AN ASSESSMENT OF THE MONKFISH RESOURCE OF NAMIBIA

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There are finer fish in the sea than have ever been caught – Irish Proverb

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ABSTRACT

Two monkfish species are caught off the coast of Namibia. These are *Lophius vomerinus* Valenciennes (1837) and *L. vaillanti* Regan (1903). *L. vomerinus* is the more abundant of the two and contributes approximately 99% to the total Namibian monkfish landings. The Namibian monkfish fishery is one of the largest and most valuable of its kind in the world. Two fishing fleets harvest the resource, *viz*. the monkfish and sole fleet and the hake directed fleet. In 1998 and 1999, monkfish were also harvested by one gillnet vessel that had an experimental right.

In this study, the biology, abundance and exploitation patterns of monkfish were investigated and used as inputs into a stock assessment framework as a contribution towards the development of a management procedure for this species.

Ground and sectioned otoliths and sectioned illicia were used to age *Lophius vomerinus*. The illicia provided more precise estimates of age, and growth was subsequently modelled using these age estimates. Growth in length and weight was best described by the three-parameter specialised von Bertalanffy model as L_t (cm TL) = 72.29 $(1-e^{-0.14(t+0.30)})$ and W_t (kg) = 3.96 $(1-e^{-0.18\ (t+0.10)})^{2.99}$ for males, and L_t (cm TL) = 111.98 $(1-e^{-0.08(t+0.36)})$ and W_t (kg) = 6.92 $(1-e^{-0.18\ (t-0.64)})^{3.03}$ for females. *L. vomerinus* is a slow-growing species with a life span in excess of 10 years.

Reproductive activity was shown to occur throughout the year, with a slight peak during the winter months. The adult sex ratio of fish > 37 cm TL was biased towards females. Length-at-50% sexual maturity was attained at 32.1 cm TL for females and 23.7 cm TL for males. The rate of natural mortality was estimated at 0.15 year^{-1}, while fishing mortality rates during the 1970s, 1980s and 1990s were estimated at 0.01 year^{-1}, 0.04 year^{-1} and 0.14 year^{-1}, respectively.

Gillnetting for monkfish (300 mm stretched mesh) was highly efficient with a moderate bycatch of around 20% during the two years of operation. The main bycatch species were red crab, spider crab, squalid sharks, rays and Cape and Deep-water hake. The mean length of the monkfish caught in gillnets (67 cm TL) was significantly larger than the monkfish landed by the trawlers (38 cm TL) and less than 1% of immature fish were landed. Gillnet catch-per-unit-effort for monkfish fluctuated between 0.03 and 0.67 kg.day^{-1}.50 m net panel^{-1}, with a soak time of between one and sixteen days.

More than 50% (by weight) of monkfish landed by monkfish and sole trawlers, consisted of fish below 36 cm TL. There was a significant increase in catches of juvenile monkfish during 1997 and 1998 in comparison to the period 1994 to 1996.

Various types of rigid sorting grids were tested to release juvenile monkfish below 32 cm TL. Five grid designs were tested. These included an “Ex-it” grid with horizontal bars spaced at 55 mm, single grids with vertical and horizontal bars spaced at 55 mm and grids with circular openings of 110 and 168 mm in diameter. The most efficient design was the grid with circular openings of 110 cm in diameter, which ensured the escape of 66% of monkfish smaller than 31 cm TL. However, studies need to be undertaken to quantify the survival of released fish and to test the feasibility of using grid sorters on commercial monkfish and sole trawling gear.

The monkfish resource was assessed by means of length cohort analyses, the Thompson and Bell predictive model and by way of a deterministic age-structured production modelling approach. The length cohort analysis models were sensitive to the rate of natural mortality and insensitive to changes in the terminal fishing mortality rate. These biases may, however, not be serious provided that estimates of abundance are used to reflect relative changes. Fish ranging between 26 and 59 cm TL are the most heavily exploited. The Thompson and Bell model predicted that the monkfish resource is exploited above MSY-levels and a reduction of approximately 40% in fishing effort would provide a higher yield. Yield-per-recruit ranged between 10 000 and 14 000 tonnes.

Results should, however, be treated with caution, as the condition of steady state was not satisfied.

The age-structured production model was tuned using trends in catch-per-unit-effort data, estimated by Generalised Linear Modeling, as well as relative abundance indices calculated from hake biomass surveys. The model was found to be sensitive to both the ‘steepness’ parameter h and estimates of natural mortality. The ‘depletion’ level of the monkfish resource is currently estimated to be 49%. Estimated coefficients of variation were high (> 63%) due to the lack of a consistent trend within the abundance indices to tune the model. Overall productivity of the monkfish resource was estimated to be approximately 16%, similar to other southern African demersal resources. Results of the risk analyses suggest that catches in excess of 7 000 tonnes may be unsustainable and that catches of 5 000 or 6 000 tonnes would decrease the risk of stock collapse and possibly lead to a recovery in the stock.

Monkfish management strategies were reviewed and these were considered in relation to the results of this study. The following management recommendations were made: to follow the precautionary approach and implement a total allowable catch for monkfish; to implement rigid sorting grids as these would be the most appropriate way in which to reduce catches of juvenile monkfish; to restrict soak time, depth of operation and implement means to reduce ‘ghost fishing’ by gillnetting and finally, to develop a management procedure for Namibian monkfish with the main objective being the sustainable exploitation of the resource.

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CHAPTER 1 - Introduction

The taxonomy of monkfish, family Lophiidae, has not been adequately resolved in southern and southwestern Africa. Four nominal monkfish species are recognised namely *Lophius upsicephalus*, *L. vomerinus*, *L. vaillanti* and *L. budegassa* (Payne and Badenhorst, 1989; Leslie and Grant, 1991).

The common anglerfish, *L. upsicephalus* with an unpigmented peritoneum, was regarded as a geographic isolate of the European *L. piscatorius* (Thompson, 1918; Barnard, 1927; Smith, 1965). Later, it was concluded that it was distinct from *L. piscatorius* (Caruso, 1983). Caruso (1983) also recognised a species with a pigmented peritoneum *viz.* *L. vomerinus* Valenciennes (1837). Two other species, both with pigmented peritonea, *L. budegassa* Spinola (1807) and *L. vaillanti* Regan (1903) have also been recorded off northern Namibia (Lloris and Rucabado, 1985; Leslie and Grant, 1991). Leslie and Grant (1991) concluded that *L. upsicephalus* was a junior synonym of *L. vomerinus* having an unpigmented peritoneum and vomerine teeth. The original description of *L. vomerinus* was based on a specimen with a pale peritoneum and an aberrant lack of vomerine teeth and that the *L. vomerinus* specimens as interpreted by Caruso (1983) closely resembles *L. budegassa* (Leslie and Grant, 1991).

The two most common monkfish species found off Namibia are *L. vomerinus* and *L. vaillanti*. *L. vomerinus* extends from northern Namibia (21°S) to Durban, South Africa (30°S, 31°E) (Leslie and Grant, 1990). *L. vaillanti* occurs north of Walvis Bay (23°S). Both are demersal species and in Namibia inhabit areas from the subtidal zone to depths of more than 600 m.

History of the Namibian monkfish fishery

Catch statistics for monkfish date back to 1974. Catches recorded by the International Commission for the Southeast Atlantic Fisheries (ICSEAF) between 1974 and 1989 increased to a peak in excess of 14 000 tonnes (1981/82) and then declined to 6 000 tonnes (1989). In view of the escalating commercial importance of monkfish, ICSEAF recommended in 1982 that efforts should be made to collect data for stock assessment purposes (ICSEAF, 1982a). The ICSEAF monkfish catch data were obtained from Divisions 1.4 (20°S to 25°S) and 1.5 (25°S to 30°S) as bycatch in the hake (*Merluccius* spp.) directed fishery (ICSEAF, 1982b). Spain indicated occasional monkfish directed fishing by some of its vessels in Divisions 1.4 and 1.5 (ICSEAF, 1982b). In 1984, Spain reported catches of two species in their surveys, *viz*. *L. upsicephalus, sensu lato* *L. vomerinus* in coastal waters between 100 and 500 m and *L. vaillanti* in waters deeper than 400 m.

Since Namibian Independence in 1990 and with the departure of foreign vessels from Namibian waters, monkfish catches initially decreased to approximately 1 500 tonnes per year in 1990, but then increased to more than 12 000 tonnes in 1994. Subsequently monkfish catches decreased to approximately 10 000 tonnes during the period 1995 to 1997. Record catches of almost 17 000 tonnes were recorded during 1998 (Figure 1.1).

Historically, monkfish constituted an important bycatch in the hake fishery. Because of increasing market demand and the subsequent escalation of its economic value a monkfish directed fishery has developed. Fishing rights to catch monkfish and sole (*Austroglossus microlepis*) with a hake bycatch quota were implemented in 1994. The monk fishery is currently managed through effort control, with limited access and a restriction of 800 horsepower on vessel capacity. These rights expire in the year 2000 for thirteen vessels in the fleet, whereas five vessels may utilise this right until 2003.

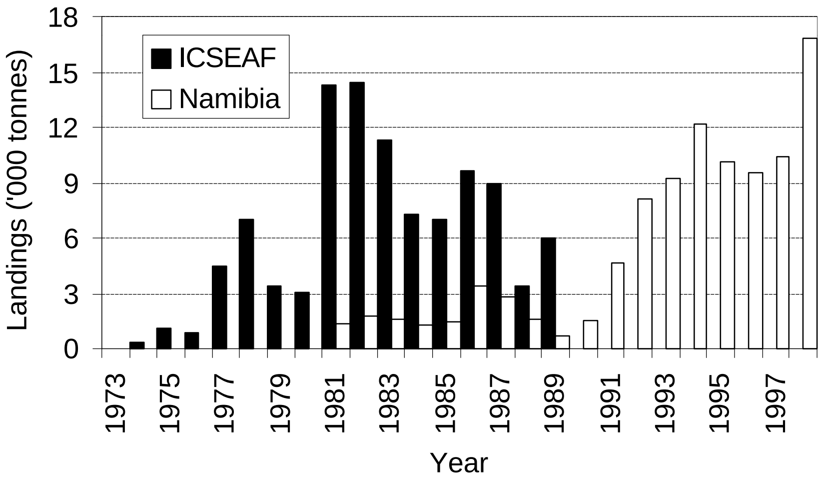

Figure 1.1: Monkfish landings as recorded by ICSEAF, South Africa and the Namibian Ministry of Fisheries and Marine Resources. For the period 1981 to 1989 it is not known whether Namibian landings were incorporated into the ICSEAF records.

The increase in landings by the monkfish and sole directed fleet from 1991 to 1994 is thought to be a result of an improvement in the efficiency of the fleet together with the increase in the number of vessels in 1993 (Table 1.1). The number of licensed vessels fishing for monkfish and sole has remained fairly constant, ranging between 15 in 1991 and 18 in 1998. Cod-end mesh sizes ranging between 75 mm and 110 mm are used.

Table 1.1: The number of monkfish and sole vessels per horsepower (HP) category from 1991 to 1998. Between 1994 and 1998 the total number of licensed vessels, at any point in time, was 18. A vessel count of more than 18 per year reflects the number of vessels fishing in that specific year due to vessel replacements, despite only 18 being licensed.

HP Category	1991	1992	1993	1994	1995	1996	1997	1998
200-399	8	8	10	10	9	8	7	4
400-599	7	4	5	5	5	5	10	8
600-799	-	3	3	3	5	6	6	8
Total	15	15	18	18	19	19	23	20

Monkfish are also caught as a bycatch in the hake directed fishery. The number of hake vessels in the demersal hake fleet has increased, but the percent monkfish caught as a bycatch relative to the total annual monkfish landings has remained more or less constant. In order to reduce the $32.5 \pm 4.7\%$ monkfish bycatch between 1994 and 1997 and to prevent occasional targeting of monkfish by the hake vessels, the bycatch levies on monkfish were increased from N$ 2 000 to 4 300/tonne in January 1998. During 1998, the hake vessels caught 17.8% of the total monkfish landed. However, this decrease in percent contribution to total landings was due to increased landings by the monkfish and sole directed fleet (Table 1.2).

Table 1.2: Namibian monkfish and hake landings and the percent monkfish landed relative to the total annual monkfish landings, as well as to the total monkfish and hake landed by the hake fleet.

Year	1994	1995	1996	1997	1998
Monkfish landed:					
Monkfish and sole vessels	8 809	6 476	6 158	7 237	13 479
Hake trawlers	3 349	3 654	3 590	3 022	2 950
Hake longliners	-	-	36	169	7
Experimental gillnet vessel*	-	-	-	-	134
Total	12 158	10 130	9 784	10 428	16 570
Hake landed:					
Hake trawlers	102076	119753	121819	104039	134366
% Monkfish by hake trawlers of:					
Total monkfish catches	27.5	36.1	36.7	29.0	17.8
Hake and monkfish catches	3.2	3.0	2.9	2.8	2.1

*Monkfish were harvested by one experimental gillnet vessel during 1998 and 1999.

Monkfish, despite having an unappealing appearance, is a highly palatable fish with a firm white flesh similar to that of rock lobster. It is sold mainly headless as tails or filleted, but a greater demand for head-on monkfish has recently emerged.

The monkfish caught off Namibia is exported mainly to Spain, Italy, Korea, Japan and France. Estimates of the economic value of monkfish are summarised in Table 1.3.

Table 1.3: Estimates of the economic value of landed monkfish (Ministry of Fisheries and Marine Resources, Namibia).

Value of Production (Million N$):								
1990	1991	1992	1993	1994	1995	1996	1997	1998
7.4	22.9	40.0	41.1	60.7	50.7	56.1	74.1	118.8

Objectives of the study

The Namibian monkfish research project commenced in 1993 and between 1994 and 1996, stock assessment research concentrated on length-based models to assess the status of the resource and to estimate relative biomass indices from hake directed research surveys (Maartens, 1998). As the resource became increasingly important in terms of landed mass and export value, it became imperative to accumulate and analyse information on the biology and abundance of the species and the exploitation patterns of the fishing industry. The principal aim of this study was, therefore, to provide the scientific information needed as inputs into stock assessment frameworks for the sustainable utilisation of the resource through biologically based management strategies.

An overview of the study area, available data and sampling methods are presented in Chapter 2. Fisheries dependent and independent data are analysed in Chapter 3, providing information on the exploitation pattern of the industry and trends in monkfish abundance. The age composition, growth patterns, estimates of natural and fishing mortality and the reproductive biology of monkfish are described in Chapters 4 and 5. These data were required as input parameters in the stock assessment frameworks. The monkfish resource was assessed by means of a length-based assessment model as well as a deterministic age-structured production model. The age-structured production model was tuned using catch-per-unit-effort and survey indices and sensitivity and risk analyses were conducted (see Chapter 8).

In the course of this study, it was established that large numbers of juvenile monkfish are harvested which may lead to growth overfishing. The exploitation of monkfish using highly size-selective gillnets and/or the implementation of rigid sorting grids to select and release monkfish below a certain size were two prospects that needed to be examined (see Chapters 6 and 7).

Namibian monkfish forms part of a two-species fishery with two separate but overlapping fishery interest groups. The first is the 'monk and sole' trawl fishery that specifically targets monkfish, with a bycatch of sole and hake. The second, is the hake trawl fishery that catches a substantial amount of monkfish as a bycatch. Quota management in both fisheries restricts hake catches. Monkfish were also harvested by one experimental gillnet vessel of which the catches were limited by a quota (see Chapter 6). The management of the monkfish resource is, therefore, difficult to resolve.

Of principal concern in the management of Namibian monkfish is the choice of regulatory measures and how one or a combination of these actions should be implemented. The options include: quota or effort control, setting of a TAC and quota allocation, curtailing of monkfish bycatch in the hake fishery, the feasibility of a monkfish directed gillnet fishery, area and/or depth zone restrictions to protect juvenile monkfish or the regulatory installation of rigid sorting grids. As a result, the Ministry of Fisheries and Marine Resources (*MFMR*) in Namibia identified the need for the development of a management plan for the monkfish resource. In aid of the above, Chapter 9 concludes this study with an overview of the management of monkfish worldwide and provides considerations for the development of a Namibian monkfish management procedure, taking into account the scientific information made available by this study.

CHAPTER 2 - Study area, available data and sampling methods

Study area

This study was carried out in Namibian waters between 17°15'S and 29°30'S and from 100 to 700 m in depth (Figure 2.1).

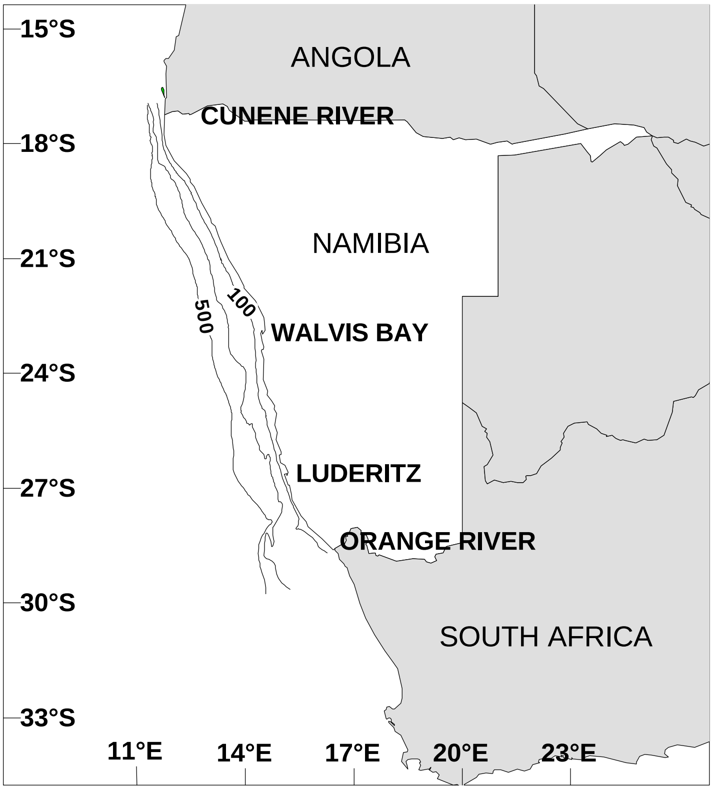

Figure 2.1: Map of the study area. The distribution of monkfish off Namibia extends between the Cunene and Orange Rivers from 100 to 700 m in depth.

The waters off the coast of Namibia form part of the Benguela system which is considered to be one of the most productive in the world (Kankondi, 1994). This is due to the cold water Benguela current system that flows northwards within 150 km off the coast between 15°S and 34°S (O'Toole and Bartholomae, 1998) and is characterised by strong coastal upwelling and high levels of plankton production (Bianchi *et al*., 1993). The frontal zone between the Angola and Benguela current and the warm retroflection zone or return current of the Agulhas system form the northern and southern boundaries of the Benguela system respectively (Bianchi *et al.*, 1993). The most important and intense upwelling cell is located in the south near Lüderitz (27°S to 28°S) and smaller and less intense upwelling regions are located off Cape Frio (18°S), Palgrave Point (20°30'S) and Conception Bay (24°S) (O'Toole and Bartholomae, 1998).

Namibia has a coastline of about 1 500 km with few sheltered bays and a coastal plain that is largely occupied by the Namib Desert. The shelf area consists of approximately 110 000 km^2, extending from the shore to depths of 350 m (Bianchi *et al.*, 1993).

Available data

The data available for the assessment of the monkfish resource can be divided into fisheries independent (research survey data) and fisheries dependent (commercial) data. The data used in this thesis were obtained from a variety of sources summarised in Table 2.1.

Fisheries independent monkfish survey data are available from the pre-Independence period between 1983 and 1990, together with data collected during hake biomass surveys on board the Norwegian *RV Dr. Fridtjof Nansen* between 1990 and 1999.

Survey data from the pre-Independence period were included for two reasons. First, to obtain an indication of the status of the resource before the development of the monkfish and sole directed fishery in the 1990s and second, to determine whether there were any seasonal trends in monkfish abundance.

Table 2.1: Sources of the data used in the different analyses.

Data type	Source
Catch history	
1974-1998	ICSEAF, South Africa and the Ministry of Fisheries and Marine Resources (*MFMR*)
Survey data	
Pre-Independence: 1983-1990	Macpherson and Gordoa (1992)
Post-Independence: 1994-1999	NAN-SIS database, unpublished data; This study
Catch-per-unit-effort	
1991-1998	*MFMR*, unpublished data; This study
Size category data	
1989-1998	*MFMR*, unpublished data; This study
MFV Loraine, 1996	*MFMR*, unpublished data; This study
‘Daily’ size category data, 1998	*MFMR*, unpublished data; This study
Biological data	
RV Dr. Fridtjof Nansen	NAN-SIS database, unpublished data; This study
March 1997-March 1998	*MFMR*, unpublished data; This study
Experimental gillnet fishing	
July 1998 – October 1999	*MFMR*, unpublished data; This study
Grid-selection data	
MFV Katima, April 1999	Lossius *et al*. (1999); This study
Physical data	
March 1997-March 1998	NOAA Satellite images: http://ferret.wrc.noaa.gov/fbin/climate_server
Length frequency data	
1978-1980	ICSEAF (1978, 1979, 1980)
1981-1984	ICSEAF (1981, 1982c, 1983, 1984b)
1996 (*MFV Loraine*)	*MFMR*, unpublished data; This study
1997 (Observer sampling)	*MFMR*, unpublished data; This study
1998 (Observer sampling)	*MFMR*, unpublished data; This study

No stock assessment work could be carried out on the monkfish data collected during the ‘old’ *RV Dr. Fridtjof Nansen* surveys due to the extremely low occurrence of monkfish in the catches. The 'new' *RV Dr. Fridtjof Nansen* replaced the vessel in 1994 and subsequently nine surveys have been conducted. Smaller bobbins were used on the footrope of the net. This increased the catchability of monkfish. These surveys are, however, still directed at hake and the gear used as well as the trawl speed differ considerably from that used by the commercial monkfish and sole directed fishing fleet. The catching efficiency of monkfish is, therefore, much reduced and the calculated biomass estimates are considered to be under estimates of the stock size.

A total of nine surveys on board the 'new' *RV Dr. Fridtjof Nansen* was conducted between 1994 and 1999 (Table 2.2).

Table 2.2: The total number of stations and the depth range sampled per survey.

Survey number	Number of hauls	Depth range (m)
Jan./Feb. '94	152	93 – 648
Apr./May '94	210	96 – 693
Oct./Nov. '94	226	68 – 650
Apr./May '95	185	88 – 667
Jan./Feb. '96	244	88 – 662
Sept./Oct. '96	194	103 – 671
Jan./Feb. '97	218	79 – 698
Jan./Feb. '98	214	79 – 889
Jan./Feb. '99	218	88 - 683

During the pre-Independence period from 1983 to 1990, seven winter and five summer surveys were conducted by Spanish researchers in the southern half of Namibia between Walvis Bay (23°S) and the Orange River mouth (29°30'S). During each survey over 70 randomly stratified stations were sampled at depths between 50 and 500 m (Macpherson and Gordoa, 1992). A bottom trawl with a cod-end of 20 mm mesh was used. All trawls were carried out in daylight and trawling time was generally 30 minutes (see Macpherson *et al.*, 1985). Species composition was determined for each trawl and biomass indices and associated standard errors were calculated for 37 species (Macpherson and Gordoa, 1992). Surface temperature data were obtained from satellite images (NOAA 9, Channel 5).

The fisheries dependent data available include catch-per-unit-effort (CPUE) data from the monkfish and sole directed fishing fleet (1991 to 1998), size category data obtained from the factories based in Walvis Bay (1989 to 1998) and 'daily' size category data from skippers on board the commercial monkfish and sole vessels (1998). In addition, observers on board commercial monkfish and sole as well as hake vessels collected monkfish length frequency data during 1997 and 1998.

Sampling methods

Biological data were obtained from the research surveys on board the *RV Dr. Fridtjof Nansen* between 1996 and 1999 and from commercial monkfish and sole vessels between March 1997 and March 1998. The methodology used during these research surveys is described briefly.

Trawl stations were randomly distributed along transects perpendicular to the coast, approximately 20 nm apart. Conductivity, temperature and oxygen concentrations were sampled with a Seabird CTD-rosette sampler. The bottom trawl net has a headline of 31 m and footrope of 47 m. The headline height was 5 m. The mesh size in the cod-end was 20 mm with a liner of 10 mm. The distance between the wings during towing, measured by a Scanmar sensor, was approximately 18 m. The area between the wings was assumed as the effective fishing area. Furthermore, the retention factor q was assumed to be equal to 1, effectively sampling all fish in the trawl path.

Trawl samples were sorted by species, weighed and counted. Length frequencies were collected for all commercially important species. Each monkfish was weighed (g), measured (TL) to the nearest centimeter and sexed.

Commercial monkfish samples were measured for total length to the nearest millimeter and total, stomach and gonad weight (g) were recorded. Monkfish were sexed macroscopically and the gonads were staged visually and assigned to one of five maturity stages (see Chapter 5).

Both sagittal otoliths and the illicia (first dorsal spines) were collected from research and commercial monkfish samples and stored dry in manila envelopes for later age determination.

CHAPTER 3 - Estimation of abundance indices and catch composition of monkfish in Namibia

Introduction

In order to assess a commercially harvested resource, it is imperative that information on its previous catch history, abundance and catch composition is known. Biomass indices and catch rate (catch-per-unit-effort) data obtained from research surveys and commercial sources respectively, have often been used to provide information about changes in fish abundance. An overview of the methods used in the analysis of fisheries independent (research survey data) and fisheries dependent (commercial data: catch-per-unit-effort, size category, 'daily' size category and length frequency data) data and a discussion of the findings, are presented.

Survey data were used to estimate recruitment and spawner biomass together with total biomass indices. Most of the data analysis pertains to *L. vomerinus*, due to the low abundance of *L. vaillanti*.

Hilborn and Walters (1992) indicated that there are various relationships that can be expected between CPUE and stock abundance. These are either hyperstability where the CPUE stays high as abundance decreases, or a proportional relationship where CPUE increases as abundance increases, or hyperdepletion where the CPUE decreases faster than abundance. Generally it is assumed that the relationship between commercial catch rate and stock abundance is linear, with CPUE being directly proportional to abundance. The scenario can be expressed by

$$C = N\,E\,q$$

where C is the catch, N is the stock abundance, E is the fishing effort, and q the catchability or efficiency of the gear. By rearranging the equation, it can be shown that CPUE is proportional to stock abundance, i.e. CPUE is an index of stock abundance

$$CPUE = \frac{C}{E} = q\,N$$

Paloheimo and Dickie (1964) defined catchability (q) by the following equation

$$q = \frac{c\,a}{A}$$

where a is the area swept by a unit of effort, c is the probability that a fish will be caught by the fishing gear, and A is the total area over which the total population is distributed. The catchability coefficient is, therefore, inversely proportional to the area over which the total population is distributed. The distribution of the population is, however, rarely, if ever, known. Gulland (1964) suggested that catchability q is probably a function of other factors, such as the area swept by the gear, the behaviour of the fishing fleet and fish and fish density. Paloheimo and Dickie (1964) further indicated that catch rates could not provide a measure of variation in abundance unless additional information on fish distribution is available. To conclude, CPUE would only be proportional to abundance or biomass when abundance is proportional to density. This would be achieved if the fish are uniformly distributed without changes in the area in which the stock occurs.

The CPUE data were analysed in two independent ways to construct an index of abundance. First by means of standardising the CPUE data from different horsepower groups and second by applying Generalised Linear Modeling (GLM). Generalised Linear Modeling (GLM) was applied to the CPUE data to account for the effects that vessel and area differences may have on abundance trends. Hilborn and Walters (1992) suggested that this method is the most appropriate way to analyse catching power information and the best tool to calculate standardised catch rates.

Possible changes in the fishing effort or operations of the monkfish and sole directed fleet in terms of depth, area and vessel size for the period between 1991 and 1998 were also investigated.

Prior to 1997, length-based catch data for monkfish are available only in the form of size category data obtained from the factories. These data were analysed and numbers of monkfish caught per size category were calculated for the period 1994 to 1998. Size category data from only two vessels are available for the period 1989 to 1990, and for three vessels between 1991 and 1993. Due to the small sample size, these data were, therefore, not included in the length-based assessment developed in Chapter 8. The size category data were also compared to similar data collected during the hake research surveys to assess how the commercial catch and size composition data relate to those from the research surveys.

In order to investigate the effects of vessel, area, depth and season on the proportions of juvenile monkfish caught, the industry was requested to indicate size category data on a 'daily' basis together with trawl information (depth and geographic trawl position) since the beginning of 1998.

An observer programme was established in 1996 in which observers sample all commercially important species for length and sex while at sea. Little length measurements of monkfish were recorded during 1997 and 1998, but the available data were, however, analysed and incorporated in the length-based assessment (see Chapter 8) together with the size category data.

Methods

Research survey data

Each of the nine surveys conducted since 1994 was analysed as follows: Station data per survey were sorted into 100 m depth ranges. The number of trawls, duration of the trawls (hours), the number of monkfish caught and the monkfish catch (kg) were recorded. The swept area (a) was calculated as

$$a = V \times t \times R \times X_2$$

where V is the velocity of the trawl over the ground when trawling and t is the time spent trawling (Sparre and Venema, 1998). X_2 is that fraction of the head-rope length, R, that is equal to the width of the path swept by the trawl or the 'wing spread', $R \times X_2$. A mean trawl speed of 3.1 knots was employed (3.0 to 3.2 knots). A raising factor for the length frequencies per 100 m of depth was calculated by dividing total area (A) (Table 3.2) by the swept area (a). The estimated number of fish (thousands) was calculated by multiplying the length frequencies obtained per 100 m of depth by the raising factor. Data from the 100 to 299 m depth interval were pooled and categorised as 'Zone 1', while data for the 300 to 399 m depth interval were categorised as 'Zone 2', which is regarded as the zone where most of the monkfish and sole directed fishing vessels operate. Data for the 400 to 699 m depth interval were pooled and categorised as 'Zone 3'. Data from stations where no monkfish were measured or stations not valid for swept area purposes (trawl not set properly, trawl torn or trawling interrupted) were excluded, whereas all zero catch stations were included.

One of the underlying assumptions was that no difference exists in the size distribution of monkfish between the northern (17°S-20°59'S), central (21°S-24°59'S) and southern (25°S-29°30'S) regions. The number of trawl stations per survey was limited by logistical constraints and sampling stratification was related to depth, rather than area. In addition, the principal aim of analysing the survey data was to estimate recruitment, spawner biomass and total biomass indices.

Immature fish and spawner biomass indices

In order to obtain indices of recruitment and spawner biomass in weight, the total numbers (thousands) of *L. vomerinus* per survey were multiplied by the weight per centimeter size class (see Chapter 4). All monkfish smaller than 31 cm TL were regarded as sexually immature and termed ‘immature fish’, whereas monkfish bigger than 31 cm were classified as belonging to the spawner biomass (see Chapter 5).

