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ASPECTS OF THE ECOLOGY AND MANAGEMENT OF THE SOUPFIN SHARK (*GALEORHINUS GALEUS*) IN SOUTH AFRICA

A thesis submitted in fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

of

RHODES UNIVERSITY

by

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February 2005

ABSTRACT

Global trends in teleost fisheries indicate significant population declines. Thus, alternative fisheries are being developed to meet the growing economic and nutritional demands of the expanding human population. Recently, it has been established that elasmobranch fisheries may fulfill these demands. As many elasmobranchs possess life-history characteristics that make them particularly vulnerable to overfishing, it is imperative to develop management strategies prior to the inception of these fisheries to ensure sustainable resource utilisation.

In South Africa, elasmobranchs have been commercially exploited since the 1930s. Although generally considered an under-exploited resource, the potential for growth within these fisheries has been recognized. In 2005, the commercial shark fishery will undergo a transition from medium to long-term rights allocations. This represents an ideal opportunity for scientists and managers to develop precautionary species-specific management plans for commercially exploitable elasmobranch species.

The soupfin shark (*Galeorhinus galeus*) is one of the principal target species in South Africa's shark fisheries. Given its inherent susceptibility to overexploitation, *G. galeus* was selected as a management priority by South Africa's regional fisheries organisation. The purpose of this study was to examine and describe the stock status of *G. galeus* in South Africa, and to develop a precautionary fishery management plan to ensure the sustainability of this resource.

Age, growth, and mortality calculations for *G. galeus* were made from research survey data collected between 1996 and 1999. A small sample size precluded independent analyses of females. The maximum recorded age for *G. galeus* was 33 years. Estimated von Bertalanffy growth parameters from observed length-at-age for males and combined sexes were: L_∞ 1542.8 mm TL, K 0.21 year^{-1}, t_0 -2.79 year^{-1} and L_∞ 1560.3 mm TL, K 0.19 year^{-1}, t_0 -3.03 year^{-1}, respectively. The age-at-50% maturity was determined to be 6 years, corresponding to 1011 mm TL for males and 1100 mm TL for combined sexes.

Natural mortality was calculated as 0.126 yr^{-1}. The rate of instantaneous total mortality was calculated as 0.27 yr^{-1}.

Catch trend analysis showed that catches and CPUE of *G. galeus* are increasing in the demersal longline fishery, and decreasing in the handline fishery. Decreasing catches and CPUE were observed in fishery-independent research survey data. The status of the soupfin shark stock was modelled using per-recruit analysis. The SB/R model indicated the soupfin shark is being optimally exploited and spawner biomass is at 43% of pre-exploitation levels. Current fishing levels (F = 0.14 yr^{-1}) approximate the F_{SB40} level (F = 0.17 yr^{-1}); thus, an increase in fishing pressure may lead to stock collapse. It was determined that the current age-at-capture (7.9 years) should be increased to 10 years, or 1420 mm TL, to maximize yield and minimize the possibility of recruitment failure.

The results of this study indicate a need for immediate scientific and management intervention in South Africa's soupfin shark fishery. An assessment report and fishery management plan for *G. galeus* was compiled, and several management options were proposed. These include the implementation of licence and size restrictions, as well as seasonal/area closures. The potential for an experimental gillnet fishery should be investigated.

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DEDICATION

This thesis is dedicated to my parents – thank you for your infinite support throughout my university career.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the following individuals for their support and contribution for the duration of this degree:

- Professor Warwick Sauer of the Department of Ichthyology and Fisheries Science (DIFS), Rhodes University for providing me with the opportunity to travel to and work in such a beautiful country. Also, thank-you for providing me with insight and support over the last two years.

- Dr. Olaf Weyl of the DIFS for granting me sanity when I hit a modelling wall – you cannot imagine how much I have appreciated your assistance.

- Dr. Tony Booth of the DIFS for his mathematical expertise and critical abilities.

- Dr. Malcolm Smale of the Port Elizabeth Museum and Mr. Marcel Kroese of Marine and Coastal Management for providing biological samples and for assistance with data compilation.

- Dr. Terry Walker – the soupfin shark god – for his willingness to impart his vast knowledge and for his role in the global conservation of such an incredible animal.

- Dr. Herman Oosthuizen, Mr. Chris Wilke, Mr. Craig Smith, and Mr. Saasa Pheeha of Marine and Coastal Management for their enthusiastic support and assistance.

- The National Research Foundation for funding this project.

- To all my friends at the DIFS – without you Grahamstown would be just another dorp! Thank-you for all your support and love and for all the wonderful experiences.

- To my parents, Dagmar, Dave, Doug, and Ewanna – you have given me more support, love and understanding than I could have imagined possible. Thank-you for sharing this journey with me.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Fisheries management

As the human population continues to grow, focus is being placed on marine resources for the provision of nutritional and economic benefits to the general populace (FAO, 2003). Increasing exploitation in recent years has led to significant, though mostly unquantifiable (Myers and Worm, 2003), changes in ecosystems, declines in economic value of fisheries and international conflicts on trade and management (FAO, 2003). This, combined with the realization that fisheries are dynamic resources that cannot be managed in accordance with centralized fisheries management strategies (Nielsen *et al*., 2004; McBeath, *in press*; FAO, 2003), led to a meeting by the FAO Committee on Fisheries (COFI) in 1991 that addressed the need for responsible international fisheries management (FAO, 2003).

The traditional aim of fisheries management strategies includes the need to ensure that biological reference points for a population or stock are developed and that the risk of exceeding these reference points is minimal (Stokke and Coffey, 2004). Other often stated objectives include resolving user-group conflicts and increasing the profitability of a fishery while preventing stock depletion and social disruption (Nielsen *et al*., 2004).

Prior to the 1990s, fisheries management was primarily based on centralized, top-down, government-implemented regulations which dictated compliance-control procedures and stakeholder involvement, in terms of access and utilization rights, within fisheries (McBeath, *in press*; Nielsen *et al*., 2004; Stokke and Coffey, 2004). With increasing international competition for local resource usage there has been a resultant increase in conflict between fishing communities and government (Nielsen *et al*., 2004; Stokke and Coffey, 2004; FAO, 2003) as local fishing communities lose access and control to the resources and foreign users (*i.e.*, foreign fishing fleets) gain more control (Nielsen *et al*., 2004).

The classical fisheries management paradigm has adverse affects on both the social climate and the resource as it is primarily market-driven and frequently appears to be politically motivated (Nielsen *et al*., 2004). The outcome is often a failure of management strategies to meet the over-riding fishery management objectives. This may ultimately result in the collapse of fisheries, for example, the Atlantic cod fishery (Brown, 2003) and the Californian *Galeorhinus galeus* fishery (Walker, 1999), and subsequent negative impacts on the fishing community.

According to the COFI, it was necessary to establish a new approach to fisheries management which would include conservation, environmental, social and economic issues (FAO, 2003). In 1995, the Code of Conduct for Responsible Fisheries (hereafter referred to as “the Code”) was adopted by the FAO. The objectives of the Code include the establishment of principles for responsible fishing and fisheries activities, promoting protection of living aquatic resources and promoting the need for nutritional security from fisheries (FAO, 1995). The development of the Code and subsequent international agreements and plans of action have led to the formulation of two concepts related to the dissolution of centralized resource management, specifically, fisheries co-management and the ecosystem approach to fisheries (EAF).

Hara (2003) defines co-management as a collaborative arrangement between government, user groups and stakeholders for effective management of a defined resource. This paradigm is closely linked to the theory of EAF, whose purpose is to “…plan, develop and manage fisheries in a manner that addresses the multiplicity of societal needs and desires, without jeopardizing the options for future generations to benefit from a full range of goods and services provided by marine ecosystems” (FAO, 2003). The FAO (2003) states that the EAF is a mechanism through which the provisions of the Code may be met and implemented as it provides guidelines for developing sustainable fisheries.

Although the classical fisheries management paradigm (*i.e.*, top-down centralized management) appears to conflict with EAF in terms of input and output objectives, the FAO (2003) maintains that EAF management processes use the same model of planning, implementation and evaluation of fisheries. The differences between the two management paradigms are solely based on broader stakeholder involvement and a more rigorous evaluation of operational objectives, decision-making strategies and management performance in the EAF (FAO, 2003).

Several problems associated with the implementation of the EAF have been identified by the FAO, scientists and managers involved in fisheries management. Firstly, there remains a general lack of knowledge regarding ecosystem structures and functioning (Garcia *et al.*, 2003). Secondly, because the principles of EAF are currently non-binding and the Code is voluntary, there is a lack of fisheries policy and legislation at both the state and international levels that makes provisions for its implementation (McBeath, *in press*; FAO, 2003; Garcia *et al.*, 2003). Lastly, competing stakeholders may be unwilling to participate in a management strategy that operates across multiple sectors and includes ecosystem conservation in its mandate (McBeath, *in press*; Nielsen *et al.*, 2004; Stokke and Coffey, 2004; FAO, 2003). Abundantly clear, however, is the continuing need to apply caution in the light of uncertainty. According to the precautionary principle, scientific and economic uncertainty should not preclude the development of measures that would prevent environmental harm (Stokke and Coffey, 2004).

The Precautionary Approach to Fisheries (PAF) (FAO, 1995) was developed to enable scientists and managers to deal with uncertainty in the face of ever-increasing exploitation of marine resources. One of the aims of the PAF is to improve conservation and management by reducing risk to fisheries through prudence when scientific evidence is not available. Unlike the conventional approach to fisheries management, the PAF endeavours to create equality between short-term and long-term resource users, considering the social, economic and environmental implications of precautionary resource management (Garcia, 1996).

As fishery and non-fishery impacts on resource abundance become increasingly evident (Myers and Worm, 2003), scientists and managers are seeking to fuse classical fisheries management with more holistic approaches, including EAF, integrated management and ecosystem-based fisheries management (EBFM) (Garcia *et al.*, 2003). The fusion of the two paradigms is significant for the management of fish stocks as the resulting model will respond to both the greater societal need for the provision of a reliable food source, livelihood and employment, as well as ecosystem requirements for responsible conservation strategies and the preservation of biodiversity (FAO, 2003).

Implementation of such an approach to management is not easily achieved, however, particularly in the case of multi-species fisheries or fisheries where little is known about the life-history characteristics of the species of concern. This is highlighted in chondrichthyan fisheries where these species are often taken as incidental bycatch or targeted as part of a multi-species fishery (Musick, 2004), and where comparatively little is known about their life-history characteristics. These factors have resulted in a lack of management for chondrichthyans due to imprecise fisheries statistics, where chondrichthyan species are either not recorded or are lumped under one broad catch category (*e.g.*, “sharks” or “skates”) (Musick, 2004), as well as the complex statistical analyses required to describe the interactions between species, gear types and environmental parameters in multi-species fisheries. Recently, however, fisheries scientists have highlighted the need to develop management strategies at the inception of elasmobranch fisheries (Musick, 1999) through the utilization and implementation of the FAO Precautionary Approach to Fisheries, thereby ensuring the conservation and long-term sustainable resource use of sharks. Although widely accepted that elasmobranch fisheries are unsustainable, it has been demonstrated that these fisheries can be sustainable if the resource is actively managed (Stevens, 1999; Simpfendorfer, 1999; Walker, 1998).

1.2 An overview of the taxonomic and biological characteristics of chondrichthyans, their place in oceanic coastal systems and the evolution of fisheries

The class Chondrichthyes is comprised of two subclasses: the Holocephalii and the Elasmobranchii. This group of fish can be distinguished from the Osteichthyes (bony fishes) primarily by the presence of dermal denticles, which have been replaced by scales in more modern fishes, and a cartilaginous skeleton (Last and Stevens, 1994). Elasmobranchs (including sharks, skates and rays) are generally divided into four groups, the squalomorphs, galeomorphs, squatinomorphs and batoids - which include 44-51 families (Bonfil, 1994). Approximately one thousand extant species of elasmobranchs have been identified, including approximately 680 species of batoids (skates and rays) and 465 species of shark (Musick, 2004). Elasmobranchs are cosmopolitan in distribution and are found in both marine and freshwater environments, from polar to tropical waters. Although taxonomically strictly inaccurate, all the Chondrichthyes (sharks, skates, rays and chimaeras) will be treated as "elasmobranchs" for the entirety of this thesis in order to avoid lengthy terminology.

As large predatory fish, elasmobranchs occupy positions at or near the top of marine trophic food webs (Stevens *et al*., 2000) and have relatively low biomass compared to that of teleosts (Musick, 2004). Cartilaginous fishes, unlike many teleosts, are inherently more vulnerable to overexploitation due to complex life-history traits, such as slow growth, late age of sexual maturity, low fecundity and mortality, and a positive correlation between the breeding biomass and number of young produced (Stevens *et al.*, 2000). Many elasmobranchs also possess behavioural characteristics (*e.g.*, segregation by sex and age and complicated migration patterns), which increase their vulnerability to environmental- and human-induced pressures (FAO, 2000).

Historically, the effects of selective predator removal have been difficult to quantify for shelf and oceanic systems (Myers and Worm, 2003). It is now widely accepted, however, that the removal of large predatory fishes through fishing or environmental degradation will have vast and negative impacts on marine ecosystems (Stevens *et al*., 2000; FAO, 2000; Baum *et al*., 2003; Myers and Worm, 2003). The effects of selective predator removal can be divided into direct and indirect effects (Stevens *et al*., 2000). According to Stevens *et al.* (2000), direct effects associated with the removal of elasmobranchs from the marine environment include a decrease in abundance resulting in density-dependent changes (*e.g.*, changes in size- and age-structures) within a population or local and/or global extinctions. Indirect effects involve changes in community structures resulting from such things as competitor removal or species replacement (Stevens *et al*., 2000). For example, Myers and Worm (2003) showed that a 90% loss of predatory fish from coastal and oceanic ecosystems due to fishing pressure resulted in changes in ecosystem structure and function, leading to consistent declines in the mean trophic level of fish catches.

The evolution of elasmobranch fisheries reveals that human consumption of elasmobranchs pre-dates recorded history. Literary evidence indicates that elasmobranchs were fished and consumed as many as 5000 years ago by Persians and Cretans (Vannuccini, 1999). Commercial exploitation of elasmobranchs, however, began after the First World War when they were targeted for food and by the leather industry (Vannuccini, 1999). The discovery that elasmobranch livers contain high levels of vitamin A lead to an increase in elasmobranch catches in the 1940s (Vannuccini, 1999; Kroese and Sauer, 1998).

Of the 465 identified shark species, it is estimated that 100 species are landed in directed and non-directed shark fisheries worldwide, although the United Nations Food and Agriculture Organization (FAO) report landing statistics for only 29 species (Vannuccini, 1999). Due to continuing declines in teleost catches there has been an increased targeting of elasmobranchs (Baum *et al*., 2003), and as many as 26 major fishing nations currently target sharks (FAO, 2000). Capture production data for sharks (including the Carchariniformes, Hexanchiformes, Lamniformes, Orectolobiformes and Squaliformes) from FAO data sets indicate that, between 1950 and 2002, shark catches increased from 51 745 tonnes to 173 796 tonnes, with a peak of 190 471 tonnes in 1996 (Figure 1.1) (FAO, 2002). Between 1976 and 1997, the production of shark meat (fresh, frozen and cured), for all countries reporting landings to the FAO, rose from 18 000 tonnes to 69 300 tonnes, with a peak of 70 800 tonnes in 1993 (Vannuccini, 1999). Since much of the global elasmobranch catches are unreported or under-reported, it is likely that these numbers are grossly underestimated. For example, the FAO estimates that more than 760 000 tonnes of elasmobranchs are caught annually (FAO, 2002), 29 000 tonnes greater than recorded landings of 731 000 tonnes (*Anon.*, 1996).

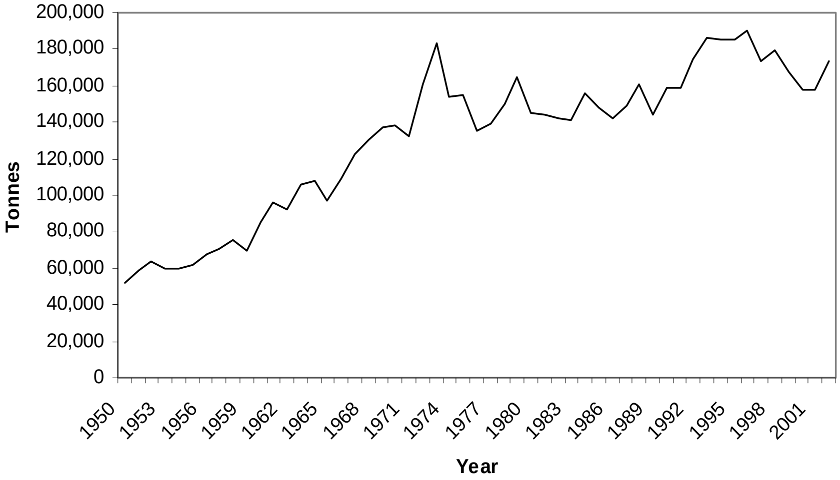


Figure 1.1. FAO global catch production (tonnes) from 1950 to 2002 for Carchariniformes, Hexanchiformes, Lamniformes, Orectolobiformes and Squaliformes combined (reproduced from FAO catch production data, 2004).

Although elasmobranchs constitute only 1% of the global fisheries catch (Walker, 1998), increasing exploitation in recent decades has led to growing international concern about the impact of fishing on shark and ray populations (Stevens *et al.*, 2000; Baum *et al.*, 2003; Myers and Worm, 2003). In 1994, the Convention on International Trade in Endangered Species (CITES) began to review the status of and trade in sharks. This led to the formation of CITES Resolution Conf. 9.17 which requested the FAO to develop guidelines for a plan of action for the conservation and management of sharks (FAO, 2000). In 1999, the International Plan of Action for the Conservation and Management of Sharks (IPOA–Sharks), developed by the FAO Technical Working Group on the Conservation and Management of Sharks, was endorsed (FAO, 2000).

According to the FAO (2000), "…the overall objective of the IPOA–Sharks is to ensure the conservation and management of sharks and their long-term sustainable use". The guiding principles of the IPOA–Sharks were formatted to support the Code of Conduct for Responsible Fisheries (FAO, 2000) in an attempt to ensure that shark fisheries (both directed and non-directed) are managed in a holistic and responsible manner. The following three guiding principles were developed to meet the overall objective of the IPOA–Sharks: i) States contributing to the fishing mortality of a species/stock should contribute to its management; ii) management and conservation strategies should adhere to the precautionary approach, thus ensuring sustainable levels of fishing mortality; iii) catches of species in low-income, food-deficit regions/countries should be managed on a sustainable basis to provide a continued source of food, employment and income to local communities (FAO, 2000).

Although growing international concern about the status of shark species has led to the formation of regional management plans by several shark fishing nations (Walker, 1998), there have been factors that have complicated the development and implementation of these plans (FAO, 2000; Walker, 1998). Firstly, the multi-species nature of most elasmobranch fisheries has resulted in under- or un-reporting of shark species in catch data (Walker, 1998). Secondly, there is a lack of fundamental data (*e.g.*, catch, effort, species, sex, length, and age composition) required for reliable stock assessments (FAO, 2000). Thirdly, information gathering on transboundary species is difficult to coordinate between states due to a lack of responsibility in international waters (FAO, 2000). Lastly, there is a general lack of funding available for monitoring, research and management of fish of such comparatively low economic value (FAO, 2000).

These factors are compounded in developing nations, where communities are dependent on elasmobranch fisheries for both their economic and social livelihoods. Although the trend in these countries is a movement from traditional fisheries to industrial fisheries, the development of management strategies has been particularly slow, as any management plan will have a large impact on both the developing economy and the food supply to the population (IFAW, 2001). In addition, historically disadvantaged persons in many developing countries exploit these resources in an attempt to meet growing demands from developed nations, resulting in substantial illegal elasmobranch fisheries (IFAW, 2001).

In Africa, elasmobranchs have been fished and traded for centuries, although much of this exploitation has historically occurred in the form of artisanal fisheries (Vannuccini, 1999; Compagno, 1994). In the 1930s, the potential for commercial exploitation was recognized when an increased global demand for vitamin A initiated an increased exploitation of elasmobranchs (Kroese and Sauer, 1998; Kroese *et al.*, 1995). Recorded chondrichthyan landings from Africa are comparatively small at approximately 5% of the global catch of 731 000 tonnes (*Anon*., 1996). Exports of shark meat peaked in 1997 at an estimated 990 tonnes (Vannuccini, 1999). The FAO, however, states that this number is underestimated as European Union (EU) imports alone of shark meat from Africa in 1997 amounted to 3 178 tonnes, exceeding reported African shark exports by approximately 2 200 tonnes (Vannuccini, 1999). Estimates suggest that more than 95 000 tonnes of elasmobranchs are caught annually in African waters, double the reported catch from official statistics (Kroese and Sauer, 1998). The major export markets for African shark meat are the EU, Yemen, Saudi Arabia and Japan (Vannuccini, 1999).

Unlike many coastal African countries, South Africa is the only African country reporting an industrial-scale directed shark fishery (Japp, 1999; Rose, 1996). According to Kroese (*unpublished data*), annual landings of shark during the Second World War exceeded 4000 tonnes and, in 1998, South Africa supplied 1 390 tonnes of shark meat to the global community (Vannuccini, 1999). Although South Africa claims a relatively short coastline, it possesses one of the most diverse assemblages of cartilaginous fishes in the world (Marine and Coastal Management, 2002), thus, there exists great potential for commercial exploitation.

The South African shark catch has been divided into two components, namely the directed fishery and the bycatch fishery. Table 1.1 illustrates the different fisheries for elasmobranchs in South Africa. Target species in the shark-directed longline fishery include the mako (*Isurus oxyrhincus*), soupfin (*G. galeus*), blue (*Prionace glauca*), hound (*Mustelus* spp.) and thresher (*Alopias* spp.) sharks, although several other species are often taken. The commercial handline fishery reports landings for 12 species of shark, including the aforementioned species, as well as dogfish (*Squalus* spp.), copper (*Carcharhinus brachyurus*), cow (*Hexanchus* spp.), dusky (*Carcharhinus obscurus*), and hammerhead (*Sphyrna* spp.) sharks, and several species of unidentified sharks and rays. On the west coast, where the majority of shark catches are made, the principal target species is the soupfin shark (*G. galeus*) (Marine and Coastal Management, 2002).

Table 1.1. A description of all existing known fisheries for shark in South Africa (reproduced from Marine and Coastal Management, 2002).

Fishery	*Area*	*Target/Bycatch*
Shark longline	West and south coast	Target
St. Joseph net	West coast	Target
Commercial handline	Inshore (to 200 m)	Target
Shark control program	East coast	Target
Domestic tuna longline	Offshore to EEZ	Bycatch
Foreign tuna longline	Offshore to beyond EEZ	Target/Bycatch
Hake longline	West and south coast (to 500 m)	Bycatch
Offshore trawl	West coast (Agulhas Bank to shelf edge)	Bycatch
Inshore trawl	South and east coast (to 200 m)	Bycatch
Prawn trawl	Natal east coast (to 600 m)	Bycatch
Commercial handline	Inshore (to 200 m)	Bycatch
Recreational line	Inshore (to 200 m)	Bycatch
Gill net / beach seine (legal and illegal)	West and south coast	Bycatch
Patagonian Tooth fishery (experimental)	Prince Edward Islands	Bycatch
Aquarium trade	n/a	Target

1.3 Management of elasmobranch fisheries in South Africa

Although a directed fishery exists for several elasmobranch species in South Africa, there has been little management of these species with the exception of the white shark (*Carcharadon carcharius*), which is currently protected under Appendix II of CITES, the ragged tooth shark (*Carcharias taurus*) and several catshark species (*Poroderma* spp.), which are currently banned from commercial exploitation. The lack of management in South Africa is due to several factors, including the multi-species nature of these fisheries and the associated difficulties with stock assessments. Non-fishery factors have also contributed to the lack of management in South Africa. For example, there has been no effort to distinguish between the shark-directed demersal and pelagic longline sectors, resulting in an over- or under-estimation of the importance of particular species in the fishery. Secondly, there has been no standardisation of catch details required from fishermen, leading to difficulties in interpreting catch data. Thirdly, a lack of research and management capacity in the regional fisheries organisation (Marine and Coastal Management) has meant that little attention has been given to the conservation and management of elasmobranchs. Lastly, the lack of a dedicated centralised shark database has resulted in the loss of valuable fisheries data and difficulties associated with analysing incomplete data sets stored in multiple databases.

User rights in the South African shark fishery are currently under review by Marine and Coastal Management (MCM). In the past, shark fishing permits were granted on an annual basis; however, recently, these permits were granted to fishermen for a four year term. Application criteria for these permits were tabled by MCM, and permits were granted to fishermen that met these criteria. In 2005, Marine and Coastal Management will begin allocating long-term user rights to the South African shark fishery. Permit terms of up to 15 years are currently being considered by MCM. Elasmobranch fisheries covered by the new permit conditions may include the commercial handline and longline fisheries (refer to Table 1.1). This represents a transition from medium- to long-term user access and provides an opportunity for scientists and managers to develop precautionary management strategies for those species that are commercially exploited, thereby ensuring sustainable resource utilisation.

Paucities in data in South African elasmobranch fisheries have presented a suite of problems to fisheries scientists and managers, including a generally poor biological understanding of, and a resultant lack of management of, commercially exploited elasmobranch species in this country. These problems are particularly evident in the soupfin shark (*G. galeus*) fisheries in South Africa, where a lack of scientific and managerial interest has resulted in a lack of data for stock assessments. Irrespective of a lack of scientific data, the precautionary approach to fisheries management states the importance of developing management strategies for commercially exploited fish species in the face of ever-increasing exploitation. Although the lack of biological and fisheries data for the majority of targeted species has precluded the development of species-appropriate management plans, it is now recognised that a precautionary approach to fisheries management must be applied in the face of this change. As the primary target species of the directed shark longline fishery, the soupfin shark (*G. galeus*) was chosen as a template species for the development of a precautionary management strategy during this transition phase. In an attempt to develop a precautionary management strategy for *G. galeus*, it was necessary to collect all available data from scientific and fishery-dependent sources and collate this information for the development of an appropriate stock assessment model.

There are several factors to consider when developing a precautionary harvest strategy for elasmobranchs. Firstly, it is necessary to define the data collected from the fishery, how these data are analysed and how the results are to be used to determine management actions (Punt *et al.*, 2001). Secondly, biological reference points (BRPs) must be pre-determined to reduce the risk of stock collapse (Punt *et al.*, 2001). Lastly, stock assessments are needed to determine the current status of the resource, relative to agreed target limit reference points and as the basis for the evaluation of alternative harvest strategies (Punt *et al.*, 2001). Through the assimilation of all available fisheries and non-fisheries data, as well as through the compilation of available data from other regions as a guideline for management, it is possible to develop a precautionary management strategy for the targeted species.

1.4 An introduction to the soupfin shark (*Galeorhinus galeus*)

The soupfin shark (tope, school shark, vitamin shark) belongs to the family Triakidae, is cosmopolitan in distribution and may be described as hemipelagic, occurring up to depths of 550 m (Olsen, 1954). Commercial fisheries for *G. galeus* exist in most parts of its range, with significant numbers being taken in New Zealand, Australia, Argentina, Uruguay, California and South Africa (Walker, 1999). Although heavily targeted since the 1920s, detailed information on soupfin shark stock structure exists only in Australia, where it has been intensively studied since the 1950s (Olsen, 1953). According to Walker (1999), trends exhibited in catch data for *G. galeus* have contributed to the view that most shark fisheries are “boom and bust” fisheries, as many *G. galeus* fisheries begin with high catch rates which rapidly decline (*e.g.*, the Californian *G. galeus* fishery). Table 1.2 describes the characteristics of *G. galeus* fisheries in Australia, New Zealand, South Africa, South America (Argentina, Uruguay and Brazil) and California.

