on the South Coast and 1.30 on the West Coast. The retrospective analysis was completed on the length of the western and South Coast data set showed an effect in 14 years without duplication of trends. Therefore it can be concluded that although biomass may be decreasing, biomass is duplicated every 14 years irregardless of catches, and that only 14 years of data is required for a change in biomass at current fishing levels to be observed.

5.4 Discussion

Estimating the selectivity of a gear is necessary to estimate the age or size that fish enter a fishery. Selectivity is therefore an important factor especially in a multigear fishery when management recommendations are being considered regarding type of gear utilized and size restrictions (Bonfil, 2004b). *M. mustelus* were found to recruit into the various fisheries at 1.4 years, corresponding to a length of 625 mm (TL). Due to the nature of the data and the paucity of data regarding gear type and selectivity, selectivity of the longline fishery and the line fishery could not be independently determined. However, measurements made at factories suggest that smoothhounds start being landed at 400 mm (TL) with most sharks falling within the 600 mm (TL) range (Chapter 4.). Age at selectivity is also smaller than age at maturity (3 years). Selectivity is further complicated as it is more determined by weight than by length, as mercury content is lower in smaller sharks (Chapter 4). An age of 1.4 years corresponds closely to the minimum size (500mm) of smoothhound sharks of economic value (large enough to process). In a similar study conducted by McCord (2005), the low incidence of larger, older *G. galeus* in the South African longline fishery was thought to be a result of a highly migratory nature, and offshore movement of adults. Although smoothhound sharks show similar sexual and age segregation larger adult *M. mustelus* are not for the most part targeted by fishermen due to low economic value.

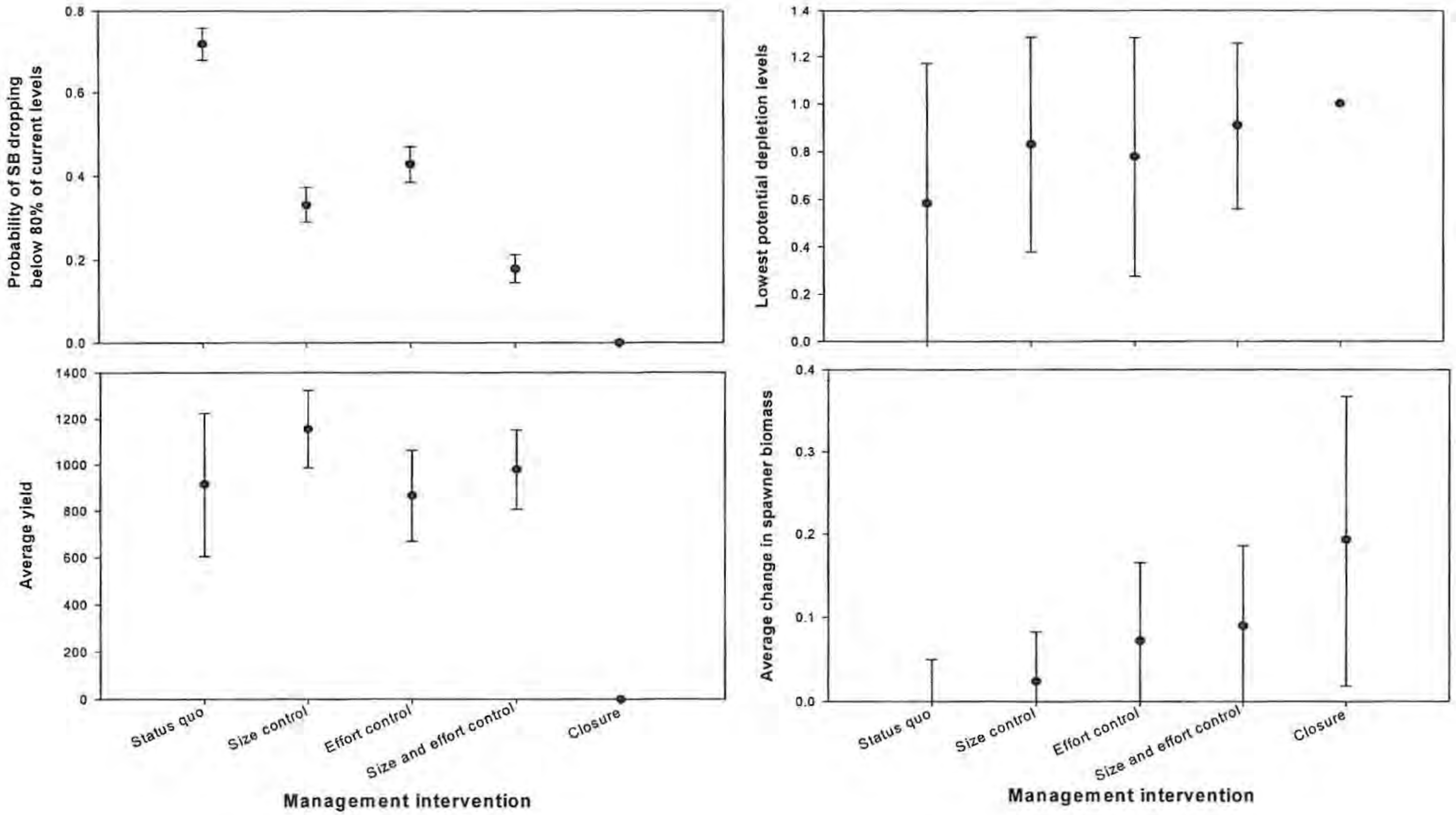


Figure 5.2 Results from the Monte-Carlo simulations from the extended per recruit model at different management intervention scenarios, showing top right the probability of spawner biomass dropping below 80% of current levels, top left; lowest potential depletion levels, bottom right; the average yield and bottom left; average change in spawner biomass.