Biomass indices from trawl survey catches

Catch per tow was weighted by area and depth in order to obtain the total biomass per survey using the following equation (Thompson, 1992):

$$T_{St} = \sum_{h=1}^{L} \mathrm{A}_h \overline{Y_h}$$

where A is the total area, L is the number of strata, A_h is the area of stratum h, T is the total biomass, $\overline{\mathrm{Y}_h}$ is the mean catch per stratum and $\mathrm{A}_h \overline{\mathrm{Y}_h}$ is the biomass of stratum h.

The variance was calculated as follows (Thompson, 1992):

$$S_h^2 = \frac{1}{n_h - 1} \sum_{i=1}^{n_h} \left(\mathrm{Y}_{hi} - \overline{\mathrm{Y}_h} \right)^2$$

where Y_{hi} is the catch for tow i in stratum h and n_h is the number of tows in stratum h

$$\operatorname{var}\left(T_{St}\right) \approx \sum_{h=1}^{L} \left(\mathrm{A}_h^2 \times \frac{S_h^2}{n_h} \right)$$

In order to calculate the confidence limits, the following equation was used:

$$T_{St} \pm t\sqrt{\operatorname{var}\left(T_{St}\right)}$$

To obtain one biomass index for 1994 (three surveys) and 1996 (two surveys), the inverse variance weighted average for the respective years were calculated. Hilborn and Walters (1992) state that if n independent estimates of quantity Q (biomass) are available as well as an estimated variance of each estimate $s_{Q_1}^2$, the best estimate of Q is the weighted mean of the independent estimates, using the inverse of variances as the weight.

$$\overline{Q} = \frac{\frac{1}{s_{Q_1}^2} Q_1 + \frac{1}{s_{Q_2}^2} Q_2 + \ldots + \frac{1}{s_{Q_n}^2} Q_n}{\frac{1}{s_{Q_1}^2} + \frac{1}{s_{Q_2}^2} + \ldots + \frac{1}{s_{Q_n}^2}}$$

Catch-per-unit-effort data

The catch-per-unit-effort (CPUE) data were obtained from the Ministry of Fisheries and Marine Resources' database and consisted of the following: license number, vessel name, date fished, geographical trawl position or grid number, duration of trawling in hours, number of trawls, depth of trawling and total weight of the catch. The skippers of the monkfish and sole directed vessels provided the CPUE data. The Namibian demersal fleet consists of hake trawlers, monkfish and sole directed trawlers and hake longliners. The hake trawlers and monkfish and sole directed trawlers can be divided into wet trawlers (WT) and freezer trawlers (FT). Only data from the monkfish and sole directed fleet were included in the analysis of the catch-per-unit-effort data, since monkfish is the target species and not only a bycatch as in the hake fishery. The catch was converted from headed and gutted (HG) weight or tail weight by a factor of 3.04 to whole round (WR) weight (Anon., 1997b).

In January 1997, new, adjusted daily catch-logs were introduced that include additional trawl information such as the geographical trawl position and start and end time of each trawl, the sea and trawl depth for each trawl and the target species. Potential outliers were excluded from the analysis and these were identified as records with obvious reporting errors (i.e. depth and geographical trawl position). A number of records had zero total catch and these were excluded from the analysis. In addition, only records on which monkfish was recorded as the target species were considered.

CPUE standardisation

The monkfish and sole directed vessels were categorised into three horsepower (HP) groups, namely 200-399 HP, 400-599 HP and 600-799 HP. Examination of residual plots of the log-transformed CPUE data showed that the data were normally distributed and the quarterly CPUE from the commercial fleet between 1991 and 1998 was calculated. In order to standardise the CPUE for all three HP groups, a single factor analysis of variance (ANOVA) was applied. Highly significant differences in CPUE were detected between the different groups ($P < 0.001$). A Tukey-test for contrasts indicated that data from the 200-399 and 400-599 HP groups could, however, be combined as they were statistically similar (Zar, 1996).

The fishing power (FP) for the 600-799 HP group was calculated to be 1.6 compared to the 200-599 HP group and after multiplication of the FP with the observed effort, an index of standardised effort was obtained.

Generalised Linear Modeling

Generalised Linear Modeling (GLM) provides a powerful and consistent method for examining the effects that vessel and area differences have on abundance trends (Hilborn and Walters, 1992). GLM was, therefore, applied to the CPUE data from the commercial monkfish and sole directed fleet between 1991 and 1998. The general factorial analysis of General Linear Modeling was used in the analysis (SPSS 7.5, 1997).

A description of the model is as follows:

$$\ln\left(cpue + d\right) = a + k_{Year \times Month} + b_{Vessels} + g_{Area} + q_{Depth} + e$$

where

a is the intercept

$k_{Year \times Month}$ is the interactions between year and month

$b_{Vessels}$ is a vessel factor that includes differences in HP, gross tonnage (GRT) and vessel type (wet / freezer)

g_{Area} is a factor for each latitude in the data set

q_{Depth} is a factor for depth

e is an error factor

d is 10% of the mean of the CPUE values

The log-transformed CPUE data and estimated d produced symmetric residuals with a stable variance. This technique is consistent with the GLM analysis of the South African hake catch rate data (Brown *et al.*, 1995).

An overall index of resource abundance, B_{Year} was estimated by

$$\mathrm{B}_{Year\ (i)\times Month\ (i)} = \left[a + \left(\frac{\sum b_{Vessels}}{\mathrm{N}_{Vessels}} \right) + \left(\frac{\sum g_{Area}}{\mathrm{N}_{Area}} \right) + q_{Depth} + k_{Year\times Month} \right]$$

with

$$\mathrm{B}_{year} = \left[\exp\left[\sum_{Month=1}^{12} \mathrm{B}_{Year(i)\times Month(i)} \right] / 12 \right] - d$$

Changes in fishing effort related to depth, area and vessel size

The fishing operations of the monkfish and sole directed fleet, in terms of percent frequency at various depths, HP group and area of operation, were analysed and compared for the period between 1991 and 1998.

Length-based catch data

Size category data

The majority of the monkfish caught by the monkfish and sole directed as well as hake directed vessels is landed as tails. These tails are sorted into different size categories either at sea or at the factories after landing. The tails are presented in different categories, either skinless, with or without the caudal fin, or skin-on with or without the caudal fin intact, depending on market requirements. Size category data were available as monkfish tails in kilograms per size category per vessel on a monthly basis from 1989 to 1998 (for some vessels the data are not divided into categories but were available on a monthly or annual basis).

Data from all the fishing vessels were not obtainable. These data were, however, considered to be a representative sample of the fleet. The data, unfortunately, had to be raised to the total monkfish landed per year for the monkfish and sole directed vessels as well as the hake directed vessels to obtain total numbers of monkfish caught for the respective years. Tail weight data (kg) per category per vessel each year were converted by a factor of 3.04 (Anon., 1997b) to obtain total weight (kg), after which the specific categories or catches were raised to the total monkfish landings for that year.

Total catch per size category (see Table 3.1) for the monkfish and sole directed and hake directed wet and freezer trawlers for the five years was obtained as follows:

Table 3.1: The tail weight range for the different size categories in which monkfish tails are landed.

Category	Tail weight range (g)
XXS*	0-50
XS*	50-100
S	100-250
M	250-500
L	500-1000
XL	1000+

* Some vessels report XXS and XS as US

1994 - Monkfish and sole directed vessels: Certain companies report catches in both the XXS and XS category, whereas other companies combine these two categories as under small (US). It was assumed that vessels with a US category land tails in both XXS and XS categories, an assumption based on observations made aboard the *MFV Loraine* during April 1996. The ratio of XXS and XS included in the US category was calculated from data of eight vessels. A ratio of 13.5% for the XXS and 86.5% for the XS was used to divide the US category into XXS and XS. The proportion that each category contributed to the total catch was obtained from the eight vessels that landed all six categories. These percentages (2.1% for XXS, 12.0% for XS, 27.5% for S, 29.6% for M, 23.6% for L and 5.3% for XL) were used to divide the landed catch from the two wet trawlers that only indicated one landing figure per year. It was assumed that these trawlers landed both XXS and XS monkfish tails, similar to the 1996 fishing-year.

1994 - Hake freezer trawlers: The available data per size category were used to obtain one landing figure per category for 1994.

1994 - Hake wet trawlers: It was assumed that the vessels reporting one landing figure per year, landed a catch proportional to the six wet trawlers where five categories (XS = 7.0%, S = 27.9%, M = 35.8%, L = 18.8% and XL = 10.6%) were reported.

The estimated catch per size category was raised to total monkfish landings for the hake freezer and wet trawlers for 1994.

1995 - Monkfish and sole directed vessels: The ratio of XXS and XS included in the US category was calculated from data of eight vessels. A ratio of 20.8% for the XXS and 79.2% for the XS was used to divide the US category into XXS and XS. The proportion that each category contributes to the total catch was obtained from the eight vessels that landed all six categories. These percentages (2.9% for XXS, 9.5% for XS, 29.0% for S, 29.4% for M, 22.5% for L and 6.8% for XL) were used to divide the landed catch from the two wet trawlers that only indicated one landing figure per year.

1995 - Hake freezer trawlers: see hake freezer trawlers, 1994.

1995 - Hake wet trawlers: It was assumed that the vessels reporting one landing figure per year, landed a catch proportional to the two wet trawlers where five categories (XS = 25.8%, S = 35.3%, M = 26.3%, L = 10.8% and XL = 1.9%) were reported.

The estimated catch per size category was raised to total monkfish landings for the hake freezer and wet trawlers for 1995.

1996 - Monkfish and sole directed vessels: The ratio of XXS and XS included in the US category was calculated from data of ten vessels. A ratio of 16.1% for the XXS and

83.9% for the XS was used to divide the US category into XXS and XS. See Monkfish and sole directed vessels, 1994.

1996 - Hake freezer trawlers: It was assumed that the vessels that reported one landing figure per year, landed a catch proportional to the two freezer trawlers where six categories (XXS = 0.2%, XS = 1.2%, S = 8.3%, M = 31.5%, L = 38.7% and XL = 20.0%) were reported. See hake freezer trawlers, 1994.

1996 - Hake wet trawlers: It was, again assumed, that the vessels reporting one landing figure per year, landed a catch proportional to the seven wet trawlers that indicated six categories (XXS = 0.2%, XS = 2.2%, S = 21.7%, M = 36.9%, L = 23.9% and XL = 15.1%).

The estimated catch per size category was raised to total monkfish landings for the hake freezer and wet trawlers for 1996.

1997 – Monkfish and sole directed vessels: The ratio of XXS and XS included in the US category was calculated from data of nine vessels. A ratio of 16.9% for the XXS and 83.1% for the XS was used to divide the US category into XXS and XS. See monkfish and sole directed vessels, 1994.

1997 – Hake freezer trawlers: See hake freezer trawlers, 1994.

1997 - Hake wet trawlers: The ratio of XXS and XS included in the US category was calculated from data of four vessels. A ratio of 2.4% for the XXS and 97.6% for the XS was used to divide the US category (three vessels) into XXS and XS.

The estimated catch per size category was raised to total monkfish landings for the hake freezer and wet trawlers for 1997.

1998 – Monkfish and sole directed vessels: The ratio of XXS and XS included in the US category was calculated from data of nine vessels. A ratio of 14.5% for the XXS and 85.5% for the XS was used to divide the US category into XXS and XS. See monkfish and sole directed vessels, 1994.

1998 - Hake freezer trawlers: No data were available.

1998 - Hake wet trawlers: It was again assumed that the vessels reporting one landing figure per year, landed a catch proportional to the three wet trawlers that indicated six

categories (XXS = 2.0%, XS = 14.8%, S = 37.2%, M = 27.8%, L = 14.8% and XL = 3.4%).
The estimated catch per size category was raised to total monkfish landings for the hake freezer and wet trawlers for 1998.

During April 1996, a commercial sampling survey was conducted aboard a monkfish freezer trawler, the *MFV Loraine*. Length frequency ranges were constructed within the different size categories. In addition, a factor was obtained to convert tail length to total length for the two monkfish species and by applying the length-weight relationship ($W = 0.0347L^{2.7714}$), the total weight (kg) of each fish was calculated per cm length class.

The mean tail weight per category was calculated in two different ways. First by

$$Mean\,tail\,weight\,/\,category = \left[\frac{\sum(W \times n)}{\sum n}\right] / 3.04$$

where W is the weight per cm class, n is the number of monkfish measured and 3.04 the conversion factor to convert tail weight to total weight.

Second the mean tail weight per category was obtained from samples of monkfish tails (boxes) that were weighed and the number of tails per box, recorded where

$$Mean\,tail\,weight\,/\,category = \frac{\sum tail\,weights\,/\,category}{\sum number\,of\,\,tails}$$

The mean tail weight per category was used to obtain numbers of fish per category for the monkfish and sole directed vessels as well as the hake directed vessels for the period 1994 to 1998.

The percent frequency of the US (XXS and XS) monkfish tails in kg of the total catch landed by the different horsepower categories (1989 to 1998) and mesh size (1994 to 1998), as well as the percent frequency of monkfish tails landed per size category (XXS to XL) between 1989 and 1998 by the monkfish and sole directed fleet, was investigated.

'Daily' size category data

Furthermore, ‘daily’ size category data for 1998 were analysed to investigate the effects of area and depth on the proportions of juvenile monkfish caught.

Observer length frequency data

Monkfish length frequency data were collected from monkfish and sole directed as well as hake directed vessels (monkfish bycatch) during 1997 and 1998. Length frequencies sampled from monkfish and sole directed vessels were raised to the total catch per trawl and to the total catch obtained per vessel for the respective years. The raised length frequency data from all the sampled vessels were combined and raised to the total monkfish landings as obtained by the monkfish and sole directed vessels. Monkfish length frequency data collected on board hake vessels were raised to the total catch per trawl. The weight of the monkfish catches was not available per trip or vessel and all the data were, therefore, combined and raised to the total monkfish landed for the respective years by the hake directed fleet. Length frequency data for both the hake and monkfish and sole directed vessels were combined, resulting in estimated length frequency distributions and numbers of monkfish caught during 1997 and 1998.

Results

Research survey data

The areas by depth for the northern (17°S-20°59’S), central (21°S-24°59’S) and southern (25°S-29°30’S) regions off Namibia, are summarised in Table 3.2. Areas (nm^2) for the 600-699 m depth zone were considered to be similar to the 500-599 m depth zone, as no area measurement is currently available.

Table 3.2: Areas in nm^2 per 100 m of depth for the northern (17°S-20°59'S), central (21°S-24°59'S) and southern (25°S-29°30'S) regions off Namibia. Note that the area measurements for the 600-699 m depth zone are assumed to be similar to that of the 500-599 m depth zone.

Area (nm^2)	100-199 m	200-299 m	300-399 m	400-499 m	500-599 m	600-699 m
North	3894	2885	2199	756	818	818
Central	7062	3691	2970	816	715	715
South	9965	3366	3349	1815	750	750

Survey information is summarised in Table 3.3 and the results of the analysis of the survey data are presented in Table 3.4.

Table 3.3: The total number of stations per survey, the number of stations where no monkfish were measured, the number of stations not valid for swept area purposes and the number of stations outside the 100 - 699 m depth range.

Survey number	Total number of stations	Number of stations where no monkfish were measured	Number of stations not valid for swept-area purposes	Number of stations in the 0-99 m depth zone
Jan./Feb. '94	152	5	3	1
Apr./May '94	210	2	6	1
Oct./Nov. '94	226	3	6	3
Apr./May '95	185	3	7	1
Jan./Feb. '96	244	0	13	2
Sept./Oct. '96	194	0	15	0
Jan./Feb. '97	218	0	3	3
Jan./Feb. '98	214	0	7	4
Jan./Feb. '99	218	2	2	2

Table 3.4: The number and duration of the trawls conducted per 100 m of depth, as well as the actual number of monkfish caught, the calculated swept area and raising factors to obtain the estimated number of monkfish caught during the last nine *RV Dr. Fridtjof Nansen* hake biomass surveys.

Survey date	Results	100-199 m	200-299 m	300-399 m	400-499 m	500-599 m	600-699 m
Jan./Feb. '94	Number of trawls	37	41	34	14	13	4
Apr./May '94		38	43	48	39	25	8
Oct./Nov. '94		47	50	52	34	25	7
Apr./May '95		28	46	42	28	18	12
Jan./Feb. '96		67	45	48	33	25	11
Sept./Oct. '96		32	47	36	32	19	13
Jan./Feb. '97		45	43	48	30	30	16
Jan./Feb. '98		47	39	46	38	20	10
Jan./Feb. '99		55	38	44	35	29	11
Jan./Feb. '94	Duration (hours)	15.6	19.5	16.4	7.0	6.5	1.8
Apr./May '94		17.4	20.1	23.5	19.5	12.9	3.8
Oct./Nov. '94		20.5	20.4	24.5	16.5	12.3	3.5
Apr./May '95		11.5	17.9	19.9	13.6	8.3	5.6
Jan./Feb. '96		26.6	18.8	21.3	14.7	11.6	5.4
Sept./Oct. '96		12.2	19.7	17.5	15.6	9.5	6.5
Jan./Feb. '97		19.2	19.3	23.4	14.5	14.9	8.0
Jan./Feb. '98		19.9	17.5	22.3	18.4	10.1	5.0
Jan./Feb. '99		21.9	17.4	21.2	17.3	14.4	5.5
Jan./Feb. '94	Number of monkfish caught	131	702	685	301	104	6
Apr./May '94		30	172	865	411	71	5
Oct./Nov. '94		101	325	645	348	72	12
Apr./May '95		42	164	404	100	14	8
Jan./Feb. '96		302	308	611	146	45	23
Sept./Oct. '96		71	303	163	91	31	9
Jan./Feb. '97		227	211	98	38	20	6
Jan./Feb. '98		43	638	396	97	35	9
Jan./Feb. '99		142	217	1140	181	86	10
Jan./Feb. '94	Swept area in (nm^2)	0.471	0.588	0.493	0.211	0.196	0.055
Apr./May '94		0.523	0.604	0.708	0.588	0.389	0.113
Oct./Nov. '94		0.617	0.614	0.738	0.498	0.369	0.105
Apr./May '95		0.346	0.539	0.598	0.408	0.249	0.168
Jan./Feb. '96		0.803	0.567	0.643	0.443	0.351	0.161
Sept./Oct. '96		0.368	0.595	0.527	0.469	0.286	0.196
Jan./Feb. '97		0.577	0.580	0.705	0.436	0.448	0.241
Jan./Feb. '98		0.599	0.528	0.673	0.553	0.303	0.152
Jan./Feb. '99		0.660	0.523	0.638	0.520	0.434	0.165
Jan./Feb. '94	Raising factor (A/a)	44.5	16.9	17.3	16.1	11.6	41.3
Apr./May '94		40.0	16.5	12.0	5.8	5.9	20.2
Oct./Nov. '94		33.9	16.2	11.5	6.8	6.2	21.6
Apr./May '95		60.4	18.4	14.2	8.3	9.2	13.6
Jan./Feb. '96		26.1	17.5	13.3	7.6	6.5	14.2
Sept./Oct. '96		56.9	16.7	16.2	7.2	7.9	11.7
Jan./Feb. '97		36.3	17.1	12.1	7.8	5.1	9.5
Jan./Feb. '98		35.0	18.8	12.7	6.1	7.5	15.1
Jan./Feb. '99		31.7	19.0	13.4	6.5	5.3	13.9
Jan./Feb. '94	Estimated number of monkfish (thousands)	5825	11869	11832	4834	1209	248
Apr./May '94		1201	2831	10406	2369	417	101
Oct./Nov. '94		3424	5266	7448	2366	445	260
Apr./May '95		2536	3023	5754	830	128	109
Jan./Feb. '96		7874	5396	8097	1116	293	326
Sept./Oct. '96		4041	5067	2633	658	247	105
Jan./Feb. '97		8231	3614	1185	295	102	57
Jan./Feb. '98		1503	12007	5013	594	264	135
Jan./Feb. '99		4502	4127	15226	1178	453	139

To obtain a stock ratio-per-size category for depths between 300 and 399 m to compare to the commercial size category data, the estimated number of *L. vomerinus* per zone over the nine surveys was calculated (Table 3.5). The sum of the estimated numbers of *L. vomerinus* for the nine surveys was calculated and an average obtained.

Table 3.5: Average estimated number of *Lophius vomerinus* (thousands) per zone, size category and total length for the period between 1994 and 1999.

Size category	Total length (cm)	Mean number in Zone 1: 100-299 m	Mean number in Zone 2: 300-399 m	Mean number in Zone 3: 400-699 m
XXS	10-16	1 226	376	2
XS	17-25	2 992	1 497	61
S	26-36	3 591	2 556	434
M	37-48	1 762	1 986	763
L	49-59	549	785	527
XL	60+	139	311	355

Immature fish and spawner biomass indices

Biomass indices for sexually immature (< 31 cm TL) and mature *L. vomerinus* obtained from data collected by the *RV Dr. Fridtjof Nansen* between 1994 and 1999 are illustrated in Figure 3.1. In the analysis of the 1999 survey data, sampling and recording errors were identified, resulting in the possible overestimation of abundance indices. The results were, however, sufficient to be used in the examination of research catch trends. The data indicate that there has been a decrease in the spawner biomass index until 1997, after which the spawner biomass increased.

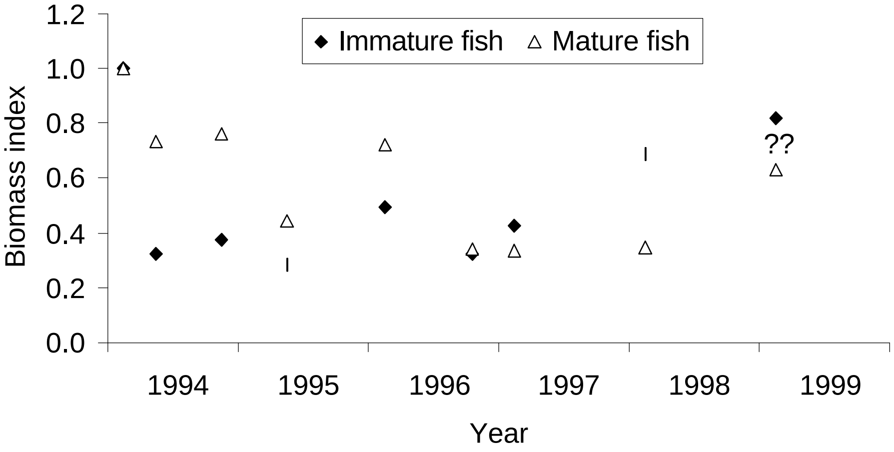

Figure 3.1: Biomass indices of the sexually immature (< 31 cm) and mature *Lophius vomerinus* as obtained from data collected by the *RV Dr. Fridtjof Nansen* from 1994 to 1999.

<u>Biomass indices from trawl survey catches</u>

The biomass indices and associated standard errors of *L. vomerinus* and *L. vaillanti* are illustrated in Figures 3.2 and 3.3. The biomass index of the principal monkfish species, *L. vomerinus*, shows a decreasing trend from 1994 to the second survey in 1996. Since the end of 1996 to 1998, the biomass indices remained more or less constant. An increase in the abundance of *L. vomerinus* is evident in 1999 (Figure 3.2). The biomass of *L. vaillanti*, which is found predominantly in the northern region, has a low biomass index and wide confidence intervals within the trawl survey. Despite this, a similar trend in the biomass indices is evident from the last survey in 1994 to 1997. An increase in abundance to a similar level as in February 1994 is evident for the survey in February 1998. The biomass in 1999, however, declined to a similar level as in 1997 (Figure 3.3).

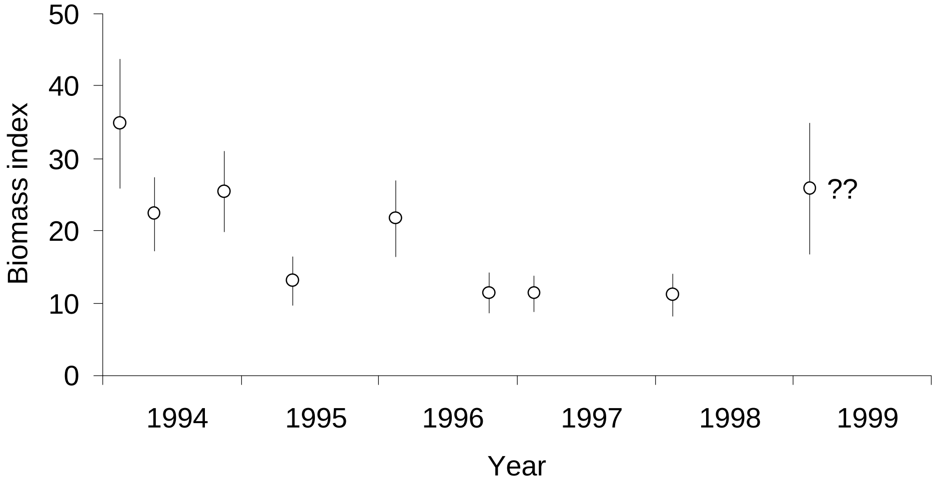

Figure 3.2: Biomass indices for *Lophius vomerinus* obtained from research surveys of the *RV Dr. Fridtjof Nansen* between 1994 and 1999. The vertical bars show the 95% confidence intervals.

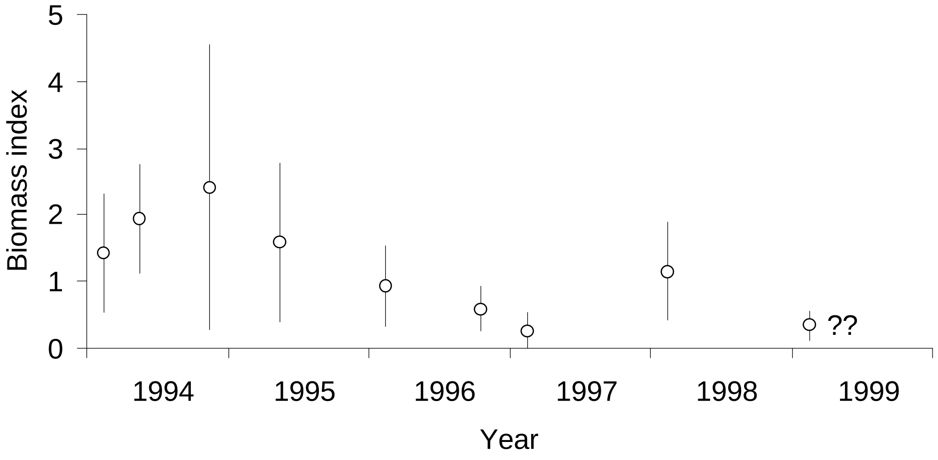

Figure 3.3: Biomass indices for *Lophius vaillanti* obtained from research surveys of the *RV Dr. Fridtjof Nansen* between 1994 and 1999. The vertical bars show the 95% confidence intervals.

Biomass indices of *L. vomerinus* as well as the inverse variance weighted averages for the period 1994 to 1999 are shown in Figure 3.4. These estimates were, together with the

CPUE indices, used to tune the age-structured production-modeling framework developed in Chapter 8.

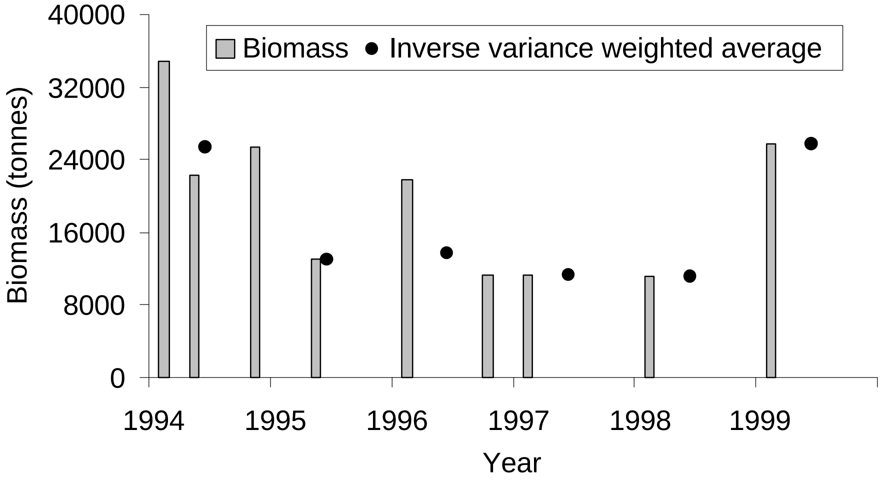

Figure 3.4: Estimated biomass and inverse variance weighted averages of *Lophius vomerinus* as obtained from data collected on board the *RV Dr. Fridtjof Nansen* between 1994 and 1999.

<u>Catch-per-unit-effort data</u>

<u>CPUE standardisation</u>

The observed quarterly CPUE from the monkfish and sole directed vessels for the period 1991 to 1998 is illustrated in Figure 3.5. Investigation of the data highlighted a pattern of fluctuating seasonal monkfish availability.

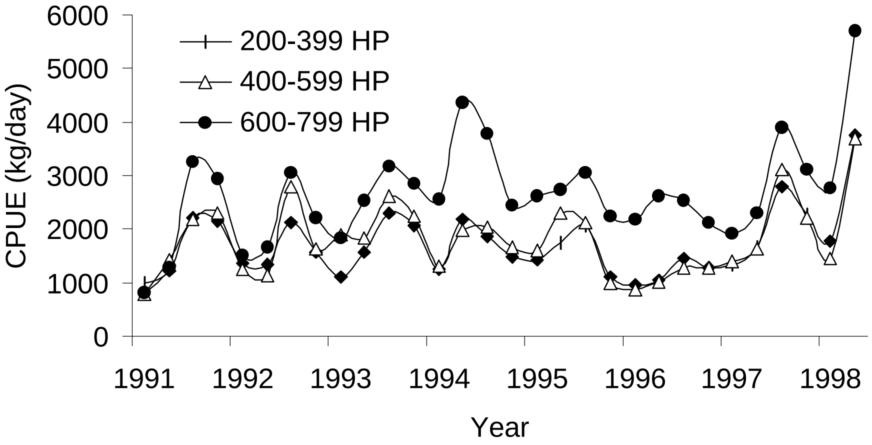

Figure 3.5: Quarterly CPUE from the monkfish and sole directed vessels per horsepower category between 1991 and 1998.

Catches of monkfish as obtained by the monkfish and sole directed vessels and the days spent at sea for the period 1991 to 1998 are illustrated in Figure 3.6. The effort or days spent at sea were similar during 1997 and 1998, but catches increased considerably.