The soupfin shark is especially vulnerable to over-exploitation, because they are particularly long-lived (some estimates suggest up 60 years) and late to mature (females mature at approximately 10-12 years and males at approximately 8-10 years) (Olsen, 1954; Moulten *et al*, 1992; Ferreira and Vooren, 1991; Francis and Mulligan, 1998; Freer, 1992). In Australia, for example, it is estimated that current biomass is between 20 and 59% of the total virgin biomass, or 19-43% of mature virgin biomass (Stevens, 2000). It has also been demonstrated that all known soupfin shark fisheries of 3000 tonnes or more have exhibited rapid stock collapse (L. J. Paul, *pers. comm.*).

Table 1.2. Characteristics of the *Galeorhinus galeus* fisheries according to region (adapted from Walker, 1999).

Region	*Start of fishery* [a]	*Vessel size(s)*	*Gear type(s)* [b]	*Current fishery status*	*IUCN rating* [c,d]
Australia	1875	small sailing vessels to 32 m	longline gillnet	Catch restrictions/ effort regulated	Vulnerable (A1bcd)
New Zealand	Early 1900s	small sailing vessels to 32 m	longline handline gillnet	Catch restrictions/ effort regulated	Near threatened
South Africa	1930	< 15 m	longline handline recreational line	Effort regulated	n/a
Argentina	Early 1940s	10-21 m	gillnet handline	No known regulations	n/a
Brazil	1970s	10-21 m	otter trawl pair trawl gillnet	No known regulations	n/a
Uruguay	1940	6-8 m	gillnet	No known regulations	n/a
California	1941	6-18 m	demersal trawl	Collapsed	n/a

[a] This denotes the first recorded catches of *G. galeus*, not necessarily the start of industrial-scale fishing.
[b] Gear types predominantly used in the directed fisheries.
[c] This rating is according to the International Union for the Conservation of Nature Species Survival Commission Red List Criteria (2003).
[d] Regions assigned a rating of "n/a" indicate assessments in progress. Expected date of completion for these assessments is year-end 2004. It is important to note that *G. galeus* was assigned a global IUCN Red List rating of Vulnerable (A1bd) in 2000.

1.5 The soupfin shark (*Galeorhinus galeus*) fishery of South Africa

In South Africa the soupfin shark fishery has existed since the 1930s, although there has been virtually no effort to manage the fishery and estimates suggest that soupfin shark constitutes approximately 21% of the total commercial handline and longline shark catch (McCord, *unpublished data*). The commercial longline fishery for this species extends from the Orange River to St. Francis Bay, with the majority of catches occurring between Gans Bay and St. Francis. The handline fishery for soupfin shark occurs primarily along the west coast (Orange River to St. Francis Bay), although catches are occasionally taken as far north as the Kei River (refer to Chapter 2, Figure 2.1). The principal landing sites for both fisheries are Cape Town, Hout Bay and Gans Bay, although soupfin sharks are also occasionally landed between Mossel Bay and East London (Figure 1.2) (MCM, *pers. comm.*, 2003).

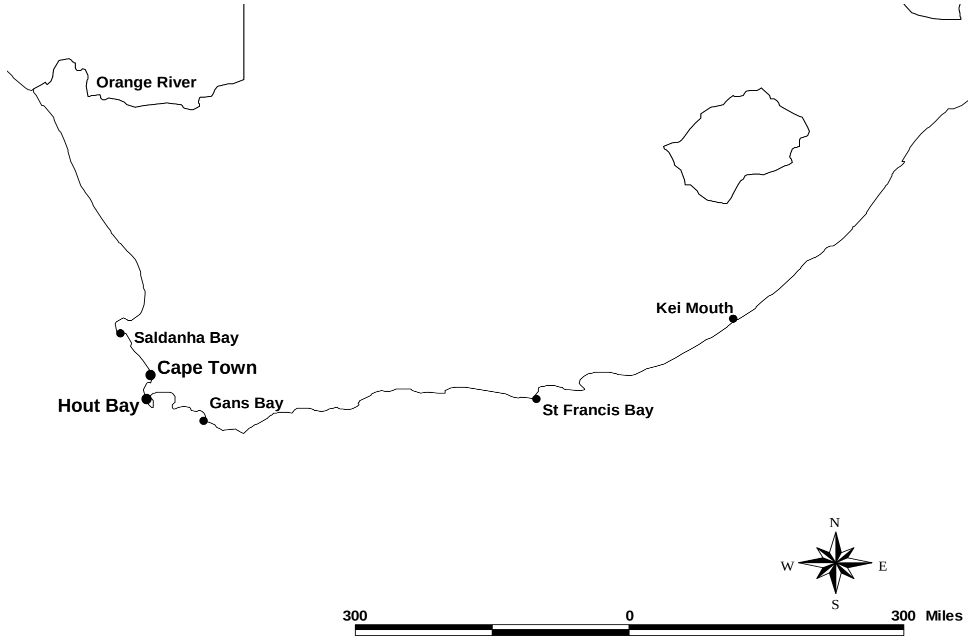


Figure 1.2. Map illustrating the principal landing sites for the commercial longline and handline fisheries for *Galeorhinus galeus* in South Africa.

Commercial longline vessels targeting soupfin shark are generally less than 30 m in length and incorporate longlines with up to 3000 hooks (Marine and Coastal Management, 2002). The majority of longline vessels use nylon monofilament Lindgren Pitman spool systems which are deployed between depths of 50 and 100 m (Marine and Coastal Management, 2002). The commercial line fishery is both shore- and boat-based (ski boats less than 10 m in length) and fishers use fishing rods, reels, line and hooks to target soupfin sharks, although basic fishing gear comprised of handlines, 3–15 hooks and sinkers are still used.

Kroese and Sauer (1998) state that commercial longline landings of *G. galeus* dropped from 250 tonnes to 70 tonnes in the 1990s; however, it is likely that these numbers are underestimated, due to species misidentification (Marine and Coastal Management, 2002). As the soupfin shark fishery is multi-species in nature, *G. galeus* is generally only targeted when catches of more valuable teleost species are low (Kroese and Sauer, 1998). This has contributed to difficulties in developing appropriate stock assessment models as fishery data is sparse, chondrichthyan catches in the multi-species fishery may be unreported, and estimates of effort are biased by the number of permits that are actually utilised during a particular fishing season. For the purposes of this study, data for the soupfin shark were obtained from fishery-dependent and –independent sources, and were compared to results obtained from all other available sources (*e.g.*, Australia, South Africa and South America). These results were used as a guideline for management. BRPs were determined, and a preliminary stock assessment for this species was conducted.

Walker (2004) states it is necessary to apply a rapid assessment technique to determine the effects of fishing on a population in the face of often insufficient data and due to the susceptibility of many elasmobranch species to overexploitation. Walker’s (2004) rapid risk assessment technique was developed in order to assess various types of “risk” to a species, including ecological risk, risk of depletion and/or risk of extinction. It ranks a species “risk” in terms of life-history parameters, taking into consideration the biological productivity of a species, including the rate of natural mortality and reproductive rate, as well as its catch susceptibility to different gear types. For example, Walker (2004) states that a species with a low rate of natural mortality, long life span and high gear encounterability will have a high risk of depletion. The values calculated for each of the aforementioned parameters are then used as a basis for arbitrary categorisation of a species risk (Walker, 2004) (Table 1.3). This technique allows scientists and managers to rapidly appraise a species and determine its level of risk to overfishing.

Table 1.3. An example of a rapid risk assessment technique for chondrichthyan species (reproduced from Walker, 2004).

Parameter	*Values for three arbitrary categories of risk*		
	Low (L)	*Medium (M)*	*High (H)*
Total mortality	>0.76	0.32-0.76	0.00-0.31
Natural mortality	>0.38	0.16-0.38	0.00-0.15
Maximum age	0-8	9-16	>16
Availability	0.00-0.33	0.34-0.66	0.67-1.00
Encounterability	0.00-0.33	0.34-0.66	0.67-1.00
Selectivity	0.00-0.33	0.34-0.66	0.67-1.00
Post-capture mortality	0.00-0.33	0.34-0.66	0.67-1.00
Catch susceptibility	0.00-0.33	0.34-0.66	0.67-1.00

When developing a precautionary species- and/or fishery-specific management strategy, it is advantageous to generate a similar decision table of biological and fisheries indicators with a simple scoring system that allows scientists and managers to rapidly outline the quality of the data collected from a fishery. Table 1.4 illustrates a rapid assessment indicator table developed for this study. This table differs slightly from that developed by Walker (2004), as it assesses the quality of fisheries, biological and life-history data. This is particularly important in developing fisheries where scientists and managers are required to identify areas within the fishery, as well as data collection processes and research techniques that should be improved. This type of indicator table will ultimately aid in the decision-making process for the management of a fishery.

Table 1.4 will be used throughout this study and will be employed in conjunction with Walker's (2004) risk assessment technique for the development of a precautionary management strategy for *G. galeus* in South Africa (Chapters 6 and 7). This table will be updated with results at the end of each chapter. A simple scoring system that rates the biological, fisheries and stock assessment data, as well as other knowledge (*i.e.*, species-specific data from other populations) was developed and is based on a scale of zero to three as follows, with a total possible score of 66:

- Unknown: score of 0
- Poor: score of 1
- Reasonable: score of 2
- Good: score of 3

"Unknown" indicates that no data has been obtained and nothing is known about a specific parameter/indicator. "Poor" indicates that some knowledge has been obtained but the certainty associated with this knowledge is low. "Reasonable" suggests that some studies have been undertaken and the certainty has increased. "Good" suggests a high level of certainty associated with parameter/indicator estimation. A low score (*i.e.*, 0 to 30) indicates an immediate need for scientific and crisis and/or new management intervention within the fishery. An intermediate score of 31 to 49 indicates that the general biological and fisheries knowledge is good; however, areas for improvement within the data collection and/or management systems may be identified. A score of 50 to 66 indicates an exceptional understanding of both the biology and the fishery, and a high degree of certainty associated with all the parameter and model estimates.

It should be noted that this is an arbitrary scoring system that is based on data quality and the certainty associated with preliminary biological and life-history analyses. The issue of data quantity should be carefully considered when developing and comparing risk assessments for all commercially utilised species. This rapid risk assessment technique should be conducted for as many species as possible to determine which species are at greatest risk, thereby allowing scientists and managers to prioritise species in terms of research and management effort.

This study is a preliminary investigation into the stock assessment of the South African soupfin shark (*G. galeus*) population. The purpose of this thesis is to examine the age, growth and life-history characteristics of the soupfin shark in South Africa to develop a stock assessment model that will allow for precautionary management of the stock. Paucities in existing data will be examined and methods for improved data collection will be identified. Chapter 2 describes the methods utilised for data collection and data assimilation. Chapter 3 describes the trends in available fishery-dependent and –independent catch per unit effort data. Chapter 4 describes the results of the biology, age, growth and mortality estimates for *G. galeus*. Chapter 5 describes the results of the population modelling from yield-per-recruit and spawner biomass-per-recruit analyses. Chapter 6 describes the development of fishery management plans (FMPs) for elasmobranchs and outlines the framework used for developing the draft FMP for the soupfin shark. Chapter 7 is a detailed FMP that provides recommendations for precautionary management of the South African *G. galeus* fishery and suggestions for future stock assessments.

Table 1.4. An example of the rapid assessment indicator table to be used throughout the current study for assessing the stock status of *Galeorhinus galeus*).

		Unknown	Poor	Reasonable	Good	TOTAL
Biological parameters	**Maximum age**					
	L_{inf}					
	L_{50}					
	A_{50}					
	M					
	Z					
	Age-at-maternity					
	Size composition					
	a) Fishery					
	b) Actual population					
	Spatial structure					
	POINTS					
Fisheries data	**CPUE**					
	Historical catch data					
	POINTS					
Stock assessment model data	**Age-specific selectivity**					
	F					
	Z					
	$F_{0.1}$					
	F_{SB40}					
	POINTS					
Other species-specific knowledge (*e.g.*, from other populations)	**Biological data**					
	Fisheries data					
	POINTS					
OVERALL SCORE						

* L_{inf} = maximum theoretical length; L_{50} = length-at-50%-maturity; A_{50} = age-at-50%-maturity; M = rate of natural mortality; Z = total mortality; F = fishing mortality; $F_{0.1}$ = an increase in fishing mortality, there will be no increase in yield or, alternately, the point on the curve where the slope is 10% of that of the origin; F_{SB40} = the point at which spawner biomass is reduced to 40% of pristine pre-exploitation levels.

CHAPTER 2

STUDY AREA AND GENERAL SAMPLING METHODS

2.1 Study area

Fishery-dependent data were collected via Marine and Coastal Management (MCM) catch-return data sheets from the entire longline and handline commercial soupfin shark (*Galeorhinus galeus*) fishing area (Figure 2.1). Fishery-independent data were collected from research surveys conducted between 1996 and 1999 on the MCM research vessel FRS *Sardinops*. During these research surveys, soupfin sharks were collected between Saldanha Bay (33°01’0 S, 17°56’60 E) and Gans Bay (34°34’60 S, 19°21’0E) on the west coast of South Africa (Figure 2.1). MCM research surveys incorporated several methods of fishing, including longline, handline, trawl nets, and monofilament gillnets. Fishing depths ranged between 13 – 205 m and fishing times (soak time) ranged between 2 – 16 hours. Hook numbers ranged from 5 – 91 hooks per longline

2.2. Sources of data

For the purposes of this study several sources of data were used, including:

- fishery-dependent catch information (as described above);
- research survey data (as described above);
- vertebral samples and associated biological information obtained from the Port Elizabeth Museum, South Africa;
- biological and life-history parameters and CPUE data, obtained from previous studies on *G. galeus* for comparative purposes (Note: sources for and descriptions of these data are described in detail in Chapter’s 3, 4 and 5).

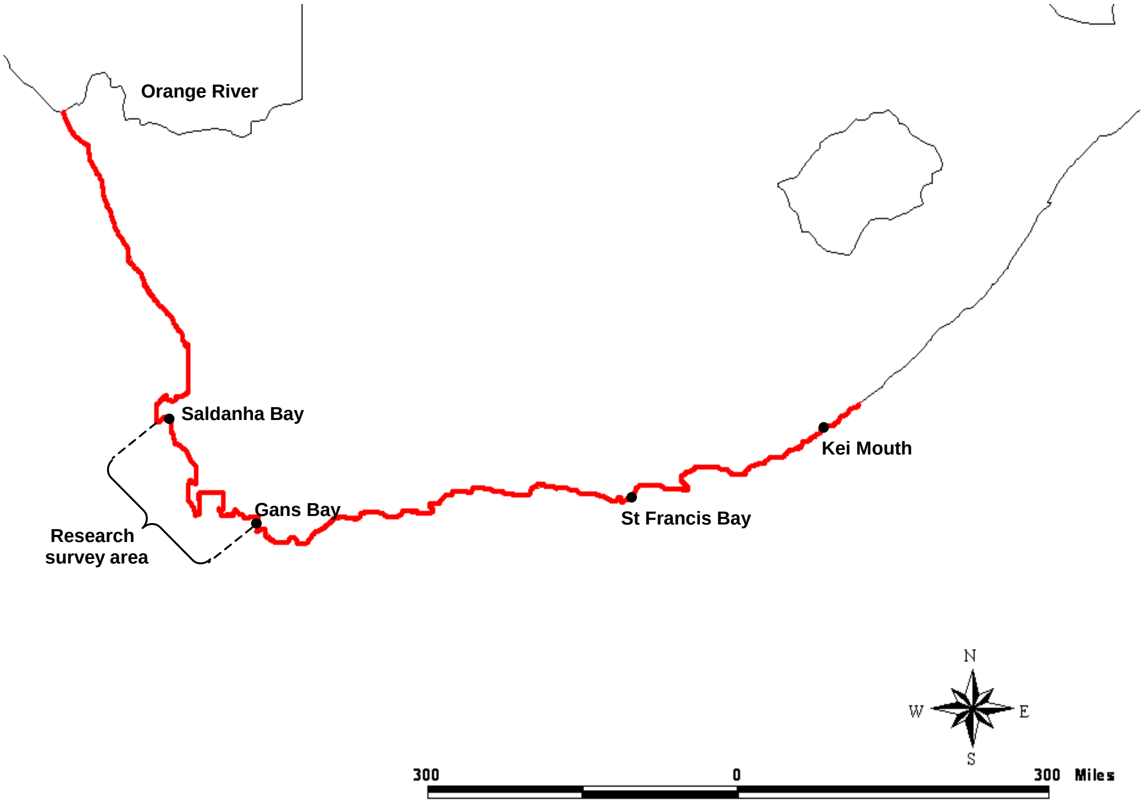


Figure 2.1. A map of the west and south coast of South Africa illustrating the distribution of the commercial soupfin shark (*Galeorhinus galeus*) longline and handline fisheries, and the research survey area.

2.3 Data analysis

Due to suspected inaccuracies in the commercial longline and handline data, an investigation into data integrity was conducted prior to data analysis. This investigation included an examination of catch records to determine whether recorded catches agreed with fishing areas, soak times and the number of hooks and/or lines used by fishermen. Upon examination of the commercial longline data, it became evident that errors resulting from improper data entry and sorting existed in the database for all years prior to 2001. Thus, catch analyses for these data are based on the years 2001 to 2003. It was also determined that inaccuracies due to a lack of data validation existed in both the longline and handline databases. Records that appeared suspect were discarded and not included in the analyses. This represented a total of 120 records in the longline database and 53 records in the handline database.

The data used for analyses in this study are as follows:

- commercial longline catch data (2001-2003);
- commercial handline catch data (1985-2003);
- research survey catch data (1996-1999);
- research survey biological information (1996-1999);
- other (as described in 2.2).

Data analysis for both the commercial longline and handline soupfin shark fisheries was simplified due to the multi-species nature of the soupfin shark fishery and associated complexities in separating catch statistics. Analyses of these data were based on the boat-based commercial longline and handline fisheries, and were used to calculate yearly catch trends. These analyses are described in detail in Chapter 3. Analyses of the fishery-independent research survey data are based on biological and catch information gathered during the research surveys. These data were used to calculate yearly catch trends and for estimating biological parameters of *G. galeus*. Analyses of these data are described in detail in Chapters 3, 4 and 5.

CHAPTER 3

CATCH TRENDS

3.1 Introduction

Reliable fishery-dependent data is required for fisheries management, as it provides information about catch estimates for target and bycatch species and the amount of effort allocated to a fishery during a given time period. Catch estimates can be made through several means, including fisheries observers, logbooks and on-shore monitoring programs (Morgan and Burgess, 2004). Similarly, effort can be defined as the number of boats fishing and/or the number of hours spent fishing. This information is critical in fisheries management, as these estimates are used to model changes in population abundance, as well as for allocating catch quotas and/or fishing permits. Likewise, fishery-independent data can be utilized to compare trends between scientific data obtained from research surveys and fishery-dependent data to determine whether similarities exist in catch trends, thereby determining the reliability of fishery-dependent data.

In South Africa, commercial catches of elasmobranchs are recorded in logbooks and returned to the regional fisheries organization (Marine and Coastal Management (MCM)) on a monthly basis. Fishery records in the demersal longline fishery include vessel names, registration codes, date, depth, hook number, soak time, and species caught (number and weight). Fishery records in the handline fishery are similar; however, these also include the number of crew per boat. Although these data are returned to MCM, it is important to note that all catch information must be interpreted with a degree of caution. As discussed by Morgan and Burgess (2004), fishers may not always record accurate data through the under-reporting of catches and incorrect identification of species. Compounding this is the lack of monitoring of landings and subsequent lack of validation of fishery-dependent commercial shark data in South Africa. However, increasing exploitation of elasmobranch species in South Africa meant it was necessary to collect, analyse and interpret these data and utilize them in the most suitable and reliable manner for the development of a precautionary management strategy for this species.

To determine whether any changes in soupfin shark population abundance in South Africa are evident, catch trends were examined and calculated for both the shark demersal longline and handline fisheries, as well as for the fishery-independent research surveys.

3.2 Materials and Methods

3.2.1 Fishery-dependent and –independent data

3.2.1.1 General catch trends

All fishery-dependent catch information was obtained from the commercial longline and handline databases at MCM. Trends in the weight of soupfin sharks caught over time were determined by calculating the total weight (kg) of shark caught for all vessels according to year. Catch trends for the commercial longline and handline fisheries were calculated for the years 2001-2003 and 1985-2003, respectively. Catch trends for the fishery-independent research survey data were calculated for the years 1996-1999.

3.2.1.2 Catch per unit effort (CPUE)

Trends in the weight of soupfin sharks caught over time as a function of effort were determined by calculating the total weight (kg) of shark caught per year for the total effort allocated per year. CPUE was calculated as the average total weight of sharks (kg) caught per hook hour for the longline fishery and research survey data, and the average total weight of sharks (kg) caught per man hour for the handline fishery. CPUE for the commercial longline and handline fisheries was calculated for the years 2001-2003 and 1985-2003, respectively. CPUE for the fishery-independent research survey data was calculated for the years 1996-1999.

3.3 Results

3.3.1 General catch trends

Catch trends for the commercial longline, handline fisheries and research surveys for the years 2001-2003, 1985-2003 and 1996-1999, respectively, are shown in Figure 3.1. Figure 3.1 illustrates that recorded catches in the demersal longline fishery were highest in 2003 and have increased from 2001 to 2003. Between 2001 and 2002, catches increased from 5867 kg to 22 247 kg. Recorded catches in the handline fishery were highest in 1993 and lowest in 2002. In 1985, the total weight of soupfin shark caught was 44 690 kg, with an increase to 140 222 kg in 1987. Recorded catches increased to 292 137 kg in 1993 and declined 22 270 kg in 2003. Recorded catches for the fishery-independent research surveys were lowest in 1998 and peaked in 1997.

3.3.2 Catch per unit effort (CPUE)

CPUE for the commercial longline and handline fisheries for the years 2000-2003 and 1985-2003, respectively, are shown in Figure 3.2. Figure 3.2 illustrates that CPUE for the demersal longline fishery was highest in 2003 at 0.26 kg/hook hour^{-1} and was lowest in 2001 at 0.01 kg/hook hour^{-1}. In 2002, CPUE was calculated as 0.02 kg/hook hour^{-1}. CPUE for the handline fishery peaked in 1993 at 0.066 kg/man hour^{-1} (1985 boats fishing) and was lowest in 2001 (920 boats fishing) at 0.005 kg/man hour^{-1}. In 1985, 1539 boats were recorded using handline to fish for soupfin shark and CPUE was calculated as 0.03 kg/man hour^{-1}. In 2000, CPUE was 0.02 kg/man hour^{-1} and the number of boats fishing was recorded as 1072. In 2003, CPUE was calculated as 0.009 kg/man hour^{-1} and 686 boats were recorded. CPUE for the demersal longline fishery is higher than CPUE for the handline fishery. Fishery-independent research surveys shows that CPUE was lowest in 1998 and 1999 at approximately 0.05 kg/hook hour^{-1} and highest in 1996 at 0.12 kg/hook hour^{-1}. CPUE in 1997 was calculated as 0.095 kg/hook hour^{-1}. To better compare CPUE for the demersal longline and handline fisheries, CPUE for the handline fishery is also illustrated for the years 2001-2003 (Figure 3.3). Figure 3.3 shows that there was an increasing trend in CPUE for the years 2001-2003 for both the demersal longline and handline fisheries. However, the increase in CPUE in the demersal longline fishery was greater than that in the handline fishery.

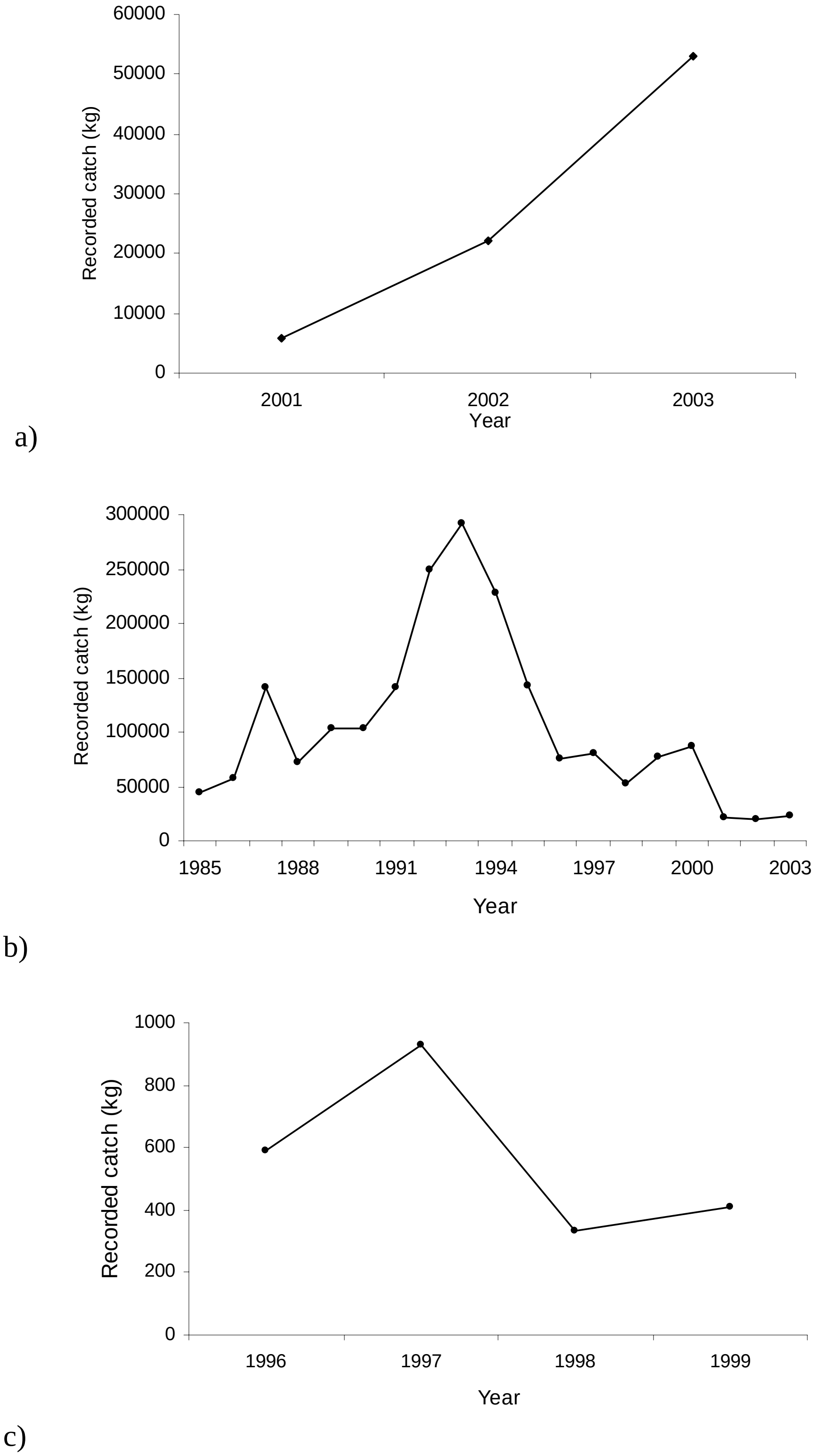


Figure 3.1. Trends in recorded catch (kg) of soupfin shark (*Galeorhinus galeus*) for a) the demersal longline fishery (2001-2003), b) the handline fishery (1985-2003) and c) the fishery-independent research surveys (1996-1999).