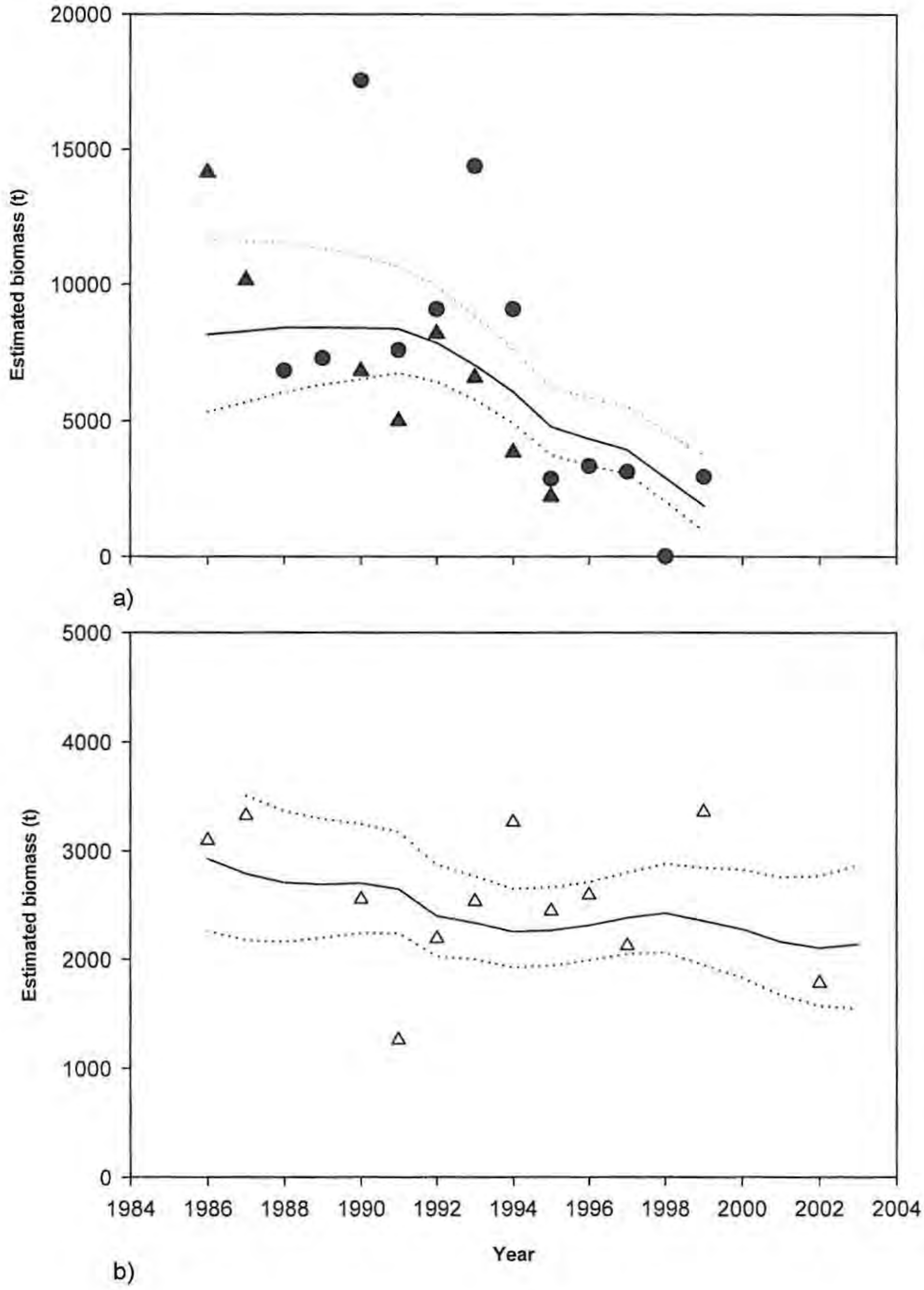


Figure 5.3 Replacement yield model estimated at 21.48% reporting rate showing *Africana* biomass indices of *Mustelus* spp from the South and West Coast of South Africa with upper and lower confidence intervals a) South Coast with upper and lower confidence intervals b) West Coast with upper and lower confidence (symbols denote biomass indices (circles denote spring biomass, and triangles denote autumn biomass indices on the South Coast), solid lines denote predicted estimates).

Per recruit analyses were used to assess stock status of *M. mustelus*. This method was chosen among other commonly used methods for sharks due to lack of accurate historical catch and effort data. Bonfil (2004a) states that per recruit models are inherently limited by their underlying assumptions. These models assume stock state at equilibrium, and that growth, mortality and recruitment remain constant over time. This is not realistic due to dynamically changing nature of biotic and abiotic marine processes affecting life-history characteristics. Per recruit models are also used to estimate instantaneous responses to fishing. The life-history strategy exhibited by *M. mustelus* and other chondrichthyans denote that such an instantaneous response is an unrealistic expectation. Furthermore, the lack of historical catch data (one of the reasons that the model is favored among managers when regarding the status of a shark stock) signify that future stock status at current fishing levels can not be determined.

These uncertainties were addressed by using three levels of mortality (estimated in Chapter 4) and by using two analytical techniques (equilibrium per recruit analysis and stochastic per recruit analyses with inclusion of an age-structured dynamic production model using Monte-Carlo simulations estimating fishing at various selectivity and fishing mortality rates). These analytical techniques all arrived at similar conclusions.

The findings from this study indicate that the fishery is being overexploited according to various BRPs. Current levels of fishing mortality are higher than both $F_{0.1}$ and F_{SB40}. Due to the sensitivity of the population to potential over-exploitation, and paucity of data regarding spawner-recruit relationship it is more appropriate to base management recommendations on the F_{SB40} biological reference point (Booth, 2004). These results , therefore, highlight the necessity of obtaining more accurate and realistic life history and fisheries information for increased certainty of stock assessment results.

Although effort for the longline shark fishery is comparatively low with as little as four of the 11 permit holders actively targeting sharks, effort in the linefishery is increasing drastically with the decrease of high value teleost species (Griffiths, 1997; Hutton *et al.*, 2001). The present estimate implies that the spawner biomass has been depleted to 21% of pristine pre-exploitation levels. This indicates that a likely increase in effort for smoothhound sharks (as teleost catches drop) will lead to a further decrease in exploitable biomass as a result of recruitment overfishing. The possibility of growth overfishing found by McCord (2005) for the *G.galeus* fishery in South Africa is, however, unlikely due to the low value of animals under 1.5 kg should also be considered with length restrictions

The ASPDM model included in the per-recruit method was useful for assessing the response of the *M. mustelus* resource to various levels of selectivity and fishing levels over a twenty year period. This approach has also made it possible to determine the age at capture and fishing level that optimizes yield. Another benefit of this approach is to determine the maximum exploitation level that the fishery can endure based on the $F_{0.1}$ strategy. The results show that at $F < 0.08$ yr^{-1} for twenty years, the probability of the yield falling below 20% of pristine levels decreases. This would be unrealistic with regards to the smoothhound shark fishery as 944 mm (TL) comes close to the upper size limit of economic value. A more realistic level optimising yield would be at $F = 0.05$ yr^{-1} where the probability of the biomass falling to below 20% of pristine pre-exploited levels in twenty years becomes negligible. The inclusion of the ASPDM model shows the limitation of the standard per recruit model. This model has also allowed for an analysis of possible future scenarios based different levels of exploitation and age at capture. This highlights the importance of not using models estimating instantaneous responses. The long-term trade-offs between maximum yield with different management intervention scenarios show that size and effort control is the best method of protecting smoothhound shark stocks. By this intervention, average yield in 20 years is 69 t lower than at current levels, but the probability of spawner biomass dropping below 80% of current levels is decreased by half.

From the replacement yield model, at current levels of exploitation, the estimated exploitable biomass has decreased even at a low reporting rate of 21.8%. The average catches appear to be 2.5 times higher than the replacement yield estimate. This suggests that 2.5 times the mass of smoothhounds are caught each year as the exploitable biomass replaced. For the *M. mustelus* stocks to remain at equilibrium, fishing levels therefore need to be reduced to the replacement yield estimate (i.e., by 34%). Yield from the fisheries estimated from factory data (Chapter 2) show that 1326 t of smoothhound sharks are landed per year. This is 3.4 times higher than the replacement yield of 387.26 t. It is also higher than the level of $F_{0.05}$ estimated by the ASPDM included in the per-recruitment model if it is assumed that fishing mortality is linearly related to catches. The retrospective analysis showed that a maximum of 14 years data is required to detect notable changes in smoothhound abundance.