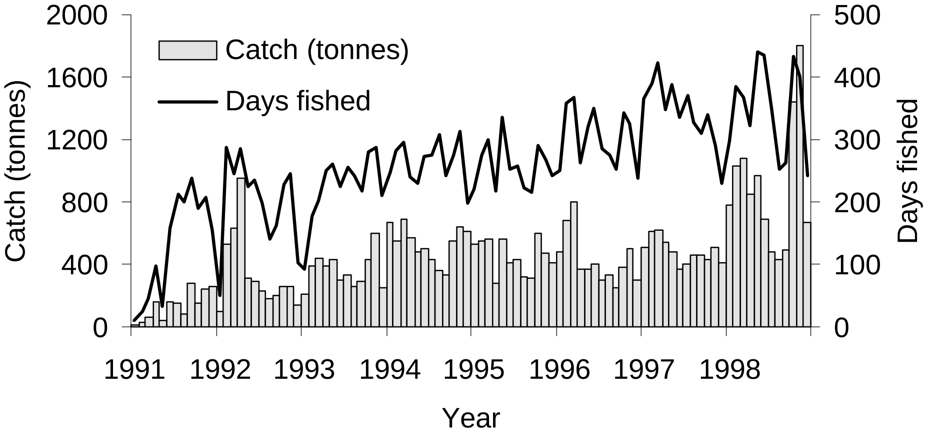

Figure 3.6: Catch (in tonnes) and the total number of days fished by the Namibian monkfish and sole directed vessels between January 1991 and December 1998.

Generalised Linear Modeling

The results from the GLM analysis are summarised in Table 3.6. All effects, i.e. area, depth, vessel type and year-month interactions, had highly significant effects on the CPUE ($P < 0.001$).

The mean annual CPUE index as obtained from the GLM analysis together with the standardised CPUE are illustrated in Figure 3.7. The two indices exhibit a similar pattern over time, but the estimates of the annual CPUE index from the GLM are much lower during 1992 and between 1994 and 1998 than the standardised CPUE index. This could be explained by the fact that the standardised CPUE index only takes into account the vessel effect, whereas GLM adjusts the CPUE series according to vessel, area, depth and year-month interactions. Between 1994 and 1996 the GLM based CPUE index decreased by an average of 24.7% on an annual basis. An increase of 42.5% on average was, however, evident between 1996 and 1998.

Table 3.6: Results from the GLM applied to the monkfish and sole directed CPUE with the factors used in the analysis.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio	Significance
Corrected model	3372.3[a]	137	24.6	91.5	$P < 0.001$
Intercept	4407.0	1	4407.0	16373.5	$P < 0.001$
Year × month	528.8	77	6.9	25.5	$P < 0.001$
Vessel	912.3	29	31.5	116.9	$P < 0.001$
Area	190.8	11	17.4	64.5	$P < 0.001$
Depth	30.6	1	30.6	113.5	$P < 0.001$
Error	5125.3	19042	0.3		
Total	1093749.6	19180			
Corrected total	8497.5	19179			

[a], $R^2 = 0.397$ (Adjusted $R^2 = 0.393$)

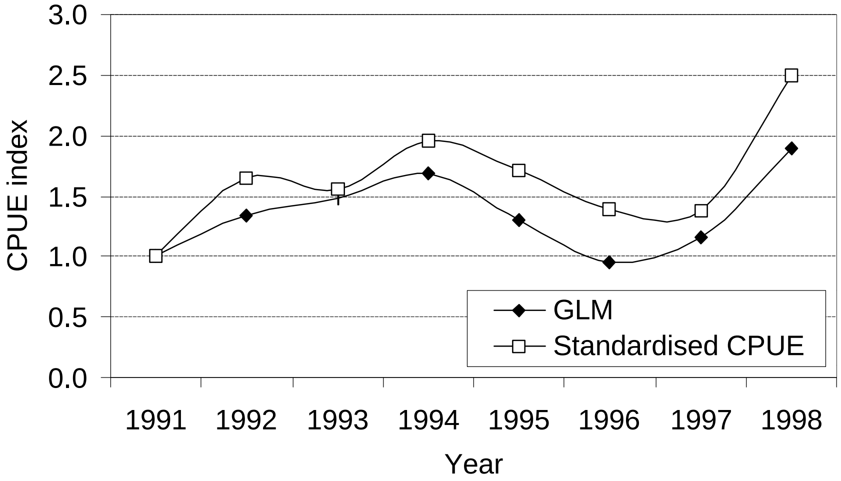

Figure 3.7: Mean annual standardised and GLM estimated monkfish CPUE between 1991 and 1998.

Changes in fishing effort related to depth, area and vessel size

Figures 3.8, 3.9 and 3.10 describe the operations of the monkfish and sole fishing fleet in terms of depth, horsepower category and area of operation. Analysis of the fishing depth data illustrates that there has been a shift in mean fishing depth between 1991 and 1998 (Figure 3.8). In 1991, most of the fishing took place in the 200-299 m depth zone. From 1992 to 1995, fishing effort in the 300-399 m depth zone increased and in 1996 some 10.6% of the effort was expended in the 400-499 m depth zone. A noticeable shift in mean fishing depth occurred in 1997, when almost equal fishing effort occurred in the 200-299 and 300–399 m depth zones. During 1998, most of the fishing effort occurred in the 300-399 m depth zone.

The percent frequency of fishing effort per horsepower category between 1991 and 1998 is illustrated in Figure 3.9 and Table 1.1. During the period 1994 to 1998 there was a decline in effort by the 200-399 HP group. Increased effort was detected within the 400-599 horsepower category between 1993 and 1998, and in the 600-799 horsepower category from 1995 to 1998.

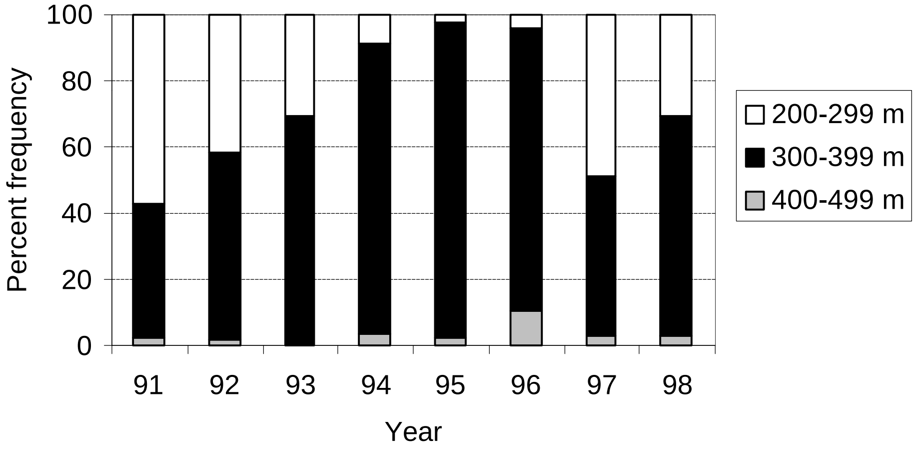

Figure 3.8: Percent frequency of the monkfish and sole directed fleet's fishing operations at various depths between 1991 and 1998.

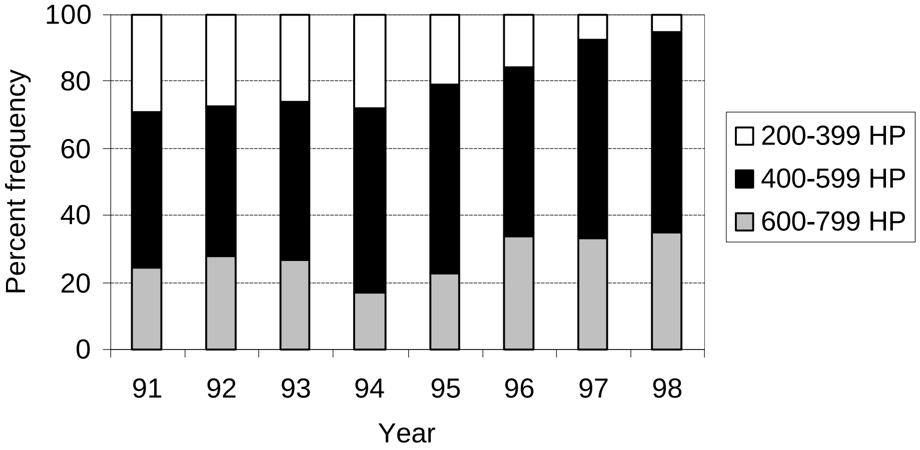

Figure 3.9: Percent frequency of the monkfish and sole directed fleet's fishing operations in each horsepower category between 1991 and 1998.

During the period 1991 to 1998 fishing intensity was greatest in the central region (21°S-24°59'S). Fishing operations, however, decreased slightly from 1991 to 1996 (Figure 3.10) and doubled between 1996 and 1998. Fishing in the southern region (25°S-29°30'S) more than doubled between 1991 and 1997, but decreased in 1998. Fishing in the northern region (17°S-20°59’S) peaked in 1996, after which it decreased to similar levels as in 1991.

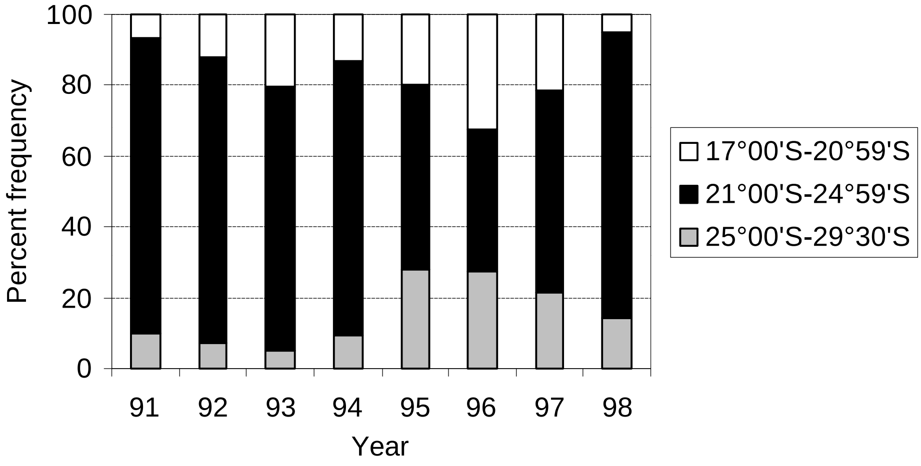

Figure 3.10: Percent frequency of the monkfish and sole directed fleet’s fishing operations in the northern (17°S-20°59’S), central (21°S-24°59’S) and southern (25°S-29°30’S) regions off Namibia between 1991 and 1998.

Length-based catch data

Size category data

The ranges of lengths and tail weights in the size categories are shown in Table 3.7.

Analysis of the data collected to convert tail length to total length resulted in

$$Total\ length = 1.4491 \times Tail\ length - 0.6386 \quad (R^2 = 0.99)\ (n = 505)$$

The results of the analysis to calculate mean tail weight-per-category are summarised in Table 3.8. These data were used to obtain numbers of monkfish per size category for the period 1994 to 1998 (see Figure 3.14).

Table 3.7: Total length and tail weight range of monkfish in the different size categories. Data were collected on board the *MFV Loraine* during April 1996.

Category	Tail weight range (g)	Total length range (cm)
XXS*	0-50	10-16
XS*	50-100	17-25
S	100-250	26-36
M	250-500	37-48
L	500-1000	49-59
XL	1000+	60 +

*Some vessels report XXS and XS as US

Table 3.8: Mean tail weight (kg) of monkfish per size category obtained during two experiments.

Size category	Mean tail weight (kg)	Mean tail weight (kg)	Mean
XXS	0.011	0.010	0.011
XS	0.063	0.070	0.067
S	0.172	0.210	0.191
M	0.331	0.370	0.351
L	0.649	0.670	0.659
XL	1.655	1.850	1.752

The percent frequency of the US (XXS and XS) monkfish tails (in kg) of the total catch landed per horsepower category (1989 to 1998) as well as per mesh size (1994 to 1998) of the monkfish and sole directed fleet is illustrated in Figures 3.11 and 3.12.

The percent juvenile monkfish caught, ranged from 9 to 18%, 8 to 24% and 3 to 16% between 1994 and 1998 for the three HP categories, respectively. The highest percent juvenile monkfish caught per HP category since 1994 was 18% by the 200-399 HP category (1997), 24% by the 400-599 HP category (1998) and 16% by 600-799 HP category (1998).

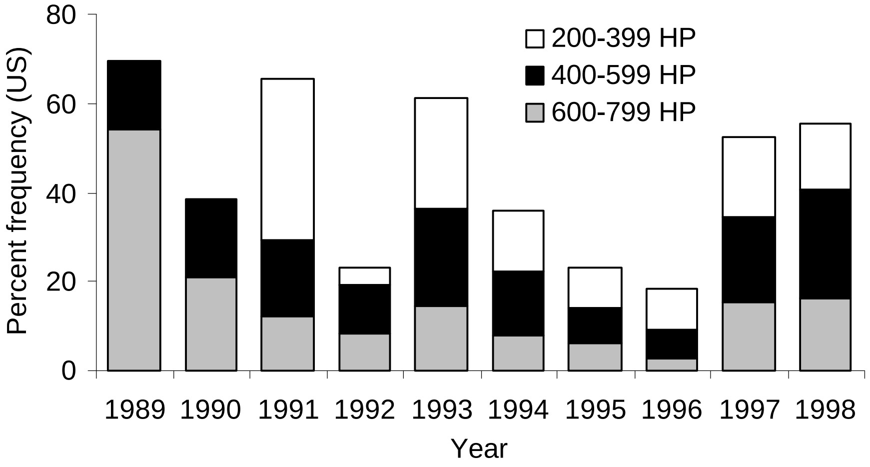

Figure 3.11: Percent frequency of the US (XXS and XS) monkfish tails (by weight) caught per horsepower category of the monkfish and sole directed fleet between 1989 and 1998.

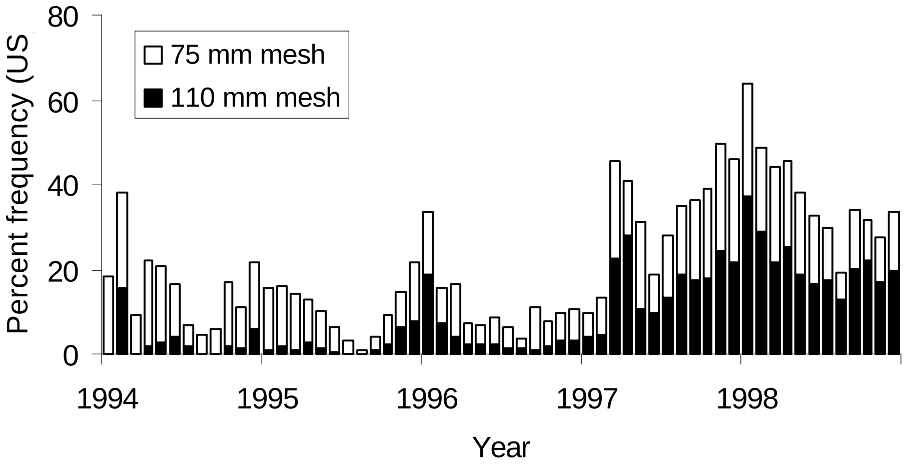

Figure 3.12: Percent frequency of US (XXS and XS) monkfish tails (by weight) landed per mesh size between 1994 and 1998 by the commercial monkfish and sole directed vessels.

During 1994 and 1995, most of the US monkfish was caught by vessels using a 75 mm mesh size whereas from 1996 to 1998, similar proportions of US monkfish were caught by vessels using both 75 and 110 mm mesh sizes. A possible explanation is that vessel replacements took place and 'new' vessels had to use a 110 mm mesh size (vessels in the 200-399 HP class decreased between 1994 and 1998, whereas vessels in the 400-599 and 600-799 HP classes increased between 1993 and 1998 and 1995 and 1998, respectively).

The percent frequency of monkfish tails landed per size category by the monkfish and sole directed fleet between 1989 and 1998 (by weight) and between 1994 and 1998 (in numbers) is illustrated in Figures 3.13 and 3.14. It should be noted that the sample size between 1989 and 1993 was small (data from two vessels between 1989 and 1990 and data from three vessels between 1991 and 1993) (Figure 3.13). Between 1994 and 1996, catches of monkfish in the US and S categories decreased (34 and 8%), while catches in the other categories (M, L and XL) increased (4, 1 and 48%). However, between 1996 and 1998 catches increased by an average of 113% in the US and 36% in the S category and decreased by an average of 20, 27 and 35% in the M, L and XL categories, respectively.

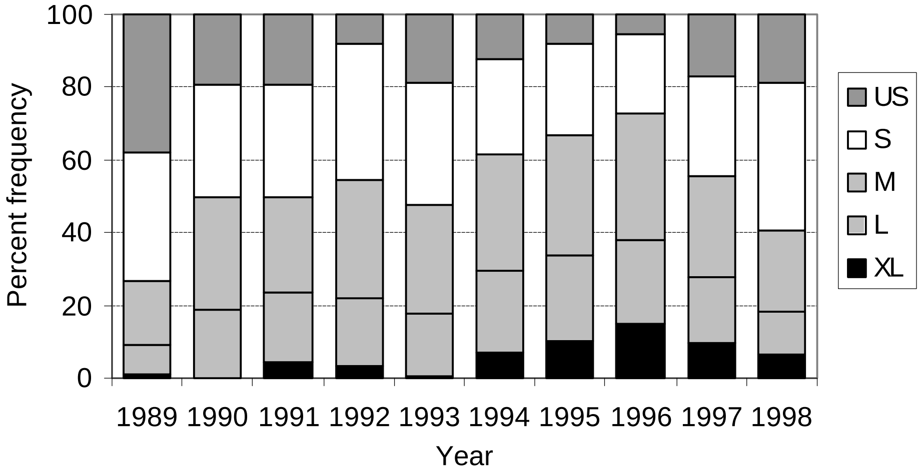

Figure 3.13: Percent frequency of monkfish tails (by weight) landed per size category by the monkfish and sole directed vessels between 1989 and 1998.

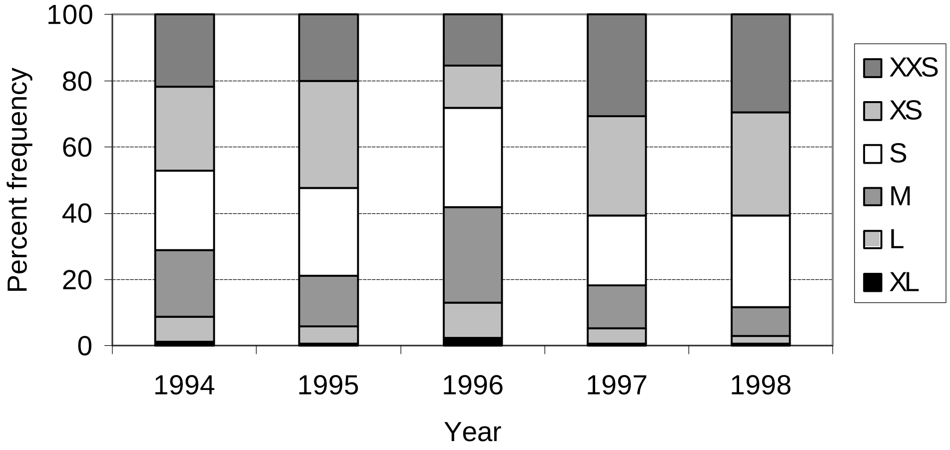

Figure 3.14: Percent frequency of monkfish tails (in numbers) landed per size category by the monkfish and sole directed vessels between 1994 and 1998.

'Daily' size category data

Analysis of the ‘daily’ size category data indicates that juvenile monkfish are caught in all latitudes along the coast of Namibia (Figure 3.15). Higher proportions of juvenile monkfish are, however, caught in the central region (21°S-24°59’S).

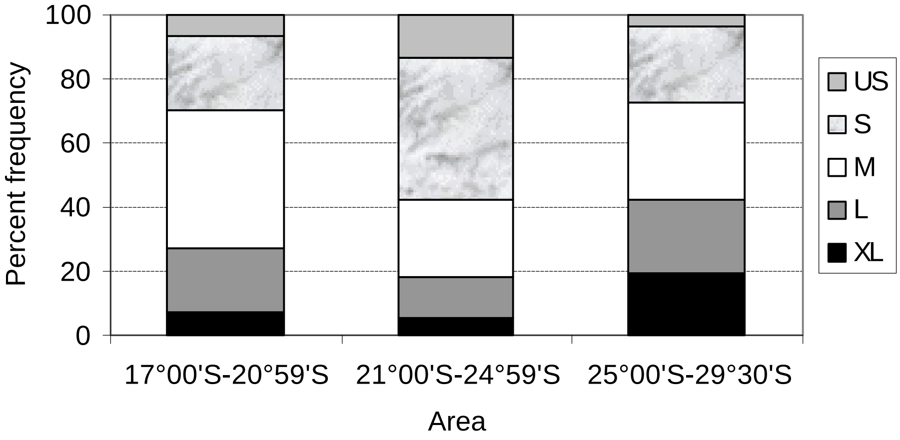

Figure 3.15: Percent frequency of monkfish tails (by weight) landed by 12 monkfish and sole directed vessels per size category and area during 1998.

Juvenile monkfish also occur in all depth ranges up to 500 m (Figure 3.16). The highest percent frequency, however, occur in the 100 to 199 and 200 to 299 m depth zones.

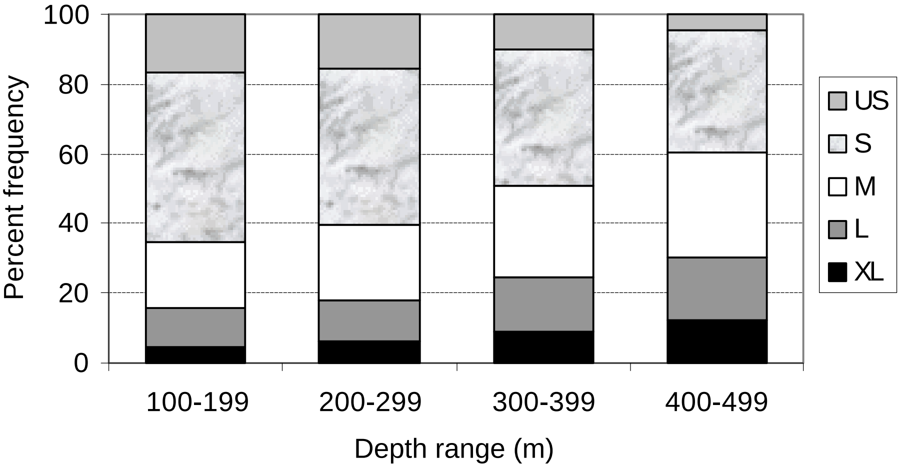

Figure 3.16: Percent frequency of monkfish tails (by weight) landed by 12 monkfish and sole directed vessels per size category and depth range during 1998.

Observer length frequency data

The length frequency distribution of monkfish (*L. vomerinus* and *L. vaillanti*) caught off Namibia during 1997 and 1998 is illustrated in Figure 3.17.

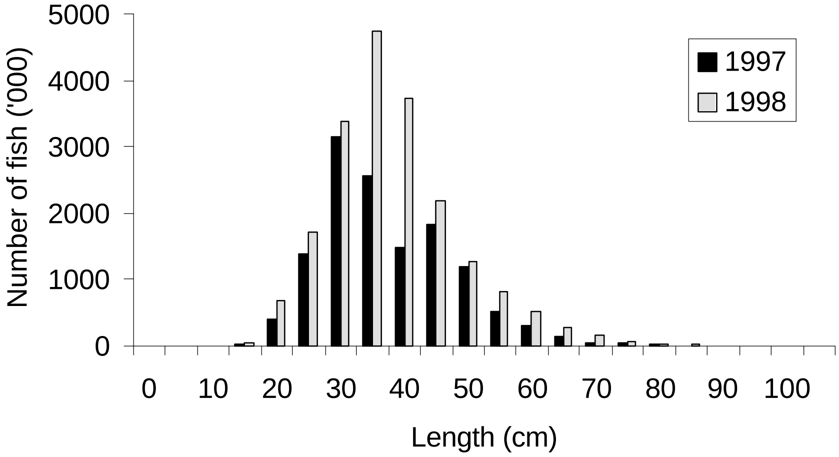

Figure 3.17: Length frequency distribution of monkfish sampled from monkfish and sole as well as hake directed vessels during 1997 and 1998. The mean length was 38 cm TL for the consecutive years.

Discussion

The biomass of *L. vomerinus* as estimated by Spanish researchers in the 1980s ranged between 59 000 tonnes in 1983 and 12 000 tonnes in 1990 (Macpherson and Gordoa, 1992). The highest biomass of 88 000 tonnes was recorded during the winter of 1986 and the lowest (9 000 tonnes) during the winter of 1989. It should be noted that the area covered in the 1980s (23°S - 29°30'S), differs from that covered by the *RV Dr.Fridtjof Nansen* in the 1990s. Moreover, the Spanish surveys were targeting hake and not monkfish (no tickler chains on the footrope of the trawl) and the estimated biomass figures for *L. vomerinus* are possibly underestimates of the true stock size and should be regarded as relative abundance indices.

Macpherson and Gordoa (1992) concluded, even though there was no significant seasonal variation in the size frequency distributions, that the availability of *L. vomerinus* to the bottom trawls was greater in summer than in winter. This increased availability was observed for all sizes and was, therefore, not associated with seasonal variations in recruitment intensity. Analysis of the data from the winter cruises indicated that the biomass of *L. vomerinus* decreased after the winter of 1985.

The fishery independent *RV Dr. Fridtjof Nansen* survey data show a decreasing trend in abundance for mature *L. vomerinus* between 1994 and 1997. On average, the indices have been fairly constant between 1996 and 1998, but increased during the survey in January/February 1999.

Unfavourable environmental conditions prevailed during 1994 and 1995. These consisted of low dissolved oxygen concentrations during 1994 and a warm water event in 1995. As a result, declining abundance trends until 1997 were evident in most commercially important stocks, including both the hake species (O'Toole and Bartholomae, 1998). These conditions possibly had a similar effect on the monkfish resource.

The distribution pattern of the mean number of monkfish in the 300-399 m depth zone per size category, obtained from *RV Dr. Fridtjof Nansen* survey data (Table 3.5) over the past five years, compares well with that obtained by the fishing industry (see Figure 3.14). The numbers of monkfish caught in Zone 2, increased by size category and length range, with the highest numbers obtained in the small (S) category. Numbers of monkfish decreased from the medium (M) to the extra large (XL) category, whilst the catchability for the medium, large and extra large classes appeared similar for the survey and commercial data. However, smaller monkfish (XXS and XS) seem to be severely under represented in the survey catches. The decreased catchability of juvenile monkfish may be the result of the type of gear used during these hake directed surveys (lighter gear, no tickler chains and the lack of clogging of the net). This is of concern as the calculated indices may, therefore, not be a true representation of monkfish recruitment to the fishery.

The standardised CPUE between 1994 and 1997 decreased by, on average 10.8% (Figure 3.7), whereas the fishing effort (days fished) increased by 15.3% between 1995 and 1997. Similar trends in the GLM estimated CPUE was evident, i.e. decline in catch rates between 1994 and 1996. The increase in fishing effort indicates that the vessels spent more time at sea. However, an overall decrease in monkfish catches was evident between 1994 and 1996. Even though the number of monkfish and sole directed vessels has remained more or less constant since 1993, there has been an overall increase in total effective fishing effort. This was a result of vessels in the 200-399 HP category being replaced by vessels in the 400-599 and 600-799 HP categories.

The question arises whether the decline in both the standardised and GLM estimated CPUE is an indication of continuous depletion of the resource, or possibly a reflection of the complex dynamics, which coincide with adjustments of the resource to changes in fishing patterns since 1991. Hilborn and Walters (1992) state that if the catch rates by a specific vessel type in a specific area is not proportional to abundance, then the abundance trend estimated from GLM will not be proportional to abundance. The solution lies in the relationship between CPUE, abundance and density.

Standardised CPUE increased by 81.8% and GLM estimated CPUE by 64.1% from 1997 to 1998 (Figure 3.7). The days spent at sea (standardised CPUE) increased by only 1.8%, thus indicating an increase in catchability of monkfish during 1998. The overall effective fishing effort did increase during 1998 (see Figure 3.9), but not enough to account for an 86.2% (Table 1.2) increase in monkfish catches by the monkfish and sole directed fleet.

A distinctly seasonal pattern emerged from the catch rates on a quarterly basis. It can be assumed that these seasonal patterns are instigated by environmental factors as no market forces and/or fishing seasons are present. Environmentally driven forces may also explain the decline in CPUE between 1994 and 1996, as well as the increase in subsequent years. Macpherson and Gordoa (1992) state that environmental factors responsible for changes in both species distribution and availability are not entirely clear. Changes have been related to sea surface temperature, persistent upwelling and dissolved oxygen levels at the bottom. Horizontal migrations of fish could be another possible cause. Jean (1965) suggested that *L. americanus* undertake seasonal migrations and Azevedo (1996) found that small *L. budegassa* prefer shallow waters and move to deeper waters as they grow.

No definitive information is, however, available on possible migration of the two *Lophius* spp. in Namibian waters.

It is evident from the size category data analysis that large numbers of juvenile monkfish (Table 3.7, Figures 3.13 and 3.14) are currently harvested, which may lead to growth overfishing. It would, therefore, be advisable to reduce the capture of these juvenile fish. From the 'daily' size category data it is clear that it would not be possible to close off areas and/or depth zones to prevent the industry from catching juvenile monkfish. An increase in mesh size from 75 to 110 mm would also not solve the catching of juvenile monkfish (Figure 3.12). During 1998 and 1999, experiments testing rigid sorting grids to size select and release juvenile monkfish were carried out on the monkfish fishing grounds off Namibia (see Chapter 7). The implementation of a rigid sorting grid, may be a possible solution to increase the length-at-first-capture of monkfish.

The percent frequency of US (XXS and XS) monkfish tails landed during 1997 and 1998 increased compared to the proportions of US monkfish landed for the period 1994 to 1996 (Figures 3.13 and 3.14). A possible explanation is that the highest percent frequency of juvenile monkfish occurred in the 100 to 299 m depth zone during 1998 and a noticeable shift in the mean depth of fishing (increased fishing effort in the 200-299 m depth zone) took place during 1997 and 1998. Also, one of the identified recruitment areas are between 23°S and 25°S (see Chapter 5) and increased fishing effort in the central area (21°S and 24°59'S) occurred during 1997 and 1998.

Data available for the assessment of the monkfish resource were obtained from different sources. The assessment was further complicated by the fact that two components, i.e. the monkfish and sole fleet and the hake fleet harvest the resource. It was, however, attempted to analyse the data to provide a holistic view of the research survey and commercial data. Overall, increasing abundance trends are evident in both the fisheries dependent and independent data series since the beginning of 1998. The reference to possible growth overfishing should, however, be noted. The results from the Generalised Linear Modeling and the survey indices were further used to tune the age-based stock assessment framework. The size category and commercial length frequency data were used as input in the length-based assessment modeling. Both the assessments, i.e. length-based and age-based, are developed in Chapter 8.