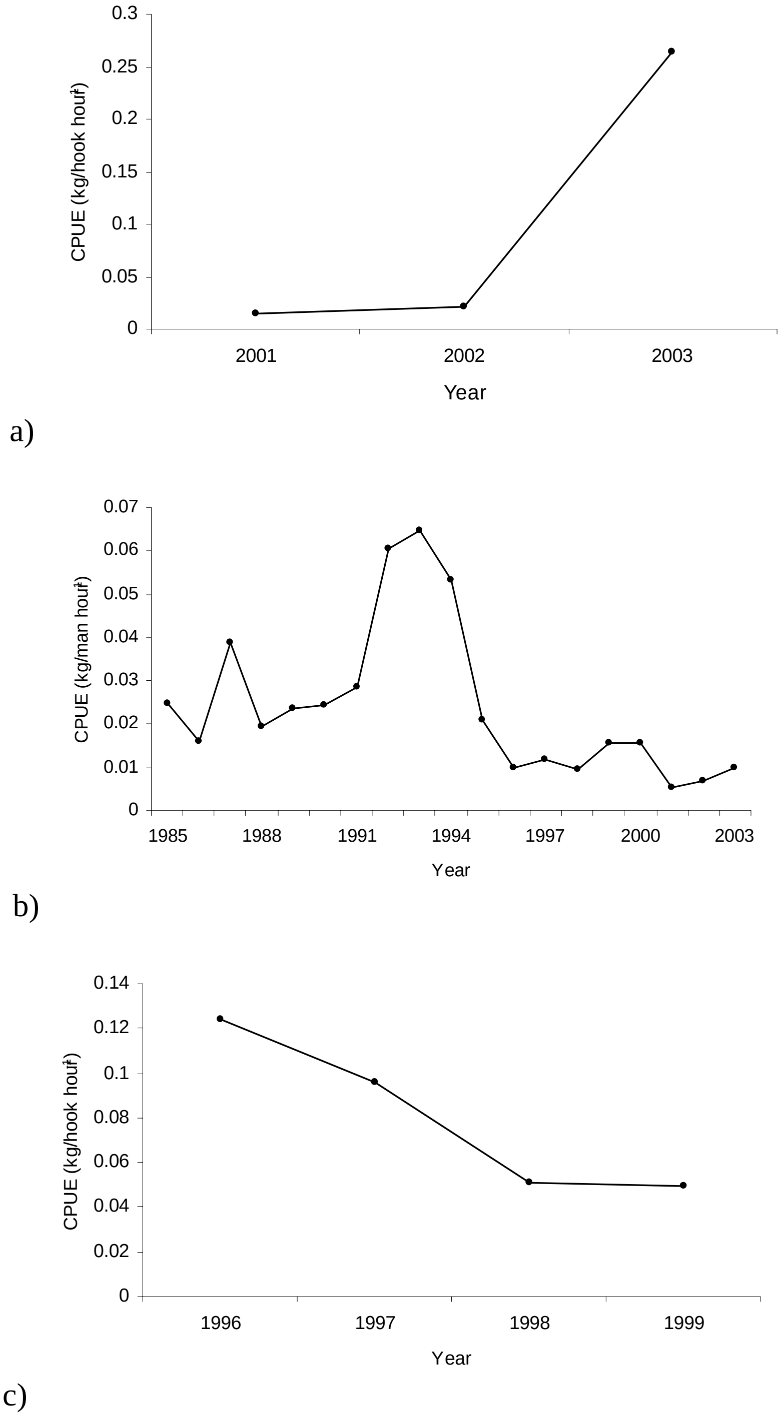


Figure 3.2. CPUE of soupfin shark (*Galeorhinus galeus*) in a) the demersal longline fishery (2001-2003), b) the handline fishery (1985-2003) and c) the fishery-independent research surveys (1996-1999). CPUE is calculated as the average catch (kg) per hook hour^{-1} (a, c) and the average catch (kg) per man hour^{-1} (b).

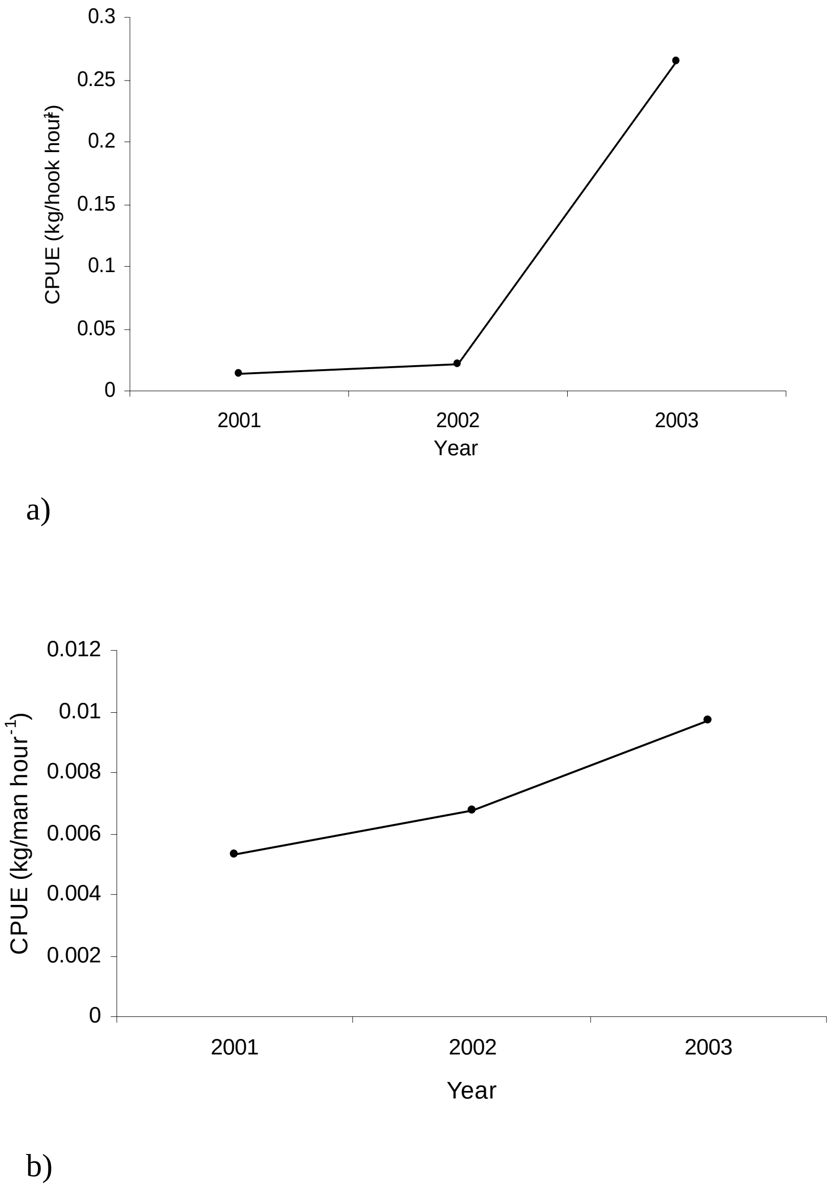


Figure 3.3. CPUE of soupfin shark (*Galeorhinus galeus*) in a) the demersal longline fishery (2001-2003) and b) the handline fishery (2001-2003). CPUE is calculated as the average catch (kg) per hook hour^{-1} (a) and the average catch (kg) per man hour^{-1} (b).

3.4 Discussion

Analysis of catch trends allows scientists and managers to determine whether changes in population abundance are evident over time. This is particularly important in fisheries where little other information is available, enabling decisions about catch quotas and permit allocations to be made when more complex statistical analyses are not possible. Although catch data allows inferences to be made about the stock, CPUE is a much better indication of the stock status (Morgan and Burgess, 2004). However, it is important to note that the stock of concern may be declining when CPUE statistics indicate an increase. This may be attributed to several factors, including the advancement of the fishing gear, movement of the fishery to more productive grounds, and advancement in the fishing abilities of the fishing crew (Morgan and Burgess, 2004).

Several factors indicate that the catch trend data in the South African soupfin shark fishery is inadequate and the analyses presented here must be interpreted with a degree of caution. Firstly, the lack of historical data for the demersal longline fishery means that population abundance and long-term trends in catches could not be calculated, thus making the comparisons between that fishery and the handline fishery difficult. Secondly, a lack of validation of fisheries data means that unidentified errors in catch records may exist due to under-reporting of catches and species misidentification. Thirdly, the lack of compliance and enforcement in both the demersal longline and handline fisheries may indicate that fishermen discard unwanted catches at sea, resulting in unaccounted fishing mortality of soupfin sharks. However, it was necessary to undertake a preliminary investigation of catch trends within these fisheries to identify any underlying trends in the soupfin shark population, irrespective of a lack of data.

Preliminary analysis of the three years of available longline data (2001-2003) indicates that both catch and CPUE are increasing. As the longline fishery is still in a developmental phase, an increase in CPUE can be expected; however, caution must be exercised as this method of fishing will inevitably become increasingly proficient. An increase in CPUE may also be attributable to the increased economic value associated with shark meat and curios in the international market (Anak, 1997) and a resultant increase in fishing pressure, and not to any increase in population abundance. The catch data from the handline fishery shows that there has been a decline in catch rates from a peak in 1993, although it was observed that fewer boats have been recorded as fishing for soupfin shark since 1993 (peak of 1985 in 1993 to 686 in 2003). There are several possible explanations for this change in catch trends. Firstly, a shift in soupfin shark distribution may have occurred in recent years to fishing areas that are less accessible to the smaller handline vessels and more accessible to the larger longline vessels. Secondly, as the soupfin shark handline fishery is a multi-species fishery, the fishing crew may be targeting more valuable teleost stocks due to an inability to catch enough sharks to make shark fishing economically viable. Thirdly, this decline in both effort and CPUE may reflect an actual decline in the population abundance.

The catch data from the fishery-independent research survey data allowed comparisons to be made between the potentially unreliable fishery-dependent data and the more reliable fishery-independent data. These analyses illustrate that there has been a decline in catches since 1997, although effort has also decreased. As the fishery-independent data covers only four years, it is difficult to determine whether this decline is a reflection of the actual state of the population status or a function of less research time spent fishing for soupfin sharks (as evidenced by the results of the CPUE data). However, both the handline data and the research survey data indicate a decline in recorded catches, likely indicating an actual decline in soupfin shark population abundance.

As there are no seasonal restrictions in the South African shark longline and handline fisheries, and the South African shark fishery is a multi-species fishery that has historically targeted shark only when catches of other fish (teleosts) are low (Kroese and Sauer, 1998), estimates of fishing effort are likely inaccurate. Also, preliminary analysis of catch data indicated that several problems exist within the data itself, compounding the aforementioned inaccuracies in the data. This resulted in difficulties in calculating and interpreting historical catch trends for the South African soupfin shark fisheries.

To increase the accuracy associated with future analyses of these data, several recommendations can be made. Firstly, it is necessary to develop a dedicated chondrichthyan database at MCM that houses all fishery-dependent and –independent catch and effort data, including bycatch information. Secondly, MCM should be responsible for validating fishery data through observer coverage of vessels and/or dockside monitoring. Thirdly, dedicated fishery-independent sampling should be undertaken to allow for comparisons between this information and fishery-dependent data, thereby increasing the reliability of catch trend analyses. Lastly, it is recommended that MCM develop a chondrichthyan field guide for fishermen that will increase the certainty associated with species identification at sea.

Walker (1999) collated catch data for *G. galeus* fisheries from southern Australia, New Zealand, the southwest Atlantic and the northeast Pacific. In southern Australia, the catch (in tonnes) for *G. galeus* peaked in the late 1960s, shortly before production began to decline due to declining stocks. A second peak in catches in the 1980s represented increased targeting of this species, although stocks have again declined as a result of restrictions on the use of gillnets and a continuing decline in stock abundance (Walker, 1999). Catch trends in New Zealand have exhibited a similar trend, with catches peaking in the early 1980s and declining since 1982 (Walker, 1999). In 1986, the total allowable commercial catch for *G. galeus* in New Zealand was set at 2590 t and this was again raised to 3106 t in 1995-1996. Commercial landings for *G. galeus* have since remained below these levels. Although catch data from the southwest Atlantic and the northeast Pacific are incomplete, these data indicate similar declines in catch trends (Walker, 1999).

The "boom and bust" nature of these fisheries (Walker, 1999) indicates that high catch levels of *G. galeus* are often followed by quick declines as a result of significant stock declines and even stock collapse (*i.e.*, the Californian *G. galeus* fishery). Given the sensitivity of this species to overexploitation (Walker, 1998) and the characteristics of *G. galeus* fisheries throughout the world (refer to Chapter 1, Table 1.2) it is evident that this species cannot withstand high levels of fishing pressure. Thus it is recommended that

MCM carefully monitor catch trends to reduce the risk of stock collapse in the South African *G. galeus* fishery. Methods through which this may be achieved are described in Chapter 7.

Table 3.1. Step 1: rapid assessment indicator table for assessing the quality of catch and effort data in the *Galeorhinus galeus* fishery. This represents both the fishery-dependent and –independent data.

		Unknown	Poor	Reasonable	Good	TOTAL
Biological parameters	**Maximum age** **L_{inf}** **L_{50}** **A_{50}** **M** **Z** **Age-at-maternity** **Size composition** **a) Fishery** **b) Actual population** **Spatial structure**					
	POINTS					
Fisheries data	**CPUE** **Historical catch data**		✓ ✓			
	POINTS		**2**			**2**
Stock assessment model data	**Age-specific selectivity** **F** **Z** **$F_{0.1}$** **F_{SB40}**					
	POINTS					
Other species-specific knowledge (*e.g.*, from other populations)	**Biological data** **Fisheries data**					
	POINTS					
OVERALL SCORE						

* L_{inf} = maximum theoretical length; L_{50} = length-at-50%-maturity; A_{50} = age-at-50%-maturity; M = rate of natural mortality; Z = total mortality; F = fishing mortality; $F_{0.1}$ = an increase in fishing mortality, there will be no increase in yield or, alternately, the point on the curve where the slope is 10% of that of the origin; F_{SB40} = the point at which spawner biomass is reduced to 40% of pristine pre-exploitation levels.

CHAPTER 4

SIZE FREQUENCY, AGE, GROWTH, AND MORTALITY OF THE SOUPFIN SHARK (*GALEORHINUS GALEUS)*

4.1 Introduction

Age determination is based on the examination of calcified structures in fishes, in which growth-increment bands, comprised of hyper- and hypo-mineralized bands, are visible. Unlike teleosts, elasmobranchs lack otoliths and scales, and age determinations are often made from other calcified structures such as dorsal spines or vertebrae. Age estimates form the basis for calculations of growth rate, maturity, mortality and productivity, and are therefore a fundamental aspect of fisheries research (Campana, 2001; Goldman, 2004). Obtaining accurate and reliable age estimates for elasmobranchs is fundamental for developing successful management strategies (Goldman, 2004), as it provides vital information about stock structure, productivity, and stock response to environmental- and human-induced pressures (*e.g.*, habitat degradation and fishing pressure) (Lessa *et al.*, 1999; Campana, 2001; Clarke *et al.*, 2002). Although inaccurate age estimates can lead to errors in stock assessment resulting in overexploitation, few attempts have been made to validate and verify species ages (Campana, 2001).

Growth-increment bands found in the calcareous structures of elasmobranchs (*e.g.*, dorsal spines and vertebrae) are used for age determination. The growth-increment bands visible in whole or sectioned vertebrae are composed of opaque (hyper-mineralized) and translucent (hypo-mineralized) bands (Walker *et al*., 1995). The formation of these bands is partially attributable to periodic changes in water temperature and food availability. Translucent bands are usually formed in the winter months, and opaque bands are formed in the summer months (Martin and Caillet, 1988). For elasmobranchs it is often assumed that these growth-increment bands represent one year of growth (Saunders and McFarlane, 1993; Moulten *et al*., 1992), although some studies have shown that two bands can be laid down in one year for some species (*e.g.*, *Cetorhinus* *maximus*) (Parker and Stott, 1965; Casey and Natanson, 1992), demonstrating the importance of validating and verifying age estimates across all age classes.

As a commercially important elasmobranch species the soupfin shark (*Galeorhinus galeus*) has been studied in many parts of its range. These studies have focused on the age and growth of the species due to the importance of this biological information in the development of stock assessments and management strategies (Grant *et al*., 1979; Ferreira and Vooren, 1991; Freer, 1992; Walker *et al*., 1995; Francis and Mulligan, 1998; Walker *et al*., 2001). In a study conducted by Freer (1992), the age structure and growth parameters of the South African population of *G. galeus* were determined. However, it seems likely that the ages in this study were underestimated due to small sample sizes, resulting in unreliable estimates of growth parameters (Walker, 1999).

Since *G. galeus* is targeted in two fisheries in South Africa (handline and longline), it is important to accurately estimate the population age structure and growth parameters to assist in the development of an appropriate management strategy. Collection of fishery-dependent data is difficult as sharks are landed headed, finned and gutted. However, research surveys originally conducted through demersal trawling and, more recently, longlining enabled scientists to collect fishery-independent data on *G. galeus*. Recently, these research surveys have ceased and survey data only exists to 1999.

This chapter aims to determine the size frequency, age, growth, and mortality parameters for *G. galeus* using vertebral age information based on all available biological research survey data.

4.2 Materials and Methods

4.2.1 Sample sizes

Between 1996 and 1999, 135 soupfin sharks were caught on longlines in the fishery-independent research surveys. Table 4.2 describes the number of soupfin sharks caught and describes the number of male, female and "unidentified" sharks caught on the FRS *Sardinops*.

Table 4.2. Number of soupfin sharks (*Galeorhinus galeus*) caught on longline between 1996 and 1999 by research surveys.

Sampling year	*Number of sharks caught*	*Number of males*	*Number of females*	*Number unidentified*
1996	34	23	5	6
1997	60	20	40	-
1998	25	17	-	8
1999	16	16	-	-
TOTAL	**135**	**76**	**45**	**14**

4.2.1.1 Sex & stage of maturity

For all sharks caught on the fishery-independent research surveys, sex was determined by external observation of the sharks and was recorded as male if claspers were present and female if claspers were absent. Stage of sexual maturity was measured on a scale ranging between 1 and 5, according to a scale developed by MCM for elasmobranchs (Table 4.3).

Table 4.3. Stage of sexual maturity for male and female *Galeorhinus galeus*.

Stage of sexual maturity	*Male*	*Female*
1	Embryo	Embryo
2	Immature	Immature
3	Adolescent	Adolescent
4	Adult	Adult
5	N/A	Pregnant

4.2.1.2 Length & weight

For all sharks caught on the fishery-independent research surveys, length and weight measurements were taken when sharks were landed on board. All length measurements were recorded in millimetres (mm). Total length (TL) was measured from the tip of the rostrum to the tip of the upper lobe of the caudal fin (Figures 4.1-4.3). Pre-caudal length (PCL) was measured from the tip of the rostrum to the pre-caudal pit. All weight measurements were recorded in kilograms (kg).

4.2.2 Age and Growth

4.2.2.1 Sample collection

Soupfin sharks (*G. galeus*) were collected between Saldanha Bay (33°01’0 S, 17°56’60 E) and Gans Bay (34° 34’60 S, 19°21’0 E) in South Africa between 1996 and 1999 during shark-directed research cruises on the MCM research vessel FRS *Sardinops*. Fish weights were recorded to the nearest kilogram, and total fish lengths were recorded to the nearest millimeter; 135 vertebral samples were collected. Another 175 vertebral samples were collected from the Port Elizabeth Museum in Port Elizabeth, South Africa. Of the 310 total samples, 80 samples were excluded due to an inability to cross-identify samples with specimens. Approximately 79% of vertebrae were removed from the post-cranial region of the vertebral column, and 21% were collected as whole vertebral columns. After collection, vertebral samples were trimmed of connective tissue, including the neural and haemal arches, and stored dry in marked sealable plastic bags.

4.2.2.2 Sample storage

Of 310 vertebrae, 230 were embedded in polyester resin (see section 4.2.2.3 below). However, 154 vertebrae (67%) were rejected due to degeneration of the corpus calcareum caused by improper storage. These vertebrae had been stored dry or in alcohol for at least five years and were almost completely distorted and/or degenerated. The remaining 76 vertebrae were also stored dry or in alcohol; however, these were sufficiently calcified to allow further analysis. Due to problems with reading vertebrae stored dry or in alcohol, it is recommended that, in future, soupfin shark vertebrae be stored frozen as this prevents degeneration.

4.2.2.3 Laboratory preparation

Several techniques were attempted to obtain age estimates, including staining whole vertebrae with alizarin red, staining sectioned vertebrae with alizarin red (according to Moulton *et al.*, 1992) and x-radiography of sectioned vertebrae (according to Officer *et al.*, 1995). Due to difficulties encountered with reading the stained vertebrae, the latter technique (x-radiography) was employed for this study.

76 vertebral samples were embedded in polyester casting resin and sectioned using a double blade diamond edge saw. Sections were an average thickness of 100 µm, and all sections were made sagitally through the focus. Each section was then labelled and placed on a light safe bag containing ILFORD cibachrome medium weight paper (CRCA.44M) and radiographed for 60 – 90 seconds at 40 kV and 6 mA. X-radiographs were examined and read using a stereo dissecting microscope under transmitted light using a magnification of 10X.

4.2.2.4 Interpretation of growth zones

Growth bands consisted of one opaque and one translucent zone. All readings were made from the corpus calcareum. Growth rings of soupfin shark vertebrae are inherently difficult to read, thus an index of readability similar to that of Officer *et al.* (1995) was constructed in order to classify vertebrae according to growth zone appearance (Table 4.4).

Table 4.4. Description of the readability index assigned to readings of vertebrae (IC = increment count). (Adapted from Officer *et al.*, 1995).

Score	*Description*
1	IC unambiguous with exceptionally clear increments.
2	IC unambiguous, but increments of diminished clarity.
3	Two IC possible, but indicated IC is most likely.
4	More than two interpretations possible; IC is best estimate.
5	No IC possible, specimen abnormal or otherwise unreadable.

Vertebrae were read twice, at intervals of three weeks, without knowledge of fish length, weight or date of capture. A mean age was accepted if the number of opaque zones for each reading was equal or the difference between age values was less than two.

4.2.2.5 Ageing precision

Goldman (2004) recommends measuring ageing bias prior to running a test to determine ageing precision. Thus, an age bias plot was constructed in order to test for systematic differences between readings. A Chi-square test of symmetry was conducted on the data to test if ageing differences were due to systematic or random error.

Estimates of ageing precision assess the reproducibility of an individual's age determinations (Campana, 2001). For this study, reading precision was measured as average percent error as defined by Beamish and Fournier (1981). According to the average percent error method, if N fish are aged and R is the number of times a fish is aged, then X_{ij} is the ith age determination of the jth fish, and the average age of a fish, X_{j}, can be calculated as:

$$X_j = \frac{1}{R}\sum_{i=1}^{R} X_{ij} \tag{1}$$

The average error in ageing the jth fish as a fraction of the average of the age estimates, average percent error (APE) is defined as:

$$APE = \frac{1}{R}\sum_{i=1}^{R} \frac{\left|X_{ij} - X_j\right|}{X_j} \times 100 \tag{2}$$

The index of average percent error (IAPE) was modelled as:

$$IAPE = \frac{1}{N}\sum_{j=1}^{N} \left\{ \frac{1}{R}\sum_{i=1}^{R} \frac{\left|X_{ij} - X_j\right|}{X_j} \right\} \times 100 \tag{3}$$

where N is the number of vertebrae with acceptable readability scores. According to Officer *et al* (1995), increment counts of zero value from vertebrae with acceptable readability scores should not be included, as such values can distort the IAPE. Thus, for the purpose of this study, vertebrae with increment counts of zero value were not included in the estimation of IAPE.

4.2.2.6 Validation

Age determination from the calcareous structures in elasmobranchs depends on the assumption that growth rings are deposited in a consistent manner throughout the lifetime of the fish. Evaluating the temporal periodicity of growth zone deposition can be classified into two terms: age "verification" and age "validation" (Campana, 2001). Age verification is the process in which an age estimate is confirmed by comparison with indeterminate age estimates (*e.g.*, marginal increment analysis), and age validation is the process in which the absolute age of an individual fish is determined through determinate age estimates (*e.g.*, tag-recapture studies) (Goldman, 2004). Validation of absolute age is costly and difficult to perform as it requires validation for all age classes (Goldman, 2004).

Two methods of age verification were attempted - centrum edge analysis and relative marginal increment analysis (RMI) - to assess seasonal band deposition. Centrum edge analysis compares the opacity and translucency of the centrum edge against month of capture in order to discern seasonal patterns of growth (Goldman, 2004). The centrum edge is categorized as opaque or translucent, the band width is measured, and the result is plotted against season of capture (Goldman, 2004). In RMI, the width of the ultimate growth band is divided by the width of the penultimate growth band, and the resulting RMI values are plotted against month of capture to determine the temporal periodicity of annulus formation. Age zero animals may not be used for this analysis, as the vertebrae possess no fully formed increments (Goldman, 2004).

4.2.2.7 Estimation of growth parameters

Length-at-age of *G. galeus* was modelled using two growth models: the three-parameter von Bertalanffy growth model (VBGF) and the Schnute growth model. The VBGF is defined as:

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

where L_t is the length at time t, L_∞ is the theoretical asymptotic length, K is the Brody growth coefficient that determines the rate at which L_∞ is attained, and t_0 the age at zero length.

The Schnute growth model is defined as:

$$L_t = \left[L_1^b + (L_2^b - L_1^b) \left\{ \frac{1 - e^{-a(t-t_1)}}{1 - e^{-a(t_2-t_1)}} \right\} \right]^{1/b}$$

where t_1 is the youngest fish sampled, t_2 is the oldest fish sampled, Lt is the length at time t, L_1 is the estimated mean length of t_1 year old fish, and L_2 is the estimated mean length of t_2 year old fish.

The parameters for each model were estimated using a non-linear downhill search to minimize the absolute and relative residuals of the sum of squares (Nelder and Mead, 1965). An absolute error structure assumes normal residuals (E_t):

$$\hat{L}_t = L_t + E_t \qquad E_t \sim N(0, \sigma^2) \qquad \text{(Schnute, 1981).}$$

where L is the model predicted length-at-age, E_t is the relative error structure which assumes that error increases with age such that:

$$\hat{L}_t = L_t e^{E^{t}} \qquad E_t \sim N(0,\sigma^2) \qquad \text{(Schnute, 1981).}$$

The quantity to be minimized for the absolute error structure of the model was:

$$SS = \sum \left(L_t - \hat{L}\right)^2 \qquad \text{(Schnute, 1981).}$$

The quantity to be minimized for the relative error structure of the model was:

$$SS = \sum \ln\left(\frac{L_t}{\hat{L}}\right)^2 \sum\left[t\ln\left(\frac{L_t}{\hat{L}_t}\right)\right]^2 \qquad \text{(Schnute, 1981).}$$

Homoscedasicity and randomness of the residuals were tested using a Bartlett's test and a non-parametric one sample runs test, respectively (as shown in Booth and Buxton, 1997). The model with the least number of parameters was chosen if the residuals were both random and homoscedastic. Parameter variance estimates were calculated using parametric bootstrap resampling with 500 bootstrap replicates. Confidence intervals were obtained from the sorted bootstrap data using the percentile method (Buckland, 1984; Efron, 1987). A power function was used to model the relationship between fish total length and weight (Pitcher and Hart, 1990).