Analysis of the data indicates that it is possible that at current levels of exploitation *Mustelus mustelus* are optimal to slightly higher than what is sustainable. These models also highlight sensitive areas where data collection techniques can be improved. A reliable shark database with accurately identified species needs to be developed. These data can be used to create a reliable time series of catch and abundance data from scientific shark dedicated surveys and commercial fisheries from 2006 onwards. This shark-dedicated database should be created, and enforced, with observers collecting accurate data to assess actual levels of underreporting. Identification of species for accurate species breakdown needs to be enforced for future *M. mustelus* stock assessment.

CHAPTER 6

TOWARDS THE DEVELOPMENT OF A PRECAUTIONARY APPROACH TO THE MANAGEMENT OF SOUTH AFRICAN SHARK RESOURCES: AN EXAMPLE OF THE *MUSTELUS MUSTELUS* RESOURCE

The South African *Marine Living Resources Act* (1998) has detailed new objectives for fisheries management. These are built on three pillars of sustainability, equity and stability. The act also emphasizes the necessity of developing fishing industries within a precautionary approach.

Rosenberg *et al.*'s (1993) concept of the sustainable use of resources[1] states that one of most important constraints to meeting its goals applies to the relative (un)certainty of scientific data. This implies that with high levels of scientific uncertainty combined with uncontrolled of catches and limited information on by-catch and discarding levels, traditional methods of management will persistently be unsuccessful (Lauck *et al.*, 1998). The common reaction to uncertainty by fisheries stakeholders is a demand for proof of potential stock collapse (Walters & Martell, 2004). Fisheries management agencies have now been given a mandate to resist such demands in terms of the "precautionary principle" (FAO, 1995; Dayton, 1998).

The precautionary approach is widely accepted as an effective management tool (Nielson *et al.*, 2004), and is used to describe the setting of safety margins in stock biomass and fishery mortality. Although actual implementation of the principle is often difficult (Nielson *et al.*, 2004), Walters & Martell (2004) states that less difficulty would be experienced in developing fisheries where main incentives for creation of the fishery is to decrease economic hardship.

[1] Rosenberg *et al.* (1993 pg 828) notes that the sustainable use of a resource should "meet(s) the needs of the present without compromising the ability of future generations to meet their own needs."

Current fisheries management approaches based on centralized government intervention have proven inadequate in terms almost any set of objectives. These objectives include preventing stock depletion, resolving user-group conflicts, increasing profitability and preventing social disruption (Nielson *et al*., 2004).

At the *Convention for International Trade in Endangered Species of Wild Fauna and Flora* (CITES) during the mid-1990's, proposals were presented seeking restrictions on the trade of shark products (Walker, 2004). The *Food and Agricultural Organization* (FAO) responded by initiating a worldwide process that launched the development of the *International Plan of Action for the Conservation and Management of Sharks* (IPOA-Sharks) in 1999 (Walker, 2004). The IPOA-Sharks provided guidelines and pressure for the approximately 80 member nations for development of *National Plans of Action for the Conservation and Management of Sharks* (NPOA-Sharks) (Walker, 2004). The IPOA-Sharks also provided guidelines for coordination of shark management at global, regional, and sub-regional levels under FAO regulations (Walker, 2004). The IPOA-Sharks forms part of the *Code of Conduct for Responsible fisheries*.

Specific actions identified by the IPOA-Sharks (IUCN, 2002) include:

- Improvement of identification, recording and reporting landings and by-catch at species level
- Improvement of shark product statistics
- Initiation of research and management efforts to CITES operating shark fisheries including:
- Compilation of life-history information
- Biological information
- Data collection
- Distribution
- Reduction of by-catch mortality

Few nations have addressed the issues of sustainable and precautionary management for shark fisheries (Walker, 2004). MCM, South Africa's national fisheries management organization, has recognized the need to adopt a precautionary approach in managing elasmobranch resources (McCord, 2005). This need was addressed by developing a draft management plan for the management plan for sharks in 2002. The objectives set by the management plan have still failed to materialise as the plan has yet to be implemented.

This thesis, and that of McCord (2005), have been the first attempts to develop a realistic management plan for shark species with limited public appeal. In conjunction with the *FAO Technical Guidelines for Responsible Fisheries on the Conservation and Management of Sharks* (2003) those areas that limit sustainable management of demersal shark fisheries are outlined as follows:

- A lack of management at a national level (McCord, 2005)
- Paucity of data regarding stock assessment (Chapter, 5)
- A lack of accurate and historic data (Chapter, 5)
- Insufficient funding required for research
- Limited monitoring of catches due to insufficient funding, resulting in unknown levels of underreporting (Chapter, 5)
- Poor data collection protocols resulting in a shark database that is inaccurate and less than useful
- Lack of identification skills (partly due to dressing of sharks, although most people cannot identify even whole sharks) adding to the poor quality of any fisheries data pertaining to sharks.

Unfortunately, these specific areas are not being addressed in South Africa. The lack of these data should not, however, rescind the development of a precautionary management plan for any demersal species of shark, including *M. mustelus*. It was initially thought that *G. galeus* was the primary target species of the demersal longline and commercial line shark fishery. This study has shown, through dedicated factory sampling (Chapter 3), that *M. mustelus* constitutes the main component of the fishery by 46%, followed by

G. galeus at 20%. In order to complete a stock assessment of *M. mustelus* it was necessary to compile all available smoothhound data. It was also vital to undertake independent sampling to processing facilities to highlight problems, inconsistencies and used to determine data accuracy and precision.

This study has conducted the first preliminary stock assessment of *M. mustelus* and has provided the formation of a draft precautionary management plan (Appendix 2). This is done with other internationally harvested species. Precautionary management plans have been developed for the porbeagle shark (*Lamna nasus*), shortfin mako (*Isurus oxyrinchus*), bull shark (*Carcharhinus leucas*), and hammerheads (*Sphyrna* spp). Considering the depletion of global fisheries mentioned in Chapter 1, especially the gummy and school shark fisheries in Australia, and the sensitivity of elasmobranchs to exploitation, it is therefore imperative for MCM to prevent over-fishing of the *M. mustelus* resource.

Fisheries management plans signify a collection of objectives developed within the framework of national fisheries policy (Walters & Martell, 2004). These policies specify the management process from a premeditated level of present and future goals (Walters & Martell, 2004). Management plans take the form of formal or informal arrangement between management authorities, fishery stakeholders, and provide and implement relevant regulations (McCord, 2005). Shark management plans are generally based on several management tools, including fishing quotas, bag limits, size and/ or gear restrictions, seasonal and area closures, and limited access to fisheries (Bonfil, 2004b).

The starting point for elasmobranch management in South Africa was reached in 2002 by implementation of restrictions governing the exploitation and processing of several shark species and finning. Prohibited elasmobranch species include the white shark *Carcharadon carcharias*, and the whale shark *Rhincodon typus*. Bag limits of 1 shark per recreational fishermen have been placed on con-commercial species such as *Poroderma africanum, Poroderma pantherinum, Triakis megalopterus,* and *Carcharias taurus*. Despite these restrictions, a comprehensive shark management plan is yet to be put into place. The demersal shark fishery of South Africa is in a unique position with regards to developing a management strategy for shark species. This is due to fishery constraints placed on fishermen by processing facilities and the relatively recent development of the fishery. The demersal shark fishery in the south-eastern and south-western Cape coast of South Africa is reasonably small with only 3 active shark-processing facilities (also see Appendix 1) (although more permits have been allocated). A small number of active shark-processing facilities mean that new regulations with regards to shark purposes would be implemented with adequate education. If the remaining permits become activated these fishers should be educated with regards to permit conditions. This should provide the opportunity for the development and implementation of a management plan based on the principle of co-management.