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CHAPTER 4 - The growth of monkfish *Lophius vomerinus* in Namibian waters, with a comparison of the otolith and illicia ageing methods

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Introduction

The correct determination of age and the accurate calculation of growth parameters are of vital importance in almost every aspect of fisheries management. Age and growth information is used in the construction of age-length keys, estimation of growth parameters, determination of stock age structure, comparison between different stocks and as input parameters in stock assessment models (Pauly, 1987). Age can be defined as some quantitative description of the length of time that an organism has lived. Growth is, therefore, the measure of the change in body size between two points in time with growth rate being the measure of change of body size as a function of time (Devries and Frie, 1996).

The growth pattern of monkfish in Namibia is poorly understood as the last assessment was conducted during the 1980s (Morales and Lombarte, 1987). To address this problem, current age estimates of *L. vomerinus* need to be accurately determined before growth parameters are calculated. The preferred method of obtaining age estimates is with the examination of hard structures (Lai *et al*., 1996). In the Lophiiformes, these structures include sagittal otoliths, vertebrae and illicia (dorsal fin spines).

The aim of this study was two-fold. First to determine which structure and what method of preparation and analysis most accurately reflects the age of *L. vomerinus* and second to use these age estimates to describe the growth pattern of *L. vomerinus* in Namibian waters.

No age and growth studies were conducted on *L. vaillanti* due to the extremely low incidence of these species in the research survey trawl catches and in the commercial catches (< 1%). It was, therefore, assumed that *L. vaillanti* exhibit similar growth patterns to those of *L. vomerinus* for later use in stock assessment modeling. The growth parameters obtained for *L. vomerinus* were used in the yield-per-recruit analysis (see Chapter 7) and the modeling frameworks developed in Chapter 8.

Materials and methods

<u>Materials</u>

In order to assess the suitability of the different hard structures to age *L. vomerinus*, sagittal otoliths and illicia were collected between 7 September and 14 October 1996 on board the Norwegian research vessel, *Dr. Fridtjof Nansen*. A total of 607 fish between 90 and 960 mm TL was collected. Each fish was weighed (g) and measured (TL) to the nearest centimeter and sexed. Both sagittal otoliths, as well as the illicia, were removed, cleaned and stored dry in manila envelopes for later age determination. A subsample of otoliths and illicia from 61 fish (90 - 650 mm TL) was used for comparison of hard tissues for age estimates.

In addition, monthly samples of *L. vomerinus* were obtained from the monkfish fishing grounds between March 1997 and March 1998. Overall, a total of 570 fish were examined, ranging in length from 146 to 904 mm TL. Most samples were taken at depths ranging between 200 and 450 m by commercial trawlers using, either 75, or 110 mm mesh cod-ends. In the laboratory, the total length (mm), total weight (g) and sex were recorded. Other data collected included stomach weight (g) and gonad weight (g). Both sagittal otoliths, as well as the illicia, were removed, cleaned and stored dry in manila envelopes for later age determination.

Preparation and comparison of hard tissues for age estimation

Several techniques were used to render the otolith growth zones conspicuous. Preparation techniques followed those described by Tsimenidis (1984), Griffiths and Hecht (1986), Morales and Lombarte (1987), Crozier (1989) and Tsimenidis and Ondrias (1994). These included the examination of burnt and unburnt longitudinal, transverse and diagonal sections as well as lateral hand-ground sections. The left otolith of the sagittal pair was hand-ground on the medial side to the nucleus using 360-grade Carborundum paper and 0.5 μm geological grinding paste. Right otoliths, of which some were burnt, were embedded in clear casting resin, sectioned to 0.2 – 0.5 mm through the nucleus using a double-bladed diamond saw, and mounted on microscope slides with DPX mountant. The burnt otoliths as well as the longitudinal and diagonal sections proved to be unsatisfactory. The ground otoliths were examined whole, immersed in a 50:50 solution of water and glycerin. The otoliths were viewed against a black background, illuminated with reflected light. The transverse-sectioned otoliths were illuminated using transmitted light. Both the ground and sectioned otoliths were read under a binocular stereo microscope at 10 × magnification.

The first fin-ray, the illicium, is a spiny ray consisting of a cutaneous excrescence from tip to base, a long and flexible stem and a thick basal bulb that is foot-shaped (Peronnet *et al*., 1992). The techniques of preparation and interpretation are described by Dupouy *et al*. (1986), Peronnet *et al*. (1992), Staalesen (1995) and Duarte *et al*. (1997). After removal of the skin, 5 cm long pieces from the lower part of the illicia were embedded in clear casting resin. These were sectioned to 0.2 – 0.5 mm at 0.5 cm from the base using a double-bladed diamond saw (Peronnet *et al.*, 1992; Duarte *et al.*, 1997). Previous experience has shown that the growth zones were most easily distinguished 0.5 cm above the base. If the cut is made too close to the base, it would result in an alveolate section containing altered bone structures unsuitable for analysis. The cuts were mounted on microscope slides with DPX mountant, illuminated using transmitted light and read under a binocular stereo microscope at 20 × magnification. Various colour filters were tested to enhance growth zone visibility, but this proved to be fruitless.

Estimation of precision

The ground and sectioned otoliths and the illicia were read by three independent and experienced readers (T. Hecht, A.J. Booth and L. Maartens). If two readings per structure agreed, the age estimate was accepted.

Campana *et al*. (1995) noted that some measure of precision is a valuable means of assessing the relative ease of determining the age of a particular structure, of assessing the reproducibility of an individual's age determinations, and for comparing the skill level of one age reader with that of others. There are two methods with which precision can be estimated. These are the average percent error method and the percent agreement method. Beamish and Fournier (1981) suggested that the Index of Average Percent Error (IAPE) was the better method for assessing the precision of age determinations compared to the percent agreement method, since the latter does not evaluate the degree of precision equally for all species. The average percent error method can be calculated for age determinations by the same reader or different readers and does not necessarily imply that the age estimates are accurate, but only relates to the consistency between the age readings.

If N fish are aged and R is the number of times each is aged then X_{ij} is the *i*th age determination of the *j*th fish and X_j is the average age calculated for the *j*th fish as

$$X_j = \frac{1}{R}\sum_{i=1}^{R} X_{ij} \qquad (1)$$

and the average error in ageing the *j*th fish, as a fraction of the average of the age estimates, APE, as

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

The Index of Average Percent Error is calculated as

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

Greater precision is achieved, as the percent error is minimised (Beamish and Fournier, 1981).

Chang (1982) suggested the use of a coefficient of variation (CV) for testing the reproducibility of ageing between readers. This can be obtained by replacing the average absolute deviation from the arithmetic mean in equation (3) with the standard deviation. The percent error contributed by each observation to the average age-class may be estimated by an index of precision (D), which is the CV divided by $\sqrt{R}$ and the percent error in each age determination made for each observation can be obtained by multiplying the index of precision (D_j) by the average age for the *j*th fish.

Interpretation and validation

The interpretation of the growth zones was conducted following the criteria by Dupouy *et al.* (1986). The hypothesis that there existed an annual succession of an optically opaque zone corresponding to the period of rapid growth, followed by a translucent zone corresponding to the period of slow growth, was tested by means of optical observations using transmitted light.

Growth parameter estimation and morphometric analysis

Length-at-age was modelled using the three-parameter specialised von Bertalanffy growth model described as

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

where $L(t)$ is the length-at-age t, L_∞ is the maximum theoretical length, K is the Brody growth coefficient synonymous to the rate at which L_∞ is attained and t_0 is the age of zero length fish. A non-parametric one-sample run test was applied to test for randomness of residuals and a Bartlett's test was used to test for homoscedasticity. Growth parameter estimates were obtained using a non-linear minimisation routine (Punt, 1992a). The most statistically suitable model was chosen on the basis of residual randomness, random trends in residuals and the lowest sum of squared residuals using an absolute or relative error structure (Punt, 1992a). Variance estimates were calculated using (conditioned) non-parametric bootstrap resampling (Efron, 1985) with 500 bootstrap resamples. Standard errors and confidence intervals were constructed from the sorted bootstrap data using the percentile method (Buckland, 1984).

The length-weight relationship $W = q\,L^b$, used to convert length to weight, was used so that weight-at-age could be expressed by a reparameterisation of the von Bertalanffy equation as

$$W(t) = W_\infty \left(1 - \exp^{-K(t-t_0)}\right)^b$$

where $W(t)$ is the weight of a fish as a function of age, W_∞ is the asymptotic weight and b and q the slope and intercept of a log-transformed linear regression. The slopes and intercepts of these regressions were statistically tested for differences (Zar, 1996).

Results

Comparison of hard tissues for age determination

Although the examination of whole otoliths yielded a clear ring pattern, it was difficult to resolve the nucleus region in older fish since the otolith thickens with increasing age, similar to the findings of Crozier (1989). Whole otoliths were, therefore, excluded from the analysis.

Of the 61 triplets of hard tissues, consisting of ground otoliths, sectioned otoliths and sectioned illicia used for the comparison, 2 (3.3%), 6 (9.8%) and 7 (11.5%) were rejected as unreadable, respectively. Age estimates of 34 (55.7%) of the ground otoliths, 22 (36.1%) of the sectioned otoliths and 1 (1.6%) of the sectioned illicia were considered to have a low reliable age determination and were rejected. There was a marked dissimilarity between the ground and sectioned otolith age estimates (Table 4.1). A maximum age of 11 years was obtained using the ground otoliths opposed to 9 years using sectioned otoliths.

Table 4.1: Sample size, total length (TL) range and observed lengths-at-age (TL ± standard error) determined from two hard structures of *Lophius vomerinus* sampled off Namibia during September/October 1996.

	Ground Otoliths			Sectioned Otoliths			Sectioned Illicia		
Age (yr)	n	TL range (cm)	Mean TL $\pm SE$	n	TL range (cm)	Mean TL $\pm SE$	n	TL range (cm)	Mean TL $\pm SE$
1	3	9-14	12.0 ± 1.5	8	9-24	15.0 ± 1.6	7	9-17	14.0 ± 1.2
2	3	11-20	16.0 ± 2.6	4	16-26	19.5 ± 2.4	11	18-29	23.3 ± 1.1
3	5	18-28	22.4 ± 1.7	3	18-25	21.7 ± 2.0	3	28-35	30.7 ± 2.2
4	2	16-33	24.5 ± 8.5	3	33-56	42.7 ± 6.9	8	35-53	40.5 ± 2.3
5	5	25-37	29.8 ± 2.6	4	26-58	40.0 ± 6.7	7	25-50	40.9 ± 3.3
6	2	29-35	32.0 ± 3.0	5	35-65	46.8 ± 5.7	3	46-56	50.7 ± 2.9
7	3	44-55	49.7 ± 3.2	3	25-56	43.7 ± 9.5	6	53-60	56.0 ± 1.2
8	1	48	48.0	2	41-60	50.5 ± 9.5	4	60-65	62.3 ± 1.3
9	-	-	-	1	29	29.0	4	53-59	55.8 ± 1.3
10	-	-	-	-	-	-	-	-	-
11	1	60	60.0	-	-	-	-	-	-

Ages estimated from ground otoliths had a 6.8% agreement between the three readers, and a 27.1% agreement within one year. Ages estimated using sectioned otoliths had a 5.5% agreement between the three readers with a 34.5% agreement within one year. In contrast, ages determined for illicia had 46.3% agreement between the 3 readers with 81.5% agreement within one year. Of the three structures examined, the illicia provided the most precise age estimates, indicated by lowest average percent error and coefficient of variation (Table 4.2).

Table 4.2: Summary of the results for the comparison of age estimates of *Lophius vomerinus* using two different hard structures.

Hard structure	Average percent error (APE %)	Coefficient of variation (CV %)	Index of precision (D)
Ground otoliths	25.8	28.2	16.6
Sectioned otoliths	27.3	22.2	13.3
Sectioned illicia	10.4	6.3	3.7

Interpretation and validation of the illicia growth zones

The growth of the illicium was noted optically as a succession of thick, opaque zones separated at regular intervals by translucent zones (Figure 4.1). In many illicia sections, narrow translucent bands resulted in growth zones with a multiple ring structure. It was noted that the opaque zones also had a tendency to split in two, hampering the interpretation of age readings, similar to the findings of Peronnet *et al*. (1992). Of the 607 monkfish samples collected during the 1996 research survey, 53 (8.7%) illicia were lacking, damaged or damaged during the cutting process. Of the remaining 554 illicia analysed, 67 (12.1%) were considered to have a low reliable age determination and were rejected. As a result, a total of 487 monkfish (193 females, 249 males and 45 juveniles) provided reliable ages and was used for the estimation of growth parameters. Of the 570 illicia analysed from the commercial samples, 326 (56%) were rejected as unreadable and the commercial samples were, therefore, excluded from all further analysis.

Figure 4.1: Illicium section of a seven-year-old *Lophius vomerinus* male (60 cm TL) captured during September/October 1996 (Magnification × 20).

Growth parameter estimation and morphometric analysis

The relative error model provided the best fit to the length-at-age data for male, female and combined sex data. Male and female growth patterns were significantly different ($F_{(3, 436)} = 27.6$, $P < 0.01$) and point estimates and estimates of associated variance for males and females are summarised in Table 4.3. Annual catch data for monkfish are not split by sex and data for both sexes (including juveniles) were, therefore, combined for later use in age-based stock assessment models (Table 4.3).

Table 4.3: Point estimates, associated standard errors and 95% confidence intervals for female, male and combined sex length-at-age data fitted using the three-parameter specialised von Bertalanffy model for *Lophius vomerinus* sampled off Namibia during September/October 1996.

	Point estimate	*SE*	95% CI
Females (n = 193)			
L_∞	111.98 cm TL	9072.81	[75.74, 42518.98]
K	0.08 year^{-1}	0.04	[0.00, 0.16]
t_0	-0.36 year	0.81	[-3.21, 0.31]
Males (n = 249)			
L_∞	72.29 cm TL	4243.14	[59.98, 169.59]
K	0.14 year^{-1}	0.04	[0.04, 0.22]
t_0	-0.30 year	1.23	[-1.98, 0.26]
Juveniles + Females + Males (n = 487)			
L_∞	95.04 cm TL	10504.71	[76.94, 49568.46]
K	0.10 year^{-1}	0.03	[0.00, 0.15]
t_0	-0.31 year	0.66	[-2.88, 0.08]

The individual lengths-at-age for male and female *L. vomerinus* are illustrated in Figures 4.2 and 4.3, whereas the observed and expected mean lengths-at-age of *L. vomerinus* (sexes combined) are summarised in Table 4.4.

Table 4.4: Observed (± standard deviation) and expected lengths-at-age of *Lophius vomerinus* sampled off Namibia during September/October 1996. Expected values were obtained from the three-parameter specialised von Bertalanffy model with a relative error structure.

Age (years)	n	Range	Mean observed length (TL cm)	Expected length (TL cm)
1	22	9-21	14.2 ± 3.2	11.7
2	99	14-28	20.2 ± 3.4	19.7
3	85	19-37	26.2 ± 3.9	26.9
4	45	24-56	34.3 ± 5.4	33.4
5	78	30-57	39.2 ± 4.6	39.3
6	76	25-60	44.8 ± 5.9	44.7
7	60	32-74	51.3 ± 8.0	49.5
8	16	39-79	56.1 ± 8.4	53.8
9	4	40-59	50.5 ± 8.1	57.8
10	2	57-59	58.0 ± 1.4	61.4

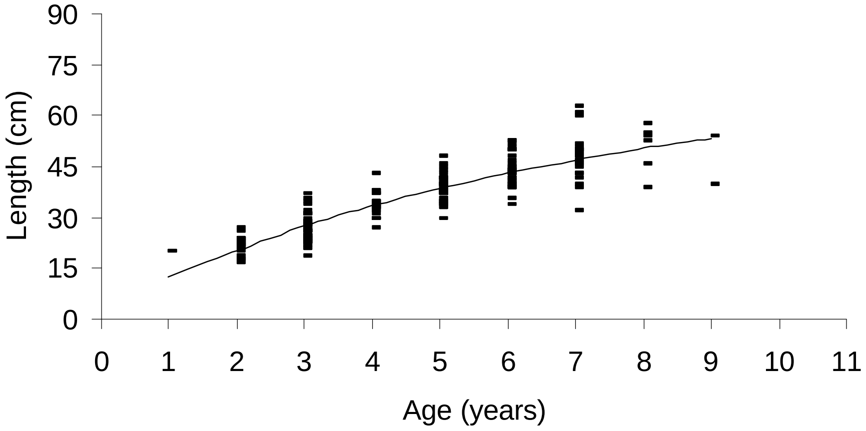

Figure 4.2: Observed individual lengths-at-age of *Lophius vomerinus* males using illicia sampled off Namibia during September/October 1996. The growth model was fitted using the relative three-parameter specialised von Bertalanffy growth model (n = 249).

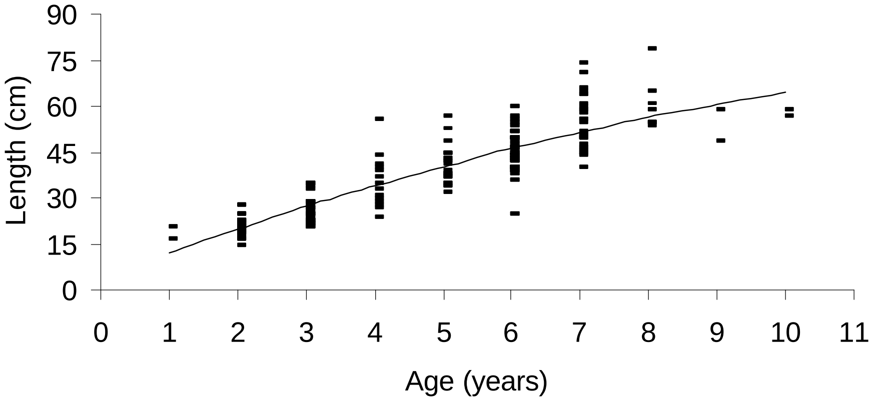

Figure 4.3: Observed individual lengths-at-age of *Lophius vomerinus* females using illicia sampled off Namibia during September/October 1996. The growth model was fitted using the relative three-parameter specialised von Bertalanffy growth model (n = 193).

The length-weight relationships for *L. vomerinus* males and females obtained from the data collected on board the *Dr. Fridtjof Nansen* during the survey in September/October

1996 and from the commercial samples between March 1997 and March 1998 are presented in Table 4.5 and Figure 4.4.

Table 4.5: Length-weight relationships of *Lophius vomerinus* males and females obtained from data collected on board the *Dr. Fridtjof Nansen* during September/October 1996, as well as from commercial samples between March 1997 and March 1998.

Data source	Males	Females
Survey: September 1996-October 1996	$W = 0.014\,L^{2.989}$ (r^2 = 0.990, n = 301)	$W = 0.012\,L^{3.034}$ (r^2 = 0.987, n = 306)
Commercial: March 1997-March 1998	$W = 0.018\,L^{2.888}$ (r^2 = 0.980, n = 263)	$W = 0.018\,L^{2.935}$ (r^2 = 0.976, n = 299)

Highly significant differences between males and females for both the survey ($F_{(6,604)} = 19.82$, $P < 0.001$) and commercial data ($F_{(1,559)} = 17.85$, $P < 0.001$) were detected. Despite differences in the length-weight relationships calculated for males and females, the survey data were combined to obtain a length-weight relationship for later use in age-based stock assessment modeling.

The length-weight relationship was used to transform the von Bertalanffy length equation to representing weight-at-age, with parameters calculated using the same routine described for the length-at-age data. Parameter estimates for males, females and the combined data are summarised in Table 4.6 and illustrated in Figure 4.5.

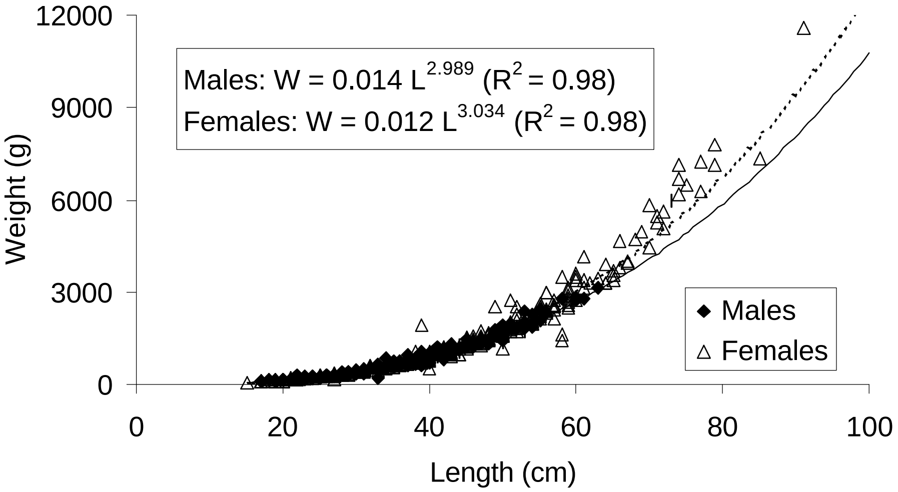

Figure 4.4: Length-weight relationships of *Lophius vomerinus* males and females calculated from data collected on board the *RV Dr. Fridtjof Nansen* during the survey in September/October 1996 (n = 607). The dotted regression line corresponds to female *L. vomerinus*.

Table 4.6: Point estimates of female, male and combined sex weight-at-age data fitted using the three-parameter specialised von Bertalanffy model for *Lophius vomerinus* sampled off Namibia during September/October 1996.

	Point estimate
Females (n = 193)	
W_∞	6.92 kg
K	0.18 year^{-1}
t_0	0.64 year
b	3.03 year^{-1}
Males (n = 246)	
W_∞	3.96 kg
K	0.18 year^{-1}
t_0	-0.10 year
b	2.99 year^{-1}
Juveniles + Females + Males (n = 487)	
W_∞	7.24 kg
K	0.15 year^{-1}
t_0	-0.09 year
b	3.06 year^{-1}

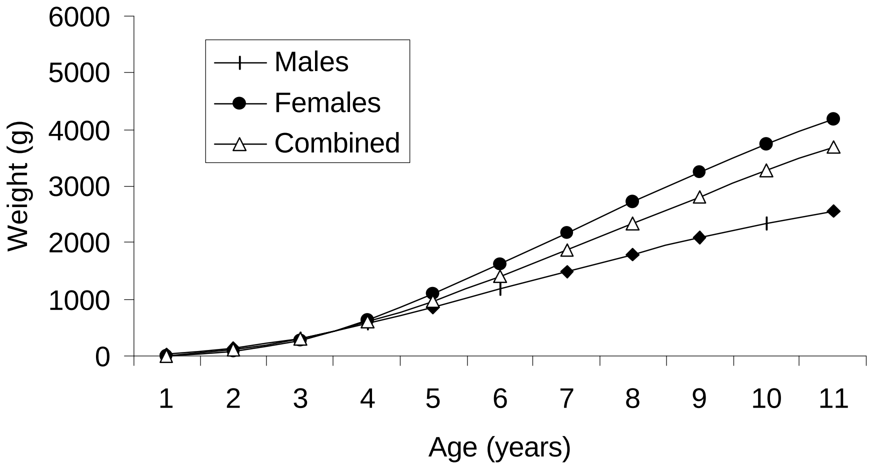

Figure 4.5: Growth in weight of male and female *Lophius vomerinus* sampled off Namibia during September/October 1996.

Discussion

Age determination in lophiid fishes presents difficulties, especially in older fish. Studies in the past have used a variety of hard-tissues, each with varying degrees of success. Tsimenidis and Ondrias (1994) using whole otoliths to age *L. piscatorius* and *L. budegassa* reported considerable problems in interpreting the growth zones, which tended to be multiple in appearance and difficult to separate. Similar findings were reported by both Griffiths and Hecht (1986) and Morales and Lombarte (1987) for *L. vomerinus* and by Staalesen (1995) for *L. piscatorius*. Illicia have subsequently been found to be the most suitable structure for age determination in *L. piscatorius* and *L. budegassa* as the growth zones were the most distinguishable (Dupouy *et al.*, 1986; Peronnet *et al.*, 1992; Staalesen, 1995; Duarte *et al.*, 1997).

During the comparison between different hard structures of *L. vomerinus* in this study, considerable difficulties were experienced in the interpretation of the growth zones using ground or sectioned otoliths. The incidence of multiple growth zones and an unacceptably high average percent error index resulted in their subsequent rejection. Sectioned illicia were, therefore, considered to be the most suitable hard structure to age this species. This was concluded as the growth zones were the easiest to interpret and the age estimates were the most precise, having the lowest average percent error and coefficient of variation.

It was noted that the optical appearance of the margin did not always indicate whether the last annulus was complete. Similar results were also obtained by Peronnet *et al*. (1992). Growth zone periodicity, while not validated in this study, was also noted by Griffiths and Hecht (1986). It was assumed that a single annulus was deposited each year for two reasons. First, the maximum age estimates and mean lengths-at-age during this study were similar for the ground otoliths and illicia. Second, the ground otolith maximum age and mean length-at-age estimates obtained during this study were similar to those of Griffiths and Hecht (1986) who indirectly validated the periodicity of an annulus using marginal zone analysis.

Griffiths and Hecht (1986) postulated that food availablity, feeding periodicity and reproductive seasonality could explain the multi-ring nature of the growth zones in ground *L. vomerinus* otoliths. Lophiiform fishes are typical lie-and-wait predators, luring their prey by moving the illicium (Pietsch and Grobecker, 1978). Gordoa and Macpherson (1990) noted that monkfish were non-selective predators with their diet being dependent on the behaviour of the prey as well as the size of their mouths. Macpherson (1985, as cited by Macpherson *et al*., 1984) also noted that *L. vomerinus* was a daytime predator, remaining inactive once it has captured its prey and that food-intake was lowest during January-February and highest in June-August. In addition, Macpherson (1985) found that there was an increase in feeding activity during January-February. This did not appear to be related to the higher abundance of Cape hake *Merluccius capensis* (its most important prey item) during these months and concluded that these differences in feeding activity might be due to internal rhythms, independent of food availability. Considering that daily or seasonal feeding periodicity affects growth and, therefore, the pattern of hard structure ring formation (Griffiths and Hecht, 1986), it is possible that the feeding behaviour of monkfish is a principal factor responsible for the multi-ring nature of the growth zones.

Modelled length- and weight-at-age revealed that *L. vomerinus* was a slow-growing species with a life span in excess of 10 years. The largest *L. vomerinus* sampled and successfully aged (79 cm TL, 8 years) was smaller than the maximum known length (117 cm TL, ICSEAF, 1980) recorded in Namibian waters. The maximum theoretical length (L_∞) predicted by the growth model, however, was larger at 95 cm but lower than the 121 cm obtained by Morales and Lombarte (1987) (Table 4.7). Female *L. vomerinus* grew larger than males, a growth pattern similar to other *Lophius* species (Quincoces *et al.*, 1998a, b). Quincoces *et al.* (1998a) also noted that *L. budegassa* females grew faster and reached older ages than males on the assumption that both sexes reached similar maximum lengths. The maximum ages attained by *L. vomerinus* males and females during this study were, in contrast, similar.

Table 4.7: A summary of the growth parameters of various *Lophius* species (sexes combined) using sectioned or ground otoliths and sectioned illicia.

Species	Method	L_∞	K	Source
L. budegassa	illicia	94	0.089	Dupouy *et al.* (1986)
L. budegassa	illicia	121.54	0.102	Duarte *et al.* (1997)
L. budegassa	illicia	100	0.110	Quincoces *et al.* (1998a)
L. piscatorius	illicia	140	0.102	Dupouy *et al.* (1986)
L. piscatorius	illicia	101.69	0.080	Duarte *et al.* (1997)
L. piscatorius	illicia	150	0.088	Quincoces *et al.* (1998b)
L. vomerinus	otoliths	73.37	0.105	Griffiths and Hecht (1986)
L. vomerinus	otoliths	121	0.041	Morales and Lombarte (1987)
L. vomerinus	illicia	95.04	0.101	Present study (1999)

Rapid and almost linear growth, with little growth depensation after sexual maturity, seems to be the rule rather than the exception in *Lophius* species (Quincoces *et al.*, 1998a, b; this study). This is of interest, as *Lophius* species tend to have a relatively high energetic contribution to reproduction, as confirmed by gonadosomatic indices. In the case of *L. vomerinus*, the gonads can contribute as much as 31% to the total mass of female fish (see Chapter 5). It would be expected that fish with a high energetic investment into reproduction after maturity would have less energy available for somatic growth. In this scenario, there would be a noticeable decrease in the growth rate after sexual maturity. In contrast, a female with a large body size would be reproductively fitter if she could accommodate a large mass of hydrated eggs prior to spawning. Information on energy partitioning in *L. vomerinus* is, however, unavailable to make further conclusions.

A number of questions remain unanswered with respect to the age and growth of *L. vomerinus* in Namibia. The optical nature of the illicia-margins is of concern as it is imperative that growth zone periodicity is validated and this needs to be addressed in the near future. The data presented in this study, therefore, cannot conclusively prove that the ages assigned are accurate. Despite the lack of direct or indirect annulus validation in *L. vomerinus*, the age and growth parameters obtained during this study can be considered the best estimates available. These data, i.e. length- and weight-at-age, maturity-at-age and selectivity-at-age will, therefore, be used as input parameters in the age-based modeling framework developed in Chapter 8. In addition, the growth parameters obtained are used as input in the yield-per-recruit (see Chapter 7) and the length-based assessments (see Chapter 8).

CHAPTER 5 - Reproductive biology and mortality of monkfish, *Lophius vomerinus*, in Namibia

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Introduction

Little is known about the life-history of *L. vomerinus* in southern African and Namibian waters. This paucity of information and the need for a biologically based management strategy have prompted an investigation into aspects of its life-history including its growth patterns, reproductive biology and mortality rates. These aspects are fundamental as input parameters in length- as well as age-structured population models.

Available data on the reproductive biology of *L. vomerinus* in Namibia are restricted to the geographical positions of recruitment areas, which are areas with high abundance of 0-aged fish. The International Commission of the Southeast Atlantic Fisheries (ICSEAF) and in particular Spanish researchers identified two separate recruitment areas, the first being off Walvis Bay (23°S - 25°S) at depths between 150 and 300 m and the second near the Orange River (28°35'S) at depths between 100 and 300 m (ICSEAF, 1984a; 1985). Recruitment took place during the winter months. These observations confirm independent data collected by the Norwegian *RV Dr. Fridtjof Nansen* during bottom trawl surveys in the 1990s (NAN-SIS database; unpublished data).

This study investigates the reproductive biology and estimates mortality rates of *L. vomerinus* in Namibian waters. Specific aspects addressed include reproductive seasonality, length frequency distribution of the different sexes, adult sex ratios, size- and age-at-sexual maturity and the estimation of natural and fishing mortality rates.

Materials and methods

Biological data were collected between March 1997 and March 1998 off Namibia from commercial monkfish and sole vessels as well as during five hake biomass surveys aboard the Norwegian research vessel *Dr. Fridtjof Nansen* (Jan./Feb. 1996, Sept./Oct. 1996, Jan./Feb. 1997, Jan./Feb. 1998 and Jan./Feb. 1999). Altogether 570 monkfish ranging in length from 146 mm to 904 mm were sampled from the commercial vessels. All the fish were weighed (g), measured (mm TL) and macroscopically sexed. Gonads were dissected from the fish, weighed (g), staged visually and assigned to one of five maturity stages (Table 5.1). Monkfish sampled during the research surveys were also weighed, measured and sexed and staged macroscopically.