4.2.3 Maturity

4.2.3.1 Length-at-maturity

The length-at-50%-maturity (L_{50}) and age-at-50%-maturity (A_{50}) for *G. galeus* were estimated by fitting a logistic ogive to the proportion of mature fish sampled during the period 1993 to 1999. Length-at-50%-maturity and age-at-50%-maturity were estimated separately for the combined sexes and for males. For females, the sample size was less than 30, so no estimate of L_{50} or A_{50} was possible. Age-at-50%-maturity was calculated using actual age estimates rather than length-converted ages. The proportion of sexually mature fish (PM_i) by length (L_i) and age was fitted using a logistic ogive of the form:

$$PM_i = \frac{1}{1+e^{-(l_i - l_{50})/\delta}}$$

where: PM_i = the proportion of mature fish in the i^{th} length class
l_i = i^{th} length (or age) class
l_{50} = mean length (or age) at 50% maturity
δ = the width of the logistic ogive, or the rate at which the population changes from 0% to 100% mature.

Maximum likelihood estimates of the parameters were obtained by minimizing the binomial likelihood (Cerrato, 1990).

4.2.4 Mortality

4.2.4.1 Natural mortality

The rate of natural mortality (*M*) was estimated using five methods that have been shown to give reasonable estimates of natural mortality for elasmobranchs (Simpfendorfer, 1998). Table 4.5 provides the equations used to estimate natural mortality. For estimates of natural mortality using Pauly's equation, a mean annual sea temperature for the west coast of South Africa of 11° C (Roberts, *pers. comm.*) was used.

Table 4.5. Methods used to estimate natural mortality for *G. galeus*. K = von Bertalanffy growth parameter; L_∞ = von Bertalanffy growth parameter; M = natural mortality; T = average water temperature (°Celsius); Z = instantaneous total mortality; t_{max} = maximum age; x_m = age at maturity. (Source: Simpfendorfer, 1998).

Method	*Relationships*
Pauly (1980)	$\ln(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T)$
Hoenig (1983)	$\ln(Z) = 1.46 - 1.01\ln(t_{\max})$
Jensen (1996) (age)	$M = \frac{1.65}{x_m}$
Jensen (1996) (growth)	$M = 1.5K(\mathit{theoretical})$
Jensen (1996) (Pauly)	$M = 1.6K$

4.2.4.2 Instantaneous total mortality

Total annual mortality for *G. galeus* was estimated using catch curve analysis. An age-length key, constructed from length-at-age data, was used to transform length frequency distributions to age frequency distributions. The length frequency data was obtained from shark-directed research surveys between 1996 and 1999. This allowed for estimation of the rate of instantaneous total mortality (Z) from the catch curve, where Z is the slope of the regression line. An estimation of fishing mortality (F) as a function of total and natural mortalities was obtained from the following equation:

$$F = Z - M$$

where Z is the rate of instantaneous total mortality and M is the rate of natural mortality obtained from Hoenig's equation.

4.3 Results

4.3.1 Size composition

Figure 4.1 illustrates the frequency of occurrence (%) of each size class of soupfin sharks caught on the fishery-independent research surveys from 1996-1999. Figure 4.2 and 4.3 illustrate the frequency of occurrence (%) of each size class of female and male soupfin sharks, respectively. The majority of sharks caught comprised the larger size classes (> 1200 mm TL). Approximately 30% of all soupfin sharks caught were between 1400 and 1500 mm TL, while about 1% was between 600 and 1800 mm TL. The majority of female sharks caught were 1500 mm, 900 mm and 1000 mm TL, at about 16%, 14% and 13%, respectively. The size-frequency distribution of female sharks is bimodal. The majority of male sharks caught were between 1400 mm and 1500 mm TL, at about 32% and 35%, respectively.

4.3.2 *Age and growth*

4.3.2.1 Suitability of vertebrae for ageing

Of the 230 X-rayed vertebral samples, 154 (67%) were classified as unreadable due to degeneration of the corpus calcareum. Seventy-six of 230 vertebrae (33%) met the criteria for ageing reliability. Fifty-three of 76 (70%) vertebral samples were from taken from males, and 23 of 76 (30%) vertebral samples were taken from females.

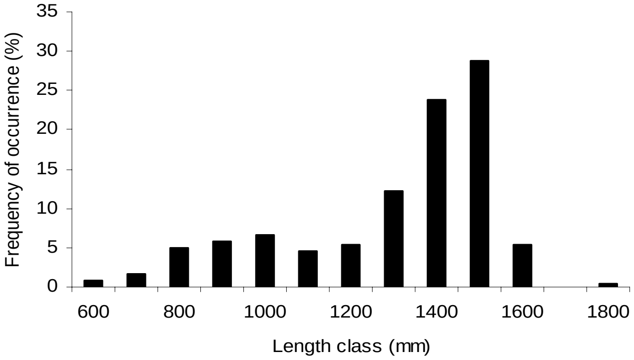


Figure 4.1. Frequency of occurrence (%) of each size class of *Galeorhinus galeus* caught between 1996 and 1999 (n=135; includes “unidentified sex”).

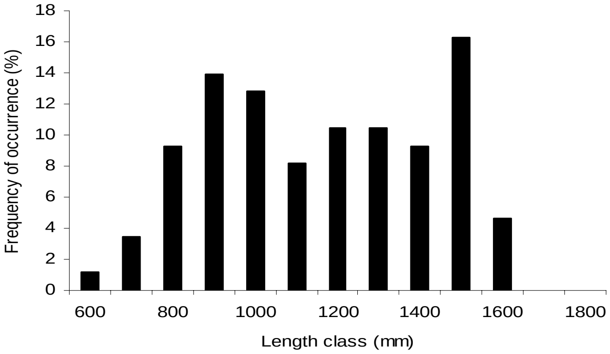


Figure 4.2. Frequency of occurrence (%) of each size class of female *Galeorhinus galeus* caught between 1996 and 1999 (n = 45).

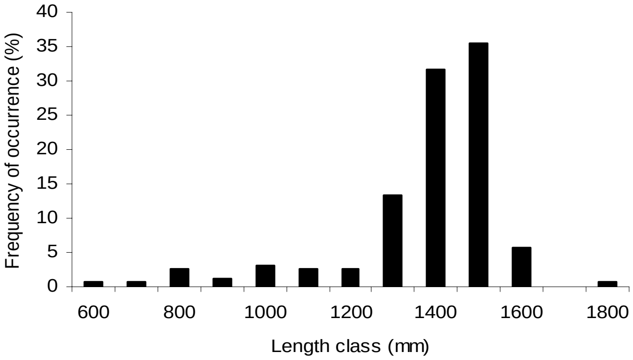


Figure 4.3. Frequency of occurrence (%) of each size class of male *Galeorhinus galeus* caught between 1996 and 1999 (n = 76).

4.3.2.2 Ageing precision

Ageing precision was tested by constructing an age bias plot and running a Chi-square test of symmetry in order to determine whether differences between readings were due to systematic or random error. Figure 4.4 illustrates the age bias plot for the two readings. A correlation coefficient of 0.98 indicates good agreement between readings. Age estimates were considered to be reasonably precise with an average percent error (APE%) of 9.7%.

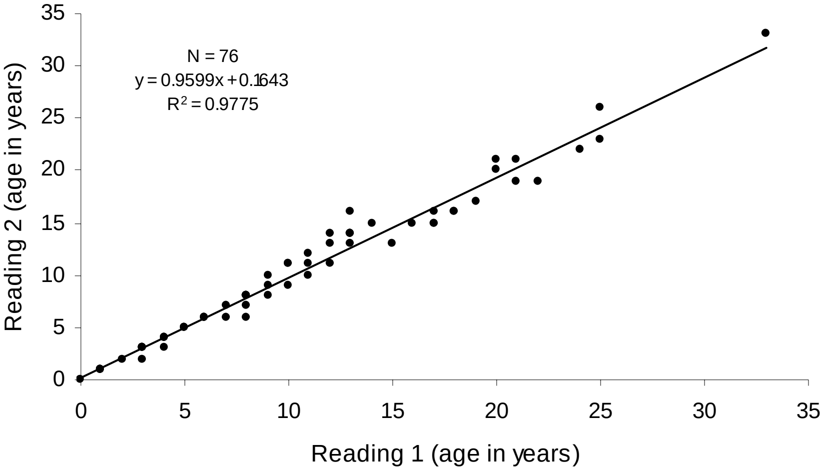


Figure 4.4. An age bias plot showing good agreement and no bias between reading 1 and reading 2.

A Chi-square test of symmetry showed that differences between the readings were due to random error rather than to systematic error ($p > 0.1$; 62 d.f.).

4.3.2.3 Validation

Due to a small sample size and incomplete sampling across months (incomplete representation of month of capture), it was not possible to validate the temporal periodicity of growth band formation through centrum edge analysis or RMI. Although vertebral samples included one tag-recapture of an oxytetracycline-injected animal, the animal was at liberty for only nine months, and there was extreme degeneration of the ultimate growth band in the corpus calcareum. In order to validate the assumption that one annulus represents one year of growth, the animal must be at liberty for one year or longer (Campana, 2001). Thus, it was not possible to use these vertebrae for validation purposes. However, as age estimates for *G. galeus* have been validated in Australia and New Zealand (Walker *et al.*, 1995), it was assumed for the purposes of this study that one annulus indicated one year of growth.

4.3.2.4 Estimation of growth parameters

The von Bertalanffy growth parameters are summarized in Table 4.6. The growth parameters for the combined sexes for *G. galeus* indicate that they achieve a maximum asymptotic total length (L_∞) of 1560.27 mm, with a growth coefficient (K) of 0.19 year^{-1} and an age at zero length (t_0) of -3.03 year^{-1}. Male *G. galeus* achieve an L_∞ of 1542.77 mm, with a K of 0.21 year^{-1} and a t_0 of -2.79 year^{-1}. There was insufficient data to estimate the growth parameters of female *G. galeus* ($n = 23$). The length-at-age von Bertalanffy growth curves for the combined sexes and male *G. galeus* are shown in Figure 4.5. An age-length key is provided in Appendix 1.

Table 4.6. Point estimates, associated standard errors (SE) and 95% confidence intervals (CI) for combined sexes and male *Galeorhinus galeus* from the von Bertalanffy growth model (n=76).

	Parameter	*Point estimate*	*SE*	*95% CI*
Combined sexes	L_∞	1560.27 mm TL	26.41	(1509.97, 1616.21)
	K	0.19·year^{-1}	0.02	(0.16, 0.23)
	t_0	-3.03·year^{-1}	0.35	(-3.77, -2.34)
Males	L_∞	1542.77 mm TL	33.58	(1479.8, 1620.57)
	K	0.21·year^{-1}	0.03	(0.17, 0.28)
	t_0	-2.79·year^{-1}	0.44	(-3.81, -2.04)

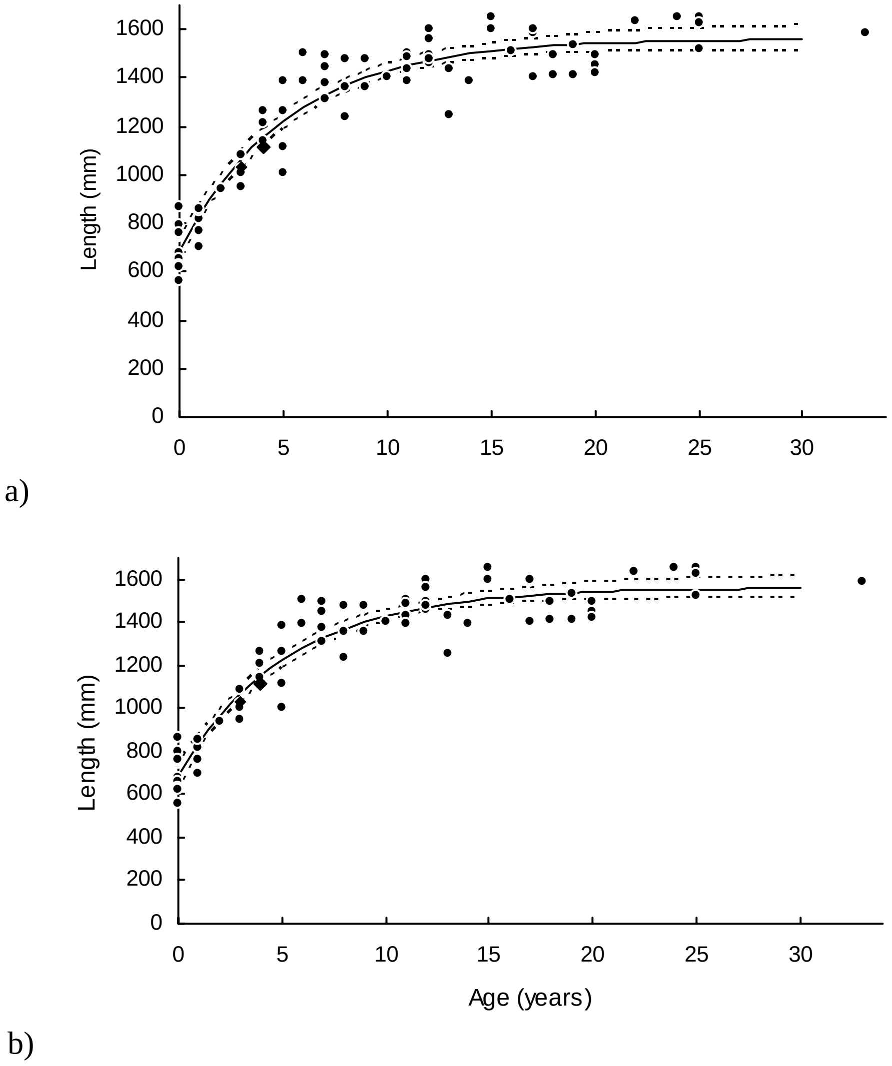


Figure 4.5. The growth curves of *Galeorhinus galeus* (a. males (n = 53); b. combined sexes (n = 76)). Dotted lines represent the upper and lower 95% confidence intervals from the bootstrapped predicted lengths-at-age.

4.3.3 Maturity

4.3.3.1 Length- and age-at-50%-maturity

Length- and age-at-50%-maturity are represented by the logistic curves presented in Figures 4.6 and 4.7, respectively. Age-at-50% maturity (A_{50}) for combined sexes and male *G. galeus* was estimated using actual estimated ages. The A_{50} of the combined sexes was 6.04 years, corresponding to a total length of 1100.0 mm. The A_{50} of males was 5.92 years, corresponding to a total length of 1010.8 mm. Small sample sizes precluded the estimation of the parameters for female *G. galeus*. Table 4.7 illustrates the parameters of the logistic curves described by sexual maturity.

Table 4.7. Parameters of the logistic curves describing sexual maturity in *G. galeus.*

	Parameter	*Point estimate*
Combined sexes	A_{50}	6.04 years
	δ	0.007
	L_{50}	1100 mm
	δ	11.7
Males	A_{50}	5.92 years
	δ	0.1
	L_{50}	1010.8 mm
	δ	9.8

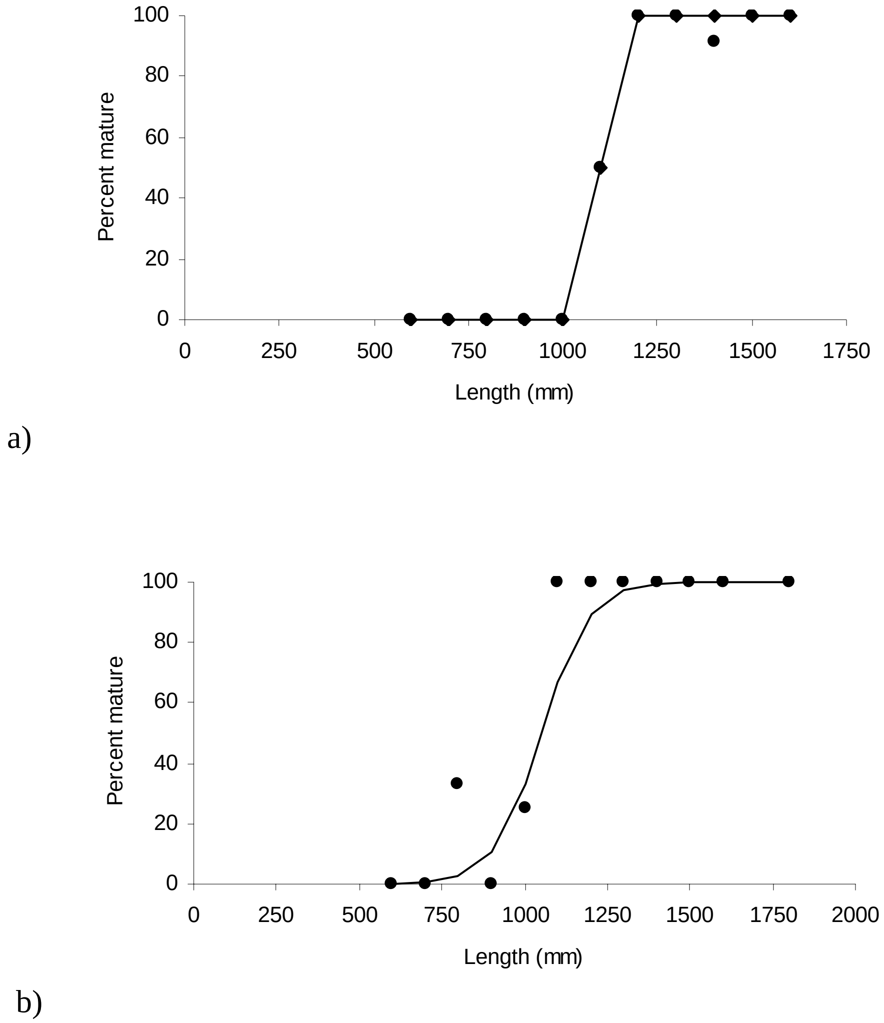


Figure 4.6. Length-at-50%-maturity for *Galeorhinus galeus* (a. combined sexes (n = 76); b. males (n = 43)). Solid circles represent observed lengths and the solid line represents the fitted model from which lengths-at-50%-maturity can be determined.

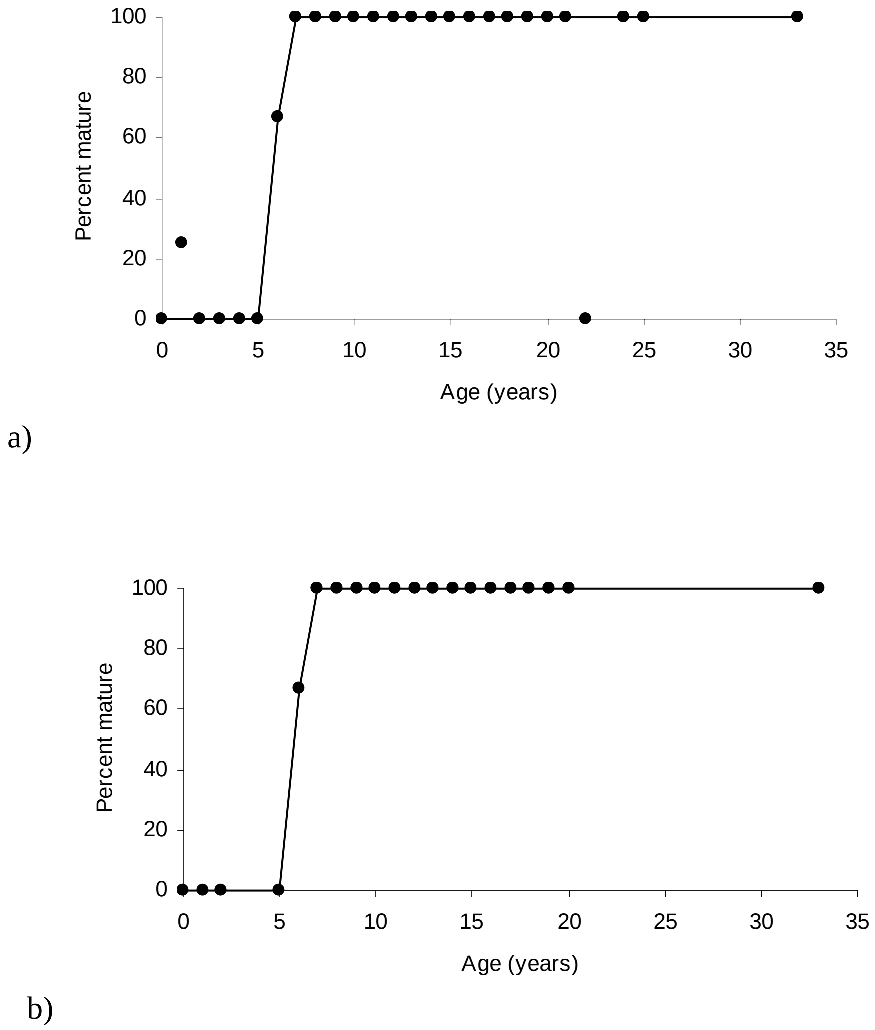


Figure 4.7. Age-at-50%-maturity for *Galeorhinus galeus* (a. combined sexes (n = 58); b. males (n = 43)). Solid circles represent observed lengths and the solid line represents the fitted model from which age-at-50%-maturity can be determined.

4.3.4 Mortality

4.3.4.1 Natural mortality (M)

Table 4.8 describes the results of each method used to determine the rate of natural mortality. Natural mortality estimates were highest using Pauly’s equation (0.41), and lowest using Hoenig’s equation (0.126). The Jensen (Pauly) and Jensen (growth) equations gave similar estimates of 0.30 and 0.29, respectively. Jensen's age-based equation gave an estimate of 0.150.

Table 4.8. Estimates of natural mortality (*M*) based on five methods for *G. galeus*.

Method	*Natural mortality (M)*
Pauly (1980)	0.412
Hoenig (1983)	**0.126***
Jensen (1996) (Pauly)	0.304
Jensen (1996) (growth)	0.285
Jensen (1996) (age)	0.150
Grant *et al.* (1979)	**(0.05,0.15)****
Walker (1970)	**0.123**

*This value indicates the value of natural mortality chosen for the purposes of this study.
**These values indicate the ranges considered for the purposes of this study. The values of 0.15 and 0.11 represent the upper and lower range limits chosen for this study, respectively (refer to page 59 for further discussion).

4.3.4.2 Instantaneous total mortality (Z)

Instantaneous total mortality (*Z*) for *G. galeus* is shown in Figure 4.8. Due to small sample sizes for ages above 11 years and incomplete sampling across ages (*i.e.*, no representation of several age classes above 11 years), instantaneous total mortality was estimated from ages 0 – 11. The rate of total annual mortality was estimated at 0.27 yr^{-1}. Using a natural mortality value of 0.126 (Table 4.8), fishing mortality (*F*) was estimated at 0.14 yr^{-1}.

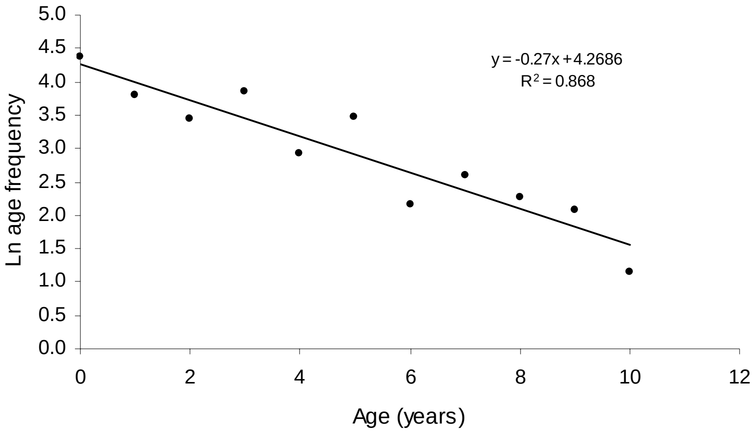


Figure 4.8. The linear regression used to estimate the rate of instantaneous total mortality for *Galeorhinus galeus*. Instantaneous total mortality was estimated from ages 0 – 11. The slope of the regression line indicates the rate of instantaneous total mortality (Z = 0.27 yr^{-1}).

4.3.4.3 Biological, age, growth, and mortality parameter estimates

Table 4.9 illustrates the parameter values determined in several studies on *G. galeus*, and the sources from which these estimates were derived, and are compared to the parameter values estimated in this study. Where appropriate, likely ranges for the values of these parameters are also given. The source from which each estimate is derived is also shown.

Table 4.9. Biological, age, growth, and mortality parameters for *Galeorhinus galeus* as described in other studies and, where appropriate, likely ranges for the values of these parameters. The source from which each estimate is derived is also shown.

Parameter	*Value**	*Geographical area*	*Source*
Maximum age	40 y	Australia	Grant *et al.* (1979)
	45 y	Australia	Moulton *et al.* (1992)
	25 y	New Zealand, South Africa	Francis and Mulligan (1998); Freer (1992)
	33 y	**South Africa**	
L_∞	1601.4 mm	South Africa	Freer (1992)
	1560.27 mm	**South Africa**	
L_{50}	1230 mm	South America	Peres and Vooren (1991)
	1350 mm	Australia	Olsen (1954)
	1340 mm	South Africa	Freer (1992)
	1580 mm	Northeast Pacific	Ripley (1946)
	1400 mm	Mediterranean	Mellinger (1989)
	1100 mm	**South Africa**	
A_{50} [a]	11 y	Australia	Olsen (1954)
	15 y	South America	Ferreira and Vooren (1991)
	10 y	South Africa	Freer (1992)
	13-15 y	New Zealand	Francis and Mulligan (1998)
	6 y	**South Africa**	
M	0.310	Australia	Kesteven (1966)
	0.123	Australia	Walker (1970)
	0.101	Australia	Grant *et al.* (1979)
	0.26	Australia	Dow (1986)
	0.126	**South Africa**	
Z	0.355	Australia	Kesteven (1966)
	0.143	Australia	Walker (1970)
	0.181	Australia	Grant *et al.* (1979)
	0.27	**South Africa**	

*Bold values indicate the base-case scenario derived from this study.
[a] These values are for females only.

4.4 Discussion

Analysis of size composition data in fishery catches is valuable information, as it may indicate which portion of the population is more frequently caught by, or is more susceptible to, a particular fishing gear (Bonfil, 2004). The size composition data analysed in this study shows that the majority of soupfin sharks caught on longlines were greater than 1200 mm TL, and sharks over 1600 mm TL were rarely caught by research surveys. This indicates that smaller soupfin sharks are not as susceptible to longline gear as larger sharks. This is supported by research that shows that longline gear exhibits knife-edged selectivity (Sparre and Venema, 1998; Thompson and Kroese, 1998), where only fish above a certain size class are caught. However, in the research survey data obtained between 1996 and 1999, female sharks greater than 800 mm TL and less than 1200 mm TL appeared to constitute an equal proportion of the catch. This is likely a result of sampling bias, as soupfin sharks segregate by sex and size, and research surveys may have been fishing in times and/or areas where females were more abundant and more likely to encounter the longline gear (*i.e.*, during pupping season or in nursery areas). More males were sampled than females and larger males (>1200 mm TL) constituted the majority of the catch. This is likely attributable to the behavioural characteristics of this species (*i.e.*, segregation by size and sex).

Modelled length-at-age revealed that *G. galeus* grow rapidly during the first seven to 10 years of life and reach a plateau around 13 years, where further growth is negligible, reaching an asymptotic length of 1560.3 mm (combined sexes) and a maximum age of 33. This is similar to the Australian population, where growth is rapid until 10 years and a plateau is reached by 15 years (Walker, 1997), although the maximum age obtained from a growth curve indicates a longevity of 40 years (Walker, 1999). A growth curve produced by Freer (1992) for South African *G. galeus* showed that they reach a maximum asymptotic length of 1601.4 mm, corresponding to a longevity of 25 years. The method of ageing used in Freer's study was likely unreliable due to suspect calculations, thus it is probable that age estimates for the larger fish in his study were underestimated (Walker, 1999). However, it seems likely that the estimate of asymptotic length (1601.4 mm) obtained in Freer's study (1992) is more accurate than that obtained in this study (1560.3 mm), as the latter was likely, once again, underestimated due to small sample sizes, particularly of large individuals.