Co-management is an innovative change to the fisheries approach as it implies a power-sharing arrangement between government and fishing communities to undertake joint management (Nielsen *et al.*, 2004). In the case of the South African shark fishery, the fishing communities' component would be replaced by the processing facilities. This approach would eliminate the majority of the limitations concerning management of South African shark species mentioned above. Inadequate funding constraining research would be of little importance as processing facilities already have well-trained staff with regards to accurate identification. The need for monitors at landing points will become inconsequential, as only one monitor per factory is required. Processing facilities have weekly supplies of elasmobranch logs and the majority are willing to provide whole sharks for biological data, which can be used by scientists for research. As shark processing facilities are joint management stakeholders and resource owners, they will understand the consequences of not adhering to shark processing regulations. This will result in a rapid increase in the quantity and quality of data for the use of stock assessment, and the eventual development of a dedicated biologically and realistically thorough elasmobranch database. Observers for fishing vessels also require training. Identification abilities of observers need to be improved with dedicated shark identification workshops. Research surveys should be conducted yearly for collection of detailed biological information for increased certainty in life-history estimations.

Methods to limit latent exploitation by inshore trawl operators need to be investigated. Paper trails from purchases should provide information of vessel type. Inshore trawl vessels commonly catching over a certain percentage elasmobranch by-catch should be reported and fined. In conjunction with limits on total amounts of shark purchased per vessel per factory would reduce "targeting of sharks" by inshore trawlers. The majority of the demersal shark longline vessels have not been activated due to permit restrictions. These issues need to be re-addressed and after a set period those still not actively using permits should be given section 28's with vessels showing little performance removed from the sector.

Dedicated *M. mustelus* tagging studies should be conducted to understand the movement patterns and nursing grounds, and provide data for validation studies.

Landings are monitored in the Eastern, Western and Northern Cape Provinces by Fisheries Control Officers falling under MCM's jurisdiction, as well as monitors under contract to MCM who have no enforcement authority. In the KwaZulu-Natal province, enforcement of the *Marine Living Resources Act* is executed on an agency basis by the provincial conservation authority, *Ezemvelo KwaZulu-Natal Wildlife*. The majority of officials in all provinces lack the species identification skills to correctly identify demersal sharks to the species level. Species identification is especially difficult for demersal sharks as they are normally landed, having been headed and gutted at sea. A species identification tool for demersal sharks logs developed during this study (Chapter 2), is expected to assist in accurate species identification.

McCord (2005) utilised the *FAO Technical Guidelines for Responsible Fisheries on the Conservation and Management of Sharks* (2003) in developing a framework for the development of a management plan for *G. galeus* in South African waters.

For the purpose of this study, the framework for the shark assessment report and draft management plan developed was used and modified with regards to *M. mustelus* and co-management objectives. The draft management plan is presented in Appendix 2.

CHAPTER 7

GENERAL DISCUSSION

7.1 Introduction

Global commercially valuable teleost resources are heavily exploited and are considered to offer limited potential for increased harvests (Baily & Jentoft, 1990). Consequently, there has been a shift in focus towards harvesting elasmobranchs as a possible solution to meet global demands for nutritional and economic security.

Unfortunately, elasmobranchs possess several life history traits (longevity, slow growth and productivity, low natural mortality and migration patterns) that that make them especially vulnerable to overfishing. To further compound problems in their management poor quality data are available regarding species identification, harvest levels and catch rates. This data uncertainty impedes the application of most management approaches, which are generally quantitative and require information on resource status obtained using stock assessment methods.

Any specific resource has unique characteristics and constraints that need to be identified and included into a plan that would be used to assist in it optimal utilisation. Management of natural resources is also shifting towards a "more holistic systems-orientated and people-centered approach", which calls for greater public participation of resource users. (Hauck & Sowman, 2003, pg 2). This thesis has identified the importance of ownership in addressing problems with data accuracy and monitoring. The inclusion of a co-management approach within the management plan would provide the initial incentive within the shark processing industry towards the collection of these data (as shown in Chapter 6).

7.2 Overview of findings

Fishery-dependent data should always be interpreted with a degree of caution. It is these data that provide information on the size and age structure of harvested fish and estimates of catch rate that are assumed to provide a relative index of abundance. Chapter 3 attempted to resolve the uncertainty within available fishery-dependent data through a validation process. Data were generally found to be inadequate as species were misidentified or not identified at all, reported catches were either lower or higher than those reported by the processing factories, and in many instances, data were often missing. As a result, validation was not possible for the line, longline, trawl and gillnet fisheries within the south-eastern and south-western Cape coasts. Observed factory numbers was used to validate the fishery as a whole, however, revealed that of all the fisheries combined, only 21.48% of the catches are reported. It must be noted again that a larger portion of catches are reported by the fisheries that target sharks than those that harvest sharks as incidental by-catch (i.e. inshore trawl fishery).

The absence of compliance and monitoring in the demersal shark fishery exacerbated the problem especially with regards to discards of unwanted catches, deliberate misidentification and underreporting of sharks caught. Misidentification of demersal sharks was approached by the development of a dressed demersal identification kit (presented in Chapter 2). This kit facilitates the identification of dressed sharks by the exclusion of complicated scientific jargon. Measurements to be taken with regards to logs were suggested, as whole lengths are seldom available.

Information obtained from the different fisheries showed that in the line, longline, trawl and gillnet fisheries both catches and CPUE are increasing. This increase in CPUE over time does not indicate an increase in stock abundance but show increased targeting driven by market forces, accredited to increases in value of South African demersal shark fillets overseas (Fouché, *pers* comm., Sharkex Fishing, Factory owner, 2005).

Elasmobranchs have been shown to contribute significantly to the livelihoods of fishers in the south-eastern and south-western Cape coast of South Africa. Breakeven price analysis showed that there were additional incentives for fishermen to target sharks.

Growth parameters estimated in Chapter 4 showed that growth was rapid when compared to other shark species and similar to other cogenerics. Smoothhound sharks attain an L_∞ of 1925.16 mm TL, with a K of 0.08 year^{-1}, and a t_0 of –3.59 year^{-1}. Maximum age has been estimated at 25 years. Growth parameters are similar for other sharks of the same genus; *M. antarctictus* (L_∞ of 1280.00 mm TL, and 2190.00 mm, k of 0.304 year^{-1}, and 0.064 year^{-1} t_0 of –0.86 year^{-1}and –4.99 year^{-1} for males and females respectively) (Moulton *et al.*, 1992); *M. californicus* (L_∞ of 1020.00 mm TL, and 1420.00 mm TL; k of 0.35 year^{-1}, and 0.22 year^{-1}, and a t_0 of –1.00 year^{-1}and –0.22 year^{-1} for males and females respectively) (Moulton *et al.*, 1992); *M. henlei* (L_∞ of 861.00 mm TL, and 976.00 mm TL; k of 0.28year^{-1}, and 0.23 year^{-1}, and a t_0 of –1.09 year^{-1}and –1.38 year^{-1} for males and females respectively)(Cailliet *et al.*, 1990). The sex-specific differences in growth between female and male sharks was similar to other *Mustelus* sharks.