Reproductive seasonality was determined by a gonado-somatic index (GSI), calculated monthly for each sex, by expressing gonad mass as a percentage of eviscerated body mass

$$GSI = \frac{Gonad\ mass\,(g)}{Eviscerated\ body\ mass\,(g)} \times 100$$

To determine adult sex ratio, male and female fish were separated into centimeter size classes macroscopically. Fish too small to sex were classified as juveniles. The lengths of male and female *L. vomerinus* were divided into the six size categories landed by the monkfish and sole vessels (Table 3.7). The hypothesis of an equal male to female ratio per size category was tested using a Chi-square goodness of fit test (Zar, 1996). Length-at-maturity was calculated by determining the proportion of reproductively active fish (stages two to four) per cm size class. The length at which 50% of fish in the sample were sexually mature (L_{50}) was calculated from the data collected on board the *RV Dr. Fridtjof Nansen* by fitting a logistic ogive of the form

$$P_L = \frac{1}{1+e^{-(L-L_{50})/d}}$$

where P_L is the percentage of fish mature at length L, L_{50} the length-at-maturity and d the steepness of the ogive.

Table 5.1: Description of the various macroscopic maturity stages for male and female *Lophius vomerinus* based on visual observations.

Stage	Description
1. Immature	Ovaries are greyish-pink in colour, relatively small, ribbon-like and appear almost empty with no vascularisation. Testes are white to tan in colour and very small.
2. Resting	Ovaries are orange-pink in colour, are larger than the immature stage and with little vascularisation. No ova are visible. Testes are white to tan in colour, much larger than the immature stage and a small amount of milt is sometimes present when dissected.
3. Developing	Ovaries are orange-coloured, highly vascular and ova are discernible by eye. Testes are blotchy cream- to tan-coloured and very firm in texture. Moderate to large amounts of milt is present when dissected.
4. Ripe	Ovaries are straw-coloured to almost clear and highly vascular. Distinct ova are present. Testes are blotchy cream- to tan-coloured with areas of pink, extremely firm in texture and copious amounts of milt are present when dissected.
5. Spent	Ovaries are grey in colour, extremely flaccid, moderately vascular and appear almost empty. Atretic ova appear as black or white dots. Testes are greyish-tan in colour, extremely flaccid, edges appear translucent and a small amount of milt is sometimes present when dissected

The rate of natural mortality, M, was inferred using both the empirical relationships derived by Pauly (1980) and the assumption of Jensen (1996) that $M/K = 1.5$. Pauly (1980) found that

$$\ln M = -0.0152 - 0.279 \times \ln L_\infty + 0.6543 \times \ln K + 0.463 \times \ln T$$

where L_∞ and K are the von Bertalanffy growth parameters (see Chapter 4) and T the mean sea temperature (°C) ranging between 9 and 11°C.

Total and fishing mortality rates were estimated using the cumulative catch curve equation and through estimating the ratio of Z/K (Jones and van Zalinge, 1981)

$$\ln C\left(L,L_\infty\right)=a+\left(Z/K\right)\times\ln\left(L_\infty-L\right)$$

where $C\left(L,L_\infty\right)$ is the cumulated catch, L is the length, L_∞ is the maximum theoretical length and a is a constant. The ratio of Z/K is the slope of the regression analysis with $Z=F+M$ or total mortality and $Z=K\times slope$. K is a curvature parameter synonymous to the rate at which L_∞ is attained (Jones and van Zalinge, 1981). The estimation of the ratio Z/K required fish length frequency data. The exploitation history of monkfish as indicated by the landing statistics between 1974 and 1997 (Figure 1.1) were divided into three time-periods. These were 1974 to 1980 (average catch of 2 900 tonnes), 1981 to 1990 (average catch of 8 400 tonnes) and 1991 to 1997 (post-Independence period; average catch of 9 000 tonnes). The time periods were chosen on the basis of exploitation, i.e. during the 1970s, monkfish were only taken as an incidental bycatch in the hake fishery compared to the 1980s, where occasional monkfish targeting occurred and during the 1990s where the monkfish directed fishery developed. Commercial length frequency data from the 1970s (ICSEAF, 1978; 1979; 1980), 1980s (ICSEAF, 1981; 1982c; 1983; 1984b) and 1990s were used in the analysis.

Results

The monthly gonado-somatic index (GSI) suggests that *L. vomerinus* have a protracted spawning season. Males have reproductive peaks in April, October and February, whilst female GSI remains high from August to October (Figures 5.1 and 5.2). There seems to be little correlation between the spawning season and sea surface temperature (NOAA: http://ferret.wrc.noaa.gov/fbin/climate_server). Low temperatures during August to October, coincided with the high GSI values for males in October and females between August and October.

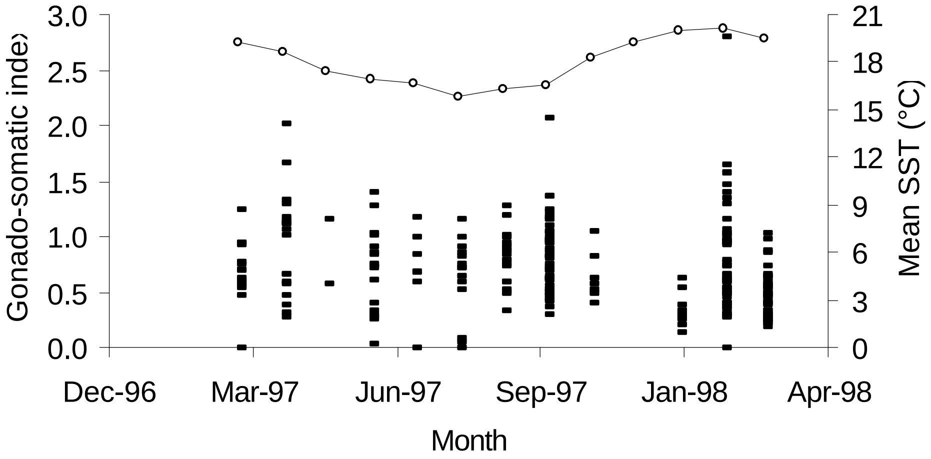

Figure 5.1: Seasonal variation of individual gonosomatic indices for *male Lophius vomerinus* sampled off Namibia between March 1997 and March 1998 (n = 261). The line corresponds to the mean sea surface temperatures.

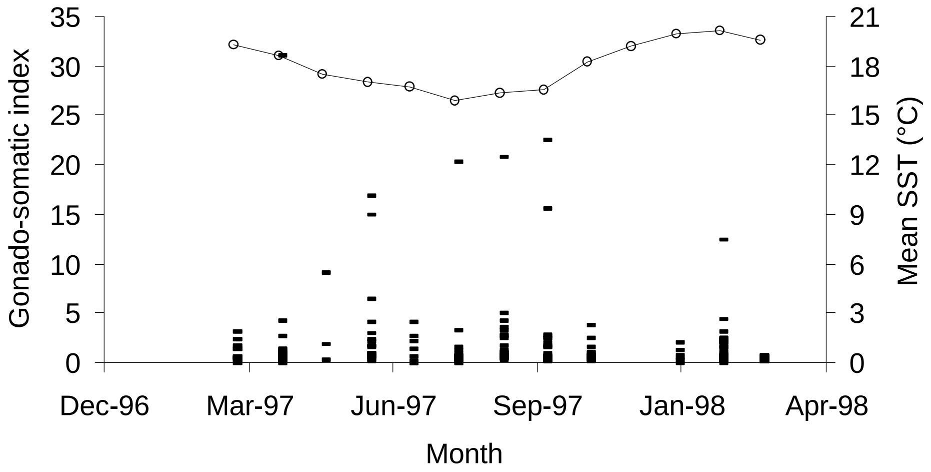

Figure 5.2: Seasonal variation of individual gonosomatic indices for female *Lophius vomerinus* sampled off Namibia between March 1997 and March 1998 (n = 296). The line corresponds to the mean sea surface temperatures.

Distinct peaks in frequency of spent testes and ovaries occurred between July and September, indicating the presence of a possible spawning season during the winter period (Figure 5.3). However, the high male GSI values during October (Figure 5.1) did not correspond well with the peak frequencies of ripe (September) and spent (August) testes (Figure 5.3). Peaks in frequency of developing ovaries can be seen in May and January, whereas the frequency of ripe and spent ovaries peaked in October (Figure 5.3).

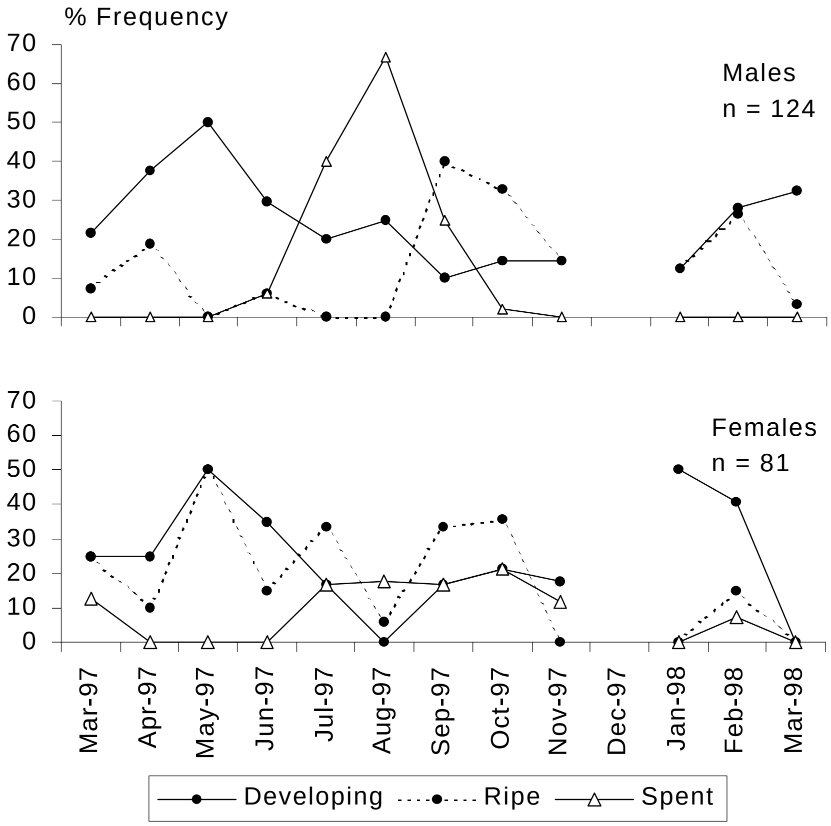

Figure 5.3: Monthly frequency of occurrence of *Lophius vomerinus* testes and ovaries in developing, ripe and spent stage.

Adult sex ratio for *L. vomerinus* (Figure 5.4) was female biased from the medium (M) size category, or greater than 36 cm TL ($P < 0.05$).

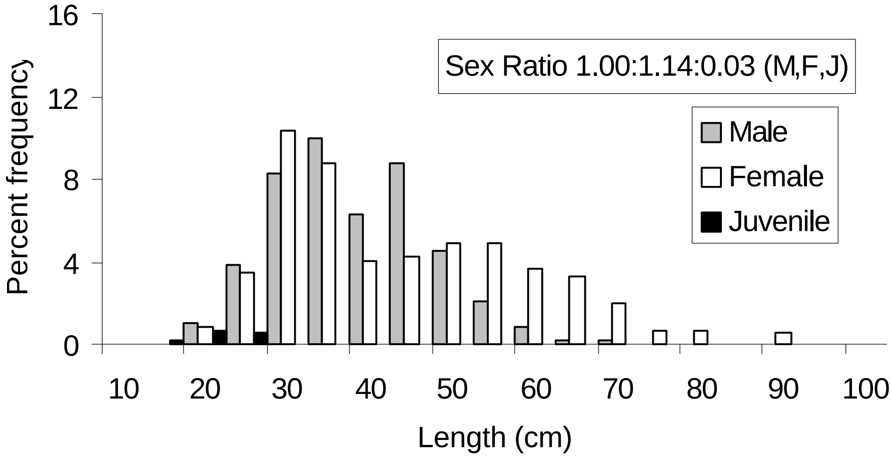

Figure 5.4: Length frequency distribution of *Lophius vomerinus* sampled off Namibia between March 1997 and March 1998 (n = 570) from commercial vessels.

Length-at-50% sexual maturity for males and females (survey data) were estimated at 23.7 cm (n = 1168) and 32.1 cm (n = 1497), respectively (Figure 5.5).

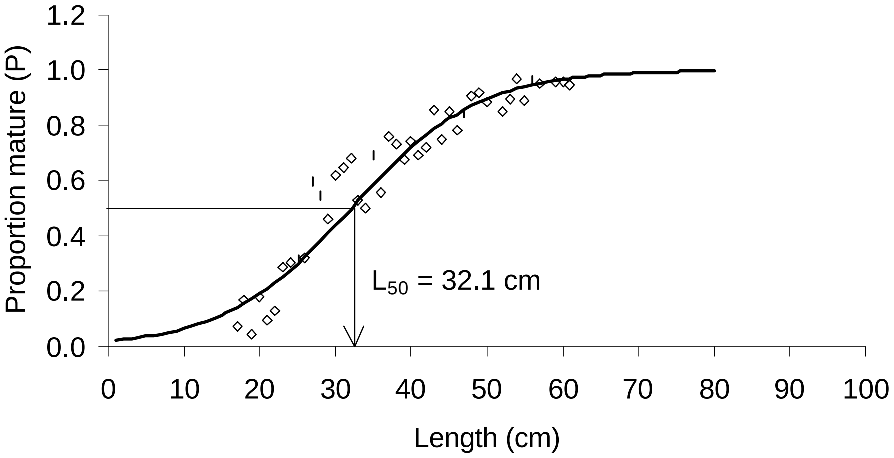

Figure 5.5: Percent sexual maturity of *Lophius vomerinus* females sampled between 1996 and 1999 on board the *RV Dr. Fridtjof Nansen*. Length-at-50% maturity was estimated using a logistic curve.

Sanchez (1987) estimated $L_\infty = 121 cm$, $K = 0.04\, year^{-1}$ and $M = 0.09\, year^{-1}$. Using Pauly's equation (1980) and different estimates of growth parameters from Sanchez (1987), Griffiths and Hecht (1986) and the present study, natural mortality ranged between 0.09 and 0.20 year^{-1} (Table 5.2), averaging at 0.15 year^{-1}. Jensen (1996) found $M/K = 1.5$ and if $K = 0.1006\, year^{-1}$ then $M = 0.15\, year^{-1}$.

Table 5.2: Natural mortality ($year^{-1}$) of *Lophius vomerinus* calculated by Pauly's equation for various combinations of L_∞, K and T.

L_∞ (cm)	K ($year^{-1}$)	T (°C)	M ($year^{-1}$)	Source
121	0.04	9	0.09	Sanchez (1987)
		10	0.09	
		11	0.09	
73.37	0.1054	9	0.19	Griffiths and Hecht (1986)
		10	0.20	
		11	0.19	
95.04	0.1006	9	0.17	Present study
		10	0.18	
		11	0.17	

The linearised length-based catch curves, under the assumption of constant (size-independent) natural mortality for the 1970s, 1980s and 1990s, are illustrated in Figure 5.6. From the length-based catch curves, total mortality (Z) was estimated as 0.164 year^{-1} (1970s), 0.194 year^{-1} (1980s) and 0.295 year^{-1} (1990s). Fishing mortality was obtained by substitution $(F = Z - M)$ with $M = 0.15$ year^{-1}. Total fishing mortality was estimated as 0.01 year^{-1} (1970s), 0.04 year^{-1} (1980s) and 0.14 year^{-1} (1990s).

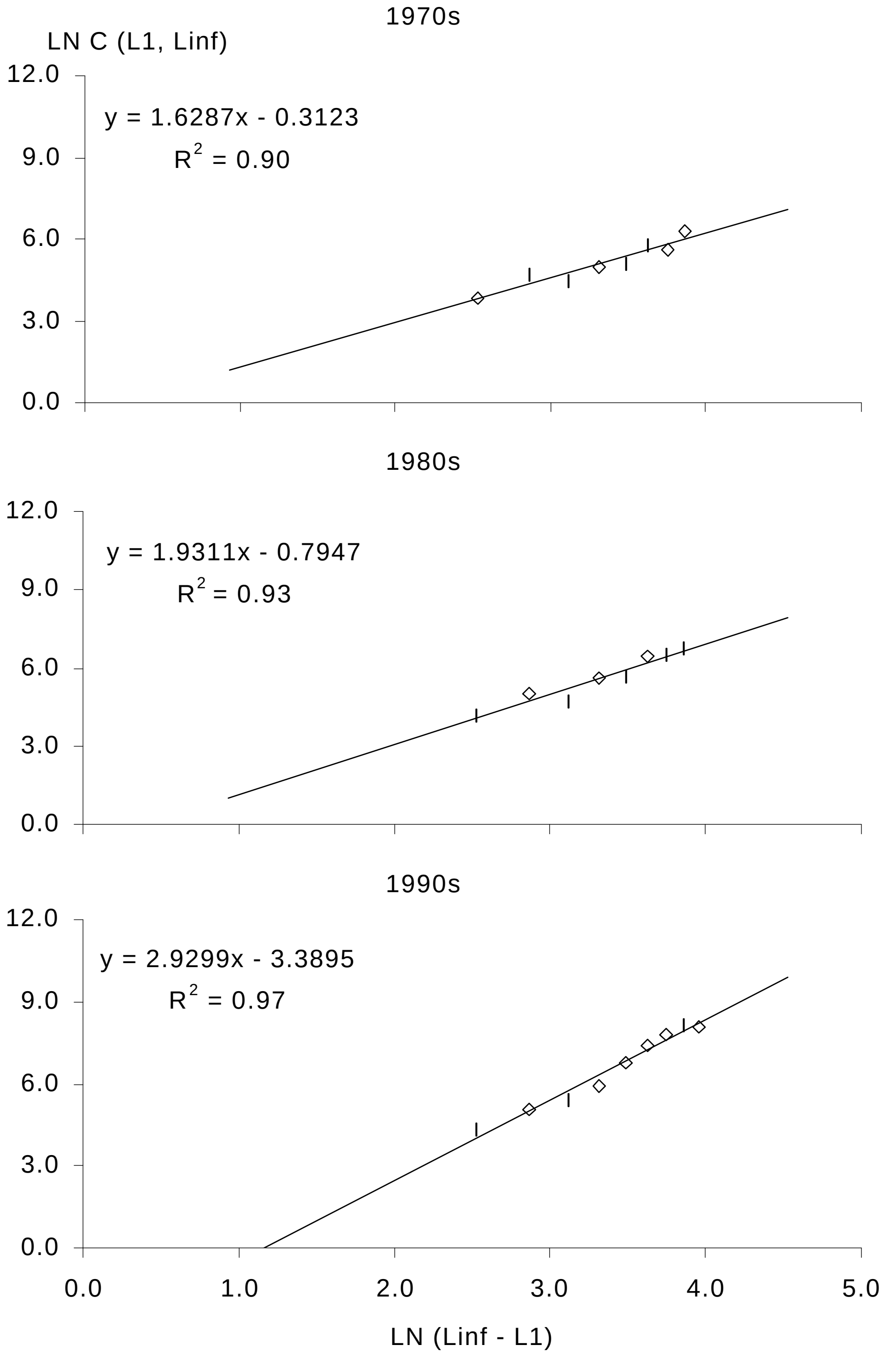

Figure 5.6: Linearised length-based catch curves of monkfish in Namibia under the assumption of constant (size-independent) natural mortality for the periods 1978 to 1980, 1981 to 1984 and 1996 to 1997.

Discussion

Data on gonadal development indicate that *L. vomerinus* spawn throughout the year with a slight increase in spawning intensity over the winter period. This is in contradiction with the assumption of Griffiths and Hecht (1986) that *L. vomerinus,* as is the case with other *Lophius* species, have a well-defined summer breeding season. Specific reasons for these observations are unknown.

Leslie and Grant (1990) found that *L. vomerinus* spawn flat gelatinous egg mass, called veils, into the water, which float near the water surface. According to Pietsch and Grobecker (1978), all female members of the Lophiiformes, with the possible exception of one species of antenariid anglerfish are thought to expel these non-adhesive, mucoid egg rafts. Veils are buoyant and have a complex structure consisting of individual chambers, each containing one to three eggs and an opening providing water circulation. This structure facilitates the broadcasting of a large number of eggs over great geographical distances providing for development in relatively productive surface waters. Additional selective advantages of the egg veil are that it may function in facilitating fertilisation of the eggs as well as protecting the eggs and larvae. When a veil is extruded from the female, it absorbs a large quantity of water and sperm may be drawn into the egg chambers through the small circulation pores in the veil, ensuring fertilisation. The eggs and larvae are protected, since the larvae remain in the egg chamber for 2 to 3 days after hatching, and predators are excluded from the egg chambers by the small size of the circulation pore (Armstrong *et al*., 1992). Leslie and Grant (1990) observed these egg veils in South African waters, but to the knowledge of the author, veils have never been recorded off the Namibian coast.

Spawning behaviour in monkfish is undocumented and is thought to occur at or near the seabed (Matsuura and Yoneda, 1986). In *L. americanus* larvae hatch from encapsulated eggs at approximately four weeks with the larvae remaining in the plankton for an additional four to eight weeks (Berrill, 1929). Similarly, collections of larval *L. vomerinus* (15 to 20 mm SL) have been documented from fine-mesh plankton nets (Leslie and Grant,

1990) in South African waters. Matsuura and Yoneda (1986) suggested that young *L. gastrophysus,* upon attaining a length of about 60 mm TL, settle to the benthos.

Female monkfish mature at a larger size and at a greater age (32.1 cm TL, 3 years) than males (23.7 cm TL, 2 years) (see Chapter 4). This appears to be a common trend among teleosts (Moyle and Cech, 1982). According to Stearns and Crandall (1989), organisms mature along a trajectory of age and size depending on demographic conditions and not at a fixed size or age. Pauly (1997) states that the relationship between fish size and egg production is highly non-linear, with large females being far more fecund than an equivalent weight of small ones. Further growth in female fish after the onset of maturity could be explained by the relationship between fecundity and size. The same argument can, however, hardly apply to male fish. Although the growth rate in males is generally less than that of immature females, male fish continue to grow after maturity. A factor favouring continued growth in males could be that an increase in size may reduce the probability of predation (Roff, 1982). In the case of monkfish, the female requires a larger body size to accommodate the egg veil. The GSI values obtained for female *L. vomerinus* were 31% (this study), 50% for *L. americanus* (Armstrong *et al.*, 1992), 37% for *L. budegassa* (Tsimenidis, 1980) and 30% for *L. piscatorius* (Staalesen, 1995), representing a sizeable energetic contribution by female lophiids to reproduction.

Instantaneous natural mortality was inferred as 0.15 year^{-1} applying Jensen's assumption or ranging between 0.09 and 0.20 $year^{-1}$ by means of Pauly's (1980) empirical method. Total mortality rates, obtained by the catch curve analysis of data collected during the 1980s, are not substantially different to those estimated by Sánchez (1987) $\left(Z = 0.21\, year^{-1}\right)$. Differences, however, were evident in total fishing mortality estimates where $F = 0.12\, year^{-1}$ (Sánchez, 1987) compared to $F = 0.04\, year^{-1}$ from the catch curve analysis. Gallucci *et al.* (1996) state that strong assumptions are made using catch curve analysis. The assumptions are that the population is in a steady state condition, recruitment is ‘knife-edged’ into the fishery and that survival of the recruited fish is described by a negative exponential function. Even though regression methods have lower precision in the sense of wider confidence intervals, they are robust to departures from model assumptions. As a result, these simple methods can be used as an approximation when the available catch data span a few time periods and/or where biological information is limited, but it is advisable to use methods that do not restrict the population to be at equilibrium.

The estimated fishing mortality during the 1990s was high, almost equal to the estimate of natural mortality suggesting that *L. vomerinus* off Namibia is subjected to high levels of fishing pressure. Since the response of a long-lived, slow growing species to increasing fishing effort is slow and difficult to detect, fishing effort will need to be carefully monitored to avoid disastrous management consequences (Adams, 1980).

The results obtained in this Chapter provided information on the reproductive biology of monkfish and approximations of natural and fishing mortality rates. Estimates of age-at-maturity and natural mortality are critical to the stock assessment framework developed in Chapter 8. Due to the general difficulty experienced in obtaining accurate estimates of natural mortality, sensitivity analysis will be carried out in the modeling framework to assess the sensitivity of the model to the parameter value. In addition, the estimated natural mortality was used in the yield-per-recruit analysis developed in Chapter 7.

CHAPTER 6 - Experimental gillnet fishing for monkfish

Introduction

‘Gillnets’ represent a multitude of gears including set nets, drift nets, nearshore, offshore and high seas nets (Northridge, 1991; Anon., 1997a). Fish caught by gillnets are, either wedged (held by the mesh around the body), gilled (held by the mesh slipping behind the opercula), or tangled (where the body does not penetrate the mesh but is retained by fin or spine entanglement) (Hubert, 1996). Gillnets are highly size-selective compared to other fishing gears (Acosta, 1994) and allow for the control of fish size caught through mesh size regulations (Acosta and Appeldoorn, 1995; Anon., 1997a). In addition, gillnets are economically efficient (Anon., 1997a).

Monkfish are caught by means of gillnets off the coasts of Spain, Norway, Newfoundland, the Faroe Islands, and Ireland (Collins *et al*., 1993; Anon., 1994; Churchill, 1994; Woll *et al*., 1995; Pereda *et al*., 1998).

The Spanish gillnet fishery for monkfish (*L. piscatorius* and *L. budegassa*) has been operating for more than 30 years with average catches of around 2 400 tonnes during the 1980s decreasing to an average of 930 tonnes during the 1990s. A mesh size of 280 mm is used and monkfish constitutes 97% of the total catch. The second most abundant species in the Spanish gillnet fishery are skates that comprise a mere 1% of the landed catch (Pereda *et al*., 1998).

A directed gillnet fishery for monkfish (*L. piscatorius*) was initiated off the northwestern coast of Norway during 1992. Annual monkfish catches increased from 880 tonnes in 1991 (bycatch in trawls and gillnets) to 4 447 tonnes in 1993, but have subsequently decreased to 2 621 tonnes in 1994 (Woll *et al*., 1995).

An experimental monkfish (*L. americanus*) fishery was developed off Newfoundland in 1993. This fishery was based on the success of European monkfish directed gillnet fisheries using large mesh (406 to 457 mm) nets. It was subsequently found that gillnets of not less than 305 mm should be employed in the fishery as the use of smaller mesh sizes resulted in decreased catch rates of monkfish and increased bycatch rates (Churchill, 1994).

As a consequence of the success of these fisheries, a Namibian fishing company applied for an experimental right to catch monkfish using gillnets in 1997. In their motivation, the company argued that predominantly large monkfish would be caught with very little bycatch, that the fish would be of a higher quality in comparison to trawled monkfish, that the nets can be set at locations where commercial trawlers cannot operate and that fishing would be more economical because of reduced fuel costs. In June 1997, an experimental gillnet right was granted to the company for one vessel, the *MFV Sylvie*. A catch restriction of 200 tonnes per year was imposed and the right was granted for a period of two years. Fishing commenced in June 1998 and in December 1998, the quota was increased to 400 tonnes wet weight for the year 1998.

In October 1999, the experimental license was withdrawn. Data on monkfish gillnet catches are, therefore, only available for the period July 1998 to October 1999 (the offloading date for the last trip was 1 October 1999). The reasons for the withdrawal of the experimental right included mis- and non-reporting of data, discarding of spoilt fish, lost nets and conflict between this vessel and the trawling and longlining fleets.

Because of the brief duration of the operation, the impact that gillnet fishing may have had on the monkfish resource cannot be assessed. The data that are available can, however, be used to provide an overview of the exploratory gillnet fishery and to comment on specific aspects such as the size composition of the catch, soak time and catch rates and the bycatch obtained during the course of the experiment. In addition, the data allowed for some comment to be made on the future feasibility of a monkfish gillnet fishery in Namibia.

Methods

Vessel and gear specifications

The vessel, *MFV Sylvie*, from which all the data were collected has a length of 29.8 m, width of 7.5 m, gross tonnage (GRT) of 212.9 tonnes, a Caterpillar 500 horsepower (HP) main engine and carries a crew of 25.

Monofilament gillnets with 300 mm stretched mesh were used with the net panels held vertical in the water column by weights and buoys. The panels presented a profile of 3 m in height (50 meshes deep) and 50 m (528 meshes) in length. The nets were joined into ‘strings’ and each ‘string’ consisted of between 150 and 350 net panels.

Data collection

Size category, length frequency and catch-per-unit-effort data were obtained from the Ministry of Fisheries and Marine Resources’ database. The captain of the vessel provided the following additional information: trip and haul numbers, dates and times at which ‘strings’ were set and hauled, geographical position of where the ‘strings’ were set and hauled, soak time in hours, depth in meters, the number of nets in a ‘string' and the direction in which the ‘strings’ were set. Information on bycatch and whether the fish were gilled, tangled or wedged was also obtained from the skipper.

Catch-per-unit-effort (CPUE) was calculated by dividing the total catch (kg) by the days fished and the number of nets in a 'string' and is expressed as $\text{kg.day}^{-1}\text{.50 m net panel}^{-1}$.

Discrepancies were, however, later identified in the information provided on numbers of monkfish caught per size category and in the bycatch data. These data were, therefore, excluded from the analysis.

A fisheries observer accompanied the vessel during July, September and October 1998 as well as from March to July 1999. During each of the observer trips, monkfish were measured for total length (TL) to the nearest centimeter.

In addition, the fishing company provided offloading reports after each trip with the export value in weight of monkfish per size category as well as the total catch of bycatch species.

Results

Catches

The monkfish tail landings per size category during 1998 and 1999 are illustrated in Figure 6.1. Between 0 and 23% of the total monkfish catches during 1998 and 1999 consisted of fish < 49 cm TL (< 0.5 kg tails). During 1998, 66% of the total catches consisted of fish > 60 cm TL (1.0 to 2.0 kg tail weight), while in 1999, the bulk of the catch consisted of fish between 49 and 59 cm TL (0.5 to 1.0 kg tail weight) (see Table 3.7).

The weight (in tonnes) of various products, i.e. tails, cheeks and heads is illustrated in Figure 6.2. Fillets were cut from fish which were damaged by Cape fur seals (*Arctocephalus pusillus*), red and/or spider crab species (*Chaceon maritae* and *Lithodes ferox*) and kingklip (*Genypterus capensis*).

The percent frequency distributions of monkfish for the (observer) periods July to October 1998 and for the period March to July 1999 are illustrated in Figures 6.3 and 6.4.