Differences in growth rates exist between the combined sexes and male *G. galeus,* with the combined sexes reaching a larger asymptotic length than males and displaying a slightly slower growth rate. This suggests that the difference in growth parameters is attributable to the females included in the combined sex analysis. This difference would likely be augmented, that is significantly different from those of males, given a larger female sample size. A difference in growth rates between male and female *G. galeus* has been demonstrated in the Australian population, where it was found that while males grow slightly faster than females, they reach a smaller asymptotic size (Walker, 1997). Similarly, slight differences in growth rates for *G. galeus* were also found in both the Brazilian and New Zealand populations (Ferreira and Vooren, 1991; Francis and Mulligan, 1998) (see Table 4.1). In many shark species it has been shown that females attain a greater maximum length than males; however, Francis and Mulligan (1998) state that this is untrue for *G. galeus* in New Zealand. This could be attributed to differences between stocks.

Uncertainties about growth parameters can lead to gross errors in stock assessment (Hoenig and Gruber, 1990), thus it is imperative to determine whether this is applicable to the South African population of soupfin shark. Through more complete sampling of the population it will be possible to increase the certainty of the growth estimates and determine whether actual differences exist between the growth parameters of male and female soupfin sharks.

Length- and age-at-50%-maturity (1100 mm; 6 years) was estimated to be lower than estimates made by Freer (1992), who determined that, in South Africa, males mature at eight to nine years (1278 mm) and females mature at 10 years (1341 mm). Walker (1999) states that small sample sizes and problems with underestimating age in older fish in Freer's study indicate that his results are likely unreliable. Length- and age-at-50%-maturity estimates for *G. galeus* from other parts of its distribution indicate that males mature at about 12-17 years and females at 13-15 years in Brazil (Ferreira and Vooren, 1991) and eight years (males) and 10-11 years (females) in Australia (Olsen, 1954; Walker, 1999).

There are several possible explanations for the comparatively low estimates of length- and age-at-50%-maturity obtained in this study, including sampling bias, small sample size, underestimation of ages, and a high level of fishing pressure that results in a decrease in length- or age-at-maturity. The majority of sharks used for estimating length- and age-at-maturity belonged to young age classes (age zero to 12), as older age classes were poorly represented in the samples. This would bias any estimate of length- or age-at-maturity by negatively skewing estimates, or underestimating the length or age at which 50% of the population is mature. Similarly, underestimating the ages of soupfin sharks and the small sample size in this study could also lead to an underestimation of length- or age-at-maturity.

It has been documented that high levels of fishing pressure can lead to a decrease in length- or age-at-maturity (*e.g.*, Buxton, 1993; Walker, 1998; Carlson and Baremore, 2002; Sosebee, 2002). This is to be expected in a fishery where older, larger fish are more selected than younger, smaller fish, resulting in a shift in life-history characteristics to compensate for over-fishing of the reproducing component of the population. Although the South African fishery for *G. galeus* has existed since the 1930s, it is unlikely that the population has been exploited to the point where it exhibits these density-dependent responses to stock reduction. This is potentially due to a mercury ban that was introduced in the 1970s (Kroese and Sauer, 1998), which prevented the sale of larger animals and likely inhibited the entry of shark fishing vessels into the fishery.

Natural mortality estimates ranged from a maximum of 0.4 year^{-1} using Pauly's empirical method to 0.126 year^{-1} using Hoenig's equation. The estimate of 0.126 (Hoenig) was accepted as being within the expected range for *G. galeus*, as they have a relatively long life span (up to 45 years although a longevity of 60 years has been suggested) and low fecundity, hence a low rate of natural mortality. Natural mortality estimates for *G. galeus* are only available for the Australian population. Recent estimates suggest a rate of natural mortality of 0.1 to 0.3 year^{-1} (Walker, 1997; Punt and Walker, 1998). Punt and Walker (1998) used a base-case choice of 0.1 year^{-1} for adult natural mortality in a stock assessment of *G. galeus* based on analyses of tagging data by Grant *et al.* (1979). Thus a representative range of natural mortalities (0.11-0.15) was chosen for the purposes of the yield-per-recruit and spawner biomass-per-recruit models. The estimated instantaneous rate of total mortality was higher than most other estimates (refer to Table 4.1), although this is likely representative of differences in stock structure.

Accurate estimates of natural mortality are important indicators of dynamics of the population and allow for reasonable estimates of sustainable rates of exploitation (Simpfendorfer *et al.*, 2004). Punt and Walker (1998) showed that natural mortality in *G. galeus* was independent of age after two years and is thus stable in the absence of harvesting. Further investigations into the natural mortality of *G. galeus* in South Africa should examine the role of density- and age-dependent mortality in juveniles and adults. Direct methods of estimating natural mortality (*e.g.*, through tagging studies) should also be investigated and applied.

In conclusion, this chapter has shown that analysis of *G. galeus* vertebrae using an X-radiographic technique was successful and allowed for reasonably precise estimates of ages. Estimates of age and growth parameters indicate that *G. galeus* is a long-lived shark that matures at a relatively late age, demonstrating that it is susceptible to over-fishing. Comparisons with other studies on the biology and life-history of *G. galeus* indicate that the estimates obtained for the biological and life-history parameters are reasonable, but that estimates can be improved with more dedicated sampling of the population. Although these estimates will be used in a preliminary stock assessment for *G. galeus* (Chapter 5), it is important to interpret the results of these estimates with caution, as there is a great amount of uncertainty surrounding them due to the incomplete and poor quality of data used for this analysis.

Table 4.10. Step 2: the rapid assessment indicator table for assessing the quality of the biological parameter estimates for *Galeorhinus galeus*. This represents both the fishery-dependent and –independent data.

		Unknown	Poor	Reasonable	Good	TOTAL
Biological parameters	**Maximum age**			✓		
	L_{inf}			✓		
	L_{50}		✓			
	A_{50}		✓			
	M			✓		
	Z			✓		
	Age-at-maternity	✓				
	Size composition					
	a) Fishery	✓				
	b) Actual population		✓			
	Spatial structure	✓				
	POINTS	**0**	**3**	**8**		**11**
Fisheries data	**CPUE**		✓			
	Historical catch data		✓			
	POINTS		**2**			**2**
Stock assessment model data	**Age-specific selectivity** **F** **Z** **$F_{0.1}$** **F_{SB40}**					
	POINTS					
Other species-specific knowledge (*e.g.*, from other populations)	**Biological data** **Fisheries data**					
	POINTS					
OVERALL SCORE						

* L_{inf} = maximum theoretical length; L_{50} = length-at-50%-maturity; A_{50} = age-at-50%-maturity; M = rate of natural mortality; Z = total mortality; F = fishing mortality; $F_{0.1}$ = an increase in fishing mortality, there will be no increase in yield or, alternately, the point on the curve where the slope is 10% of that of the origin; F_{SB40} = the point at which spawner biomass is reduced to 40% of pristine pre-exploitation levels.

CHAPTER 5

YIELD-PER-RECRUIT ANALYSIS OF THE SOUPFIN SHARK (*GALEORHINUS GALEUS*) POPULATION OF SOUTH AFRICA

5.1 Introduction

The purpose of stock assessment is to utilise all sources of available information to provide advice to managers about the status of a fished population, as well as to determine the effect of various management strategies on a population (Bonfil, 2004). Although this approach has been commonly used for many teleost species, stock assessment and resultant management strategies have been virtually non-existent for elasmobranch populations (Musick, 2004). This is primarily due to a lack of biological and fisheries information resulting from the historically low economic value of these fisheries (Walker, 1998). Also, the view that conventional fisheries stock assessment models (*e.g.*, surplus-production models) are inappropriate for elasmobranchs, due to the peculiarities of their biology and life-history strategies (Holden, 1977), has hindered the use of less complex models for describing the status of many elasmobranch populations (Bonfil, 2004). However, the recent increase in global demand for shark products has resulted in an increased effort by fisheries scientists to assess the status of many exploited elasmobranch populations (IFAW, 2001), regardless of the paucity of data. Table 5.1 illustrates the types of stock assessment methods that have been used for elasmobranchs, the species to which the model has been applied, and the country/fishing area that has undertaken the assessment (adapted from Bonfil, 2004), and compares this to the current situation in South Africa.

Table 5.1. A description of stock assessment methods applied to elasmobranch fisheries, the species to which the model has been applied and the fishery that has applied the method(s), and a comparison to the elasmobranch fishery in South Africa (adapted from Bonfil, 2004).

Fishery	*Species*	*Stock assessment methods*	*Stock status*
Southern Australia	*Galeorhinus galeus* *Mustelus antarcticus*	Surplus production, delay-difference, age-structured models	Overexploited, under recovering regulations
Canada	*Lamna nasus*	Catch curves, catch rate trends, age-structured models	Overexploited, under severe recovering regulations
New Zealand	*Galeorhinus galeus* *Squalus acanthias* *Callorhincus milii* *Mustelus lenticulatus*	None, quotas established through *ad hoc* methods	Recovered after overexploitation or unknown
United States (east coast)	*Carcharhinus spp.*	Bayesian surplus production models	Overexploited, under recovering regulations
Gulf of mexico	*Carcharhinus spp.*	None	Unknown, likely heavily overexploited
Argentina	*Mustelus schmitii* *Galeorhinus galeus* *Carcharhinus brachyurus*	None	Unknown, likely heavily exploited
South Africa	*Galeorhinus galeus* Approx. 11 other species	None	Unknown, but likely overexploited

As a result of a study conducted by Holden (1977), the trend in elasmobranch stock assessment has been to utilise more complex, age-structured models (Holden, 1977; Bonfil, 2004). However, this type of model requires detailed information regarding the age-structure of a population, a thorough understanding of the complexities of a species life-history and reliable fisheries data – information that is often unavailable. Due to the low resilience of many elasmobranch populations to exploitation, it is of utmost importance to develop stock assessment models that fit the available (albeit limited) data in order to provide a precautionary approach to managing these exploited stocks.

Similar to many shark fishing nations, the data for the soupfin shark (*G. galeus*) stock in South Africa is limited, with virtually all biological, life-history and catch information obtained from scientific research surveys. As the soupfin shark is especially vulnerable to overexploitation (Walker, 1998), and as it comprises one of the target species of the directed shark longline fishery in South Africa, the aim of this chapter is to develop a stock assessment model based on the available data to determine the status of the stock.

Bonfil (2004) states it is imperative to employ a suite of appropriate stock assessment models to a population including the use of both simple and complex models, if possible. This allows cross-comparisons of alternate results and enables coincidences, patterns and inconsistencies within the results to be detected. This method can establish whether problems exist within a data set, as well as guide further acquisition of key information through research (Bonfil, 2004). Several stock assessment models were considered for assessing the stock status of *G. galeus* in South Africa.

5.1.1 Yield-per-recruit models

Per-recruit models, considered the least complex form of age-structured models, allow scientists to determine the level of yield that can be obtained from a stock, depending on different levels of age of entry to the fishery and changing levels fishing mortality (Bonfil, 2004). Although there are several disadvantages associated with per-recruit models (*e.g.*, the model is static and assumes no relationship between stock size and recruitment, and cannot be used for making projections regarding stock size, according to different management strategies), these models do not require historical catch-and-effort information and are relatively simple to implement due to their limited data requirements (Quinn and Deriso, 1999; Bonfil, 2004). Another advantage of per-recruit models is the ability to incorporate biological reference points (BRPs) using age-specific selectivity information to predict the effects of age of entry to the fishery and different harvesting strategies on yield and spawner biomass (Quinn and Deriso, 1999). BRPs represent fishing mortalities or abundance levels that are specified to reduce the risk of stock collapse and define optimal harvesting strategies (Quinn and Deriso, 1999). Commonly used BRPs are $F_{0.1}$ and $F_{\max}$.

$F_{0.1}$ is defined as the point on the yield-per-recruit curve where, with an increase in fishing mortality, there will be no increase in yield or, alternately, the point on the curve where the slope is 10% of that of the origin (Quinn and Deriso, 1999). $F_{\max}$ is defined as the fishing mortality which maximizes yield-per-recruit (Quinn and Deriso, 1999), irrespective of the level of spawner biomass. This BRP is often too high and leads to stock declines as a result of recruitment failure (Hilborn and Walters, 1992). Hence, it is now considered more appropriate to base fisheries management recommendations on BRPs obtained from spawner biomass-per-recruit models (Butterworth *et al*., 1989; Booth, 2001).

Commonly used BRPs obtained from spawner biomass-per-recruit models are F_{SB40} and F_{SB25} (Butterworth *et al.*, 1989). These BRPs are defined as the point at which spawner biomass is reduced to 40% and 25% of pristine pre-exploitation levels, respectively. If spawner biomass-per-recruit is reduced to below 40% of pre-exploitation levels, the population is considered to be close to collapse due to recruitment over-fishing, particularly if the population of concern exhibits low fecundity and high parental investment (Booth, 2001). Booth (2001) also suggests that a BRP of F_{SB40} should be utilized if the spawner-recruit relationship is unknown. Given the conservative life-history strategy of the soupfin shark and the lack of information regarding the spawner-recruit relationship, F_{SB40} was considered appropriate for the spawner biomass-per-recruit model developed for *G. galeus*.

5.1.2 Age-structured population dynamics models

Age-structured population dynamics models (ASPDMs) consider the age structure of a population and allow for estimation of absolute biomass and the effect of density-dependence on mortality (Punt *et al*., 2001). ASPDMs have been used for assessing various fish stocks, including both teleosts and elasmobranchs (Hampton and Fournier, 2001; Punt *et al*., 2001). In an ASPDM developed by Punt and Walker (1998) for the soupfin shark stock of southern Australia, the model estimated the sex-specific characteristics for a fully age-structured population (*i.e.*, sex-specific growth and the pupping process), and used Bayesian estimation to assess the risk associated with the uncertainty of the parameter estimates required in the modelling process and compare alternate future management strategies (Punt *et al*., 2001; Bonfil, 2004). Thus, a major advantage of this modelling approach is the ability of the model to evaluate the implications of alternate management measures on a particular stock (Punt and Walker, 1998). Another advantage of this model is the ability to incorporate the movement patterns of the sharks, selectivity of the fishing gear and spatially disaggregated data to evaluate the effects of species-specific behaviour on the fishery and the stock status (Walker, 1999). Table 5.2 describes the parameters required for an ASPDM based on the model developed for *G. galeus* by Punt and Walker (1999).

Although the ASPDM, and particularly a spatially disaggregated ASPDM, has several advantages over simpler models (*e.g.*, YPR/SBR models), it also possesses several disadvantages that must be considered prior to and during model development. Walker (1999) states the results of the model are highly sensitive to the method of standardization of catch-and-effort data (*e.g.,* how zero catches are handled). The results of the model may also be highly inaccurate if information regarding the productivity of the species is lacking (Walker, 1999). As this information is not available for most shark species, it is important to interpret the ranges of maximum sustainable yield-per-recruit (MSYR) with a degree of caution.

Table 5.2. Parameters required for an age-structured population dynamics model (ASPDM).

Parameter requirements
Basic population dynamics
Pup production
Catches
Length & mass
Gear selectivity
Availability
Initial conditions
Natural mortality
Tagging data*

*This data is required for spatially disaggregated ASPDMs.

In this chapter, yield-per-recruit and spawner biomass-per-recruit models were developed to determine the status of the South African soupfin shark stock. These models included estimates of age-specific selectivity, maturity and levels of mortality. The biological reference points of $F_{0.1}$, F_{max}, F_{SB25} and F_{SB40} were used to describe the response of the stock to different harvesting strategies, as well as to determine the optimal harvesting strategy and age-at-first capture for *G. galeus* in South Africa. An initial investigation into data integrity indicated that the use of an ASPDM was not possible.

5.2 Materials and Methods

5.2.1 Yield-per recruit and spawner biomass-per-recruit

5.2.1.1 Age-specific selectivity

Age-specific selectivity was estimated using actual age estimates rather than length-converted ages. The age-specific selectivity was modelled using a logistic model (Butterworth *et al.*, 1989) described as:

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

where S_a is the selectivity of the gear on a fish of age a, a_{50} is the age-at-50%-selectivity, and δ is the parameter that describes the rate at which selectivity changes from values near 0 to values near 1. As δ tends to zero, this function approaches knife-edged selection (Butterworth *et al.*, 1989).

5.2.1.2 Per-recruit analyses

Per-recruit analysis is used to describe the *G. galeus* population of South Africa in terms of growth, recruitment and mortality of individuals (Bonfil, 2004). This model is based on the assumptions that recruitment and growth parameters are constant and the stock is in a state of equilibrium (Bonfil, 2004; Butterworth *et al*., 1989). For the purposes of this study, F_{SB25} was used as a biological reference point at which the stock is at a high risk of collapse, while $F_{0.1}$ and F_{SB40} are the biological reference points that will maximize long-term yield.

Yield-per-recruit was calculated using a model similar to that of Thompson and Bell (Chen and Gordon, 1997). The general equation is described as:

$$Y = \sum_{t=t_R}^{t\lambda} C_t W_t$$

where Y is the yield, C_t is the catch in numbers of the tth age class, W_t is the average weight of fish in the tth age class, t_R is the age of entry to the fishery, and t_λ is the maximum age of the fish in the fishery. Incorporating the catch equation and exponential survival function (Ricker, 1975), the yield-per-recruit model becomes:

$$\frac{Y}{R} = \sum_{t=t_R}^{t_\lambda} \left[W_t S_t F \frac{1-\exp^{-S_t F - M_t}}{S_t F + M_t} e^{-\sum_{k=t_R}^{t-1}(S_k F + M_k)} \right]$$

where S_t is the selectivity coefficient for fish of age t, F is the fishing mortality for recruited fish, and M_t is the rate of natural mortality for age t. In the yield-per-recruit analysis, the parameter M_t is assumed to be constant for all age classes (Bonfil, 2004).

Spawner biomass-per-recruit as a function of F is described as follows:

$$\frac{S}{R} = \sum_{t=t_R}^{t_\lambda} \left[W_t \Psi_t e^{-\sum_{k=t_R}^{t-1}(S_k F + M_k)} \right]$$

where Ψ_t is the proportion sexually mature fish at age t and W_t is the mass of a fish of age t at the start of the year, such that:

$$W_t = q(L_t)^b \quad and \quad L_t = L_\infty(1 - e^{-K(t-t_0)}),$$

where L_∞, K and t_0 are the von Bertalanffy growth parameters, and q and b are the mass-length relationship parameters.

5.2.1.3 Input parameters

All input parameters, excluding estimates of Z, F and age-specific-selectivity (S_t), were obtained from Chapter 4. Due to uncertainties associated with estimates of natural mortality

(*M*) and age-at-50%-maturity (A_{50}), a range of values was used to calculate the BRPs (Punt and Walker, 1998; Thompson and Kroese, 1998; Grant *et al.*, 1979). Table 5.3 provides a summary of these parameters.

5.2.1.4 *Estimating* $F_{0.n}$ and $F_{SB(x)}$

The value of $F_{0.n}$ was obtained numerically by solving the equation:

$$\left.\frac{dYPR}{dF}\right|_{F=F_{0.n}} = 0.n\left.\frac{dYPR}{dF}\right|_{F=0} \qquad \text{(Punt, 1997)}$$

where a slope of 10% and 0% correspond to $F_{0.1}$ and $F_{\max}$, respectively.

The fishing mortality that corresponds to the quantity of $F_{SB(x)}$ was obtained by solving the following equation:

$$SBR_{cur(x)} = (SBR_{F=0}) \times (x)$$

where $F_{SB(x)}$ is the fishing mortality that reduces spawner biomass-per-recruit to *x*% of the pristine pre-exploitation level $(SB/R)_{F=0}$.

Isopleth diagrams were generated for the yield-per-recruit model to describe the response of yield-per-recruit to combinations of fishing mortality (*F*) and age-at-capture (t_c). The $F_{0.n}$ and SBR_x biological reference points are graphically represented on the isopleths. Data for the isopleth diagrams were obtained from analysis in Microsoft Excel, and all isopleths were generated using SigmaPlot 8.0.

Table 5.3. Summary of the input parameters used in the yield-per-recruit and spawner biomass-per-recruit analyses for *Galeorhinus galeus* in South Africa. L_∞ represents the asymptotic length (mm TL), K is the Brody growth coefficient, t_0 is the age at zero length, Z is the instantaneous rate of total mortality, M is natural mortality, and F is fishing mortality.

Parameter	*Estimate*
L_∞	1560.27 mm TL
K	0.19˙yr^{-1}
t_0	-3.03˙yr^{-1}
Z	0.27 yr^{-1}
F	0.14 yr^{-1}
M	0.126 yr^{-1} (range 0.11 – 0.15)
Q mass-length relationship	0.00001
B mass-length relationship	2.87
Age-at-maturity (A_{50}) logistic	6.04 yrs (range 6 – 12)
Delta	0.1
Age-at-capture (t_c) logistic	7.9 yrs
Delta	5.3
Maximum age	33 yrs

5.3 Results

5.3.1 *Age-specific selectivity*

Selectivity of the demersal longline fishery for *G. galeus* on the west coast of South Africa is shown in Figure 5.1. The age-at-50%-selectivity was estimated as 7.94 years. This age corresponds to a total length of 1329 mm TL.

5.3.2 *Per-recruit analyses*

Yield-per-recruit and spawner biomass-per-recruit curves for *G. galeus* from the west coast of South Africa at the current age-at-capture (t_c = 7.94 years) and at three levels of natural mortality of (0.11, 0.126 and 0.15 year^{-1}) are illustrated in Figure 5.2.

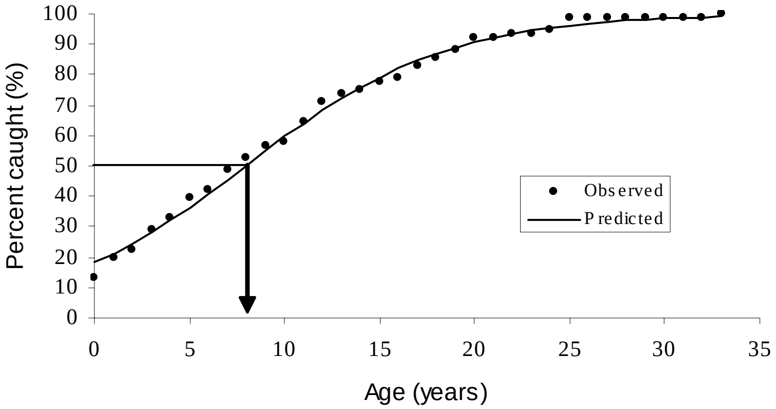
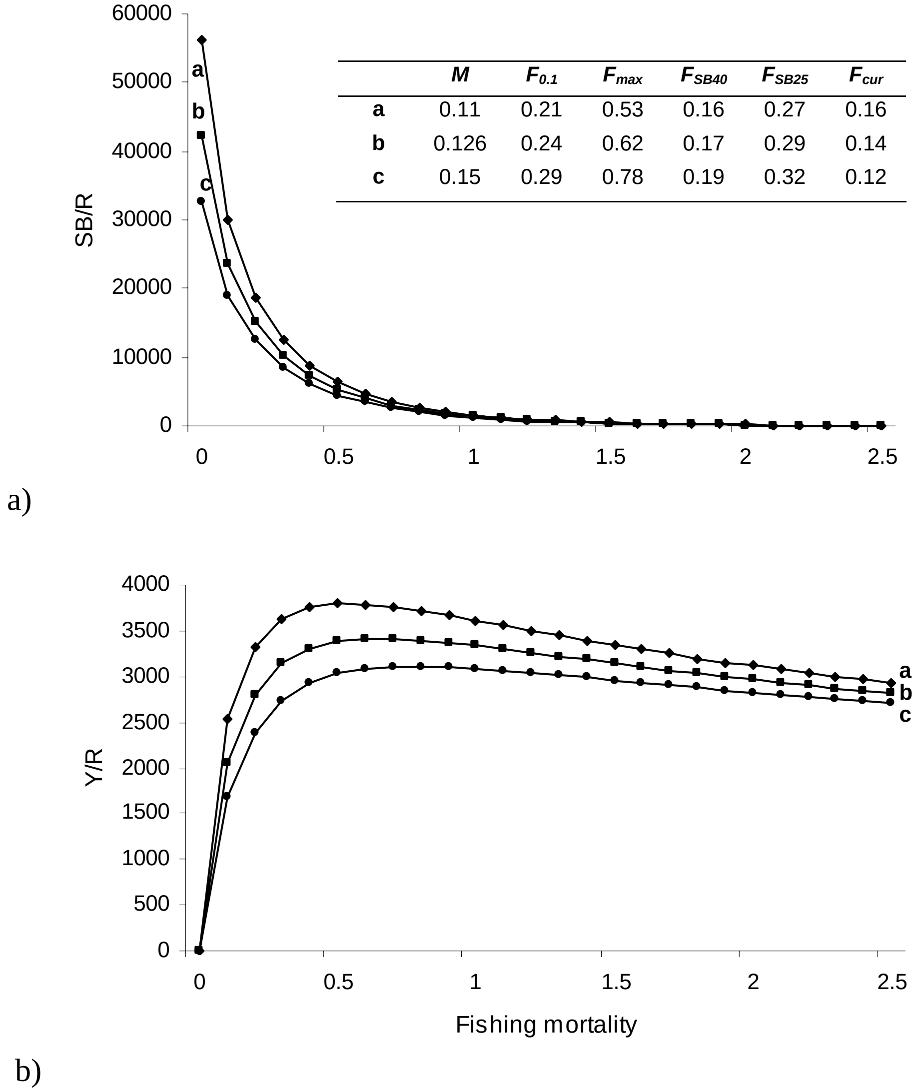


Figure 5.1. Selection ogive for *Galeorhinus galeus* in the demersal longline fishery (n = 76) on the west coast of South Africa. The solid line connected to the solid arrow represents the current age-at-50%-selectivity (7.9 years).



	M	$F_{0.1}$	F_{max}	F_{SB40}	F_{SB25}	F_{cur}
a	0.11	0.21	0.53	0.16	0.27	0.16
b	0.126	0.24	0.62	0.17	0.29	0.14
c	0.15	0.29	0.78	0.19	0.32	0.12

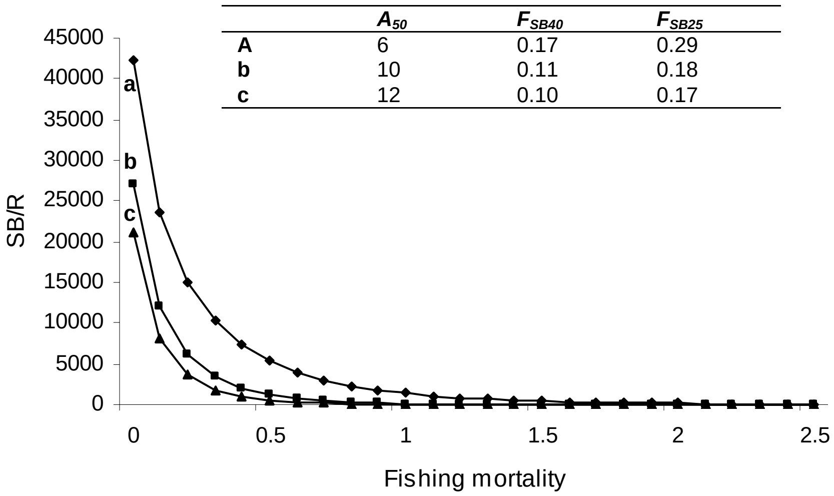
Figure 5.2. (a) Spawner biomass-per-recruit (SB/R) and (b) yield-per-recruit (Y/R) as functions of fishing mortality (with biological reference points) for *Galeorhinus galeus* at different levels of natural mortality (*M*); t_c = 7.94 years. The letters on the graphs represent the three mortality scenarios as shown in the table of biological reference points.