Females matured at 1204 mm (TL) corresponding to an age of 9.1 yrs. However, they only begin to get targeted at 800 mm (TL) in the Southern Cape, whilst 600 mm (TL) size classes are being targeted in the Eastern Cape. The majority of females are, therefore, targeted at a size well below that of 50% maturity on both coasts. This is was not the case for male smoothhound sharks.

Natural mortality was across all ages was estimated at 0.08 yr^{-1} and considerably lower than other species in the genus (*M. californicus* and *M. henlei* at 0.37 and 0.29 yr^{-1}, respectively (Moulton *et al.*, 1992; Cailliet *et al.*, 1990)).

The smoothhound shark resource off the south-eastern and south-western Cape coast was assessed by three dynamic pool models; yield per recruit, spawner biomass per recruit and an extended yield and spawner biomass per recruit. Due to the longevity of elasmobranches the per-recruit model was extended over a 20 year time-frame to simulate resource responses to management options. A surplus production method chosen was the replacement yield model, which estimates that harvest level required to maintain exploitable biomass at medium-term levels. $F_{0.1}$ was estimated as 0.034 yr^{-1} and F_{MAX} was estimated as 0.045 yr^{-1}. F_{SB40} was estimated as 0.031 $year^{-1}$. In all cases, current fishing mortality was higher than the target BRPs considered. The extended per-recruit model tested the outcome of different management scenarios, *Size and effort control* showed the least probability of pristine biomass falling below 20% of current levels in 20 years (where selectivity was set at 3 years). The replacement yield model showed that the average catches over the past decade are 2.5 times higher than the replacement yield on the South Coast and 1.30 times higher on the West Coast. A comparison of the models showed that current catches need to be reduced for long-term sustainable exploitation of *M. mustelus* at a precautionary limit. Although the more complex models are often perceived as a more realistic representation of fish population dynamics, the simple models often perform better as fewer parameters are required. With the large uncertainty that is implicit with shark data, further uncertainty surrounding estimation of large numbers of parameters only reduces the ability of models to produce useful information (Ludwig & Walters, 1985). The simple replacement yield model is the most realistic representation of the smoothhound population dynamics.

7.3 Conclusions

Many shark resources worldwide are showing signs of overexploitation (Francis, 1989, Cortéz, 2002) and the South African *M. mustelus* and *G. galeus* (McCord, 2005) resources appear to be no different. Sustainable fisheries for sharks are possible particularly when the species are small, mature early and have relatively large number of young (as with *M. mustelus*).

The fishery for *M. mustelus* is similar to that of the gummy shark fishery in Australia with regards to size restrictions and life-history strategies. Analysis of the data in Chapter 5 indicates that it is possible that at current levels of exploitation *Mustelus mustelus* are optimal to slightly higher than what is sustainable. The extended per recruit model at the scenario where *Size* and *Effort* control was immediately implemented, showed that if selectivity is set at 3 years rather than 1.4, catches are restricted to smoothhound sharks below 12 kg, and fishing mortality is halved the probability of spawner biomass falling to below 20% of pristine biomass within the next 20 years is insignificant. Although this scenario has shown to be theoretically feasibly in this study, application of the limit would prove more difficult as smoothhound sharks are being caught as by-catch in the inshore trawl fishery.

Decreasing demersal shark resources such as *M. mustelus* in South Africa highlight the importance of an effective management plan for sustainable exploitation of resources. Decreasing global fish resources suggest that centralised and highly regulated approaches to management are not working (Jentoft *et al.*, 1998; Berkes *et al.*, 2001). These management systems are generally considered to be highly inappropriate in developing fisheries of developing countries due to down scaling of government departments, limited financial resources over large distances, and restricted human capacity to manage resources (Berkes, *et al.*, 2001; Pitcher *et al*, 1998).

Adequate *Size* and *Effort* control is only possible in the south-eastern and south-western Cape coast of South Africa with the implementation of co-management principles within the governing managing plan. As few demersal shark-processing facilities operate in these areas market restrictions are simple and cost effective. Ownership of resources, which would be decided by industry stakeholders, would provide incentive to protect sharks within applied restrictions. The need for many compliance and monitoring officials is decreased and very few trained officers could achieve a higher percentage sampling per month / year. Factors that have inhibited studies such as this one would be addressed specifically with regards to certainty of scientific data.

M. mustelus are heavily exploited in the south-eastern and south-western Cape coast of South Africa. The demersal shark fishery in South Africa targeting smoothhound sharks is in its infancy.

Due to the characteristics of the fishery a co-management approach can be attempted within a management framework. Combined with the rise in public awareness of the tourism potential and importance of sharks. A unique situation is presented where industry stakeholders could be involved in the management process. This involvement and feeling of ownership may prevent the *M. mustelus* resource from declining to the extent where fishers that rely on the smoothhound and demersal shark captures to defray fishing costs and provide towards their economic and social well-being.

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APPENDIX 1

SHARK FISHING SOCIO-ECONOMIC QUESTIONAIRE
Access Point Questionnaire

Questionnaire Number: ____________________ Date: ___________ Time __________

Location: Boat Reg. #

Own Boat: Y N Type: deckboat Skiboat Inflatable

Commercial A Semicommercial B Charter C Recreational D

Skipper information

RH if not who ________________________

Sex: M F Race:

Age: (1) 16-20 (2) 21-25 (3) 26-30 (4) 31-35 (5) 36-40 (6) 41-45 (7) 46-50 (8) 51-55 (9) 56-60 (10) 61+

Home Language: English Afrikaans Other:

Place of Residence: Country

Level of Education: 1) No schooling 2) Grade 0 3) Grade 1 4) Grade 2
5) Std 1 to Std 4 6) Std 5 to Std 7 7) Std 8 to Std 9
8) Std 10 9) Higher (Degree/diploma)

Other Occupation:

Income bracket (month): A <R2 000 B R2 001-R5 000
C R5 001-R10 000 D R10 001-R15 000
E R15 001-R25 000 F >R25 000
G Pension

Any other sources of income:

% of income generated by fishing ______________________________

Number of dependants:

Section 2: catch and effort

Crew size: Estimated ages: <20 20 – 40 >40 Number of rods:

Crew Composition: Male ________ Female___________

Where did you fish?____

Time started?__________________ Time ended:___________________

Preferred type of fish targeted

Game
Reef
Bait
Bottom

Linefish species targeted

	Beach Price		Beach Price

Sharks targeted

	Beach Price		Beach Price

Launching site________________________
Bait obtained from____________________
Bait type

Type	Cost
Sardine	
Squid	
Prawn	
Other name:	

Caught on trip

Species	Number	Kept	Released	Price

Section 3: Equipment

Registered length (m)		Value at purchase	

Total tackle costs		Market value of vessel	
Registered crew #		Replacement value of vessel	
Shaft power (KW)		Gear replacement cost	
Total hold capacity (m^2)		Electronic replacement cost	
Storage facilities		Most recent refit cost	
Motor and Trailer costs		Year vessel purchased	

Vessels annual running costs

Fuel and Lubricant costs (R.)		Insurance costs (R.)	
Statutory costs, permits licence levees, fees (R.)		Repair/Maintenance costs (R.)	
Renumeration wages (R.)		Gear replacement costs (R.)	
Other labour costs (R.)		Cooling costs (R.)	
Provision/Store costs (clothes, victuals etc.(R.))		Bait costs (R.)	