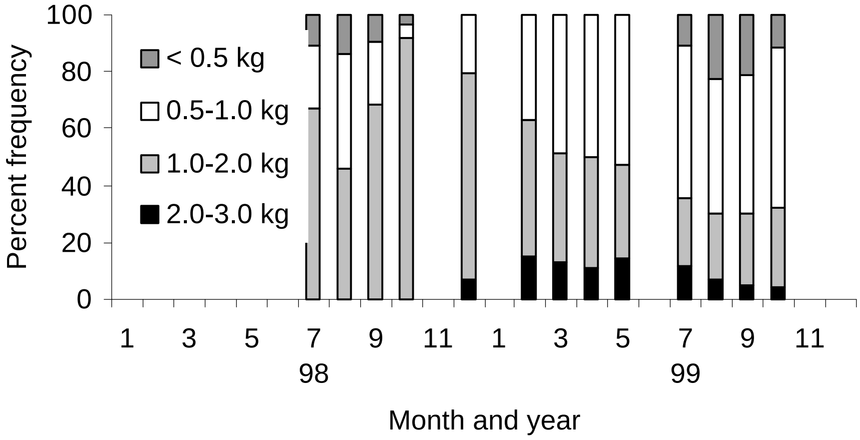

Figure 6.1: Percent frequency of monkfish tails (kg) landed per size category by the *MFV Sylvie* for the period July 1998 to October 1999. (Note that the offloading date for the last trip was 1 October 1999).

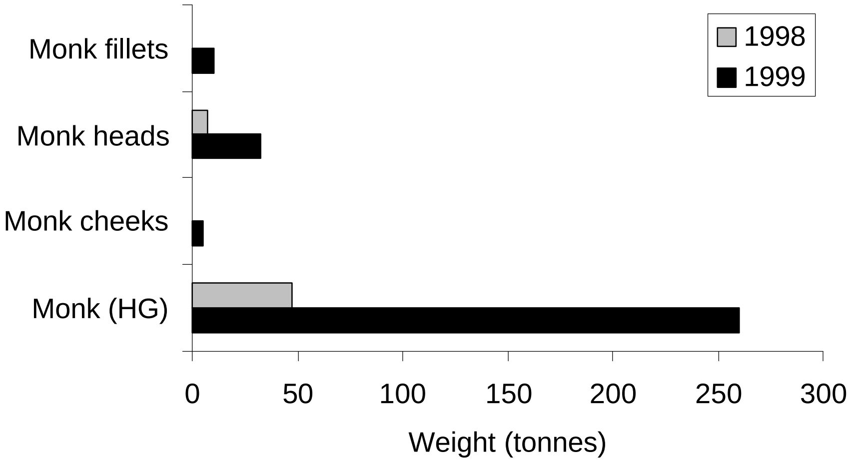

Figure 6.2: Weight (tonnes) of monkfish products landed by the *MFV Sylvie* for the period July 1998 to October 1999 (HG = headed and gutted).

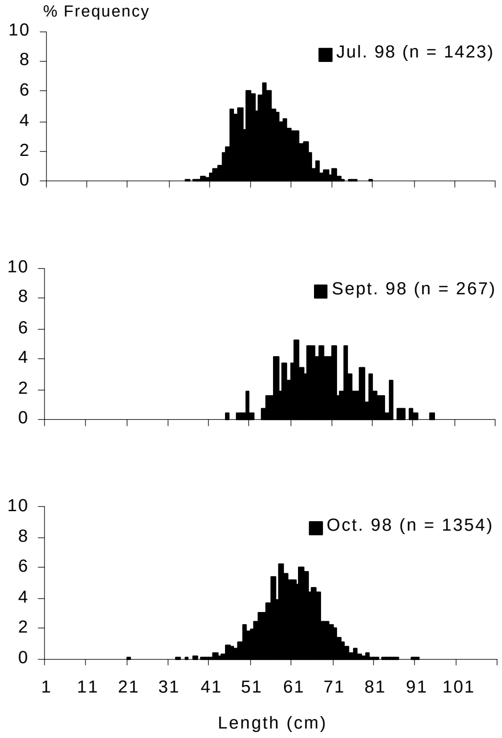

Figure 6.3: Length frequency distributions (%) of gillnet caught monkfish sampled during July, September and October 1998.

Monkfish sampled during July to October 1998 ranged between 21 and 91 cm TL, with a mean length of 58 cm TL (Figure 6.3) compared to a length range of between 22 and 102 cm TL (mean 70 cm TL) for the period March to July 1999 (Figure 6.4).

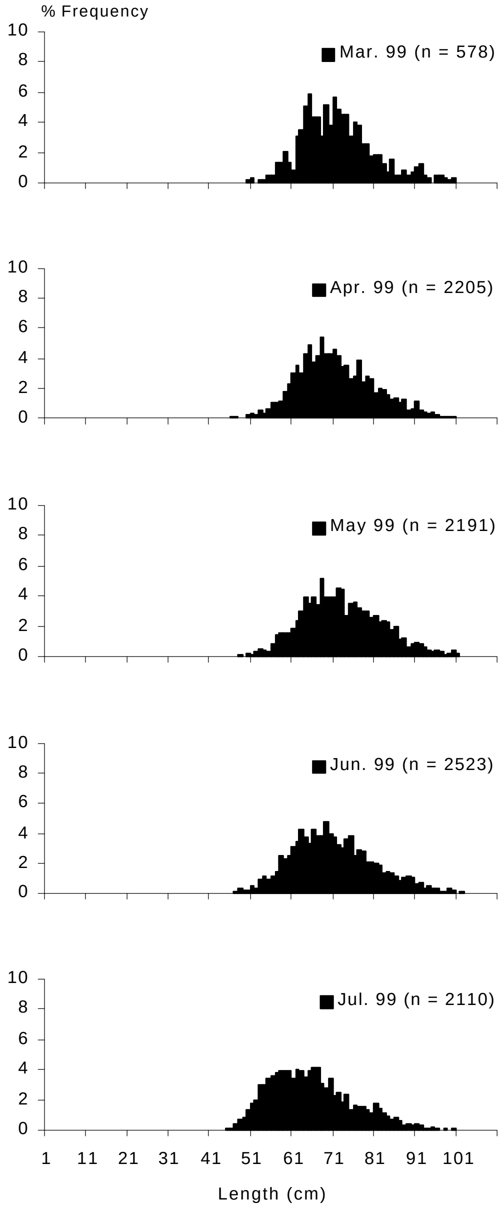

Figure 6.4: Length frequency distributions (%) of gillnet caught monkfish sampled between March and July 1999.

Bycatch

The main bycatch species in the gillnets were red crab, spider crab, squalid sharks, rays and Cape and Deep-water hake (Figure 6.5).

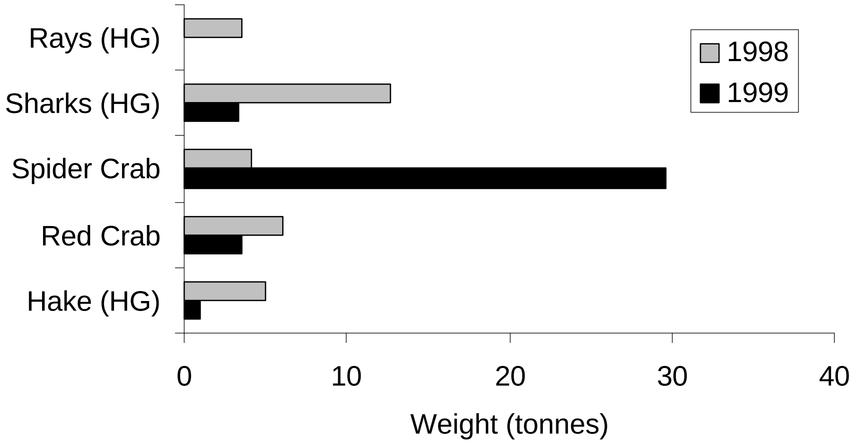

Figure 6.5: Weight (tonnes) of the main bycatch species landed by the *MFV Sylvie* for the period July 1998 to October 1999 (HG = headed and gutted).

The percent species composition of the total landings between July 1998 and October 1999 is summarised in Table 6.1. Monkfish constituted approximately 71% of the total landed catches in 1998, increasing to 91% in 1999. During 1998, sharks and hake species made up 17 and 5% of the total landed catches respectively, whereas spider crab and sharks comprised 5 and 2% of the total landed catches up to October 1999.

Table 6.1: Percent frequency of landed monkfish and the principal bycatch species caught by gillnets between July 1998 and October 1999 and the average percent frequency per species for 1998 and 1999.

Date	Monkfish	Hake	Red crab	Spider crab	Sharks	Rays	Sole
1998							
Jul.	71.5	18.5	0.2	-	5.9	3.9	-
Aug.	96.2	3.4	-	-	0.3	-	0.1
Sept.	56.0	2.4	7.1	-	31.8	2.7	-
Oct.	44.3	2.4	3.1	1.1	45.9	3.2	-
Dec.	86.0	0.4	3.5	5.4	1.0	3.7	-
Average	70.8	5.4	2.8	1.3	17.0	2.7	-
1999							
Feb.	66.3	0.0	4.6	14.1	15.0	-	-
Mar.	85.9	0.2	1.5	10.3	2.1	-	-
Apr.	95.1	0.4	0.4	3.7	0.3	-	-
May	85.4	0.0	0.5	12.6	1.5	-	-
Jul.	97.9	0.1	0.3	1.4	0.2	-	-
Aug.	99.7	0.3	0.0	0.0	0.0	-	-
Sept.	100.0	0.0	0.0	0.0	0.0	-	-
Oct.	100.0	0.0	0.0	0.0	0.0	-	-
Average	91.3	0.1	0.9	5.3	2.4	-	-

Catch-per-unit-effort

Catches of monkfish (in tonnes) together with the total number of days fished per month between July 1998 and September 1999 are illustrated in Figure 6.6. From the available data, there is no evidence to suggest that catches follow a seasonal pattern. During 1998, monkfish catches ranged between 8 (October) and 26 tonnes (August), whereas in 1999 catches increased from 13 tonnes in January to 139 tonnes in September. In 1998, effort was highest in September and November and in 1999 effort was greatest in February and May.

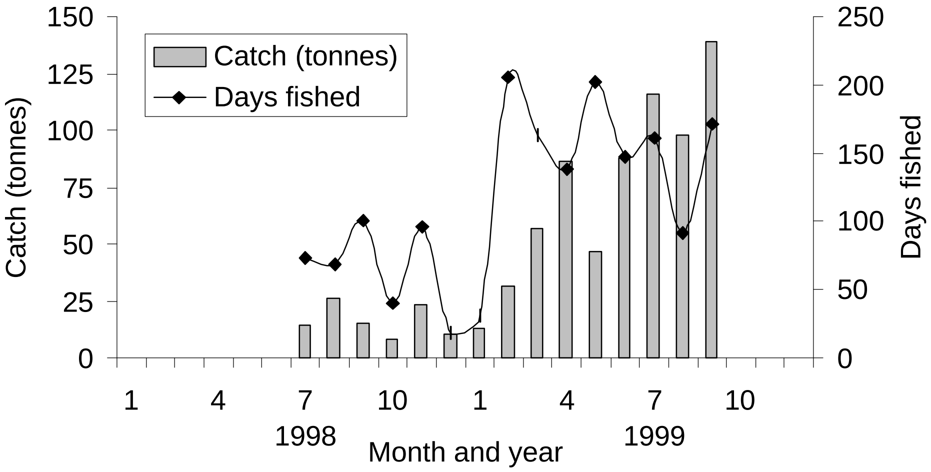

Figure 6.6: Monkfish catches (in tonnes) and the total number of days fished by the *MFV Sylvie* for the period July 1998 to September 1999.

Catch-per-unit-effort (CPUE) of monkfish was expressed in kg.day^{-1}.50 m net panel^{-1} (Figure 6.7). The CPUE fluctuated between 0.03 (February 1999) and 0.67 kg.day^{-1}.50 m net panel^{-1} (December 1998).

Gillnet fishing occurred mainly at depths between 300 and 499 m (88%). The least amount of effort was expended in the 100 to 299 and 500 to 699 m depth zones (4 and 8% respectively). Fishing intensity was greatest in the area between 24°00'S and 25°59'S. Gillnet 'strings' were always deployed in either a south-north or north-south direction.

Soak time was highly variable and ranged between one and sixteen days (Figure 6.8). Analysis of variance showed a highly significant difference among monkfish catches at different soak times ($P < 0.001$). CPUE was highest at a soak time of five days, whereas longer and shorter soak times resulted in decreased catch rates (Figure 6.8).

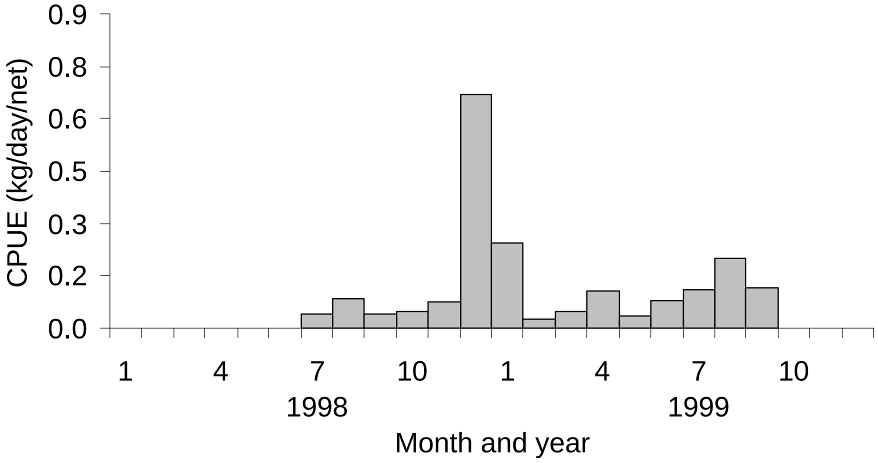

Figure 6.7: Monthly CPUE of monkfish in kg per day per 50 m net panel for the period July 1998 to September 1999.

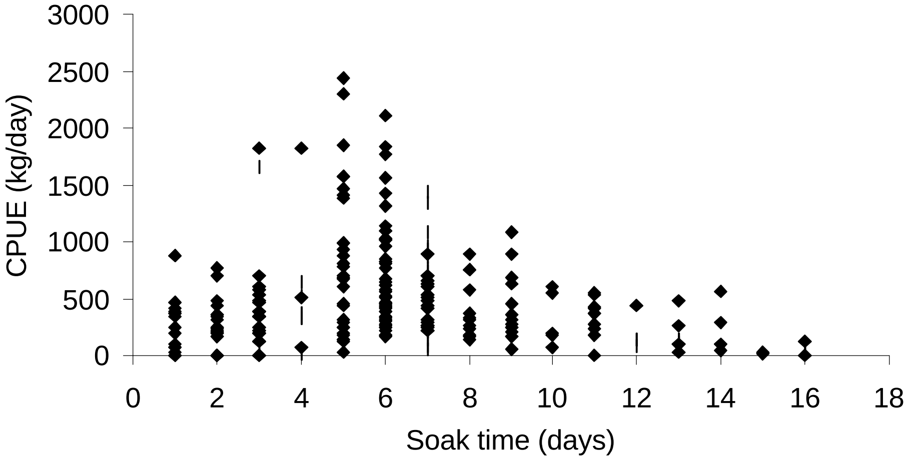

Figure 6.8: Gillnet soak time in days and the catch-per-unit-effort (CPUE) in kg.day^{-1} for the period July 1998 to September 1999 (n = 118).

Discussion

Gillnetting by the *MFV Sylvie* occurred in the same areas and depth zones as the monkfish and sole trawling operations. The mean size of monkfish caught by gillnets was, however, considerably larger (58 and 70 cm TL during 1998 and 1999, respectively) than those caught by the monkfish and sole trawlers (38 cm TL during 1998). This is ascribed to the size selective nature of gillnetting. The size range of monkfish caught by gillnets was also narrower than those landed by trawlers. The reason for this is that the size range of fish caught by gillnets of a specific mesh size decrease sharply for fish smaller and larger than the modal size for that mesh size (Acosta, 1994). A rule of thumb is that few fish are caught in gillnets that differ by more than 20% of the selectivity pattern of a specific mesh size (Engås and Løkkeborg, 1994). Monkfish lengths ranged between 34 and 70% (lower bound) and between 39 and 53% (upper bound) of the mean length. Size selection of fish caught by gillnets, however, depends on whether the fish are gilled, wedged or tangled as well as the hanging ratio (the length of the net mounted on float and lead lines divided by the length of the unmounted, fully stretched net) of the nets (Acosta and Appeldoorn, 1995; Hickford and Schiel, 1996; Hickford *et al*., 1997). Hickford *et al*. (1997) indicated that fish with projections on their bodies (fins and spines) are more likely to be snagged in the mesh, thus entangling the fish. As tangling is less size selective than wedging or gilling (Hickford and Schiel, 1996) the size range of fish caught will, therefore, be greater than those of smooth fusiform fish (Hickford *et al*., 1997). Monkfish caught by the *MFV Sylvie* were mainly entangled (pers. obs.) and this accounts for the larger than 20% deviation from the mean length. Acosta and Appeldoorn (1995) identified the hanging ratio, HR, as one of the main determinants of the range of lengths of fish retained. The HR determines the shape of the mesh and the effect of the HR is greatest on species caught through tangling. The lower the ratio, the more the diamond-shaped mesh is elongated vertically and the more efficient gillnets become in entangling fish (Hubert, 1996). Acosta and Appeldoorn (1995) found that small meshes and a small HR would capture more small fish, usually gilled, whereas nets with a high HR and large mesh size will capture fewer, but larger fish. No information on the HR of the nets used by the *MFV Sylvie* is, however, available for comparison.

Globally, minimum gillnet mesh size for monkfish is highly variable. Norway uses a 360 mm mesh, the Faroe Islands 300 mm (some 280 mm) and fishers in the North Sea use 262 mm (Woll *et al*. 1995). The mesh size (300 mm) used by the Namibian gillnet vessel, seemed adequate as hardly any monkfish smaller than the length-at-50% sexual maturity were selected (see Chapter 5).

Gillnet CPUE ranged between 0.03 and 0.67 $kg.day^{-1}.50$ m net $panel^{-1}$ in comparison to catch rates of between 1.0 and 4.0 $kg.day^{-1}.net^{-1}$ in Norway during 1992. Gillnet catch rates off Norway did, however, decrease to 0.3 $kg.day^{-1}.net^{-1}$ during 1993 (Woll *et al*., 1995). Catching efficiency and selection are affected by mesh size, net twine, the hanging ratio of the nets and the method of fishing (Hamley, 1975). Lazar and DeAlteris (1992) identified depth, area, season and the number of nets in a ‘string’ to significantly affect catch rate and composition. Hubert (1996) also noted that the visibility, stiffness, elasticity, smell and breaking strength of mesh material might have a substantial effect on CPUE. Wardle *et al*. (1991) emphasised the importance of gillnet colour on catch rate. Green, nylon monofilament gillnets were used in Namibia, but the extent to which the above-mentioned factors may have influenced CPUE, are unknown.

Other factors which affect gillnet catch rates include the length of the nets and the soak time and net damage (Hamley, 1975; Acosta, 1994; Engås and Løkkeborg, 1994; Hubert, 1996). Gillnet catch rates of monkfish in Namibia decreased at a soak time of more than five days. Even though catches decreased by weight, it cannot be concluded with certainty that catches of monkfish (and bycatch species) in numbers were subject to the saturation effect with increasing soak time as no information on numbers of monkfish and bycatch species are available. Theoretically, a decrease in numbers with increasing soak time should occur, as the net becomes more noticeable to the fish due to the activity of fish struggling to escape from the net. Engås and Løkkeborg (1994), however, suggested that fish in the net might also attract other fish to the gear, therefore raising the probability of capture. The behavioural response of monkfish on encountering gillnets is, however, unknown.

There is a direct relationship between soak time and the rate of scavenging and spoilage (Churchill, 1994; Pereda *et al*., 1998). To reduce spoilage, a regulation restricting the soak time to two days was implemented in Norway (Woll *et al*., 1995). In Namibia, a soak time of more than ten days resulted in monkfish spoilage of around 85% and all spoilt fish were discarded (E. Shilongoh, fisheries observer, pers. comm.). Clearly, from a resource usage and management perspective, this is unacceptable.

In this study, Cape fur seals, red and/or spider crab species and kingklip were the main predators of monkfish in gillnets. Seals scavenged monkfish in the gillnets by biting the fish off behind the head, and were responsible for the greatest amount of damage. While the ‘strings’ were hauled, Cape fur seals scavenged around 2% of the total monkfish catch (E. Shilongoh, fisheries observer, pers. comm.). Red and/or spider crab species and kingklip caused damage by eating the flesh from the tails and heads.

Even though the database for gillnetting is limited, the available information allows for some comment on the future feasibility of gillnetting in Namibia and the advantages and disadvantages of gillnetting are listed in Table 6.2.

Table 6.2: Summary of the advantages and disadvantages of gillnet fishing.

Advantages	Disadvantages
Highly size selective	Non degradable nets and ‘ghost fishing’
Low bycatch rates	Conflict
Economically efficient	Wastage
Area of operation	Mortality of marine mammals and seabirds

Gillnets are economically efficient and may out-compete vessels using other types of gear by being able to catch more fish at a lower cost (Anon., 1997a). In addition, gillnets are highly size selective, little bycatch is taken (Table 6.1) and gillnets can be set at locations where trawlers cannot operate.

However, gillnets are environmentally unfriendly as they are predominantly made of synthetic non-biodegradable twine (Prado, 1997). If the gear is lost, this may result in 'ghost fishing'. Biodegradable twine can, however, be used to attach the netting to the frame ropes. This has the advantage that the netting would drop out of the ropes and 'ghost fishing' would be reduced (Prado, 1997).

Though conflict has arisen between trawlers, longliners and the experimental gillnet vessel, this may be solved by legislation to ensure separation of the competing gears. The Namibian trawling component, e.g. suggested that gillnet operations only be allowed at depths > 550 metres.

Wastage occurs due to fish falling from the nets while being hauled or when spoilt fish are discarded. Also, fish could be injured in an attempt to escape from the nets leading to additional mortality (Northridge, 1991).

Seals, dolphins and seabirds were caught by gillnets (E. Shilongoh, fisheries observer, pers. comm.). Marine mammals are occasionally killed in almost all fisheries, but the catching of unduly large proportions of air breathing animals (mammals, birds and reptiles) may threaten individual species with low resilience to exploitation (Northridge, 1991). Too little information is, however, currently available on the magnitude of catches of air breathing animals and the impact that this may have on population numbers of the species concerned.

Furthermore, gillnets can selectively remove adults from the population and it may be detrimental to the stock in the long-term, if strict catch (Payet, 1997) and/or mesh regulations are not enforced.

If a gillnet fishery for monkfish in Namibia were to be reconsidered, then the following regulations should apply: (i) soak time of gillnets should be restricted to < 5 days to prevent spoilage and subsequent discarding of fish, (ii) preventative measures should be implemented to avoid ‘ghost fishing’ such as biodegradable twine, (iii) all gillnetters should be fitted with a VMS to prevent fishing on trawler grounds, (iv) mesh sizes should be regulated on the basis of spawner biomass, (v) all gillnetters must submit accurate data e.g. weights and numbers of the target and bycatch species, and that non compliance with any of these regulations will result in the forfeiture of the fishing right.

However, at this stage of the evolution of the monkfish fishery in Namibia, it is suggested that the precautionary principal (FAO, 1996) should prevail. A more controlled gillnetting experiment could be undertaken (under strict conditions) to obtain sex disaggregated catch-at-age estimates and gillnet selectivity-at-age data to compare the manner in which trawling and gillnet fishing may impact the monkfish resource. However, as the effect of trawling on the monkfish resource is still not fully understood (see Chapter 8), the introduction of another full-time or permanent fishing method or gear type should be approached with caution.

CHAPTER 7 - Size selection and release of juvenile monkfish using rigid sorting grids

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Introduction

Excluders or bycatch devices are the terms used for all devices that exclude unwanted portions of the catch. These include undersized individuals, certain fish or crustacean species and marine mammals that are usually discarded by fishers as they normally cannot be utilised and/or are of low economical value (Isaksen and Valdemarsen, 1994; Eayrs *et al.*, 1997; Anon., 1998d). Devices of this nature include rigid sorting grids or excluders that have been used to reduce finfish bycatch in some shrimp fisheries as well as the bycatch of sea turtles in shrimp trawls (Isaksen and Valdemarsen, 1994; Eayrs *et al.*, 1997).

During 1998, 59% of the total monkfish catches (by weight) landed by monkfish and sole trawlers off Namibia consisted of fish smaller than 37 cm TL. Length-at-50% sexual maturity of female monkfish is attained at 32.1 cm TL (see Chapter 5) and fish smaller than 26 cm TL comprised 19% (see Chapter 3, Figure 3.13) of the total monkfish catches by the monkfish and sole trawlers during 1998. The harvesting of such quantities of juvenile fish may lead to growth overfishing. Length- and age-at-first-capture of monkfish, therefore, need to be increased so that the fish can grow to a sufficient size to maintain an adequate spawner biomass and thereby ensure a future sustainable fishery.

Management can address the capture of juvenile monkfish by several means. Mesh size regulations, for example, have been widely used since the 1950s to minimise the capture of undersized fish (Soldal and Engås, 1997). Other possible solutions are to close off areas and/or depth zones to prevent the capture of juvenile monkfish. It was, however, concluded that the closure of specific areas and/or depth zones as well as increased mesh size regulations will not prevent the industry from catching juvenile monkfish (see Chapter 3). A third possibility would be to make use of selective trawl gear. Size selection of fish mainly occurs in the cod-end of the trawl, provided that the meshes are open, allowing fish to pass through, and that the fish actively seek a way out (Isaksen and Valdemarsen, 1994). As the size of the catch increases, the effective mesh openings are reduced. As a result, cod-end escape is reduced and fish have to put forth effort to penetrate the meshes and escape (Larsen and Isaksen, 1993; Isaksen and Valdemarsen, 1994). The design of cod-ends with square, instead of diamond mesh configurations and the use of short lastridge ropes to hold the meshes open have improved the size selectivity of cod-ends (Isaksen and Valdemarsen, 1994; Eayrs *et al.*, 1997). The development of a practical solution, a device (rigid sorting grid or excluder) that is included in front of the cod-end, started late 1989. These devices significantly improved the selectivity of trawling operations both with regard to species and size selection (Isaksen and Valdemarsen, 1994; Eayrs *et al.*, 1997). The practical idea is to provide a stable opening in the cod-end through which fish can escape despite changes in towing speed and catch size, amongst others (Larsen and Isaksen, 1993).

Scientists of Ifremer in Lorient, France, were the first to experiment with rigid sorting grids to size select and release undersized monkfish (*L. piscatorius* and *L. budegassa*), megrim and rays. The aim of conducting these experiments was to reduce the high proportions of these species that were discarded annually (Meillat *et al.*, 1994; Applegate, 1995; Anon., 1998a). A rectangular sorting grid was tested. The latter consisted of vertical bars spaced at 110 mm and horizontal bars spaced at between 50 and 60 mm. It was reported that by using rigid sorting grids, monkfish landings could increase by 20 to 30% in three to five years' time (Anon., 1998a). By using the grid, the discard rate was reduced by 60% during the experimental trials and the efficiency of the trawl was increased due to increased water flow through grid and, therefore, the trawl (Anon., 1998a).

Namibian monkfish were positively size-selected during a hake (*M. capensis* and *M. paradoxus*) grid-selection experiment in January 1998. The experiment was conducted aboard a commercial hake trawler *MFV Zenica.* A rigid single stainless steel sorting grid was installed in front of the trawl cod-end. The grid length was 180 cm, the width 122 cm and the bar-spacing (vertical) 45 mm. Small fish escaping through the grid bars were collected in a small meshed bag attached over the net opening above the grid. Hauls in which monkfish were measured, showed distinct and constant selectivity values for the species. It was, however, concluded that the 45 mm bar-spacing was too small, and further experiments were needed to determine the optimal specifications of a monkfish grid-selection system (Isaksen *et al*., 1998).

Following the January 1998 grid-selection experiment, a more rigorous experiment to size select and release small monkfish in Namibia was carried out on board the *RV Welwitchia* during November 1998 (Lossius, 1999). An "Ex-it" grid-selection system or small fish separator was installed in the extension piece of the trawl consisting of an hourglass-shaped net tube and a stainless steel grid assembly (see Figure 7.1: Note that for this experiment a grid with vertical bars was used). The sorting grid consisted of eight small grids, hinged together with an average bar spacing of 55 mm. Monkfish released through the grid were collected in a 50 mm mesh top cover while the remainder of the fish were passed on into the cod-end. In addition, a panel consisting of 50 mm mesh was installed in front of the grid to guide the fish to the top of the grid (Lossius, 1999). The results indicated that approximately 44% of monkfish smaller than 31 cm TL were released (Table 7.3), as well as large proportions of the bycatch, leaving a ‘cleaner’ catch. In addition, biological data on length, width and height measurements of monkfish were collected to establish the optimal dimensions of a grid for monkfish (Lossius, 1999). Results indicated that no monkfish bigger than 45 cm TL should manage to pass through a grid with an average bar spacing of 54.5 mm. Lossius (1999) found that the width of a monkfish varies more than the height when compared to the length. It was, therefore, suggested that the rectangular openings, as used by the French, might be an option for future grid-selection experiments in Namibia, as this accounts for both the width and height of monkfish. Lossius (1999) also concluded that selection of monkfish through a grid with vertical bars would depend on the ability of the fish to turn 90° rather than on the size of the fish. It was, therefore, suggested to also test a grid with horizontal bars. A grid with horizontal bars spaced at 55 mm was tested by the French and 63% of monkfish smaller than 31 cm (Table 7.3) were released through the grid (Applegate, 1995).

The aims of this study were threefold. First to provide an overview and an assessment of the experiment carried out in April 1999. Second, to undertake a series of calculations to estimate the financial loss due to the release of fish through the rigid sorting grid and to estimate the long-term gain based on a yield-per-recruit analysis. Finally, considerations on the survival of released fish and plans for future monkfish grid-selection work off Namibia are presented.

Methods

Rigid sorting grids

Lossius (1999) estimated that a monkfish 5.5 cm in height and 16.8 cm in width is approximately 32 cm TL. Since the length-at-50% sexual maturity of female monkfish is 32.1 cm TL (23.7 cm TL for males) (see Chapter 5), it seemed appropriate to aim for releasing monkfish smaller than 32 cm TL.

Five different grids were tested. The first grid was the "Ex-it" grid with horizontal bars spaced at 55 mm (ca. 210 cm long and between 75 and 169 cm wide) (Figure 7.1). The second was a single grid with horizontal bars spaced at 55 mm (ca. 1650 mm long and 1470 mm wide) (Figure 7.2) and the third a single grid with vertical bars spaced at 55 mm. The fourth and fifth grids were single grids with circular openings (110 and 168 mm diameter) (Figure 7.3).