Maximum yield-per-recruit fluctuated with changes in natural mortality (Figure 5.2) with the highest level of yield attained at the lowest level of natural mortality (0.11 year^{-1}) (curve *a*). $F_{0.1}$ and F_{max} increased with increasing natural mortality. $F_{0.1}$ ranged between 0.21 – 0.29 yr^{-1} and F_{max} ranged between 0.53 – 0.78 yr^{-1} (Figure 5.2). This indicates that productivity increases with increasing natural mortality. Fishing mortality ranged between 0.12 – 0.16 yr^{-1}

and was highest at the lowest level of natural mortality (M = 0.11 yr^{-1}). At the current level of natural mortality (*i.e.*, base-case scenario M = 0.126 yr^{-1}) (curve *b*), fishing mortality (F = 0.14 yr^{-1}) is lower than $F_{0.1}$. This suggests that the current exploitation level is below optimum.

SBR also decreased with increasing natural mortality (Figure 5.2), with the highest levels attained at the lowest level of natural mortality (M = 0.11 yr^{-1}). F_{SB40} ranged between 0.16 – 0.19 yr^{-1} and F_{SB25} ranged between 0.27 – 0.32 yr^{-1}(Figure 5.2). As a percentage of the pristine pre-exploitation level, spawner biomass-per-recruit ranged between 38% and 44%. At the current level of natural mortality (M = 0.126 yr^{-1}), spawner biomass-per-recruit was estimated at 43% $(SB/R)_{F=0}$. This indicates that spawner biomass is at an optimum level as a percentage of the pristine unfished condition. Although the estimate of F_{cur} is lower than $F_{0.1}$, the current estimate of spawner biomass suggests that an increase in fishing pressure will result in recruitment over-fishing.

Due to uncertainty associated with the current age-at-maturity estimation (six years), a spawner biomass-per-recruit curve was constructed using three estimates of age-at-50%-maturity (6, 10 and 12 years) (Figure 5.3) (also refer to Chapter 3, Table 3.1).



	A_{50}	F_{SB40}	F_{SB25}
A	6	0.17	0.29
b	10	0.11	0.18
c	12	0.10	0.17

Figure 5.3. Spawner biomass-per-recruit as a function of fishing mortality (with biological reference points) for *Galeorhinus galeus* at different levels of age-at-maturity (A_{50}).

SBR declined with increasing age-at-maturity (Figure 5.3), with the highest levels attained at the lowest age-at-maturity (6 years). F_{SB40} and F_{SB25} ranged between 0.10 – 0.17 yr^{-1} and 0.17 – 0.29 yr^{-1}, respectively (Figure 5.3). SBR as a percentage of the pristine pre-exploitation level ranged from 22% to 43% for an age-at-maturity between six and 12 years. SBR at the current age-at-maturity (*i.e.*, base-case scenario A_{50} = 6 years) was estimated at 43% (SB/R)$_{F=0}$. These results indicate that estimates of spawner biomass, as a percentage of the pristine unfished condition, are sensitive to the choice of age-at-maturity. However, given the base-case scenario (A_{50} = 6 years), the results suggest that the fishery is currently exploited at a level that will maintain spawner biomass slightly above the F_{SB40} biological reference point.

Isopleths describing yield-per-recruit, with harvesting strategy and spawner biomass reference points, as a function of age-at-capture and fishing mortality are shown in Figure 5.4 and Figure 5.5, respectively. Figure 5.4 illustrates that the current fishing mortality (0.14 year^{-1}) is lower than $F_{0.1}$, confirming the observation that current fishing pressure is below the optimal exploitation rate (Figure 5.2). The dashed line represents the current age-at-capture (*i.e.*, base-case scenario 7.9 years). The point indicated with an **X** in Figure 5.4 illustrates the age-at-capture that optimizes yield based on the $F_{0.1}$ harvesting strategy. This corresponds to ages ranging between 9 and 11 years. The **X** also indicates the maximum exploitation level that the fishery can withstand based on the $F_{0.1}$ harvesting strategy. For the *G. galeus* fishery in South Africa, this estimate is approximately 0.17 yr^{-1}. The dotted line in Figure 5.4 also indicates that the age-at-capture that maximizes yield approximates 9.7 years. This is greater than the current age-at-capture, indicating the possibility of growth over-fishing in the fishery. Figure 5.5 illustrates that spawner biomass generally increases with increasing age-at-capture, although yield tends to decrease. The dashed line represents the current age-at-capture (*i.e.*, base-case scenario 7.9 years). F_{SB40} was estimated as 0.17 yr^{-1} and F_{SB25} was estimated as 0.29 yr^{-1}. At the current position, spawner biomass as a percentage of the pristine pre-exploitation level (SB/R)$_{F=0}$ was estimated at 43%. This indicates that the current exploitation level (0.14 yr^{-1}) is slightly below F_{SB40} (0.17 yr^{-1}).

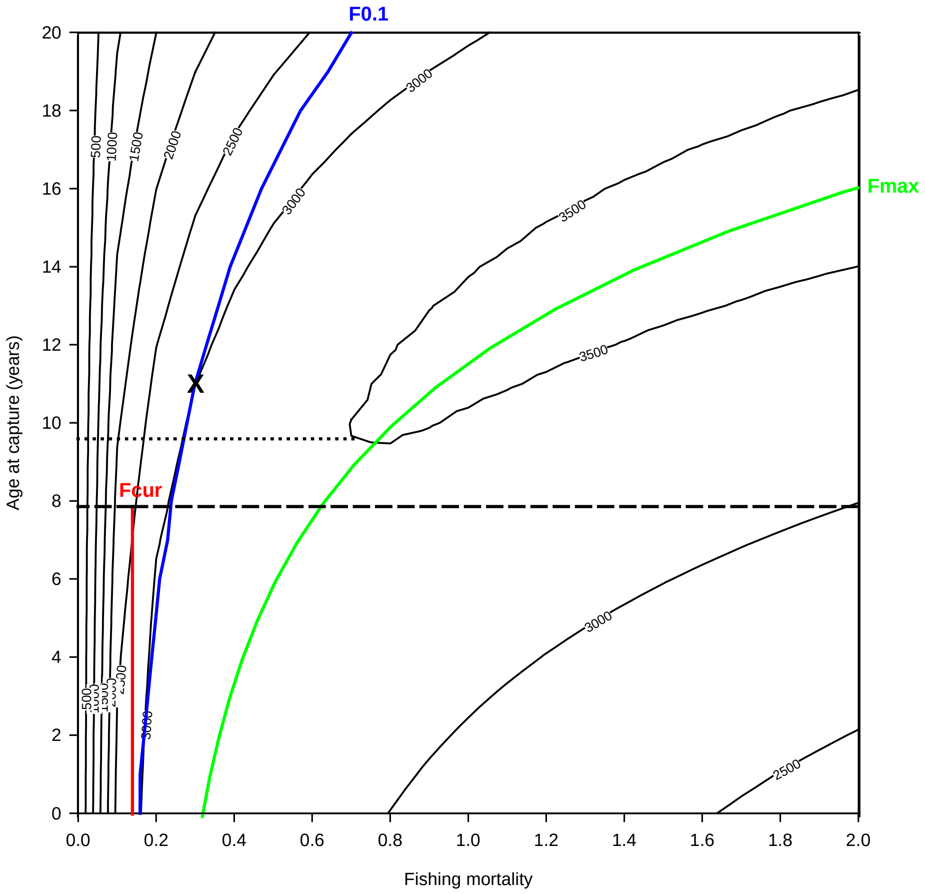


Figure 5.4. Isopleths of yield-per-recruit as a function of age-at-capture and fishing mortality. The green and blue contour lines represent the 0% and 10% slope isopleths of F_{max} and $F_{0.1}$, respectively. The horizontal dotted line represents the age at which yield is maximized (9.7 years). The vertical red line represents the current F (0.14 yr^{-1}). The horizontal broken line represents the current age-at-capture (7.9 years). The current position of the fishery is represented by the intersection of the vertical red line with the horizontal dashed line. X represents age-at-capture that optimizes yield, and the maximum exploitation level the fishery can withstand based on the $F_{0.1}$ harvesting strategy.

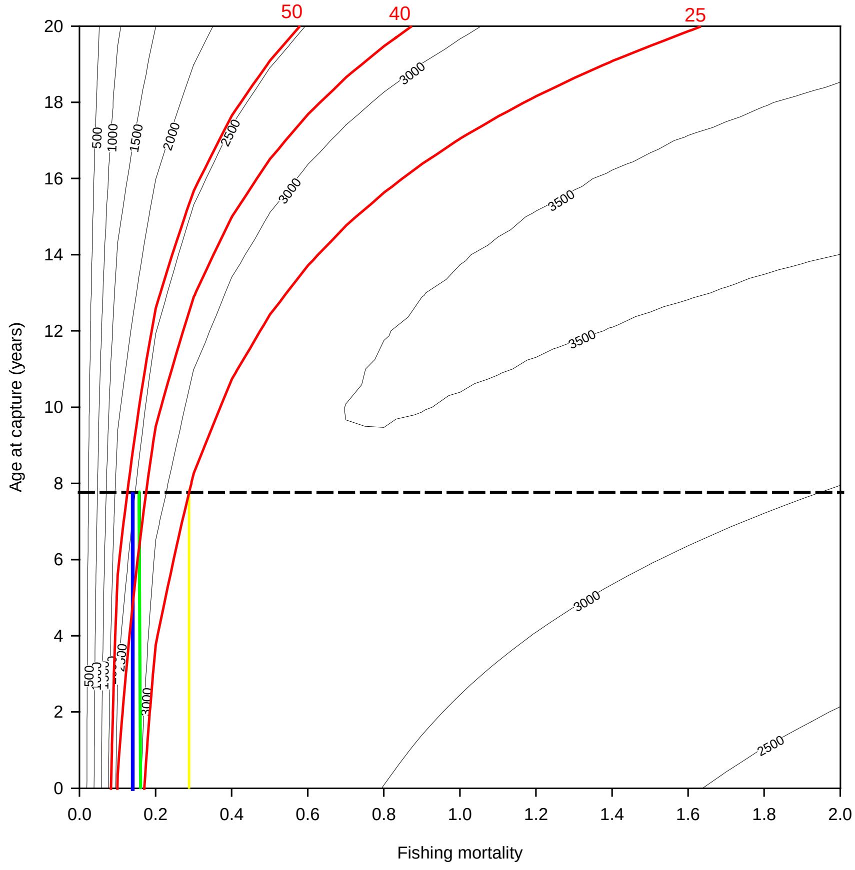


Figure 5.5. Isopleths of yield-per-recruit as a function of age-at-capture and fishing mortality. The red contour lines marked 25, 40 and 50 represent the points at which spawner biomass drops to 25%, 40% and 50% of the pristine pre-exploitation level, respectively $(SB/R)_{F=0}$. The horizontal broken line represents the current age-at-capture (7.9 years). The vertical green and yellow lines represent F_{SB40} and F_{SB25}, respectively. The current position of the fishery (SB = 43%) is represented by the intersection of the vertical blue line with the horizontal broken line.

5.4 Discussion

Determining the selectivity of a gear type is necessary to estimate the age or size composition of the fish in a fishery. This is also an important factor to consider when developing management recommendations regarding the type of gear utilized and the minimum sizes of a fishery's target species (Sparre and Venema, 1998). By investigating the demersal shark longline fishery in South Africa, it was determined that soupfin sharks (*G. galeus*) are recruited into the fishery at an age of 7.9 years, corresponding to a length of 1329 mm TL. This indicates that the soupfin shark is recruited into the fishery at an age older than the age-at-maturity (six years). However, the high incidence of juveniles in catches from the longline research surveys indicates that the gear is highly non-selective and targets both juveniles and sexually mature individuals. The low incidence of larger, older fish in catches may be a result of the highly migratory nature of these fish. It may be hypothesized that larger individuals may remain further offshore or in different areas than juveniles. This hypothesis is supported by the tendency of soupfin sharks to segregate by sex and age (Walker, 1999).

Per-recruit analyses were used to assess the stock status of *G. galeus* due to the lack of historical catch and effort data. However, per-recruit models are inherently limited by their underlying assumptions. Primarily, per-recruit models assume that the stock is in a steady state, and growth, mortality and recruitment remain constant over time (Bonfil, 2004). This assumption is unrealistic due to the dynamic nature of the biotic and abiotic marine environment, which will inevitably impact the growth, survival and recruitment of a population (Malcolm, 2001; Bonfil, 2004). This suggests that there is uncertainty associated with the per-recruit models, although this is a reality associated with all stock assessment models (Bonfil, 2004).

In an attempt to increase the certainty associated with the results of the per-recruit analyses, several steps were undertaken. These included the use of three levels of natural mortality, three estimates of age-at-maturity, and the use of two analytical techniques (per-recruit analysis and the three dimensional modelling approach). The two analytical techniques, assuming the base-case scenarios, arrived at similar conclusions.

The findings from this study indicate that the fishery is being sub-optimally exploited according to the $F_{0.1}$ harvesting strategy, although estimates of current spawner biomass (43%) indicate that the fishery is fully exploited $(SB/R)_{F=0}$. The current fishing level is below $F_{0.1}$, although it approximates F_{SB40}. Due to the lack of information regarding the spawner-recruit relationship and the sensitivity of this population to over-exploitation, it is more appropriate to base management recommendations on estimates obtained from the spawner biomass-per-recruit model (Booth, 2001), specifically the F_{SB40} biological reference point. These results, however, highlight the importance of obtaining more biological, life-history and fisheries information to increase the certainty associated with the results.

Information obtained from MCM (*pers. comm.*, 2004) indicates that current effort levels are low. Considering that only six permits were recorded for active soupfin shark fishing in 2003-2004, the estimate that the spawner biomass has been depleted to 43% of its pristine pre-exploitation level suggests that an increase in fishing pressure will likely lead to stock collapse as a result of recruitment over-fishing. Combined with the high incidence of juveniles in catches, it is possible that growth over-fishing may also be occurring. Thus, it may be necessary to increase the age-at-first-capture by imposing length restrictions on the fishery.

The three-dimensional modelling approach undertaken in this study was useful for describing the response of yield and spawner biomass-per-recruit to different levels of fishing mortality and age-at-first-capture. From this approach, it was possible to determine the age-at-capture that optimizes yield, as well as the maximum exploitation level that the fishery can endure based on the $F_{0.1}$ harvesting strategy. These analyses indicated that the age-at-capture that optimizes yield is 9.7 years or more. This estimate is higher than the current age-at-capture (7.9 years). This is supported by the three-dimensional modelling approach which illustrates that, with an increase in age-at-first-capture to approximately 10 years, there will be little decline in yield and the level of spawner biomass will increase. At this age, the fish are expected to be 1420 mm TL instead of 1329 mm TL (the current length-at-capture). It is therefore suggested that 10 years would be a suitable age-at-capture.

The three-dimensional modelling approach also indicates that the fishery can probably withstand exploitation levels close to 0.24 year^{-1} based on the $F_{0.1}$ harvesting strategy. However, as the $F_{0.1}$ harvesting strategy does not take into account any effects of fishing mortality on spawner biomass, it is instead recommended that the highest exploitation level be limited to the F_{SB40} level (0.17 yr^{-1}), in order to ensure there is no recruitment failure.

Although an investigation was conducted into the use of an ASPDM for modelling the soupfin shark population status, it was determined that there was insufficient historical and biological data to permit the use of this model. For example, it was not possible to calculate pup production due to the lack of pregnant female sharks in the samples, and the lack of information available for calculating the length-dependent availability of soupfin sharks to the fishery. Plus, it was not possible to calculate the pre-exploitation population levels due to the lack of historical catch data.

However, analyses of these data indicated the areas in which data collection techniques may be improved such that subsequent stock assessments may be based on an ASPDM. Firstly, MCM must develop a dedicated shark database to create a reliable time series of catch and abundance data from both the commercial fishery and scientific research surveys. This will allow comparisons between the two fisheries to be generated and will act as an observer-independent validation system for fisheries catch data. Secondly, research surveys should be conducted to collect more detailed biological information on this species to increase the certainty associated with the life-history parameter estimates, thereby increasing the certainty of the model estimations. Thirdly, tagging studies should be conducted to improve the understanding of the spatial structure of the population. Fourthly, it is recommended that MCM initiate an onshore and vessel observer program such that fisheries data may be validated through independent means. The methods through which these objectives may be achieved are further discussed in Chapter 7.

The results from this study indicate that the soupfin shark fishery of South Africa is fully exploited and exploitation levels approach F_{SB40}. In order to maximize yield, the age-at-capture should be increased to approximately 10 years (1420 mm TL) from 7.9 years (1329 mm TL). This would also increase the level of spawner biomass to well above the F_{SB40} level. This would require an increase in, and standardization of, the hook sizes used in the demersal shark longline fishery or a change in gear type from demersal longlines to gillnets, thereby enabling the fishery to be more size-selective. Given the sensitivity of the soupfin shark to over-exploitation (Walker, 1999), these measures would ensure that no growth or recruitment over-fishing of the stock would occur and the fishery for this shark in South Africa under current exploitation levels would be sustainable. Further management options for this fishery will be examined and tentative recommendations will be made in Chapters 6 and 7.

Table 5.4. Step 3: the rapid assessment indicator table for assessing the quality of the YPR/SBR parameter estimates for *Galeorhinus galeus*. This represents both the fishery-dependent and –independent data.

		Unknown	**Poor**	**Reasonable**	**Good**	**TOTAL**
Biological parameters	**Maximum age**			✓		
	L_{inf}			✓		
	L_{50}		✓			
	A_{50}		✓			
	M			✓		
	Z			✓		
	Age-at-maternity	✓				
	Size composition					
	a) Fishery	✓				
	b) Actual population		✓			
	Spatial structure	✓				
	POINTS	**0**	**3**	**8**		**11**
Fisheries data	**CPUE**		✓			
	Time-series of catch & effort		✓			
	POINTS		**2**			**2**
Stock assessment model data	**Age-specific selectivity**			✓		
	F			✓		
	Z			✓		
	$F_{0.1}$			✓		
	F_{SB40}			✓		
	POINTS			**5**		**5**
Other species-specific knowledge (*e.g.*, from other populations)	**Biological data** **Fisheries data**					
	POINTS					
OVERALL SCORE						

* L_{inf} = maximum theoretical length; L_{50} = length-at-50%-maturity; A_{50} = age-at-50%-maturity; M = rate of natural mortality; Z = total mortality; F = fishing mortality; $F_{0.1}$ = an increase in fishing mortality, there will be no increase in yield or, alternately, the point on the curve where the slope is 10% of that of the origin; F_{SB40} = the point at which spawner biomass is reduced to 40% of pristine pre-exploitation levels.

CHAPTER 6

GENERAL DISCUSSION: TOWARD THE DEVELOPMENT OF A FISHERY MANAGEMENT PLAN

6.1 Introduction

The political climate in South Africa since 1994 has been conducive to change in all sectors, including fisheries resource management. The *Marine Living Resources Act* of 1998 detailed new goals on fisheries management and stressed the importance of transformation and co-management in the fishing industry. The new fisheries policy also stated that the use of the precautionary approach was imperative, in light of these changes, for fisheries development and management (*Anon*., 1998). Although the precautionary approach is a widely accepted principle in fisheries management (Nielsen *et al.*, 2004; McBeath, *in press*), actual implementation of this paradigm is often difficult. This is primarily attributable to a lack of institutional capacity designed to oversee the use of such policies, inadequate development of precautionary management strategies, and user conflicts that often preclude the use of such strategies (Oosthuizen, 2003). These factors are highlighted in elasmobranch fisheries where species are especially vulnerable to overexploitation and there is a lack of scientific knowledge concerning elasmobranch life-history and biology, and where many elasmobranch fisheries have historically been multi-species in nature (Musick, 2004).

With the development of the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks), it was recognized that a precautionary approach to elasmobranch management was required to protect the target and bycatch species and ensure the sustainability of these fisheries (IUCN, 2002). Since the adoption of the IPOA–Sharks in 1999, nations contributing to the mortality of elasmobranchs have been under pressure to participate in the conservation and management of elasmobranch species through the preparation of National Shark Assessment Reports and the implementation of National Shark Plans (Musick, 2004). However, as the guiding principles of the IPOA–Sharks are non-binding, few nations have adequately addressed the issues of sustainable and precautionary management for these fisheries (Musick, 2004). Currently, only 29 of 125 known shark fishing nations have reported progress on the development and implementation of comprehensive Shark Assessment Reports and/or NPOA–Sharks (IUCN, 2002). These shark fishery management plans (SFMPs) are generally based on several management tools, including:

- fishing quotas
- limited fishery access
- fishing area closures
- seasonal closures
- size and/or gear restrictions
- recreational bag limits

Table 6.1 describes several existing and developing SFMPs by country and the various management tools used for monitoring those fisheries.

In South Africa, the national fisheries management organization (NFMO), Marine and Coastal Management (MCM), has recognized the need to manage its elasmobranch fisheries using the precautionary approach to fisheries management (PAF). However, unlike many other shark fishing nations, this country is faced with several challenges, including a lack of data required for stock assessments and limited biological knowledge of commercially exploited elasmobranch species. To address the need for precautionary management of these fisheries and meet the requirements stipulated in the IPOA–Sharks, MCM developed a draft management plan for the conservation and management of sharks in 2002. This report established that, in regard to South African elasmobranch resources, there is currently:

- a lack of management at the national level
- a lack of data required to undertake stock assessments for target and bycatch species

- a lack of reliable fisheries data required to develop sector management plans for the elasmobranch fisheries
- inadequate monitoring of the fisheries and poor data collection protocols resulting in insufficient reporting of shark catches
- inadequate knowledge of elasmobranch species and their population status
- inadequate regulations for management of protected and/or vulnerable species
- insufficient numbers of scientists working in the field
- Insufficient funding required for basic scientific research on elasmobranchs.

However, it was concluded that these factors should not preclude the development of a precautionary management plan for commercially exploited elasmobranchs, particularly the soupfin shark (*Galeorhinus galeus*) which is a primary target species of the demersal longline and handline fisheries in South Africa (Marine and Coastal Management, 2002). Similar to all elasmobranch fisheries in South Africa, there was a lack of reliable fisheries and biological data for the soupfin shark. In order to conduct a stock assessment of this species, it was necessary to compile all available data on the South African stock and compare this to biological data and fisheries data obtained from other areas (refer to Chapter 4, Table 4.1). This enabled the development of a preliminary stock assessment based on all known data (Chapter 5) and the formation of a draft precautionary management plan for this commercially exploited species (Chapter 7).

Precautionary management plans have been developed for several elasmobranch species, including the porbeagle (*Lamna nasus*) and shortfin mako (*Isurus oxyrinchus*) sharks in Canada, and many large pelagic coastal shark species such as the bull (*Carcharhinus leucas*) and hammerhead (*Sphyrna* spp.) sharks in the United States. There has also been a global precautionary management strategy developed for the whale shark (*Rhyncodon typus*) by the Convention on International Trade in Endangered Species (CITES) in 2000. These plans ensure that these species do not become depleted and that directed fisheries and/or markets do not develop (National Marine Fisheries Service, 2003). Considering the histories of soupfin shark fisheries in Australia, New Zealand, South America and Brazil (refer to Chapter 1, Table 1.2), and the sensitivity of this species to overexploitation, MCM felt it necessary to prevent further depletion of the soupfin shark stock using a similar approach to fisheries management.

Table 6.1. Existing shark fishery management plans by shark fishing nation, the year the plan was developed and the management tools used for monitoring the population status (adapted from Camhi *et al*., 1998).

Country	Management Plan	Management tool(s)[*1]
Australia	1998	LE AC MS GR FD RBL BM
Canada	1995	Q LE PF BM
Mexico	Developing	LE AC MS
South Africa	Developing	Q LE GR PF RBL
United States (Atlantic coast)	1993	Q CS MS PF RBL BM
United States (Pacific coast)	1993[2]	LE AC MS PF RBL BM

[*] LE: limited entry; AC: area closure; MS: minimum size restriction; GR: gear restriction; FD: finning discouraged; RBL: recreational bag limit; BM: bycatch monitoring; Q: quota(s); PF: prohibition on finning; CS: closed seasons.

[1] Note: these tools may describe species-specific management tools, not a management strategy for all nationally exploited elasmobranch species. For more information refer to Camhi *et al*., 1998.

[2] Based on a tri-state management system, including California, Oregon and Washington.

The FAO (2000) details a basic framework for Shark Assessment Reports and Shark Plans in an attempt to assist scientists and managers with the development and implementation of elasmobranch management strategies. Although the FAO recognizes that the objectives and guiding principles of FMPs developed for elasmobranchs will vary according to the quantity and quality of scientific information available for species management, this basic framework provides the necessary tools for the development of a precautionary management strategy.

Fishery management plans (FMPs) represent a suite of management and scientific objectives that are developed within the context of a nation’s fisheries policy. FMPs detail how management is to be conducted from both a strategic and a tactical level – that is future and present management goals – and describes who is responsible for management (Die, 2002; FAO, 2000). An FMP is a formal or informal arrangement between management authorities, the fishery and other stakeholders, which provides details on management rules, regulations and implementation strategies that are relevant to the fishery (FAO, 2000). At a minimum, an FMP should specify how the management objectives will be met (*e.g.*, through identification of optional management actions) and implementation strategies should be proposed (Die, 2002).

The contents of an FMP are dependent on several variables, including the context within which a fishery occurs (*e.g.*, international, national and regional legislation) (Die, 2002) and the data available for detailing the biological characteristics of a species and for stock assessments. Although the general outline of an FMP will vary, Die (2002) states that it should at least contain the following:

- a description of the fishery and established user rights
- management objectives
- the method in which these objectives will be achieved
- the review and/or appeal process
- the consultation process for review and appeal

Since management objectives in an FMP often conflict (*i.e.*, resource conservation versus socio-economic gain), the plan must acknowledge these conflicts and identify the method(s) through which the conflicts may be resolved. In this manner, it will be possible to determine target limit and reference points through the development of operational objectives (Die, 2002).

Although the development of a Draft Shark Management Plan (SMP) in 2002 and the implementation of restrictions governing the exploitation and processing of several shark species (including *Carcharias taurus*, *Poroderma africanum*, *P. pantherinum*, and *Carcharodon carcharias*) represent a starting point for managing exploited elasmobranch species in South Africa, the Draft SMP has yet to be finalised and formally accepted by the South African government. Combined with the political changes since 1994, South Africa is in a unique position to develop SFMPs for commercially exploited shark species in a fisheries climate that can be described as an experimental attempt to meld species conservation with equitable human and economically sustainable development. Thus, it seems reasonable to combine the objectives of past successful SFMPs from established shark fishing nations, such as Australia and Canada, with objectives specific to the current climate in South Africa and coordinate an FMP that incorporates basic scientific, management and human issues in its mandate.

For the purpose of this study, the FAO Technical Guidelines for Responsible Fisheries on the Conservation and Management of Sharks (2000) was utilized to provide the basic framework for developing an assessment report and draft management plan for the soupfin shark (*G. galeus*). To supplement this framework, shark management plans from Canada, Australia and the United States were examined and relevant guidelines were incorporated. The framework for this assessment report and draft management plan is outlined in this chapter and the full report including management measures is detailed in Chapter 7.