Section 4: Employee details

Employee name	Level of Schooling	Organizational title	Annual Salary from range	Race	Gender (M/F)

* Total monthly income categories, A=<R2 000, B=R2 001-R5 000, C=R5 001-R10 000, D=R10 001-R15 000, E= R15 001-R25 000, F= R>R 25 000

Do you take charters? Y N If Yes, how many in the last year?______________

On average how many per trip?______________

How much do you charge per person?__________

On average how many charters do you take per year__________________________

Section 5: Management and Fisher Attitudes

In your opinion which of the following regulations are effective management tools?

Min Size	Bag limits	Closed Seasons	Marine Reserves

If other specify:____

Do you Obey these regulations:

Min Size____Bag limits___Closed Seasons__________Marine Reserves_________

Fining___________

Identification capabilities

1	2	3	4	5	6	7	8	9	10

____

____

What percentages of shark catches are discarded___________________

Has your catch ever been inspected by an inspector? Y N

If Yes how often? 1 in 5 trips 1 in 10 1 in 20 1 in 50+

Remarks as to alternative management strategies:____________________________

____

____

APPENDIX 2

PROPOSED FISHERY CO-MANAGEMENT PLAN AND ASSESSMENT REPORT FOR THE SMOOTHHOUND SHARK *MUSTELUS MUSTELUS* IN SOUTH AFRICA

1. Introduction

Smoothhound sharks, belonging to the genus *Mustelus* and comprising of three species in South Africa, are abundant and commercially valuable.

Recent results of a stock assessment completed on *Mustelus mustelus* have indicated that the resource is overfished (Da Silva 2007). These results highlight the need a scientific management plan for smoothhound sharks in general, and *M. mustelus* in particular.

This management plan is designed to govern the exploitation of smoothhound shark species in the following five years within a precautionary management approach. This plan also assumes that the exploitation patterns for other shark species off South Africa are similar to *M. mustelus* thereby allowing *M. mustelus* to be used as an indicator of exploitation

The intent of this management plan is to provide reliable information on growth, mortality and stock status of *Mustelus mustelus* and other commercially exploited shark species.

1.2 Issues

Smoothhound sharks are commonly caught and actively targeted off Southern African waters by inshore trawlers, long-lining operations, line-fishing boats, shore based anglers and recreational fishermen. The decline in linefish species (Griffiths, 1997) has led to increased exploitation with more fishermen actively targeting smoothhound sharks and other demersal shark species. Intensive shark fishing occurs in Struis Bay, Stil Bay, Gans Bay, Mossel Bay and Port Elizabeth. No restrictions are currently in place with regards to any demersal shark species including smoothhound sharks. *Mustelus mustelus* is the primary target of both the demersal longline and commercial line fisheries and, together with the soupfin shark *Galeorhinus galeus,* contributes the most economic value to the overall shark catch. Few management measures are currently in place for sharks. Those in place are restricted to the prohibition of certain species and bag limits.

Marine and Coastal Management (MCM) has expressed interest in developing this industry along a sustainable precautionary management plan as there is increasing concern regarding the actual numbers of sharks caught annually. As sharks are particularly vulnerable to overexploitation management intervention is necessary.

1.3 By-catch species

The secondary targets of economic value in the demersal smoothhound shark fishery are *G. galeus*, *C. obscurus*, *C. brachyurus*, *M. palumbes*, and *S. zygaena* shown in order of importance. Other sharks caught of lesser value include *T. megalopterus*, *C. limbatus*, *N. cepedianus*, *A. vulpinus*, and *S. lewini*, and several *Raja* spp. All *Squalus* spp. are discarded, as they have no economic value.

1.4 Finning and flake

The practice of finning was officially banned in 1998 under the *Marine Living Resources Act* (Anon, 1998) factories are prohibited from purchasing trunks without fins, and special permits are required for drying and processing fins. Processing factories for the most part do not handle fins, which are sold in bulk to fin exporters. *Mustelus mustelus* are not prized for their fins although other demersal shark species over 12 kg are primarily bought for finning purposes. Smoothhound sharks and other demersal species ranging from 1.5 to 12 kg are primarily caught for fillets, which are sold as flake to Australia.

1.5 Landings and value of the fishery/ markets

Export statistics for smoothhound sharks and other demersal species are more reliable than catch statistics provided by MCM. This information is currently being analysed by TRAFFIC in an analysis of international trade of South African marine organisms. South African export sharks are lumped into one broad category whilst several categories including species and product distinctions are listed for e.g. in the Australian Bureau of Statistics where categories include but are not limited to:

- Dogfish and other sharks, fresh or chilled (excluding fillets, livers and roes)
- Dogfish and other sharks, frozen (excluding fillets, livers and roes)
- Dried shark fins (excluding smoked)
- Smoked shark fins

Recommendations for initial export categories applicable to the demersal shark fishery in South Africa are:

- Smoothhound shark fillets, fresh or chilled
- White-spotted smoothhound shark fillets, fresh or chilled
- Dusky shark fillets, fresh or chilled
- Bronzy shark fillets, fresh or chilled
- Hammerhead shark fillets, fresh or chilled
- School shark fillets, fresh or chilled
- Dried shark fins, small hound and school sharks (which would include *M. mustelus*, *M.palumbes*, *G. galeus* and occasional *T. megalopterus*)
- Dried shark fins, *Carcharhinus* spp. per set of individual fins (which would include *C. obscurus*, *C. brachyurus*, and some *C. limbatus*)

These categories would encompass all valuable shark products currently being exported. Although the categories pertaining to fins are not split within species, the associated weight of related carcasses would give an accurate estimate of species fin export. Fin categories are split with regards to the fin value, with *Carcharhinus* spp (being the most valuable). The majority of smoothhound sharks are exported to Australia, with small numbers exported to countries within the EU (especially *Sphyrna* spp.), and used locally in restaurants under the pseudonyms of whitefish, cape whitefish and cape whiting. All fins are exported to Japan through independent exporting agencies.

Most sharks are exported in sizes smaller than 8 kg due to inflexible mercury regulations. The only sharks exported at larger sizes are the smoothhound sharks and white-spotted smoothhound sharks, as these species have lower mercury content than other species mentioned. Data obtained from the Australian commonwealth bureau of statistics suggest that since 1998 the total customs value received by the three processing facilities for shark fillet export is AU$ 1.4 billion. The actual value may be higher, as years of known export from South Africa have been excluded from this database.

2 Management objectives

2.1 Long-term objectives

Long-term objectives for this fishery obtained from this study include:

- Maintenance of spawning biomass at 40% of unfished levels
- Using a precautionary approach to guide decision making
- Implementation of effective, efficient and transparent co-management strategy ensuring the sustainability of the smoothhound shark resource in South Africa.

2.2 Specific management objectives within the context of the National Fisheries policy

2.2.1 Biological objectives

a) To understand the biological characteristics of the smoothhound shark

b) To manage the demersal smoothhound shark fishery according to these biological characteristics to ensure long-term sustainable resource use. It is also recommended that a maximum weight restriction of 8 kg be imposed on demersal shark species catches, and a minimum weight of 1.5 kg. Minimum weight of other species needs investigation with regards to maturity and reproduction, as it has been found that 40% are juvenile.