Grids with circular openings were included as it was assumed that monkfish passively tumble in the trawl rather than actively swim to seek a way out of the net (Lossius *et al.*, 1999). Theoretically monkfish would, therefore, have a better chance of passing through circular openings in comparison to narrow bars. The choice of a bar distance of 55 mm and the 168 mm diameter (∅) circular openings was based on the length/width/height relationship for monkfish (Lossius *et al.*, 1999).

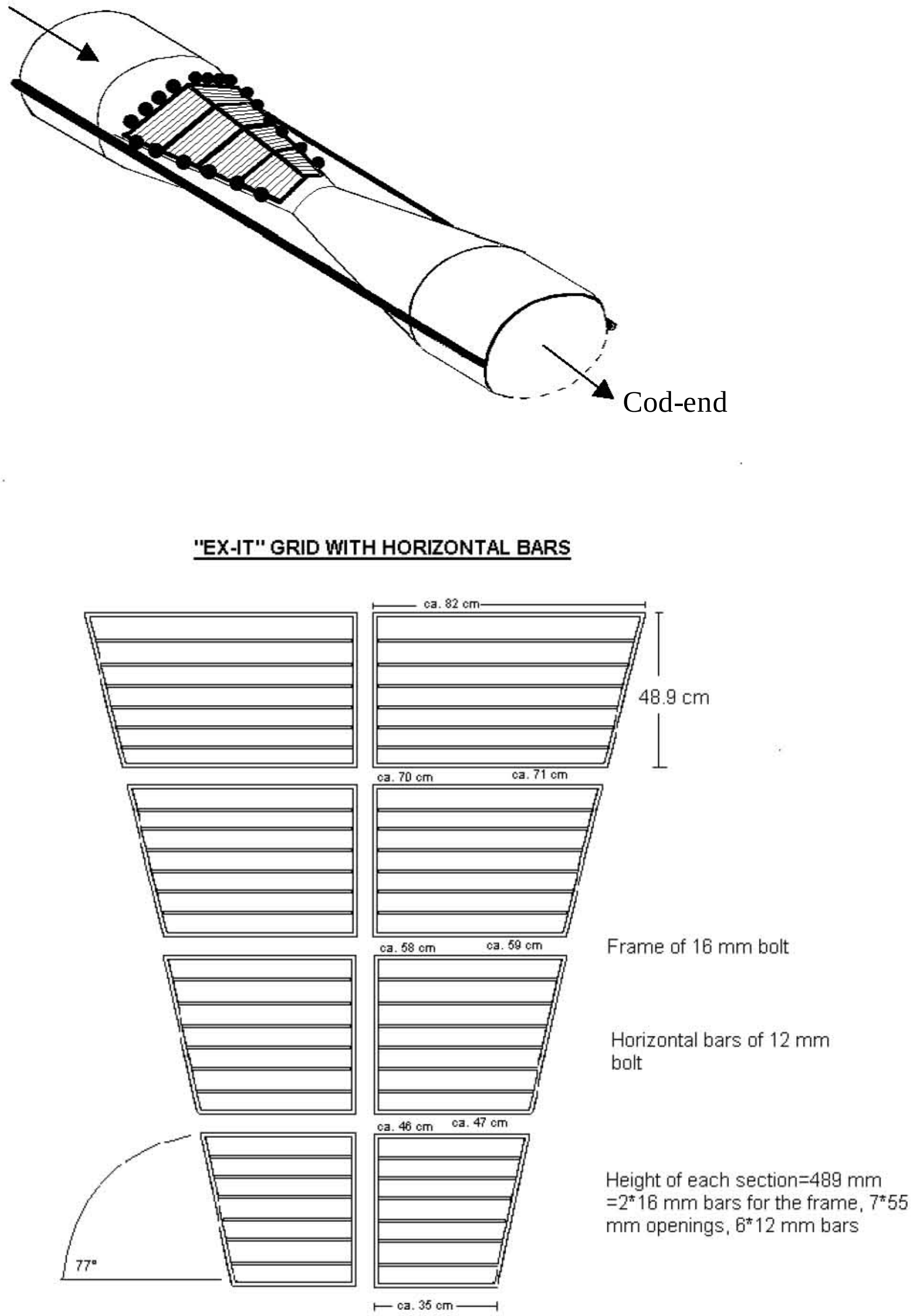

Figure 7.1: The "Ex-it" rigid sorting grid in the trawl extension with horizontal bars spaced at a distance of 55 mm (Lossius *et al.*, 1999).

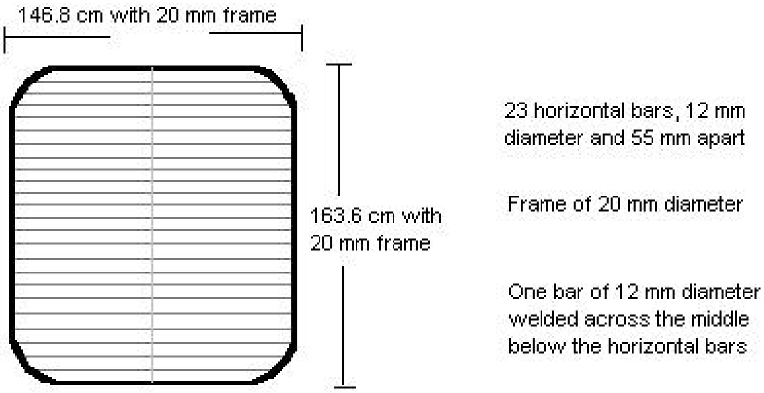

Figure 7.2: The single rigid sorting grid with horizontal bars spaced at 55 mm (Lossius *et al*., 1999). This grid, turned 90° became the single grid with vertical bars spaced at 55 mm.

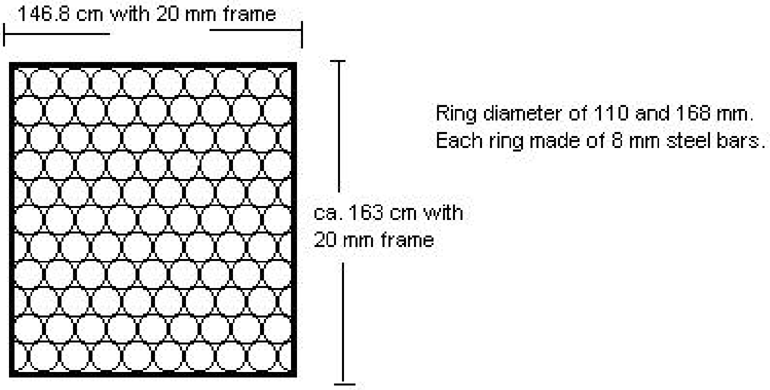

Figure 7.3: The single rigid sorting grid with circular openings. Grids with circular openings 110 and 168 mm ∅ were tested (Lossius *et al*., 1999).

Grid-selection

The grid-selection experiment was carried out between 12 and 24 April 1999 on board a commercial hake trawler *MFV Katima*. The vessel has a length of 51.1 m, width of 9.5 m, gross tonnage (GRT) of 829.5 tonnes and horsepower (HP) of 1250. Morgere trawl doors and an 'Albatross' monkfish trawl with tickler chains on a 63.9 m footrope were used. The headline was 50.3 m; the sweeplines were 45 m and the cod-end mesh size, 110 mm. During trawling, the wingspread ranged between 34 and 37 m and the headline height was approximately 1.2 m (Lossius *et al.*, 1999).

A total of 49 hauls were carried out in the area between 24°04'1"S/13°17'2"E and 24°38'9"S/13°41'7"E and at depths of between 339 and 441 m. A Scanmar sensor fastened on the grid monitored the grid angle (usually between 23 and 35°) as well as the waterflow at this point. Scanmar door- and headline sensors monitored trawl operations. The towing speed was approximately 3 knots and the average tow duration was two hours.

In order to study the behaviour of monkfish as they encounter the different grids, a low light underwater SIT video camera was mounted a few meshes in front of the grid. The camera was mounted in a stainless steel frame, connected by cables to a digital video recorder and batteries housed in a watertight aluminum container. Artificial light was used since observations were made between 339 and 441 m depth. Video footage could unfortunately not be obtained due to technical problems experienced with the underwater camera during the experiments.

After each haul, the cod-end and collecting bag were emptied separately on deck. Depending on the size of the catch, either all fish were measured for total length (TL) to the nearest centimeter, or a subsample of fish was measured for larger catches.

Numbers of monkfish per cm size class for the two bags were plotted and selectivity parameters calculated by means of the selectivity programs CC Selectivity (ConStat, 1995) and CC 2000 (ConStat, 1999). Two sets of selectivity data were obtained by using two different methods. The first method provided a selection curve after pooling all the length frequency data from the hauls ('pooled data'). The second method takes the average of the selection parameters and calculates a new selection curve based on the average values ('single haul analysis') (Lossius *et al.*, 1999).

The selection parameters L_{25}, L_{50} and L_{75} are the lengths at which 25%, 50% and 75% of the fish are retained in the cod-end respectively. The length range from L_{25} to L_{75}, which is symmetrical around L_{50}, is called the selection range SR.

The probability that a fish will escape through the bar openings of a rigid sorting grid depends on its shape and in particular on its body depth in relation to the bar distance of the grid. Proportionality is assumed between d_{50} (the body depth at which 50% of the fish are retained) and bar distance where

$$d_{50} = A \times \textit{(bar distance)}$$

and A is a constant (Sparre and Venema, 1998).

As body depth is approximately proportional to body length, a similar expression applies to the length of the fish

$$L_{50} = SF \times \textit{(bar distance)}$$

where SF is the selection factor (Sparre and Venema, 1998).

Selectivity curves for each of the different grid designs were calculated using the CC2000 program, that implements the SELECT method for indirect selectivity experiments with towed gears. The SELECT method is used to maximise a conditional likelihood function that corresponds to estimation of an associated curve, rather than the selection curve itself (ConStat, 1999):

The log-likelihood function is given by

$$l(q) \propto \sum_{l} \left[n_T(l) \times \log\left(r(l;q)\right) + n_c(l) \times \log\left(l - r(l;q)\right) \right]$$

where n_T is the catch in the main cod-end, n_c is the catch in the collecting bag and r is the retention factor.

The selection curve associated with the logit link function is given as

$$\log it\left(r\left(l;q\right)\right) = \log\left(\frac{r\left(l;q\right)}{1-r\left(l;q\right)}\right) = a + b \times l$$

where

$$r\left(l;q\right) = \frac{\exp\left(a + b \times l\right)}{1+\exp\left(a + b \times l\right)}$$

$q = \left(a\, , b\right)^T$, and the two parameters, a and b are to the slope and intercept.

Optimal diameters corresponding to certain L_{50}-values and the expected selection range given the estimated circle diameters were calculated through linear regression of the results obtained from the 'single haul analysis'.

Yield-per-recruit

A length-transformed yield-per-recruit model was applied (Sparre and Venema, 1998) to determine the effect of changes in length-at-first capture on yield-per-recruit

$$Y/R = \frac{F}{K} \times A \times W_\infty \times \left[\frac{1}{z} - \frac{3U}{z+1} + \frac{3U^2}{z+2} - \frac{U^3}{z+3}\right]$$

where $U = 1 - \frac{L_c}{L_\infty}$ or the fraction of growth to be completed after entry into the exploited phase; $A = \left[\frac{L_\infty - L_c}{L_\infty - L_r} \right]^{M/K}$ and $z = \frac{Z}{K}$.

F = fishing mortality, M = natural mortality and Z = total mortality. L_∞ and K are the von Bertalanffy growth parameters, W_∞ is the asymptotic body weight (Chapters 4 and 5), L_c is the length-at-first capture and L_r the length-at-recruitment.

Monkfish caught during 1997 and 1998 ranged between 10 and 102 cm TL with a mean length of 38 cm TL (see Chapter 3, Figure 3.17). Length-at-50% sexual maturity for female monkfish was estimated at 32.1 cm TL (see Chapter 5). The mean length-at-first capture of fish that have not reached 50% sexual maturity during 1997 and 1998 was estimated at 26 cm TL. Length-at-recruitment was chosen as 10 cm TL and the yield-per-recruit was calculated for values of length-at-first capture ranging between 25 and 40 cm TL.

Results

Grid-selection

Monkfish were released by each of the five rigid sorting grids, but to a variable extent (Figure 7.4).

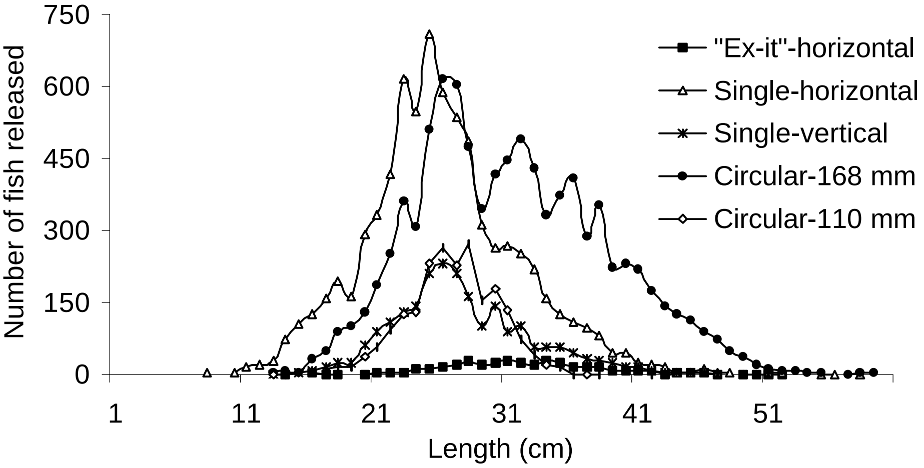

Figure 7.4: Length frequency distributions of the total number of monkfish released through the "Ex-it", single with horizontal and vertical bars spaced at 55 mm and the rigid sorting grids with circular openings 110 and 168 mm ∅.

The length frequency distributions of the total number of monkfish caught as well as the number of monkfish retained in the cod-end and released in the collecting bag by the five different rigid sorting grid designs are illustrated in Figures 7.5 and 7.6.

Very few fish was released by the "Ex-it" rigid sorting grid (9%) while the single grids with horizontal, vertical and circular openings 110 mm ∅ released larger proportions (39%, 32%, 28%, respectively). The grid with circular openings of 168 mm ∅, released most of the monkfish caught (80%). The size of monkfish released by the various grids ranged between 14 and 52 cm TL for the "Ex-it" grid, 8 to 58 cm TL for the single grid with horizontal bars and 13 to 51 cm TL for the single grid with vertical bars. The grid with circular openings 168 mm ∅ released fish between 13 and 59 cm TL, whereas the grid with circular openings 110 mm ∅ released monkfish between 13 and 42 cm TL.

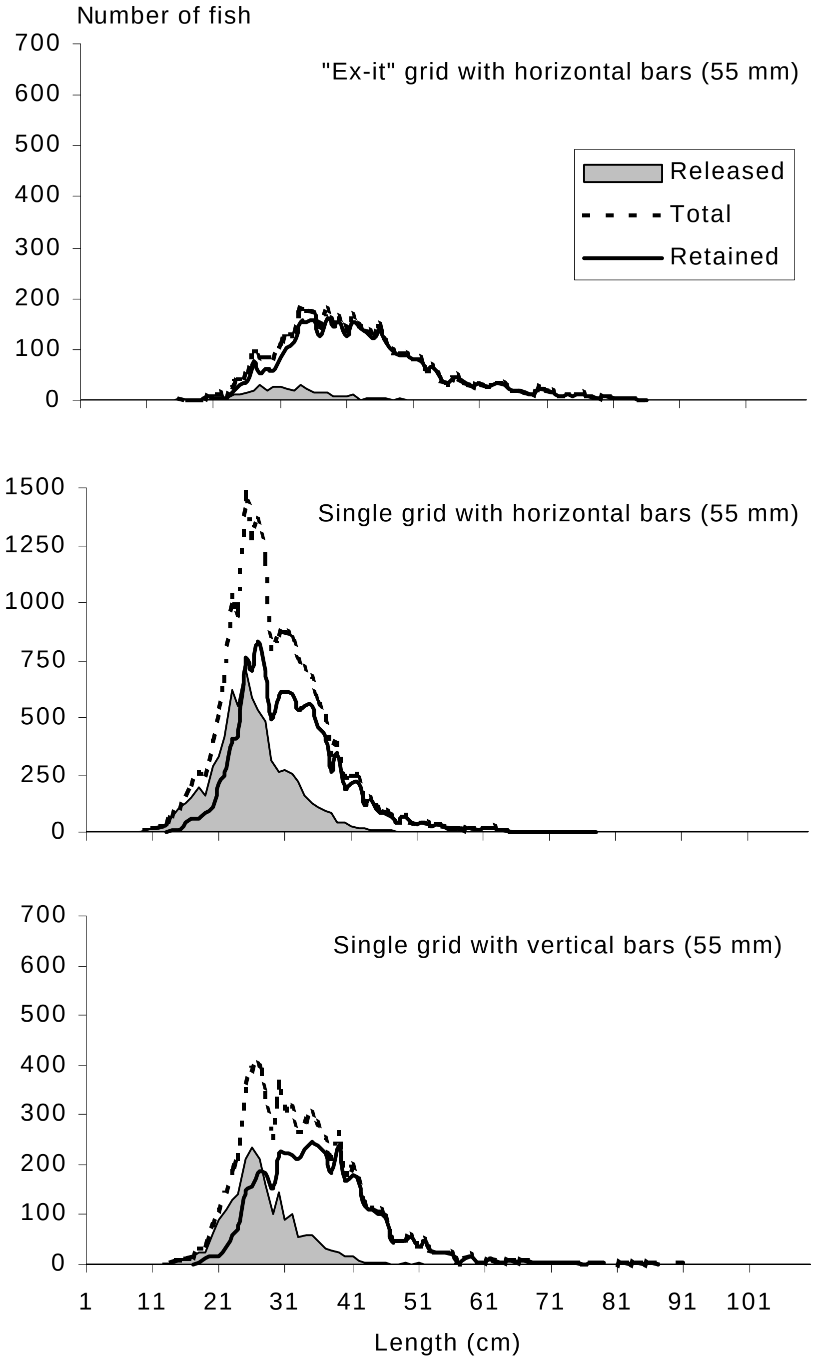

Figure 7.5: Length frequency distributions of the total number of monkfish caught as well as those monkfish retained in the cod-end and released through the "Ex-it" grid, single grid with horizontal bars and single grid with vertical bars spaced at 55 mm.

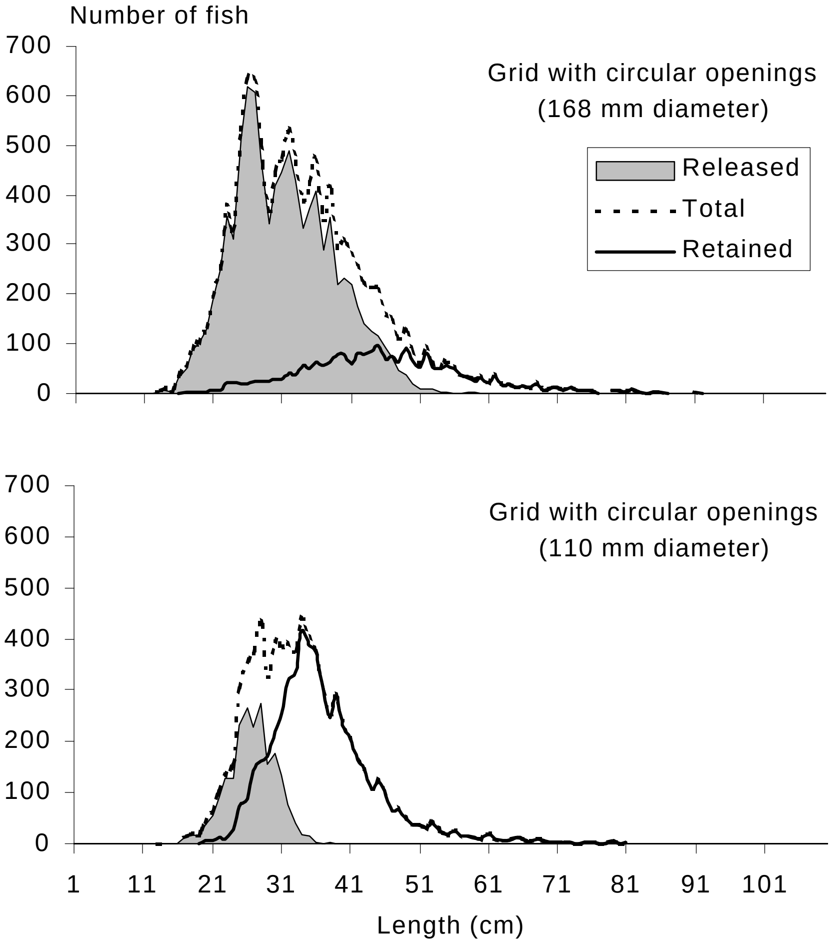

Figure 7.6: Length frequency distributions of the total number of monkfish caught as well as those monkfish retained in the cod-end and released through the grids with circular openings 168 and 110 mm ∅.

Selection curves for the five different rigid sorting grids are depicted in Figure 7.7.

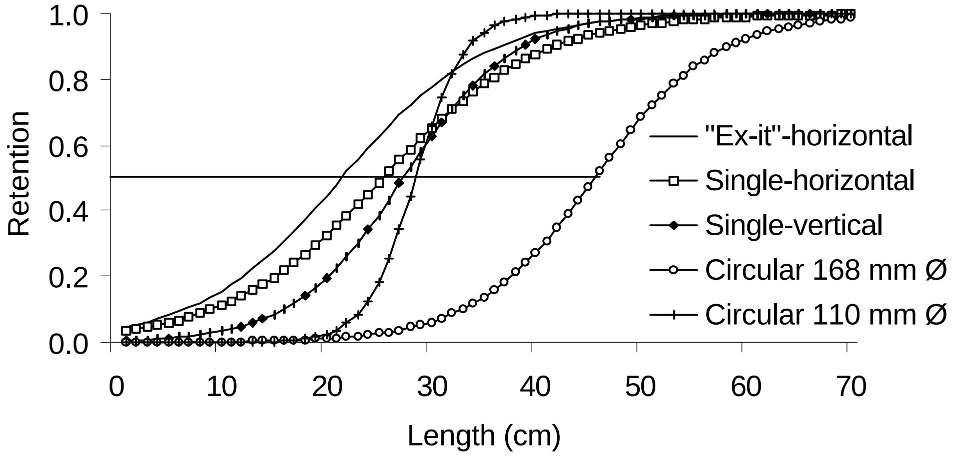

Figure 7.7: Selection curves for the five different grid designs as obtained from data collected aboard the *MFV Katima* during April 1999.

A summary of the selection data from the 'pooled' and 'single haul analysis' is provided in Table 7.1. The selection range was narrowest for the grid with the circular openings 110 mm ∅, followed by the single grid with vertical bars and the grid with circular openings 168 mm ∅.

Even though the grid with 168 mm ∅ circular openings gave good selectivity results, too many of the larger monkfish were released. As a result, the grid with 110 mm ∅ circular openings was made during the course of the cruise and tested. The circular openings for this grid were deliberately made too small, to obtain a good basis for linear interpolations between results upon which to calculate an optimal diameter for future use. Results obtained by the grid with 110 mm ∅ circular openings indicated sharp sorting (a selection curve more to the left) and a narrow selection range of 5.1 cm.

Table 7.1: Selection data ('pooled' and 'single haul analysis') calculated using the programs CC Selectivity and CC 2000. The data were collected during a survey on board the *MFV Katima* during April 1999.

Grid type tested	'Pooled' data			'Single haul'		
	L_{50}	SR	SF	L_{50}	SR	SF
"Ex-it" - horizontal bars 55 mm	21.5	14.9	3.9	21.2	15.2	3.8
Single - horizontal bars 55 mm	25.4	16.2	4.6	27.1	13.9	4.9
Single - vertical bars 55 mm	27.4	11.3	5.0	28.3	10.1	5.2
Single - circular openings 168 mm ∅	45.6	12.6	5.4	46.1	11.7	5.5
Single - circular openings 110 mm ∅	28.5	5.1	5.2	29.1	4.7	5.3

Linear regression between the results obtained from the 'single haul analysis' resulted in $L_{50} = 2.94 \times \varnothing - 3.33$ ($R^2 = 0.88$) and $SR = 1.36 \times \varnothing - 10.52$ ($R^2 = 0.60$). Different diameters and the corresponding selection range that can be predicted for specified L_{50}-values were calculated and are summarised in Table 7.2. It was estimated that the circular openings of a grid need to be 120 mm ∅ to obtain an L_{50} of 32 cm and that a selection range of approximately 5 cm can be expected.

Table 7.2: Calculated circle diameters for different L_{50}-values and the expected selection range (SR).

L_{50}	Diameter (cm)	Expected SR
30	11.3	4.1
31	11.7	4.5
32	12.0	4.9
33	12.3	5.4
34	12.7	5.8
35	13.0	6.2
36	13.4	6.7
37	13.7	7.1
38	14.0	7.5
39	14.4	7.9
40	14.7	8.4

Yield-per-recruit

The results obtained from the length-based yield-per-recruit are illustrated in Figure 7.8.

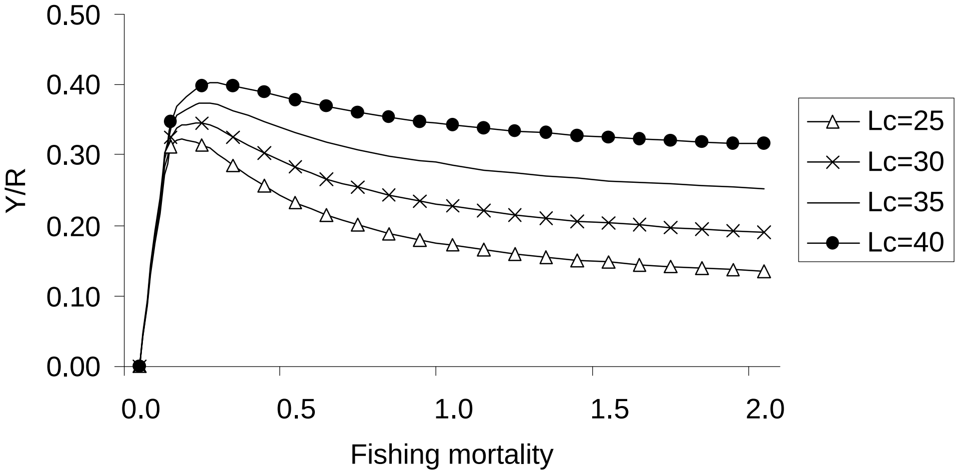

Figure 7.8: Yield-per-recruit (Y/R) curves and fishing mortality (F) for different lengths-at-first capture (L_c) of monkfish. Length-at-recruitment is kept constant at 10 cm TL.

By delaying length-at-first capture, an increased yield is observed which is maximised at a greater fishing effort. It was estimated that the total yield would increase by 10%, 19% and 27% if the length-at-first capture is increased from 25 cm to 30, 35 and 40 cm respectively.

Discussion

Of the five rigid sorting grids tested, the "Ex-it" and single grids with horizontal bars spaced at 55 mm gave the widest selection range. As these grids lie at an angle, the openings are in fact smaller than the bar distance. Fewer fish would, therefore, be released at lower grid-angles unless the fish actively seek a way out. Due to the shape of the "Ex-it" grid, the grid-angle is low over most of the grid, decreasing from the first panel backwards. This low grid-angle may be responsible for the fact that the "Ex-it" grid, compared to the single grid with horizontal bars, released fewer fish. Compared to the French experiment, where 63% of monkfish smaller than 31 cm were released, the single horizontal grid with similar bar spacing released only 51% of the fish below 31 cm. A higher fraction (20%) of fish bigger than 31 cm were also released in comparison to the 4% obtained by the French experiment (Table 7.3). It was anticipated that selection through a grid with vertical bars would depend on the ability of a monkfish to execute a 90° turn, rather than on the size of the fish (Lossius, 1999). The "Ex-it" rigid sorting grid with horizontal bars, however, released a mere 30% of fish smaller than 31 cm compared to 44% for the same grid with vertical bars, tested in November 1998. A bigger bar spacing for both the "Ex-it" and single grids with horizontal bars may, however, increase selectivity. The increase of 10 mm in bar spacing between the single grids with vertical bars tested on board the *MFV Zenica* and *MFV Katima* made a significant difference in the fraction of small fish (≤ 30 cm TL) released (10% vs. 57%) (Table 7.3).

The steepness of the selection curve (the SR) is measured between L_{25} and L_{75}. The single rigid sorting grid with vertical bars gave a slightly narrower selection range than the grid with circular openings of 168 mm ∅, but the shape of the curve (Figure 7.7) is somewhat different to that obtained for the grid with circular openings. It is evident that in the case of the single grid with vertical bars, the length at which all fish are captured (L_{100}) is reached more gradually when compared to the selection range of the grid with circular openings.

The results obtained with the rigid sorting grids with circular openings showed the greatest potential. The rigid grid with 168 mm ∅ openings released 96% of monkfish smaller than 31 cm. Unfortunately, it also released 70% of the monkfish bigger than 30 cm, making it unsuitable for use by the monkfish and sole trawlers (Table 7.3). The fraction of fish smaller than 31 cm TL retained and released in France (rectangular grid: 110 × 50 mm) and Namibia (grid with 110 mm ∅ openings) were similar (Table 7.3). A possible explanation for the similarity in results using two different grid designs (rectangular vs. circular openings) could be that both the circular and rectangular openings limit the width of monkfish rather than the height. Monkfish behaviour in the trawl might shed some light on why these two designs are more effective in releasing juvenile monkfish. Larsen and Isaksen (1993) identified water flow, grid angles, size of the escape areas as well as visual stimuli to affect fish behaviour and escape. It is, therefore, unfortunate that video footage was not available for analysis.

Linear interpolations between diameter-, L_{50}- and SR-values indicate that grids with circular openings of 120 and 130 mm ∅ would result in L_{50}-values of 32 and 35 cm respectively. To further develop the present technology, a research cruise has been planned for February 2000 to test rigid sorting grids with circular openings of 120 and 130 mm ∅.

Table 7.3: Size selectivity of rigid sorting grids tested in France as well as during grid-selection experiments off Namibia.