6.2 Framework for the Shark Assessment Report and Draft Management Plan for *Galeorhinus galeus*

1 Introduction
  1.1 Issues

2 Biological synopsis
  2.1 Distribution
  2.2 Biological characteristics
  2.3 Diet

3 Overview of the fishery
  3.1 Bycatch species
  3.2 Gear
  3.3 Finning
  3.4 Participants
  3.5 Location of the fishery
  3.6 Timeframe of the fishery and area restrictions
  3.7 Landings and value of the fishery/markets

4 Management objectives
  4.1 Long-term objectives
  4.2 Specific management objectives within the context of the national fisheries policy
    4.2.1 Biological objectives
      a) to establish the biological characteristics of the stock
      b) to manage the fishery according to these characteristics to ensure long-term sustainable resource use

    4.2.2 Economic objectives
      a) to ensure the fishery is economically viable across all sectors

    4.2.3 Social objectives
      a) to develop the fishery in a manner that will maximize commercial opportunity

    4.2.4 Governance objectives according to the principles of the new Fisheries Policy of South Africa.

5 Consultative process
  5.1 Scientific
  5.2 Government-Industry
  5.3 Links with other planning initiatives

6 Stock status
  6.1 Methods for collection of data

- 6.2 Data processing, storage and accessibility
- 6.3 Stock assessment
- 6.4 Biological advice review process
- 6.5 Biological management reference points
- 6.6 Research
- 6.7 Prospects for the future (2005-2010)

7 Current management issues
- 7.1 Conservation
- 7.2 Habitat disruptions

8 Management strategy
- 8.1 Suggested management measures for 2005-2010

9 Enforcement measures
- 9.1 Overview
- 9.2 Main program activities
- 9.3 Enforcement issues and strategies

10 Financial responsibilities
- 10.1 Industry and/or other harvesters
- 10.2 Marine and Coastal Management

11 Performance review
- 11.1 Management plan evaluation criteria

12 Synthesis

Table 6.2. Step 4: the rapid assessment indicator table for assessing the overall quality of the data for *Galeorhinus galeus*. This represents both the fishery-dependent and –independent data and includes a rating of all other known data.

		Unknown	**Poor**	**Reasonable**	**Good**	**TOTAL**
Biological parameters	**Maximum age**			✓		
	L_{inf}			✓		
	L_{50}		✓			
	A_{50}		✓			
	M			✓		
	Z			✓		
	Age-at-maternity	✓				
	Size composition					
	a) Fishery	✓				
	b) Actual population		✓			
	Spatial structure	✓				
	POINTS	**0**	**3**	**8**		**11**
Fisheries data	**CPUE**		✓			
	Time-series of catch & effort		✓			
	POINTS		**2**			**2**
Stock assessment model data	**Age-specific selectivity**			✓		
	F			✓		
	Z			✓		
	$F_{0.1}$			✓		
	F_{SB40}			✓		
	POINTS			**5**		**5**
Other species-specific knowledge (*e.g.*, from other populations)	**Biological data**				✓	
	Fisheries data				✓	
	POINTS					**2**
OVERALL SCORE						**20**

* L_{inf} = maximum theoretical length; L_{50} = length-at-50%-maturity; A_{50} = age-at-50%-maturity; M = rate of natural mortality; Z = total mortality; F = fishing mortality; $F_{0.1}$ = an increase in fishing mortality, there will be no increase in yield or, alternately, the point on the curve where the slope is 10% of that of the origin; F_{SB40} = the point at which spawner biomass is reduced to 40% of pristine pre-exploitation levels.

Table 6.2 indicates that the total score (20) obtained from the rapid assessment indicator table throughout this study is far below the total possible score of 66 points. This signifies the poor quality and quantity of fishery-dependent and –independent data currently available for *G. galeus* in South Africa.

Table 6.3 indicates the level of risk of overfishing for *G. galeus* based on the rapid assessment technique developed by Walker (2004). It was determined that the parameters with unknown values should be given a risk category of "high" due to the importance of these parameters in determining the stock status and the species sensitivity to overexploitation. Although the quantity and quality of data available for calculating CPUE trends were limited, the uncertainty associated with these estimates suggest that CPUE trends should be given a risk category of "high" for the longline fishery (a three-year analysis indicates increasing CPUE trends) and "medium" for the handline fishery (a 17-year analysis indicates decreasing CPUE trends).

Table 6.3. Assessment of the level of risk of overfishing for *Galeorhinus galeus* based on biological parameter estimates and trends in CPUE calculated in this study (as developed by Walker, 2004).

Parameter	*Values for three arbitrary categories of risk*		
	Low (L)	*Medium (M)*	*High (H)* *
Total mortality			0.27
Natural mortality			0.126
Maximum age			33
Availability			✓
Encounterability			✓
Selectivity			✓
Post-capture mortality			✓
Catch susceptibility			✓
CPUE trends			
a) Longline: increasing			✓
b) Handline: decreasing		✓	

* Shaded values denote parameters for which estimates were not possible due to the confines of the data.

The results of the rapid assessment indicator table and risk assessment indicate that *G. galeus* is at high risk of overexploitation. As a score of 20 represents an immediate need for scientific and management intervention within the fishery, and given the imminent changes within the fishery, as well as the history of *G. galeus* fisheries throughout the world, it is recommended that MCM implement a precautionary management strategy to ensure the sustainability of the stock. Several options for developing a precautionary management strategy for this fishery are given in Chapter 7.

CHAPTER 7

ASSESSMENT REPORT AND PROPOSED FISHERY MANAGEMENT PLAN FOR THE SOUPFIN SHARK (*GALEORHINUS GALEUS*) IN SOUTH AFRICA

7.1 Introduction

The results of the rapid assessment technique developed for this study (refer to Chapter 6, Table 6.2) indicate the need for immediate scientific and management intervention in the soupfin shark (*Galeorhinus galeus*) fishery in South Africa. Thus the following plan is designed to govern the exploitation of the following shark species during 2005-2010:

- Soupfin shark (*G. galeus*)

7.1.1 Issues

G. galeus has been exploited in South Africa since the 1930s and comprises one of the primary species of interest to the commercial shark fishery. Traditionally, this species has been caught on the west coast by gillnet, longline and handline fisheries. *G. galeus* has historically been targeted when catches of more valuable teleost stocks are low. Currently this species is caught by longline and handline fisheries; no legal gillnet fishery exists for *G. galeus*. With the continuing decline of teleost stocks and the increasing domestic and international economic value of sharks, there will likely be an associated increase in targeting of the soupfin shark.

The regional fisheries organization - Marine and Coastal Management (MCM) - has expressed interest in developing this fishery and will be issuing long-term fishing rights for the commercial shark fishery in 2005. Although sharks are generally considered to be an under-exploited resource in South Africa, MCM recognizes the need to apply caution in light of these developing fisheries as shark populations are viewed as especially vulnerable to over-exploitation. This is due to the life-history characteristics exhibited by many species of elasmobranchs, particularly the slow growth rate, late age-at-maturation and production of relatively few young.

Few management measures exist for elasmobranchs in South Africa. This is primarily attributable to the limited scientific information available on the status of stocks and a lack of research capacity at MCM. Table 7.1 describes the existing management measures for elasmobranchs in South Africa. The intent of this study and draft management plan is to provide the basis for reliable calculations of growth, mortality and yield by stipulating the scientific data required from both the commercial and research fisheries. The data obtained from this study presents one of the first detailed stock assessment studies of a commercially exploited elasmobranch species in South Africa, and is an effort to create a precautionary approach to management to ensure the sustainability of the *G. galeus* fishery.

Table 7.1. Existing management measures for elasmobranchs in South Africa.

Management measure	*Area and/or species affected*
Limited entry	Fishing & processing permits required
Quotas	Recreational bag limits
Limited to recreational fishing	Ragged tooth shark (*Carcharius taurus*); catsharks (*Poroderma spp.*)
Gear restrictions	Gillnets banned for commercial fisheries
Prohibition on finning	All species
Protected species under CITES	White shark (*Carcharodon carcharius*)

The current stock assessment for *G. galeus* indicates that the resource may be fully exploited and fishing mortality should be stabilized to prevent further stock depletion. The assessment determined that current levels of fishing mortality should be sustainable. The need to maintain current spawner biomass and recruitment levels is important and this plan provided recommendations in this regard. The plan focuses on the management of *G. galeus* over a five year period (2005-2010) and should be reviewed at the end of the aforementioned time, provided there are no socio-economic or biological factors that necessitate immediate actions.

7.2 Biological synopsis

7.2.1 Biological characteristics

G. galeus is ovoviviparous and produces litters of approximately 15-40 pups, after a gestation period of about 12 months. The parturition period is estimated as at least three years. In South Africa, pregnant females appear to constitute the majority of the catch in the spring months. Pups are born at approximately 40 cm TL. Females and males mature at about 110-150 and 110-120 cm TL, respectively. This corresponds to an age range of 6-12 years for females and 6-10 years for males. Soupfin sharks may live to an age of 40 years, although some tagging estimates suggest greater than 60 years. The maximum recorded size is approximately 200 cm TL. A diagram of *G. galeus* is shown in Figure 7.1.

7.2.2 Distribution

The soupfin shark (*G. galeus*) is a cosmopolitan temperate species that occurs in the south Atlantic, eastern North Atlantic and eastern North and South Pacific. It is also found on the west and south coasts of South Africa, New Zealand and southern Australia. This species is primarily demersal, occurring on the continental shelf and upper slope to depths of approximately 550 metres. The soupfin shark is highly migratory and segregates by sex and age.

Although it is a widely distributed species that has been heavily fished throughout its range, little detailed information is available on its stock structure, with the only detailed stock assessments available from Australia. In South Africa, the soupfin shark is reported to occur from the Orange River to East London (Figure 7.2). Little information is available on the migration patterns of this species as no tagging experiments have been conducted, although they appear to aggregate in South African waters during autumn (March – May) and spring (September – November).

7.2.3 Diet

The diet of the soupfin shark is comprised primarily of pelagic and benthic teleosts, including hake, snoek, mackerel, sardines, gurnard, herring and remoras. Invertebrates such as octopus, squid, crabs, and shrimp have also been recorded in the stomachs of soupfin sharks. Likely natural predators include larger elasmobranchs, such as white (*Carcharodon carcharias*) and mako (*Isurus* spp.) sharks.

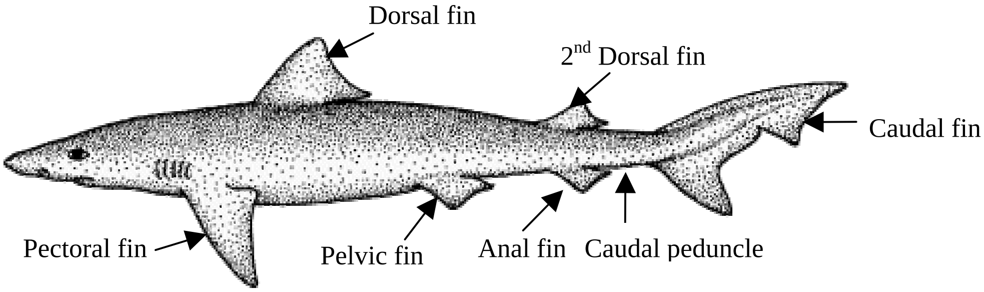


Figure 7.1. Lateral view of the soupfin shark (*Galeorhinus galeus*).

7.3 Overview of the fishery

7.3.2 Bycatch species

The primary non-targeted catch and/or discarded bycatch species of the soupfin shark fishery are *Mustelus mustelus* and *M. palumbes*. Other species that are occasionally taken are *Triakis megalopterus*, *Hexanchus griseus*, *Carcharhinus obscurus*, *Carcharhinus brachyurus*, *Poroderma africanum* and *P. pantherinum*, *Notorynchus cepedianus*, *Squalus acanthias*, and *S. megalops*. Several *Raja* species are also occasionally caught.

7.3.3 Gear

G. galeus were originally targeted with handlines, but have more recently been caught with short longlines and gillnets. In 1948, due to concerns about high catches and the high proportion of pregnant females in the catch, a minimum mesh-size restriction of nine inches was implemented in the gillnet fishery. There is currently no legal gillnet fishery for the soupfin shark.

G. galeus are caught by commercial demersal longline and handline vessels. Longline vessels are generally less than 30 metres in length and deploy up to 3000 hooks per line, per day. These vessels fish between depths of 50 to 100 m. Vessels in the handline fishery are generally less than 10 m in length and fish from inshore waters to approximately 200 m off the shoreline. Fishers use 3 – 15 hooks per handline. This species is also caught in small numbers in the recreational rod-and-reel shore-based fishery.

7.3.4 Finning

Finning refers to the removal and retention of the shark fins, while the rest of the carcass is discarded at sea. The practice of “finning” was officially banned in South African waters in 1998 under the *Marine Living Resources Act*. Although largely undocumented, finning is thought to be a source of high mortality for many elasmobranch species. It is unlikely that finning contributes to the mortality of the soupfin shark, although this species is prized for the value of its fins, as the flesh can be processed and sold as biltong in Africa or as steaks in Australia, Asia and Europe.

7.3.5 Participants

The first shark directed longline permits (all species) were issued in 1991. Between 1991 and 1994, 31 permits were issued annually. Between 1995 and 2000, permit numbers have ranged from 23 (2000) to 35 (1995). In 2003, 23 shark fishing permits were issued, with 16 of these permits recorded as actively fishing for sharks (all species). In 2004, six permits were estimated as actively fishing for soupfin shark.

The shark fisheries within South Africa remain unrestricted in terms of the by-catch levels retained per vessel, with the exception of bag limits for hake (*Merluccius capensis*; *M. paradoxus*) and kingklip (*Genypterus capensis*). There is no gear or seasonal restrictions imposed on the longline fishery.

The handline fishery is also multi-species in nature, with participants targeting sharks when teleost catches are low. Between 1985 and 2003, an average of 1627 handline vessels were recorded as actively fishing for soupfin shark. Although the number of handline permits was reduced during the interim rights phase, there is currently no gear, seasonal or effort restrictions on traditional linefish permits.

In post-transformation South Africa, it has been recognized that there is a need for transformation within the fishing industry, as this industry has been predominantly owned and operated by white corporations. MCM policy states the importance of integrating previously disadvantaged individuals (PDIs) into commercial fisheries wherever possible through capacity building and restructuring of the various fishing sectors. It is of utmost importance to consider the role of transformation in South Africa's shark fisheries.

In 2005, MCM will be making the transition from medium-term to long-term shark longline fishing permits. Permit allocations will be based on documented proof that harvesters have targeted shark during years specified by MCM. No decision has been made regarding the number of long-term permits to be issued, although permit allocations are expected to be made by July 2005. During the permit allocation process, it is recommended that MCM evaluate the position of PDIs in the shark fishing industry (whether in the fishing or processing sectors) and take an active role in redistributing the permits accordingly. This may be achieved by encouraging industry members to increase the number of PDIs employed in the different sectors through implementation of government policy regarding transformation.

7.3.6 Location of the fishery

The South African fisheries for soupfin shark occur primarily along the west coast from Orange River to St. Francis Bay although fishermen have recorded catches to Kei River. Figure 7.2 illustrates the fishing areas of both the demersal longline and handline fisheries. Commercial vessels most often target soupfin shark during autumn and spring when catches are highest, although small catches are recorded year-round.

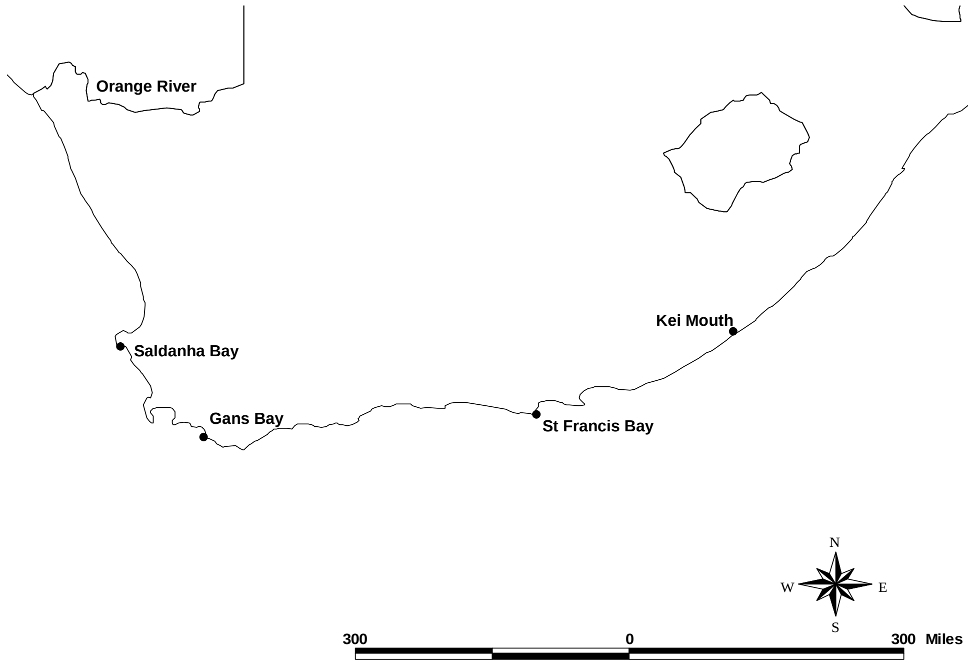


Figure 7.2. A map illustrating the fishing areas for the demersal longline and handline fisheries for the soupfin shark (*Galeorhinus galeus*).

7.3.7 Timeframe of fishery and area restrictions

No seasonal or area restrictions apply to the shark fishery of South Africa. This is due to the need to acquire more scientific data on all commercially exploited species. Pregnant soupfin sharks appear to comprise a high proportion of catches in some areas during spring, suggesting that females move in-shore during this time in order to pup. It is hypothesized that Gans Bay may be a nursery area for this species, although this has not been confirmed. Commercial longline vessels also catch a large number of pregnant females near Tsitsikamma, indicating another possible nursery area.

It is recommended that tagging studies be conducted and research surveys undertake a thorough sampling of the population in different areas along the coast of South Africa. This will allow scientists to identify critical habitats for *G. galeus* and ensure the sustainability of the resource through potential seasonal and area restrictions on the fishery. The findings from these studies may require a re-evaluation of the permit conditions, thus stipulations regarding permit re-evaluation must be contained in the original permit conditions. This may help prevent any legal retaliation by the fishing industry at such time as the restrictions are enforced.

7.3.8 Landings and value of the fishery/markets

Export statistics for soupfin shark from South Africa are unreliable, as export data generally group shark species into one broad category. It should be noted, however, that there has been an increase in overall shark exports during the last ten years. This may be attributable to several factors, including the relaxation of mercury restrictions (resulting from more effective testing), increased overseas demand, the political change within South Africa (making these products more acceptable), and the favourable exchange rate.

Soupfin shark is exported as frozen fillets to several countries including Australia and Japan, as well as countries within the EU. Dried soupfin shark meat is sold and consumed in South Africa, while some of this biltong is also exported to West Africa. Shark fins are exported to the Far East and Australia. Soupfin sharks larger than ~7 kg are generally not exported due to stringent mercury tests applied to larger animals in the international market, specifically Australia. The landed value for soupfin shark is approximately ZAR 4 – ZAR 50 per kilogram. This value range is likely to great to allow for any stability in the fishery for such a product.

7.4 Long-term objectives for the fishery

- maintain the stock at the F_{SB40} level until further scientific information is available
- use a precautionary approach to guide decision-making
- implement an effective and efficient management strategy that will ensure management arrangements in the South African soupfin shark fishery result in conservation & sustainable resource use
- develop a cooperative management strategy between industry, managers and scientists

7.5 Specific management objectives of the FMP in the context of the national fisheries policy

- **Biological objectives**

1) The biological characteristics of the soupfin shark have been established and are shown in Chapters 4 and 5. Table 7.2 shows a summary of the biological characteristics and life-history parameters of the soupfin shark in South Africa.

2) Manage the fishery according to these biological characteristics and ensure long-term sustainable resource utilisation. It is recommended that, until advanced stock assessment is possible, fishing mortality should not exceed the F_{SB40} level (0.17 yr^{-1}). This level is close to the current level of fishing mortality (0.14 yr^{-1}). It is also recommended that a minimum length restriction of 1420 mm TL be imposed on the fishery. This would maximize yield and ensure there is no recruitment failure. Detailed recommendations are given in section 7.8.

Table 7.2. Summary of the biological characteristics and life-history parameters for *Galeorhinus galeus* in South Africa.

Parameter	*Estimate*
L_∞	1560.27 mm TL
K	0.19 yr^{-1}
t_0	-3.03 yr^{-1}
Z	0.27 yr^{-1}
F	0.14 yr^{-1}
M	0.126 yr^{-1} (range 0.11 – 0.15)
Q mass-length relationship	0.00001
B mass-length relationship	2.87
Age-at-maturity (A_{50}) logistic	6.04 yrs (range 6 – 12)
Delta	0.1
Current age-at-capture (t_c) logistic	7.9 yrs
Delta	5.3
Maximum age	33 yrs

- **Economic objectives**

3) MCM and the commercial shark fishing industry are obligated to understand the socio-economic consequences of any management actions. To determine the economic status of the soupfin shark fishery, MCM should conduct a detailed socio-economic survey of the demersal longline, handline and processing sectors. This would include economically efficient commercial production through experimentation with alternate fishing gear (*i.e.*, gillnets) and fishing areas. It is recommended that MCM investigate the economics of this fishery to determine the impact of length restrictions on the export market.

- **Social objectives**

4) MCM is obligated to continue developing the fishery in a manner that will maximise commercial opportunity within the fishing sector by providing opportunity for employment, human resource development and transformation. This development should adhere to current government policies regarding transformation within the fishing industry.

- **Governance objectives**

5) Manage the soupfin shark stock according to the principles of the new Fisheries Policy of South Africa:
    i. ecological sustainable development
    ii. precautionary principle
    iii. responsible fishing
    iv. scientific integrity

6) Produce a plan to ensure compliance. Targets should be set and monitored through a yearly review process. This process should involve an assessment of compliance targets and the monitoring process by the Chondrichthyan Management Working Group (MWG) (refer to Section 7.6.3 for detailed information on the MWG).

7) Offshore and onshore monitoring should play an integral role in compliance and research objectives.

7.6 Consultative process

7.6.2 Scientific

There are no government scientists tasked with researching the commercially exploited shark stocks. However, the Chondrichthyan Working Group (CWG), comprised of

independent elasmobranch researchers from South Africa, provides the scientific basis for determining management priorities for elasmobranchs in South Africa.
The CWG is a working group commissioned by the Chief Director of MCM to provide long-term scientific and management advice on elasmobranchs to MCM. Several MCM scientists participate in the working group. The CWG holds biannual meetings to address issues regarding elasmobranch research, management and conservation.

This forum should continue to provide unbiased scientific and management advice to MCM shark research officials as well as contribute to joint research ventures between the two organisations.

7.6.3 Government-industry

It would be advantageous to both the scientific and fishing communities if consultations for review and planning of policy and for developing the tactical basis for management of the fishery were conducted. This may be achieved through the creation of a Management Working Group (MWG) dedicated to providing advice on the day-to-day management of elasmobranchs to MCM. It is recommended that this working group be comprised of industry representatives, scientists, managers, socio-economists and an MCM- and industry-appointed lawyer. This would lead to greater government-industry collaboration, ultimately resulting in better collection of catch, effort and biological data as the fishing industry takes a more participatory and responsible role in management. A committee of this nature could provide the principal forum for discussion on elasmobranch FMPs in South Africa.

Any minor changes to this management plan could be considered on an annual basis by MCM. Major biological and assessment analyses would be conducted within MCM in collaboration with the CWG. Amendments could then be presented to the aforementioned government-industry committee for consultation and review.

Due to the highly migratory nature of the soupfin shark, effective management will require international cooperation including all other users of this stock. The migration pattern of the soupfin shark stock in South Africa has not been described although it is likely that this stock extends to southern Namibia and outside the EEZ of South Africa. Tagging studies will confirm the migration pattern of *G. galeus*. If it is determined that this stock migrates into the Namibian EEZ, it will be necessary to develop an international management strategy. This may be accomplished under the auspices of the Benguela Current Large Marine Ecosystem (BCLME) initiative.

7.6.4 Links with other planning initiatives

There are several initiatives in South and southern Africa that may provide linkages with this FMP to develop conservation measures that will ensure the sustainability of the soupfin shark stock. These include the Benguela Current Large Marine Ecosystem (BCLME) initiative, the South African Fisheries Policy, the *Marine Living Resources Act* of South Africa, and the Southern African Development Community (SADC). These linkages may include the creation of marine protected areas in vulnerable nursery areas as well as bi- and/or multi-lateral management agreements. Activities linked to the socio-economic development of the soupfin shark fishery may also be supported by these initiatives.

The International Plan of Action for the Conservation and Management of Sharks (IPOA–Sharks) provides a platform for the conservation and management of sharks. Under this initiative, South Africa is in the process of developing a National Plan of Action for the Conservation and Management of Sharks (NPOA–Sharks), which will govern, among other things, the commercial exploitation of elasmobranchs. The FMP for the soupfin shark represents the first step in ensuring that these fisheries are sustainable.

7.7 Stock status

7.7.2 Methods for collection of catch, effort and biological data

It is recommended that MCM develop standardized data collection techniques for fishery-dependent and –independent sampling. To improve the reliability of data, a field identification guide for elasmobranchs should be developed and distributed to industry, scientists and monitoring/compliance individuals. This will improve existing problems with species identification. On-board and shore-based observers should monitor data collection and validate data whenever possible. Observer coverage of at least 5% is recommended. An example of information required in logbooks for commercial shark fishers is as follows:

Biological Data:

- species
- total length (mm) measured from the tip of the rostrum to the end of the upper lobe of the caudal fin
- pre-caudal length (mm) measured from the tip of the rostrum to the beginning of the caudal fin/end of the caudal peduncle
- weight (g or kg)
- sex
  a) males: claspers present
  b) females: claspers absent

Fishing Data:

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

Although it is unlikely that fishers will record all the biological data for each shark caught, it is necessary that a sub-sample from each fishing trip be recorded. This may be enforced in the permit conditions. With observer monitoring, this data can be validated.

7.7.3 Data processing, storage and accessibility

One of the major issues regarding the management of South Africa's commercial shark fishery is the lack of a dedicated database to store commercial and scientific data on shark species. To address the issues of data loss, data validation and data storage, MCM must develop, as a high priority, a database solely dedicated to the storage of this information. Two databases (one commercial-fishery-based and one research-based) should be created using a computer program such as Microsoft Access®. Data collected for the research database should include at least five table types:

- Station:
  a) strata
  b) station number
  c) date
  d) time
  e) location
  f) vessel type
  g) gear type
  h) environmental information
- Catch:
  i) total number of fish caught
  j) total weight of fish caught
- Length:
  k) length
  l) weight
- Biology:
  m) stomach contents
  n) stomach volume
  o) sex
  p) maturity status
- Other:
  q) OTC injection

r) tag/release number

Data collected for the commercial database should include, but not necessarily be limited to, the information listed in subsection 7.7.1.

7.7.4 Stock assessment

Detailed stock assessments have not been conducted for any commercially exploited elasmobranch species in South Africa. This is the first assessment for the soupfin shark. This assessment was based on demersal longline landings from 2001-2003, handline landings from 1985-2003 and research survey data from 1996-1999. Catch and effort information was based on all three fisheries, while biological data was based on the research survey data. Biological data was not available from the commercial fisheries. CPUE data was limited as a result of data loss from the commercial longline database. This information allowed for estimates of age and growth, as well as life-history parameters. Resource status was based on yield-per-recruit and spawner biomass-per-recruit models, a three-dimensional modelling approach, and trends in commercial catches. Present fishing mortality was compared to $F_{0.1}$ and F_{SB40} levels in order to provide advice for management strategies.