2.2.2 Socio-economic objectives

MCM and the commercial shark fisheries are obligated to understand the socio-economic consequences of management actions.

2.2.3 Governance of objectives within the principles of the new fisheries policy of South Africa

Manage the smoothhound shark stock according to the principles of the new Fisheries Policy of South Africa with special emphasis on:

i. ecological sustainable development
ii. precautionary principle towards a co-management paradigm
iii. responsible fishing

iv. scientific integrity

The plan needs to be produced with expected levels of compliance. Fishery targets should be set and monitored through a yearly review process after five years. The yearly review process should involve assessment of compliance targets and monitoring by the Chondrichthyan Management Working Group Unit (MWG) (suggested by McCord, 2005) composed of fisheries extension staff and Shark Stakeholder Committees (SSC's) representing the interests of the stakeholders. Monitoring of processing facilities should play a fundamental role in compliance and research objectives.

3 Consultative process

3.1 Scientific

There are no current scientists involved with researching exploitation of commercial shark species at a government level. The South African *Chondrichthyan Working Group* (CWG) is comprised of independent interested researchers providing the scientific basis for determining priorities for management of elasmobranchs. This working group was commissioned by the Chief Director of MCM to provide long-term scientific management advice for elasmobranchs to MCM. The CWG holds biannual meetings regarding research management and conservation of elasmobranchs. However, due to lack of funding the CWG were unable to meet in 2006. Funding for the CWG is of utmost importance and should continue to provide unbiased scientific advice to MCM officials regarding long-term management. The CWG also contributes to joint research ventures between the two organizations resulting in studies such as the present one.

3.2 Government-Industry

Consultations for review and planning of policy will be the most important component of the management plan for elasmobranchs. This can be achieved by the creation of the MWG comprised of industry stakeholders (owners of shark-processing facilities), scientists (including the CWG), managers, socio-economists, TRAFFIC representatives, an MCM appointed lawyer and the SSC. The SSC will be comprised of elected individuals from areas actively involved in targeting elasmobranchs representing the various line and longline fishers and the compliance officers of these areas. It is recommended that the areas represented be from Port Elizabeth, St Francis Bay, Mossel Bay, Still Bay, Vlees Bay, Hermanus (Kleinbaai, Gansbaai), False Bay, and Saldanha Bay.

All invited parties should be invited to add any issues regarding management objectives. This should lead to greater government-industry collaboration with all interested stakeholders involved in the better collection of data (catch, effort and biological) from the fishing industry, reolve conflict between industry and government, and hopefully, improve management decisions. The MWG will ultimately decide the co-management strategy and percentage ownership by interested parties. The MWG will decide on ownership with the co-management concept.

The management plan should be completely transparent to stakeholders who will be informed of any minor changes thereof. Amendments could then be presented to the MWG for consultation and review.

3.3 Links with other planning initiatives

Several acts and policies are currently in place in South Africa including the BCLME (which ceases at the end of 2007), the South African Fisheries Policy, the *Marine Living Resources Act* of South Africa these would provide useful if linked with this fisheries management plan. These linkages may include creation of marine protected areas in vulnerable nursery areas as well as bi-and/or multi-lateral management agreements (suggested by McCord, 2005). This study has benefited by working alongside TRAFFIC and a representative of TRAFFIC has suggested the possibility of hosting dedicated shark identification workshops for compliance officers and managers. These workshops will be in conjunction with identification workshop regarding other marine organisms that are commercially traded. The identification kit developed in this study will form part of this workshop and whole and dressed sharks will be donated by shark-processing facilities in the south-western Cape. TRAFFIC has the funding and the interest to initiate these workshops.

All organizations making profit under the auspices of *eco-tourism* should provide help to researchers, this will be later in the management plan. The IPOA-Sharks provide a platform for the conservation and management of sharks. South Africa is in the process of developing a National Plan of Action for the Conservation and Management of Sharks (NPOA-Sharks). This platform will govern the commercial exploitation levels of elasmobranchs. The fisheries management plan for *M. mustelus* as an indicator of exploitation levels will represent the first step in ensuring future sustainability of the demersal shark fishery.

4 Stock status

4.1 Methods of collection of data

Standard data collection needs to be developed for fishery dependent and fishery-independent sampling. The dressed demersal shark identification key developed in this study should be distributed to industry, scientists, monitoring/compliance individuals and all other interested parties. This should resolve problems with species identification. Due to the management bottleneck created by the existence of only three shark-processing facilities, the need for shore-based observers is reduced. Sea-based observers would still be required as sampling at processing facilities will not provide information on shark discards at sea. An example of important information required is listed below this information should be included in logbooks, collected by monitors and from factories.

Biological Data

- Species –reasons for deciding on species (i.e. presence or absence of interdorsal ridge) for later validation by researchers in the situation where misidentification is suspected
- Total length – measured from the rostrum tip to upper lobe caudal fin tip
- Standard length – measured from rostrum tip to caudal peduncle (at the base of the caudal fin)
- In most cases these two lengths are not available due to dressing of sharks, therefore alternates recommended are:
- DOCL – measured from the dorsal origin to the upper lobe caudal fin tip
- DOCP – measured from the dorsal origin to the caudal peduncle
- Weight (whole and log (kg))
- Sex

Fishing Data

- gear used
- modifications of aforementioned gear
- location (latitude and longitude)
- time of set and retrieval
- depth
- water temperature
- fishing conditions

It is unlikely that fishers will record all the biological data, but sub-samples of one randomly selected processing day per month should be collected from each of the shark processing facilities. All sharks processed on that day should be identified, measured, sexed, and maturity should be assessed. This should be enforced in the permit conditions under the co-management agreement. Location of capture can be recorded on factory purchase slips. This method will make it possible to validate elasmobranch data.

4.2 Dedicated shark database

The lack of accurate shark data has inhibited most attempts at elasmobranch research. High priority (within MCM) must be given to the development of a dedicated shark database. This database must include commercial-fishery and research based components. Data collected for the research database should include:

a) Station:

- Strata
- Station number
- Date
- Time
- Location
- Vessel type
- Gear type
- Number of fishers on vessel
- Environmental information

b) Catch

- Total number of fish caught / species
- Total weight of fish caught /species
- Total number of discard
- Total number of fish used as bait

c) Length

- Length (TL, SL, DOCL and DOCP)
- Weight

d) Biology

- Stomach contents

- Stomach volume
- Sex
- Maturity
- Presence of parasites

e) Other

- Presence of tags (OTC injection etc)
- Tag number if animal is tagged

4.3 Stock assessment

Stock assessment has not been completed for most commercially exploited elasmobranchs. McCord (2005) and Da Silva (2007) have conducted preliminary assessments on soupfin and smoothhound sharks, respectively.

It appears that for the smoothhound shark resource that current levels of exploitation are either optimal or slightly too high. Data integrity was however questionable and the analyses had highly variable results. The results showed that exploitable biomass is declining steadily with spawner biomass per recruit being at 21% of unexploited levels.

It is recommended that a detailed information pertaining to biological parameters that are used as stock assessment inputs be collected. These include estimates of age and longevity, growth rate, mortality rate and sexual maturity

It is also recommended that the commercial data collection and data storage protocols are improved. This include extensive time series data on catch and effort

4.4 Biological advice review process

The current stock assessment needs to be reviewed every five years due to sensitivity of *M. mustelus* (and other sharks) to exploitation. At this stage, any changes in the *M.*

mustelus will be evident such a change will require appropriate management interventions. This review will be the responsibility of MCM, prior to changes further meetings between the MWG and SSC is necessary.

4.5 Research

It is vital to the success of a management plan for MCM to conduct an intensive research programme concerning smoothhound sharks as it constitutes the primary species targeted in this fishery.

5 Future prospects (2007-2012)

For a goal towards the development of a sustainable smoothhound fishery that fishing mortality should not be increased. Further entry into the fishery should therefore be stopped as the fishery cannot support further fishing mortality. Size restrictions should be set at 8 kg to minimize sizes of *M. mustelus* exploited.

6 Current management issues

6.1 Management strategy

The co-management initiative for the smoothhound fishery will consist of input controls based on processing facilities quotas as decided by the interested parties. It is recommended that further entry into the demersal longline fishery be restricted as very few permit holders actively participate in catching sharks. After further research a second review should take the form of a performance review after 5 years. This review should include a review on factory performance regarding compliance with management regulations. The participation in a satisfactory amount of research projects should be considered. Factories not complying with regulations and aiding research should be removed from consideration in the allocation of 5 year rights. Permits allocated, but not activated should be withdrawn.

7 Suggested management measures for 2007-2012

Immediate-term plan (1a): Restrictive licensing

Long-term rights were allocated in 2006, these will be monitored and stakeholders not actively using the resource should have their permits revoked. Vessel size should be restricted to < 30m, and area restrictions should be imposed so that longlines are not interfering with catches from linefishers. Shark-processing facility permits should be allocated and factories should be restricted to purchase within specified locations (tonnage purchases per month per species should be monitored). Stringent enforcement of regulations at factories should be in place at all times to ensure that permit conditions are kept to and that prices are not controlled by the processing facilities. Permit allocations in the line fishery should be further investigated by MCM and restrictions should be imposed on this fishery as a precautionary measure.

Discussion: This co-management initiative is based on a precautionary management strategy to prevent depletion of the smoothhounds stock. Vessel size restrictions will prevent growth of the fishery capacity through the development of superior fishing technology. The impact of the linefishery is much larger than that of the longline fishery. However the socio-economic questionnaires given suggest that fishers need the income from targeting elasmobranchs. Therefore fishing mortality should be halved. This fishery should be closely monitored by MCM.

Immediate-term plan (1b): Size restrictions

A maximum size of 8 kg should be placed on smoothhound sharks. Factory owners and monitors fishing various processing facilities should rigorously enforce this. Factories repeatedly caught with oversized animals would not be considered for allocation of long-term rights. This would encourage factories to not purchase larger animals thereby restricting animals. Line and longline fishers should also be educated in the advantages of releasing larger animals (> 8 kg) through pamphlets or lectures.

Note: Given the current stock status of *M. mustelus* as an important resource ad indicator of exploitation (1a) and (1b) should be implemented simultaneously.

Medium-term plan (1c): Seasonal/area closure

This option could limit current catches, length at capture, protect vulnerable nursery areas and possibly control effort levels

Long-term pan: Experimental co-management initiative

The first five years of co-management should be re-assessed as to its efficiency and compliance with monitors and researchers

Discussion: Intensive monitoring is required

7.2 Performance indicators to measure achievements of objectives

Performance indicators allow for the monitoring of progress during the objective setting process. Performance indicators for biological and socio-economic objectives for the smoothhound shark fishery need to be determined.

Biological: A time-series of catch and effort data is required to necessary for stock assessment purpose.. It is therefore imperative that MCM develop a dedicated elasmobranch database for fishery-dependent and fishery-independent. The database should be created as soon as possible.

Socio-economic: The socio-economic study as completed by Da Silva (2007) should be extended to include more fishers and regions within different seasons. This data should be used to determine the extent to which fishers need to target sharks to subsidize fishing costs in periods of poor fishing conditions.

8 Enforcement measures

8.1 Overview

The permit conditions developed by MCM for co-management of smoothhound sharks should reflect the objectives of the fisheries management plan. The conditions should be supported by MCM through enforcement action to ensure compliance.

8.2 Main program activities

All enforcement of management regulations should be carried out by MCM and by monitors at the various factories. Dockside monitoring should be carried out in areas were these are already in place. Monitoring officials will be required to undergo intensive training as to identification purposes and types of data to be collected. The main program activities for enforcing regulations of the shark fishing industry should include the following

- Prohibition of finning by weight restrictions
- Fins landed should be an appropriate proportion of quantity of carcasses
- Monitoring of seasonal or area closures (where and if implemented)
- Monitoring permit conditions
- Bycatch restrictions
- Attendance of monitors, scientists and MCM officials to MCM-TRAFFIC identification workshops
- Logbooks requirements as developed by MCM
- Effort control
- VMS monitoring sea fishing activity
- Dock-side monitoring

Stringent enforcement of regulations at factories should be in place at all times, and monitored by random spot-checks. Spot checks to be carried out on at least 5 days per months with day and factory selected at random.

8.3 Enforcement issues and strategies

The primary issue limiting enforcement in South Africa is the lack of funding required for implementing monitoring program within the shark fishery. This will have been for the most, in part, been eliminated by the co-ownership initiative. It is recommended that 5% dockside coverage be implemented and stringent enforcement of factory regulations be implemented. A portion of the cost associated with enforcement should be covered by the industry.

9 Financial responsibilities

9.1 Industry and/or other harvesters

Licensing and levy fees paid by industry stakeholders should cover the costs associated with monitoring and provide funding for bi-annual meetings by the CWG.

9.2 Marine and Coastal Management

MCM should be responsible for a portion of the costs associated with routine monitoring of the landings, and monitoring of the shark processing facilities. MCM should also be responsible for costs associated with reporting (e.g. reports, media coverage etc.)

9.3 Eco-tourism insutries

All tourism operations making profit under auspices of shark eco-tourism should be required to provide funding for CWG bi-annual meetings.

10 Performance review

10.1 Management plan evaluation criteria

To determine the effectiveness of this fishery management plan, it is necessary to review and evaluate performance targets, annually. In the case of the stock assessment this should be completed at the end of the 5-year period. Performance targets include management, scientific and enforcement criteria's. These targets are as follows:

- Decreasing current fishing mortality levels
- Complete a second follow up stock assessment at the end of the 5 year period
- Complete stock assessment for all species targeted
- Develop and maintain dedicated shark database by 2008
- Implement a dedicated commercial shark research program at MCM
- Implement identification and data collection workshops in conjunction with TRAFFIC
- Monitoring shark processing facilities
- Monitor compliance with regulations and research
- Ensure no further shark processing facilities gain permits
- Assess the impact of any area/seasonal/gear restrictions on the industry
- Record the number and nature of permit violations per annum of vessels, fishers and factories

11 Synthesis

The work presented here describes the development of a precautionary management plan with a co-management initiative for *M. mustelus* in South Africa, as an indicator of level of exploitation. It intends to provide the platform for implementation and development of the fishery through transition from medium-to long-term fishing rights. The intention is that is that the plan be submitted to the Deputy Director General at MCM for commitment and amendment, and it is hoped that a revised version will serve as official basis for management of smoothhound shark fishery in the future.

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