Although the limitations of the model must be recognized, yield-per-recruit analysis suggested that the estimate of $F_{0.1}$ (0.24 yr^{-1}) is unsustainable, and this level of fishing mortality will likely lead to recruitment failure. It was determined that F_{SB40} (0.17 yr^{-1}) is a more appropriate exploitation level for the soupfin shark stock, and that this level of fishing mortality approaches F_{cur} (0.14 yr^{-1}). Natural mortality was determined to be about 0.13 yr^{-1}. This assessment showed that increasing the size-at-capture to 1420 mm TL (10 years) will maximize yield and increase spawner biomass levels to well above the F_{SB40} level. It was determined that the soupfin shark is currently fully exploited in South Africa.

It is recommended that fishing mortality be stabilized at current levels and no more than six demersal longline permits be allocated for the soupfin shark fishery. It is also recommended that MCM assess the impact of the handline fishery on the soupfin shark stock and determine whether it is necessary to implement TACs or TAEs in this fishery. Given the uncertainties concerning the biological and life-history parameter estimates of the soupfin shark from this first stock assessment, as well as those concerning the stock distribution and nursery areas, it is recommended that MCM dedicate research survey time to the collection of this data and re-analyse the information for a review process in 2010. This will allow for the development of an age-structured population dynamics model, including tag-recapture data and age-dependent mortality levels, and will increase the certainty associated with the estimates of stock status. Finally, it is recommended that MCM improve the commercial data collection and data storage protocols such that extensive time series of catch and effort information may be developed. Management options are provided in section 7.8.

7.7.5 Biological advice review process

It is recommended that this stock assessment be reviewed, at a minimum, every five years, due to the sensitivity of the soupfin shark stock to overexploitation. At this time interval, it can be determined whether any changes in the biological status of the stock are evident and appropriate management recommendations can be made. This review process should be the responsibility of MCM scientists. Prior to changes in the FMP, a second review process, including MCM and the CWG, should be conducted. If major changes in the stock are evident, it will be necessary for MCM to consult with industry members prior to any amendments to the permits.

7.7.6 Biological management reference points

Until such time as more data on the biology, life-history and fisheries are available, it is recommended that the biological management reference point (BMRP) of F_{SB40} be used by management officials to manage the soupfin shark stock. Due to the lack of information about the spawner-recruit relationship and the sensitivity of this stock to overexploitation, this BMRP will ensure the current level of spawner biomass is maintained and there is no recruitment failure. As more data become available, it will be possible to develop more complex models, such as a fully age-structured population dynamics model. This type of model will increase the certainty associated with the estimates of biological and life-history parameters and allow for the development of more appropriate BMRPs.

7.7.7 Research

Although it is recognized that MCM has to divide scarce resources between many fisheries sectors, it is recommended that MCM conduct or outsource an intensive research program on the soupfin shark, as it constitutes one of the primary species of interest to the shark fishery in South Africa. This research will result in a substantial increase in our understanding of soupfin biology and population dynamics. On-board collection of detailed measurements and tissue samples by fisheries observers will also be beneficial to this understanding. Research to identify nursery areas and migration patterns should be conducted using archival satellite pop-up tags and spaghetti tags. Emphasis should be placed on the collection of biological data, particularly size and age of sexual maturity, to prepare for future stock assessments. It is also recommended that a research program designed to estimate hooking mortality be conducted in the recreational shark fishing industry.

7.7.8 Prospects for the future (2005-2010)

A sustainable spawning stock of soupfin shark will require an overall fishing mortality that is considerably less than $F_{0.1}$ (0.24 yr^{-1}). Fishing mortality should not exceed 0.17 yr^{-1}, and it is recommended that fishing mortality levels be stabilized at F_{cur} (0.14 yr^{-1}). Directed commercial effort, in terms of the number of demersal shark longline permits issued, should not increase above six permits as a precautionary guideline for this FMP. Due to the apparent size and sex segregation, reduced mortality of mature females may be achieved by area and/or seasonal restrictions where large females are present. The possibility of an exploratory gillnet fishery for soupfin shark should be investigated and bycatch levels of other species should be monitored. Management options are detailed in section 7.8.

7.8 Current management issues

7.8.2 Conservation

Sharks are considered to be especially vulnerable to overexploitation, and global shark populations are considered to be declining. Thus, all shark species of commercial importance in South Africa should be monitored carefully and conservatively managed. A conservative approach to management will require collaboration with the shark fishing industry and government, as well as other stakeholders. This will facilitate research into the stock status of commercially exploited shark species. As one of the primary target species of the shark fishery in South Africa, research on the biology and life-history of the soupfin shark should be a priority for MCM. Performance requirements for shark fishers should be closely monitored by MCM officials.

7.8.3 Habitat disruptions

Habitat disruptions that may be associated with the demersal shark longline and handline fisheries may include the disruption of nursery areas of the soupfin shark. Other disruptions may include bycatch of unwanted species or commercially valuable teleosts resulting from gear interference in migration/swimming routes. It is recommended that MCM investigate this through detailed tagging studies and bycatch monitoring.

7.9 Management strategy

The management strategy for the soupfin shark fishery may consist of input controls based on effort regulation. It is recommended that effort in the demersal longline fishery not exceed six permits. A second stock assessment for this species should be conducted at the end of this plan (2010), and scientists should aim to develop a fully age-structured population dynamics model that can predict biomass levels and the effects of age-dependent mortality on the stock status.

7.9.2 Suggested management measures for 2005-2010

- **Immediate-term plan (1a): Restrictive licensing**

  The number of permits issued for the demersal shark longline fishery should be limited to six allocations. Permit allocations should be based on an individual's or company's ability to prove historical access to the fishery in terms of landings of soupfin shark over a period decided by MCM (in accordance with the transition to long-term rights allocations). Vessel size should be restricted to < 30m. Permit allocations in the handline fishery should be further investigated by MCM and restrictions should be imposed on this fishery as a precautionary measure (refer to Figure A at the end of this document).

  Discussion: This management approach is based on a precautionary management strategy to prevent depletion of the soupfin shark stock. Vessel size restrictions will prevent the growth of fishing capacity through the development of superior fishing technology. The impact of the handline fishery on the soupfin shark stock is not known; however, existing records, poor as they may be, show catch rates and catch per unit effort to be declining. This fishery should be closely monitored by MCM and a limited number of traditional linefish permit holders should be allowed to target shark, perhaps based on historical performance.

- **Immediate-term plan (1b): Size restrictions**

  A minimum size restriction of 1420 mm TL for the soupfin shark should be imposed on the demersal longline and handline fisheries (refer to Figure A at the end of this document).

  Discussion: Size restrictions should be imposed on a fishery as a precautionary management measure. To maximize yield under the $F_{0.1}$

harvesting strategy and maintain current spawner biomass levels, a minimum size of 1420 mm TL is recommended. This may be achieved through landing regulations, the increase of hook sizes used in the demersal longline fishery, or through the release of smaller individuals. If it is determined that fishers must release smaller sharks, a study which monitors hook mortality should be conducted by MCM to determine whether the level of hook mortality is unsustainable. Due to the low economic value associated with larger sharks resulting from poor quality of the meat, this management option is may prove difficult to implement.

Note: Although (1a) and (1b) may be implemented separately, it is recommended that they be implemented simultaneously, given the current stock status.

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

  This option could maintain current effort levels and length-at-capture (1329 mm TL), but would impose seasonal or area restrictions on the fishery (refer to Figure A at the end of this document).

  Discussion: It is hypothesized that a nursery area exists in Gans Bay, on the south coast of South Africa. Due to the sensitivity of these areas to habitat destruction, seasonal/area closures should be considered. However, the lack of data regarding the pupping process of the soupfin shark precludes the implementation of this management measure. Further investigations on the breeding habits of the soupfin shark should be conducted by MCM to determine the necessity of seasonal/area restrictions. If it is determined that these restrictions should be implemented, it will be possible to monitor vessel activity around/in these areas or during these times through the vessel monitoring system (VMS).

- **Long-term plan: Experimental gillnet fishery**

  Gillnet fishing for soupfin shark has been shown to be a sustainable method of fishing in Australia. An experimental gillnet fishery could be implemented in the handline sector for a limited number of permits, as stipulated by MCM (refer to Figure B at the end of this document). It is recommended that this permit number not exceed one permit per vessel and be restricted to a maximum of 10 vessels as a precautionary measure. This fishery could be implemented in addition to the demersal longline fishery (refer to Figure B) and is referred to as a long-term plan, as it may only be implemented after a thorough scientific feasibility study.

  Discussion: An experimental gillnet fishery must also be based on a precautionary approach to management. Further investigations into this option should be conducted by MCM to determine appropriate mesh sizes and net lengths. This fishery would require intensive monitoring of bycatch as well as vessel activities. Vessel activities could be monitored through the VMS by MCM.

7.9.3 Performance indicators to measure achievement of objectives

Performance indicators allow progress to be monitored during the objective setting process. Performance indicators and target/limit reference points for the biological and economic objectives for the soupfin shark fisheries are given in Table 7.3. Scientific and management performance indicators for the immediate and medium-term plans are given in Table 7.4.

Table 7.3. Possible biological and socio-economic performance indicators and target/limit reference points to be used in the soupfin shark (*Galeorhinus galeus*) fishery.

		Criteria to be measured	**Management objective**	**Performance indicator**[1]	***Target reference point**	***Limit reference point**
Biological	**Immediate term plan (1a)**	Sustainability of the soupfin shark stock	Productive capacity sustained with low risk	Annual catch/CPUE	Annual catch/CPUE equal to current levels	Annual catch/CPUE not to exceed F_{SB40}
	Immediate term plan (1b)	Sustainability of the soupfin shark stock	Productive capacity sustained with low risk	Annual catch/CPUE/size classes	Annual catch/CPUE equal to current levels	Minimum size of 1420 mm TL
	Medium term plan (1c)	Sustainability of the soupfin shark stock	Productive capacity sustained with low risk	Annual catch/CPUE/size classes/proportion of pregnant females/proportion of immature sharks	Annual catch/CPUE equal to current levels	Decrease the proportion of pregnant females and immature sharks in catches
	Long-term plan	Sustainability of the soupfin shark stock	Productive capacity sustained with low risk	Annual catch/CPUE/bycatch levels	Annual catch/CPUE equal to current levels with low levels of bycatch	Annual catch/CPUE not to exceed F_{SB40}
Socio-economic		Economic efficiency	Economically efficient commercial production	Fishery profit • Income per fisher? • Export value? Commercial CPUE	Maximize fishery profit	To be determined from a socio-economic survey – should not decrease below current levels

[1] Shaded area denotes immediate and medium term management options. For more detail on scientific and management performance indicators, refer to Table 7.4.

*Note: These are suggestions only. They should be analysed and adjusted according to MCM protocol and with continued fishery development.

Biological: A time-series of catch and effort data is required to meet these objectives. It is also necessary to develop a dedicated elasmobranch database for both fishery-dependent and –independent data to allow for proper storage of data, which can be used for biological and stock assessment analyses. Database development should be conducted as soon as possible by MCM. The management measures suggested here must be further investigated by MCM.

Socio-economic: A socio-economic study should be conducted by MCM to determine the value of the soupfin shark fishery in terms of local economic benefits, fisher income and the export value of the fishery. Economic projections should be made by MCM and the economic achievements of the fishery should be compared to these.

Table 7.4. Possible scientific and management performance indicators for the immediate and medium term management plan (1a to 1c) to be used in the soupfin shark (*Galeorhinus galeus*) fishery.

	Criteria to be measured	**Scientific objective**	**Target**
a) Immediate-term plan	Fishery-independent scientific progress (*e.g.*, development of an ASPDM*)	Create management working group (MWG)	Quarterly review of development progress by CWG
		Develop dedicated database	Biennial review of progress by MCM officials
		Conduct biennial research surveys	Annual review of data collection progress by MCM & CWG
		Begin tagging studies	2 archival pop-up tags by 2006; 500 spaghetti tags by 2006
		Initiate independent observer coverage	5% vessel coverage by 2010
		Begin development of ASPDM	Annual review of all above objectives & indicators; supervision of ASPDM by MCM & CWG
		Re-assess the fishery	To be conducted by 2010
b) Medium-term plan	Identification of sensitive habitats (*e.g.*, mating & nursery areas)	Conduct biennial research surveys	Annual review of data collection progress (*i.e.*, specifically pregnant females and juveniles) by MCM & CWG
		Continue tagging studies	Identify mating seasons and nursery areas by 2010

*ASPDM: age-structured population dynamics model.

7.10 Enforcement measures

7.10.2 Overview

The permit conditions developed by MCM for the long-term shark fishing rights, to be issued in 2005, should reflect the objectives of this FMP. MCM should support these conditions through enforcement action to ensure that the conditions are respected.

7.10.3 Main program activities

All enforcement should be carried out by MCM and by on-board and dockside monitors. The main program activities for enforcing the regulations of the shark fishing industry should include the following:

- prohibition of finning
- stipulation that fins must be landed in appropriate proportion to the quantity of carcasses
- monitoring of seasonal or area closures (if implemented) and permit conditions
- gear restrictions (if implemented)
- bycatch restrictions
- stipulation that sharks must be landed with pelvic fins and caudal peduncle attached to the carcass to facilitate species identification and sex determination
- logbook requirements as developed by MCM
- effort control
- VMS to monitor at-sea fishing activity
- on-board and dockside monitoring for all shark landings at a minimum of 5% vessel coverage

Note: These should be analysed and adjusted according to MCM protocol and with continued fishery development.

7.10.4 Enforcement issues and strategies

The primary enforcement issue in South Africa is a lack of monetary resources required for implementing a dedicated monitoring program within the shark fishing industry. However, in 2005, an onshore monitoring program is expected to be implemented at key landing sites across the country. To ensure that shark fishing regulations are met by fishers, it is recommended that a minimum of 5% vessel coverage be introduced. This may be achieved by both on-board and dockside monitoring, as well as through the implementation of the VMS, which can monitor fishing activities at sea. A portion of the cost associated with this method of enforcement should be covered by the industry. Figure 7.3 illustrates the principal landing areas where onshore observer monitoring should occur, as well as recommended sites for onboard vessel coverage.

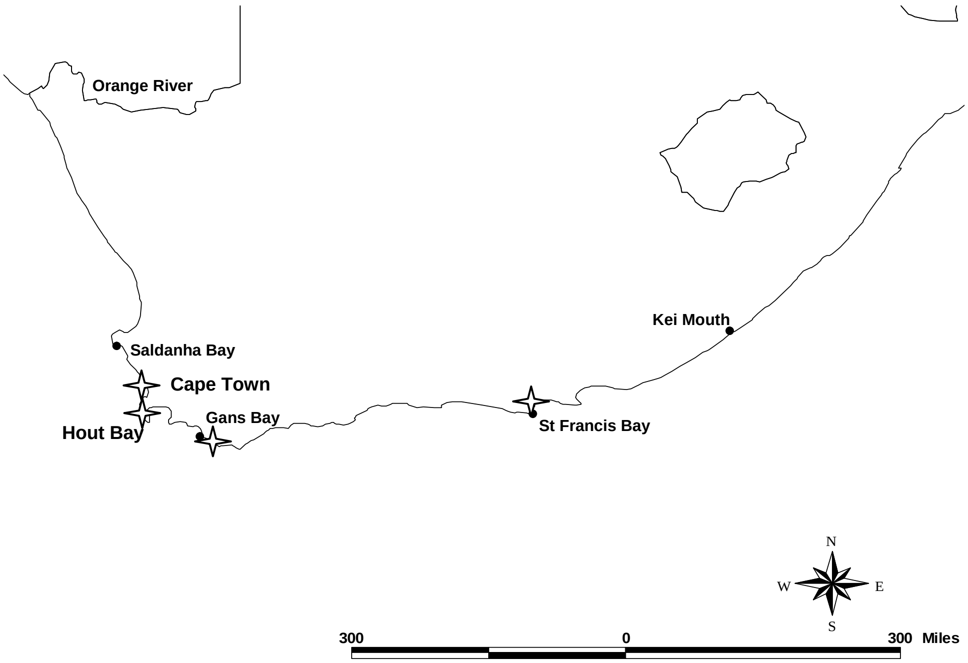


Figure 7.3. Map illustrating landing areas that should be included in the onshore and vessel observer programs. (● denotes all landing areas; ✧ denotes areas where primary shore-based observer coverage should occur based on the principal landing sites for *Galeorhinus galeus*).

7.11 Financial responsibilities

7.11.2 Industry and/or other harvesters

Industry participants should be required to cover or share the costs associated with monitoring by funding certified at-sea observers and dockside monitors. These costs would be in addition to the licensing fees. If an at-sea observer is required, field and travel costs for the observer should be the responsibility of the license holder.

7.11.3 Marine and Coastal Management

MCM should assume the costs associated with routine monitoring of the landings, managing and surveillance of the shark fishery. MCM should also be responsible for any costs associated with reporting on the fishery (*e.g.*, public forums, reports).

7.12 Performance review

7.12.2 Management plan evaluation criteria

To determine whether this FMP meets its goals, it is necessary to review and evaluate performance targets, either annually or, in the case of a stock assessment, at the end of this plan period in 2010. Performance targets include management, scientific and enforcement criteria. These targets are as follows:

- stabilize the current level of fishing mortality, corresponding to a level of 0.14-0.17 yr^{-1}, to ensure the sustainability of the soupfin shark stock
- complete a second stock assessment for soupfin shark by 2010
- develop and maintain a dedicated shark database by 2006
- implement a dedicated commercial shark research program at MCM, including at-sea research and capacity building within the department by 2006
- monitor the percent of fishing trips that collected accurate biological and fisheries logbook data

- ensure the number of demersal shark longline permits does not exceed six until a re-assessment of the stock in 2010
- assess the impact of the handline fishery on the soupfin shark stock (both socio-economically and biologically)
- assess the impact of any area/seasonal/gear restrictions on the stock status
- assess the impact of any area/seasonal/gear restrictions on the industry
- achieve a minimum of 5% observer coverage (in terms of number of days at sea) by the end of this plan
- record the number of hours spent on annual enforcement
- record the number and nature of permit violations per annum

7.13 Synthesis

The work presented here describes the development of a precautionary management plan for the soupfin shark *G. galeus* in South Africa. Its intent is to provide a basis for implementation and development of the fishery during the transition from medium- to long-term shark fishing rights. As such, there are certain practical factors that are not accounted for in this FMP, including financial, time and institutional constraints.

It is intended that this plan be submitted to the Deputy Director General at MCM for comment and amendment, and it is hoped that a revised version will serve as the official basis for management of the soupfin shark fishery in the future.

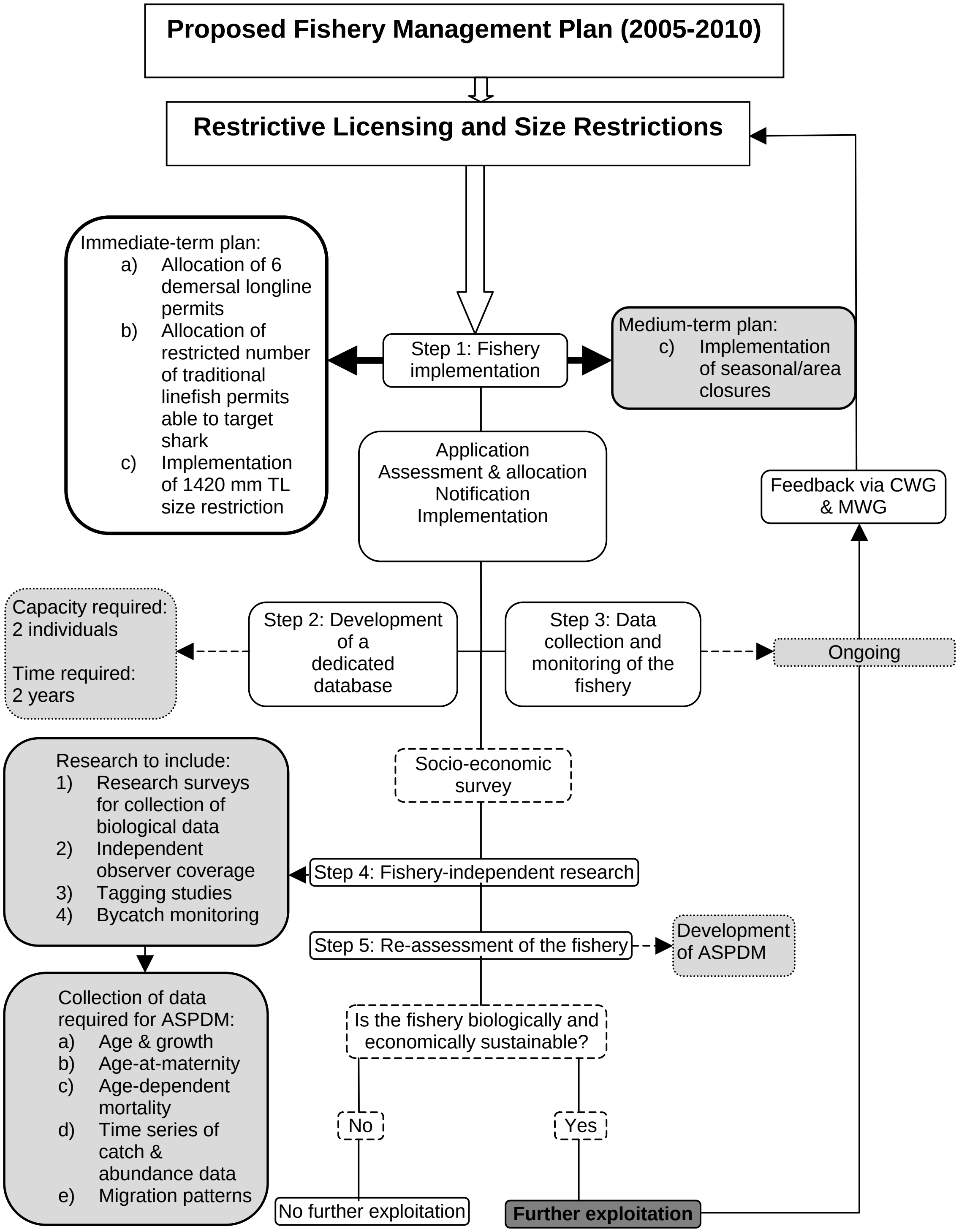


Figure A. Immediate and medium-term plan: Protocol for the allocation of restrictive licenses and implementation of size restrictions and/or implementation of seasonal/area closures and further development of the demersal longline fishery for soupfin shark (*Galeorhinus galeus*) in South Africa.

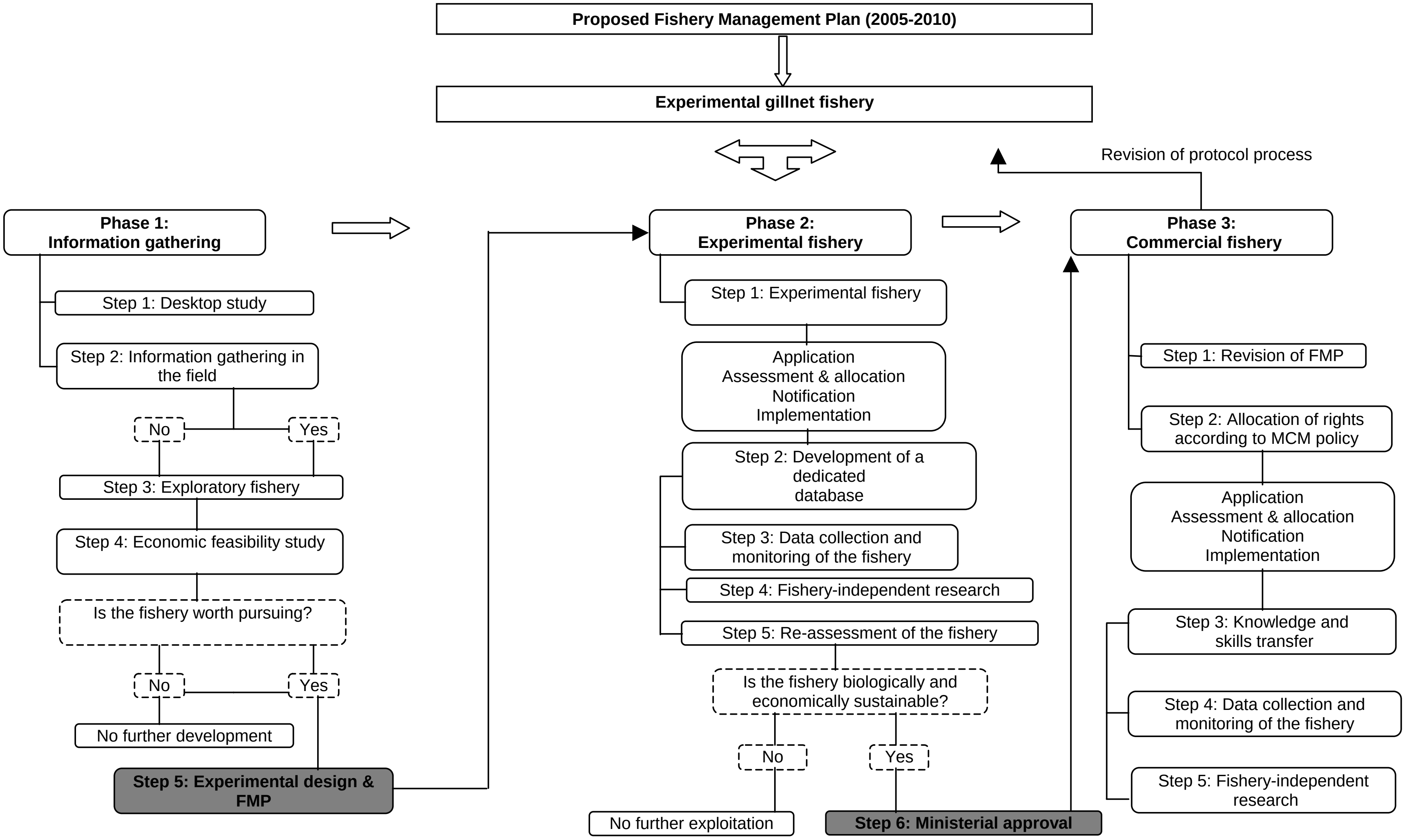


Figure B. Long-term plan: Protocol for the development of an experimental gillnet fishery for soupfin shark (*Galeorhinus galeus*) in South Africa.

Appendix 1. Length-at-age key for *Galeorhinus galeus* in South Africa.

Total Length (mm)	**Age (years)**																				
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	**TOTAL**
500-599	1																				1
600-699	4																				4
700-799	4	2																			6
800-899	1	3																			4
900-999			2	1																	3
1000-1099				4		2															6
1100-1199					1	1															2
1200-1299					2	1			1					1							5
1300-1399						1	1	3	1	2		1			1						10
1400-1499								2	1	1	1	3	3	1				1	2	1	16
1500-1599							1					1	1				1	1		1	6
1600-1699													1			2		1			4
TOTAL	**10**	**5**	**2**	**5**	**3**	**5**	**2**	**5**	**3**	**3**	**1**	**5**	**5**	**2**	**1**	**2**	**1**	**3**	**2**	**2**	**9**

Appendix 1 (cont'd).

Total Length (mm)	**Age (years)**														
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	**TOTAL**
500-599															0
600-699															0
700-799															0
800-899															0
900-999															0
1000-1099															0
1100-1199															0
1200-1299															0
1300-1399															0
1400-1499	3														3
1500-1599						1								1	2
1600-1699			1		1	2									4
TOTAL	**3**	**0**	**1**	**0**	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**9**

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