Grid type	Disposition	Retained	Released	Source
Ifremer (France)				
Rectangular grid: 110 × 50 mm	≤ 30 cm	13 (32%)	28 (68%)	Applegate (1995)
	> 30 cm	130 (99%)	1 (1%)	
Rectangular grid: 110 × 65 mm	≤ 30 cm	19 (22%)	69 (78%)	Applegate (1995)
	> 30 cm	110 (92%)	10 (8%)	
Grid: horizontal bars 55 mm	≤ 30 cm	23 (37%)	40 (63%)	Applegate (1995)
	> 30 cm	122 (96%)	5 (4%)	
MFV Zenica				
Single grid with vertical bars 45 mm	≤ 30 cm	474 (90%)	53 (10%)	This study (1999)
	> 30 cm	408 (57%)	304 (43%)	
RV Welwitchia				
"Ex-it" grid: vertical bars 55 mm	≤ 30 cm	4195 (56%)	3282 (44%)	This study (1999)
	> 30 cm	16313 (87%)	2471 (13%)	
MFV Katima				
"Ex-it" grid: horizontal bars 55 mm	≤ 30 cm	361 (70%)	158 (30%)	This study (1999)
	> 30 cm	3427 (94%)	226 (6%)	
Single grid: horizontal bars 55 mm	≤ 30 cm	5697 (49%)	5993 (51%)	This study (1999)
	> 30 cm	5870 (80%)	1502 (20%)	
Single grid: vertical bars 55 mm	≤ 30 cm	1268 (43%)	1679 (57%)	This study (1999)
	> 30 cm	3442 (86%)	555 (14%)	
Single grid: circular openings 168 mm ∅	≤ 30 cm	211 (4%)	4490 (96%)	This study (1999)
	> 30 cm	2038 (30%)	4661 (70%)	
Single grid: circular openings 110 mm ∅	≤ 30 cm	916 (34%)	1815 (66%)	This study (1999)
	> 30 cm	4546 (94%)	290 (6%)	

A critical constraint for the introduction of selective gear technology in a fishery is the survival of fish escaping from the fishing gear (Beltestad and Misund, 1996; Soldal and Engås, 1997). Design modifications to improve selectivity are, in all cases, based on the assumption that fish released are undamaged, stressed undiscernibly and are able to fully recover from encountering a selective device (Chopin and Arimoto, 1995). Beltestad and Misund (1996) conducted mesoscale as well as field experiments on mackerel and saithe and found that 5% (control group) and 40% (experimental group) of the mackerel died one month after the experiments were conducted. Mortalities in the saithe experiment were insignificant. The mackerel fishery in Norway is quota controlled (200 000 tonnes) and assuming a rigid selection grid is implemented, releasing 35% of the catch of which approximately 40% suffer long-term mortality, it would thus mean that an additional fishing mortality of 40 000 tonnes would be induced. Chopin and Arimoto (1995) also stressed that fish dying as a direct result of stress and injuries, or indirectly due to disease and predation associated with gear damage may lead to an increased level of unaccounted fishing mortality. Soldal and Engås (1997) conducted experiments using a coastal shrimp trawl with a 'Nordmore' grid (Isaksen *et al.*, 1992) and found that cod, haddock and whiting had a 100% survival rate after an observation period of 5 to 12 days. These fish, however, did not pass through net meshes or between the metal bars of a grid to escape (Soldal and Engås, 1997). Previous studies have, however, shown a 96% (135 mm diamond mesh) and 92% (metal sorting grid with 55 mm bar-spacing) survival of released haddock (Soldal *et al.*, 1991; Soldal *et al.*, 1993). Fish are exposed to physical strains, e.g. from swimming in front of the trawl and through contact with the net walls. Attempts to escape through the cod-end during trawling may result in skin injuries (Soldal and Engås, 1997). Chopin and Arimoto (1995) indicated that factors such as predation on injured fish and the ability to fully recover from injuries are difficult to monitor and that these factors are usually not included in mortality studies. Fish not dying, on the other hand, may have their growth and reproductive capacity impaired.

Possible injuries to monkfish, followed by mortality, upon passing through grids cannot be excluded. Monkfish do not have scales, but do have very thin and delicate skins. In addition, it is unknown how resilient monkfish are to injuries. Chopin and Arimoto

(1992) stated that a cause of concern in any fishery where gear selectivity is to be used as a management tool should be to conduct adequate research on the fate of escapees. Further experiments should, therefore, be undertaken to study the survival of monkfish released by a rigid sorting grid before sorting grids are fitted to all nets as a measure to prevent the excessive harvesting of juvenile monkfish.

During 1998, 59% of the total monkfish landed by weight belonged to the extra extra small (XXS) (10 to 16 cm TL), extra small (XS) (17 to 25 cm TL) and small (S) (26 to 36 cm TL) size categories (Chapter 3). Analysis of the data indicated that 100, 84 and 33% of the monkfish (in numbers) in the XXS, XS and S categories would be released if a rigid sorting grid with circular openings 110 mm ∅ were to be fitted to the nets. Market prices for monkfish range from N$ 11.00 to N$ 23.00 for the XXS to S and N$ 33.00 to N$ 42.00 for the medium (M) to extra large (XL) categories. The industry, therefore, has an economic incentive to catch larger monkfish. The short-term economic loss using a rigid sorting grid with circular openings 110 mm ∅ was estimated to be 8% of the total value. In addition, the bycatch of sole during the experiments was reduced to zero, but catches of sole (536 tonnes in 1997 and 400 tonnes in 1998) are insignificant when compared to monkfish catches (almost 17 000 tonnes in 1998). The yield-per-recruit analysis, however, indicates that the total yield of monkfish would increase by 19% if the length-at-first capture of monkfish were increased from 25 to 35 cm. The short-term economic loss could, therefore, be regarded as negligible in comparison to the predicted long-term gain in terms of value and yield.

The yield-per-recruit model used in this study was merely to determine and illustrate the effects that changes in lengths-at-first capture have on yield-per-recruit. Assumptions underlying the yield-per-recruit model are: recruitment is constant, yet not specified; all fish of a cohort are hatched on the same date; recruitment and selection are 'knife-edge' and fishing and natural mortalities are constant from the moment of entry to the exploited phase (Sparre and Venema, 1998). The main disadvantage of the model is its assumptions of steady state (King, 1995). A justification for the use of yield-per-recruit models is that recruitment of juveniles appears to be independent of spawner biomass over a wide range of stock sizes and yields and can, therefore, be expressed in terms of yield-per-recruit when recruitment is treated as a constant (Jones, 1984). Once a suitable grid design to size select and release juvenile monkfish in Namibia has been identified, an in-depth analysis will be conducted to assess and evaluate the short-term economic loss and the long-term gain in yield.

Valuable information for the appraisal of rigid sorting grids as a technical measure to reduce the capture of juvenile monkfish was provided by this study. Further experiments are, however, needed to determine the optimal grid design, and experiments should be carried out to study the survival of monkfish released by these grids. The final stage of the grid-selection studies for monkfish would involve close co-operation with the industry to test the feasibility of using these grids on board commercial monkfish and sole vessels.

CHAPTER 8 - Stock assessment of monkfish in Namibia

Introduction

Since the 1940s, fisheries science has developed quantitative methods for the management of fish stocks (Smith, 1986). Stock assessment refers to mathematical methods used to estimate current abundance, harvesting rate and productive potential of a fish stock. The type of data available dictates which stock assessment technique is appropriate, such as length-based, age-based and biomass dynamic (production) methods (Hilborn, 1992).

The data available for the assessment of the monkfish resource are a time-series of annual catches from 1974 to 1998, catch-and-effort data from the commercial monkfish and sole directed fleet between 1991 and 1998, biomass indices obtained from data collected by the *RV Dr. Fridjof Nansen* between 1994 and 1999, size category data from the industry between 1994 and 1998 and length frequency data collected by observers on board commercial monkfish and sole, as well as hake vessels during 1997 and 1998. No time-series of catch-at-age data are available. The nature of the data, therefore, makes it impractical to apply certain of the standard stock assessment techniques. Standard age-structured estimation procedures such as *ad hoc* tuned Virtual Population Analysis (Butterworth and Andrew, 1984; Pope and Shepherd, 1985; Butterworth *et al*., 1990), Integrated Catch Analysis (Deriso *et al*., 1985) and Adaptive Frameworks (ADAPT, e.g. Gavaris, 1988) can, therefore, not be applied due to the lack of annual catch-at-age data.

Assessment techniques that do not require annual estimates of the age composition are the biomass dynamic (surplus production) models (Schaefer, 1954, 1957). These models are, however, insufficiently flexible for the evaluation of alternative harvesting strategies such as the introduction of a minimum size limit, since the latter would change age-specific selectivity patterns (Punt *et al*., 1995).

An analytical method that could be applied is length cohort analysis (LCA) (Jones, 1979, 1984). This method requires estimates of the total numbers caught by the commercial fishery and the data are used to construct a synthetic cohort when information about growth and mortality is available (Lai and Gallucci, 1988). The outputs are estimates of absolute stock size and fishing mortality per size group. The latter can be used as input for the prediction of stock biomass and yield (Lai and Gallucci, 1988) using e.g. the Thompson and Bell prediction method (Sparre and Venema, 1998) resulting in an estimate of maximum sustainable yield (MSY).

An assessment technique, such as an age-structured production model (ASPM) that takes into account the age-structured nature of the fish population, but does not require estimates of the age composition on an annual basis (Punt, 1994; Punt and Japp, 1994; Booth and Punt, 1998) could also be applied.

Hilborn (1990), Punt (1994) and Geromont and Butterworth (1997) used age-structured production models to examine the catch history of hake (*Merluccius* spp.) off the coasts of Namibia and South Africa. The western North Atlantic bluefin tuna as well as South Atlantic albacore have both been assessed using an ASPM (Butterworth and Punt, 1992; Punt *et al*., 1992; Punt *et al*., 1995), as well as the kingklip (*Genypterus capensis*) (Punt and Japp, 1994) and panga (*Pterogymnus laniarius*) (Booth and Punt, 1998) resources off South Africa.

The aims of this study were first to apply a length-based assessment model and to use the results obtained as input for a prediction model (Jones, 1984; Sparre and Venema, 1998) and second to apply an age-structured production model (Punt, 1994; Punt and Japp, 1994; Booth and Punt, 1998) to assess the status of the monkfish resource.

Length-based modeling

Methods

Jones' length-based cohort analysis

Length cohort analysis (LCA) requires a length composition, representative of the catch under steady state conditions (Jones, 1984). The cohort analysis was applied to data from two different sources as well as time periods. Data used were size category data (mean number of monkfish per size category) for the period 1994 to 1998, assumed to be in equilibrium, as well as data (mean number of monkfish per cm size class) collected by observers on board commercial vessels during 1997 and 1998 (see Chapter 3). Furthermore, the results obtained by the LCA using the observer data were compared to a LCA applied to size category data for the same period.

The lower class limits of the commercial size categories (see Table 3.7) were taken as L_1 equaling 10, 17, 26, 37, 49 and 60 cm TL. Recruitment was assumed to take place at $L_{1\,first} = 10\,cm$ and $L_{1last} = L_{terminal} = 60\,cm$. Length frequency data collected by the observers between 1997 and 1998 were split into 5 cm size classes with $L_{1\,first} = 10\,cm$ and $L_{1last} = L_{terminal} = 66\,cm$.

The terminal length interval (+ group) for the size category data was taken as all fish bigger than 60 cm (Table 3.7). Addison (1989) stated that the terminal length interval should have a lower bound of less than 70% of L_∞ as this will minimise errors in the model's output due to errors in the estimates and variances of L_∞ and K. The + group for the size category data was pre-determined, but for the observer data it was chosen as all fish bigger than 66 cm.

Length intervals were chosen as narrowly as possible to ensure that the data were reasonably smooth and also since the precision of the LCA increases with smaller length intervals. Lai and Gallucci (1988) stated that the size of the length interval must, however, provide an interval of individuals not too small and Addison (1989) suggested that $M\,\Delta t < 0.3$ for all size classes.

Natural mortality $M(L_1, L_2)$ and fishing mortality $F(L_1, L_2)$ were assumed to be constant for all fish belonging to a size category. Sensitivity analyses were, however, carried out for different values of natural mortality ($M = 0.09$ yr^{-1}, $M = 0.15$ yr^{-1} ('base case') and $M = 0.20$ yr^{-1}) (see Chapter 5).

Length groups were converted into age intervals by the inverse von Bertalanffy equation

$$t(L_1) = t_0 - \frac{1}{K} \times \ln\left[1 - \frac{L_1}{L_\infty}\right] \tag{1}$$

where $t(L_1)$ is length at age t, t_0 is the intercept on the x-axis corresponding to zero length and the growth parameters, K and L_∞ are considered species specific constants, i.e. K is similar for all length classes/categories. The age corresponding to a certain length class can be calculated when $t_0 = 0$. Let age t correspond to L_1 and age $t + \Delta t$ to L_2 then, $L_1 = L(t)$ and $L_2 = L(t + \Delta t)$. The notation for the number caught C can then be changed to

$$C(t,\ t + \Delta t) = C(L_1, L_2)$$

where Δt is the time it takes for an average fish to grow from length L_1 to length L_2. By subtracting the two inverse von Bertalanffy equations corresponding to L_1 and L_2, Δt can be calculated

$$\Delta t = t(L_2) - t(L_1) = \frac{1}{K} \times \ln\left[\frac{L_\infty - L_1}{L_\infty - L_2}\right] \tag{2}$$

The cohort analysis equation

$$N(t) = \left[N(t+\Delta t)\times \exp\left(M\times \Delta t / 2\right) + C(t, t+\Delta t)\right]\times \exp\left(M\times \Delta t / 2\right) \qquad (3)$$

can be converted into a length-based version by substituting $\exp\left(M\times \Delta t / 2\right)$ with $\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)^{M/2K}$. The equation then becomes

$$N(L_1) = \left[N(L_2)\times\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)^{M/2K} + C(L_1, L_2)\right]\times\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)^{M/2K}$$

where

$$\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)^{M/2K} = H(L_1, L_2)$$

that is equal to the inverse of the fraction of $N(L_1)$ that survive natural deaths during the time period from $t(L_1)$ to $t(L_1) + \Delta t / 2$. $H(L_1, L_2)$ is also referred to as the natural mortality factor and $N(L_1)$ is the number of monkfish attaining L_1.

$$N(L_1) = \left[N(L_2)\times H(L_1, L_2) + C(L_1, L_2)\right]\times H(L_1, L_2) \qquad (4)$$

The calculation procedure starts with the last group and the length-based form of the catch equation is used

$$C(L_1, L_2) = N(L_1)\times\frac{F}{Z}\times\left[1 - \exp(-Z\times\Delta t)\right] \qquad (5)$$

Theoretically $\Delta t = \infty$ and then $C(60,\infty) = N(60) \times \frac{F}{Z} \times [1 - \exp(-Z \times \Delta t)]$ or $N(60) = \frac{C(60)}{F/Z}$

and where observer data were used, $C(66,\infty) = N(66) \times \frac{F}{Z} \times [1 - \exp(-Z \times \Delta t)]$ or $N(66) = \frac{C(66)}{F/Z}$.

The exploitation rate (F/Z) is calculated by

$$F/Z = C(L_1, L_2) \Big/ \left[N(L_1) - N(L_2) \right] \tag{6}$$

The exploitation rate for the last length group was calculated through a guestimate of the terminal fishing mortality, F_t. The terminal fishing mortality F_t was first assumed to be equal to the average fishing mortality of the previous three length classes (around 0.12) as it was not expected to observe differences in catchability or selectivity of the oldest monkfish size or length classes. The F_t was, however, increased to a value equal to 0.20 since Addison (1989) stated that the model is insensitive to errors in the terminal exploitation rate and advised to rather over-estimate F_t. The sensitivity of the cohort analysis to a range of values (0.10 to 0.24) for F_t was, however, tested.

Fishing mortality per length group was calculated by $F = M \times (F/Z) / (1 - F/Z)$ and the total instantaneous rate of mortality (Z) by $Z = F + M$.

The annual mean number of monkfish in the sea per length class needs to be calculated to determine the mean biomass

$$\overline{N}(L_1, L_2) \times \Delta t = \left[N(L_1) - N(L_2) \right] \Big/ Z \tag{7}$$

and for the last length group by

$$\overline{N}(L_1,\infty)\times\ \Delta t = N(60)/Z(60,\infty)\ \text{or}\ \overline{N}(L_1,\infty)\times\ \Delta t = N(66)/Z(66,\infty)$$

The body weight is calculated from

$$\overline{w}\,(L_1,L_2) = q\times\left[\frac{(L_1+L_2)}{2}\right]^b \tag{8}$$

where q and b are the constants of the length-weight relationship.

Average biomass is calculated by

$$\overline{B}\times\ \Delta t = \overline{w}(L_1,L_2)\times\left[N(L_1)-N(L_2)\right]/Z \tag{9}$$

and yield during a year by

$$Y(L_1,L_2) = \overline{w}(L_1,L_2)\times C(L_1,L_2) \tag{10}$$

Thompson and Bell prediction model

Input data for the prediction model included the fishing mortality per length or size class (F-at-length-array), annual recruitment $N(L_1)$ as calculated from the LCA and the parameters q and b from the length-weight relationship. New values of F are obtained by multiplying the reference F-array as a whole by a certain factor, X (Sparre and Venema, 1998).

$$N(L_2) = N(L_1) \times \left[\frac{L_\infty - L_1}{L_\infty - L_2} \right]^{-FX + M/K} \qquad (11)$$

where $Z = FX + M$

$$C(L_1, L_2) = [N(L_1) - N(L_2)] \times X \times F / FX + M \qquad (12)$$

In order to calculate the yield (catch in weight) per length group the catch C (in numbers) must be multiplied by the mean weight of the length group (see Eqs. 8 and 10).

The annual yield is the sum of the yield of all length groups, $\sum Y(L_1, L_2)$ and the corresponding mean biomass multiplied by Δt can be calculated applying Eq. (9).

Results

Jones' length-based cohort analysis

Results from the length cohort analyses using the size category data between 1994 and 1998 as well as the size category and observer data for the period 1997 to 1998 for three choices of natural mortality M are summarised in Table 8.1.

Both the mean population number ($\sum \overline{N}$) and mean biomass ($\sum \overline{B}$) increased as natural mortality increased, whilst the average of the fishing mortalities calculated for all size classes, decreased.

The mean population number for different values of F_t ranging between 0.10 and 0.24 (observer length frequency data from 1997 to 1998) can be seen in Figure 8.1. It is evident that low values of F_t had more effect on the population numbers than higher values.

Table 8.1: Results from the length-based cohort analyses for the size category data from 1994 to 1998 and 1997 to 1998 as well as the observer data for the period 1997 to 1998 for three choices of natural mortality M .

	M = 0.09 yr^{-1}	M = 0.15 yr^{-1}	M = 0.20 yr^{-1}
Size category data (1994 – 1998)			
$\sum \overline{N}$ (millions)	60.63	69.91	79.66
$\sum \overline{B}$ (tonnes)	33 586.55	36 979.80	40 410.28
$\overline{F}$	0.37	0.33	0.30
Size category data (1997 – 1998)			
$\sum \overline{N}$ (millions)	71.40	80.92	90.79
$\sum \overline{B}$ (tonnes)	33 136.29	36 341.13	39 565.44
$\overline{F}$	0.42	0.38	0.34
Observer data (1997 – 1998)			
$\sum \overline{N}$ (millions)	63.88	74.32	85.42
$\sum \overline{B}$ (tonnes)	31 128.39	35 504.86	39 986.29
$\overline{F}$	0.36	0.32	0.28

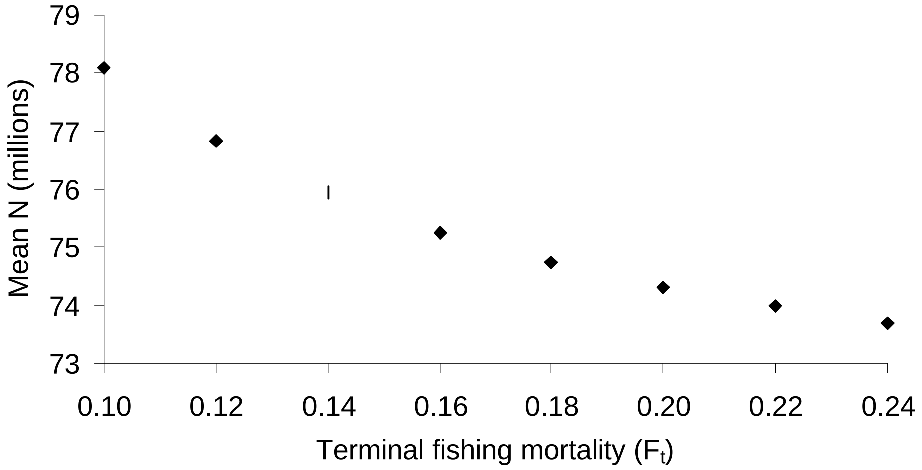

Figure 8.1: Plot of mean population number (N) against a range of F_t-values for the length cohort analysis based on monkfish length frequency data collected by observers from 1997 to 1998.

Population numbers N and fishing mortalities F obtained through length cohort analysis for the three scenarios are shown in Figures 8.2 to 8.4.

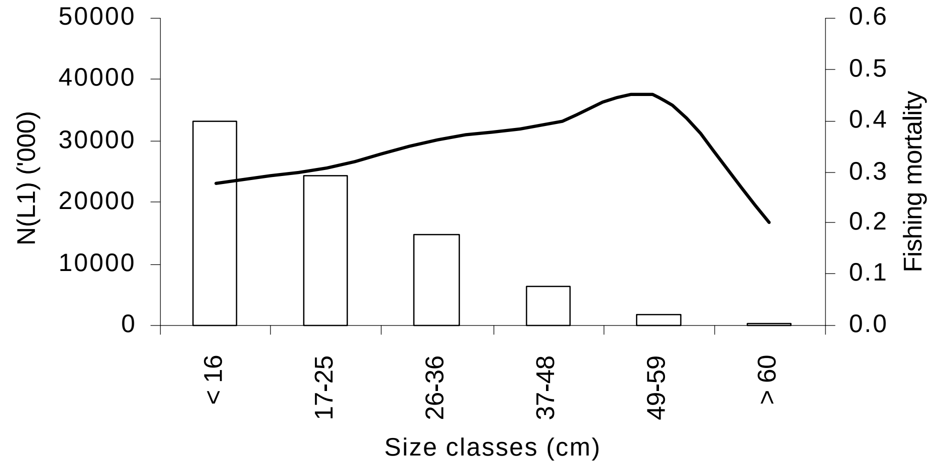

Figure 8.2: Population number (N) (bars) and fishing mortalities (F) (line) as obtained through length cohort analysis using monkfish size category data for the period 1994 to 1998.

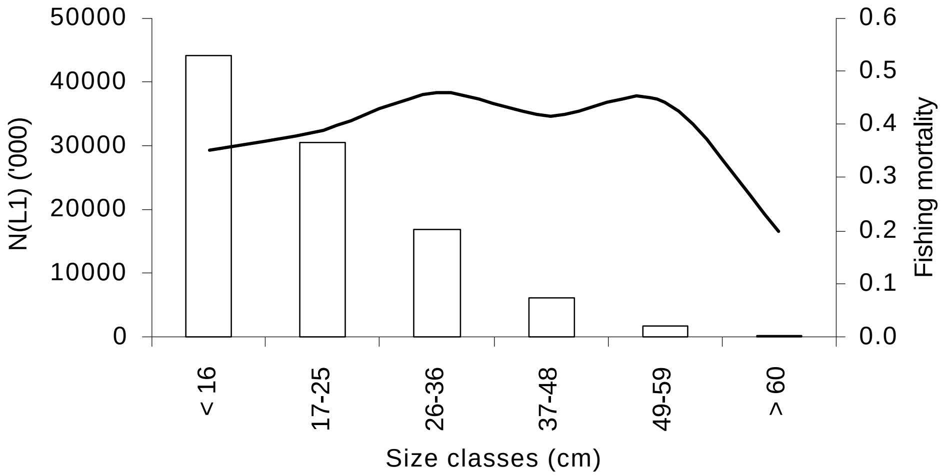

Figure 8.3: Population number (N) (bars) and fishing mortalities (F) (line) as obtained through length cohort analysis using monkfish size category data for the period 1997 to 1998.

Figure 8.4: Population number (N) (bars) and fishing mortalities (F) (line) as obtained through length cohort analysis using length frequency data collected by observers for the period 1997 to 1998.

Thompson and Bell prediction model

The results of the length-based Thompson and Bell prediction model are shown in Figure 8.5. The yield-per-recruit curves show that for the three scenarios the present level of fishing effort is well above that giving the maximum sustainable yield and a reduction in effort would, therefore, give a higher yield (Sparre and Venema, 1998). A summary of the results for the 'base case' analyses (Figure 8.5) and when effort is reduced by 40% and 50% can be seen in Table 8.2.

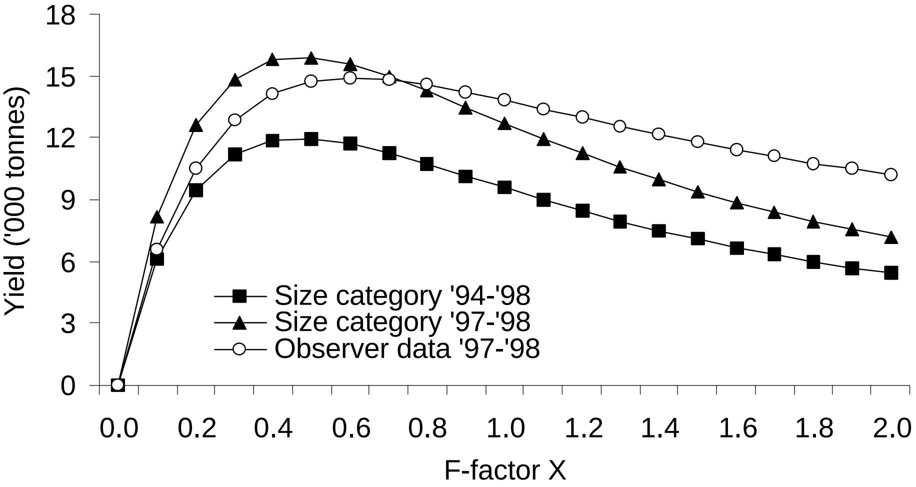

Figure 8.5: Yield-per-recruit of monkfish as calculated by the length-based Thompson and Bell prediction model. The F-factor $X = 1$ indicates the current state.

Table 8.2: Results from the Thompson and Bell prediction model for the 'base case' assessment as well as when fishing mortality is reduced by 40% or 50%. Values for the F-factor X are in parenthesis.

	‘Base case’	40% Reduction	50% Reduction
Size category data (1994-1998)			
$Y_{current}$ $(\times 10^3)$	9.6	11.7	12.0
Y_{MSY} $(\times 10^3)$	12.0 (0.5)	12.0 (0.8)	12.0 (0.9)
$\overline{B}_{current} \times \Delta t$ $(\times 10^3)$	23.2	49.6	62.0
$\overline{B}_{MSY} \times \Delta t$ $(\times 10^3)$	62.0 (0.5)	64.9 (0.8)	69.6 (0.9)
Size category data (1997-1998)			
$Y_{current}$ $(\times 10^3)$	12.7	15.6	15.9
Y_{MSY} $(\times 10^3)$	15.9 (0.5)	15.9 (0.8)	15.9 (0.9)
$\overline{B}_{current} \times \Delta t$ $(\times 10^3)$	30.8	65.9	82.3
$\overline{B}_{MSY} \times \Delta t$ $(\times 10^3)$	82.3 (0.5)	86.2 (0.8)	92.5 (0.9)
Observer data (1997-1998)			
$Y_{current}$ $(\times 10^3)$	13.8	14.9	14.7
Y_{MSY} $(\times 10^3)$	14.9 (0.6)	14.9 (1.0)	14.9 (1.2)
$\overline{B}_{current} \times \Delta t$ $(\times 10^3)$	35.8	66.0	79.5
$\overline{B}_{MSY} \times \Delta t$ $(\times 10^3)$	66.0 (0.6)	66.0 (1.0)	66.0 (1.2)

Age-based modeling

Methods

Estimation procedure

An age-structured production modeling approach involves constructing a deterministic age-structured model to simulate the population dynamics of the stock and tuning it to available abundance indices (Table 8.3) by maximising a likelihood function.

Table 8.3: Adjusted CPUE data, calculated using Generalised Linear Modeling, for monkfish from the commercial monkfish and sole directed fleet between 1991 and 1998 and biomass indices as obtained from data collected by the *RV Dr. Fridtjof Nansen* between 1994 and 1999.

Year	CPUE (kg/day)	Biomass indices (tonnes)
1991	1756.6	-
1992	2334.0	-
1993	2584.2	-
1994	2921.9	25 459.0
1995	2278.0	13 132.2
1996	1676.8	13 732.3
1997	2017.7	11 374.9
1998	3277.4	11 158.9
1999	-	25 826.5

The underlying age-structured population dynamics model and the likelihood function are described as follows:

Resource dynamics

Population abundance is governed by the exponential decay model and can be described by the following recursive equations

$$N_{y+1,a} = \begin{cases} R_{y+1} & if \quad a = 0 \\ N_{y,a-1}\, e^{-M_a - S_{y,a}F_y} & if \quad 0 < a < \max \\ N_{y,\max-1}\, e^{-M_{\max-1} - S_{y,\max-1}F_y} + N_{y,\max}\, e^{-M_{\max} - S_{y,\max}F_y} & if \quad a = \max \end{cases} \qquad (13)$$

where

$N_{y,a}$ is the number of fish at age *a* at the start of year *y*,

R_{y+1} is the number of 0-year-olds at the start of year *y*,

M_a denotes the natural mortality rate on fish of age *a* (assumed to be independent of age and time),

$S_{y,a}$ is the age-specific commercial selectivity for year *y*,

F_y is the fully selected (asymptotic) fishing mortality in year *y*, and

max is the maximum age (a lumped plus-group).

Annual recruitment

The number of recruits at the start of year *y* is deterministically related to the previous year's spawner stock biomass using the Beverton and Holt stock-recruit relationship

$$R_y = f \, \frac{a \, SB_{y-1}}{b + SB_{y-1}} \tag{14}$$

where a and b are spawner biomass-recruitment parameters defining the curve, SB_{y-1} is the spawner biomass at the previous year y and f is the recruitment multiplier. In a deterministic framework where there is no recruitment variability such as this study, $f = 1$. Spawner biomass is calculated by the equation

$$SB_y = \sum_{a=0}^{\max} N_{y,a} \, W_a \, \Psi_a \tag{15}$$

where Ψ_a is the proportion of fish at age *a* that are sexually mature and W_a is the begin-year mass of a fish of age *a*

$$W_a = q \left(L_a\right)^b \tag{16}$$

$$L_a = L_\infty \left(1 - e^{-K(a - t_o)}\right) \quad (17)$$

$$\Psi_a = \begin{cases} 0 & a < a_m \\ 1 & a \geq a_m \end{cases} \quad (18)$$

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

In order to work with estimable parameters that are more meaningful biologically, the stock-recruit relationship is re-parameterised where a 'steepness' parameter, which describes the curvature of the stock-recruitment curve, is defined. The 'steepness' parameter *h* is, therefore, defined as the fraction of the number of recruits at unexploited equilibrium expected when the spawner biomass is reduced to 20% of its pristine level (Francis, 1992). From this we can derive the stock-recruitment parameters as follows

$$a = \frac{4 h R_0}{(5h - 1)} \quad (19)$$

$$b = \frac{SB_0 (1 - h)}{(5h - 1)} \quad (20)$$

(Note that *h* is not defined at 0.2, as there is no surplus production, therefore, a value of 0.2001 is used in the assessment).

Initial conditions

The model is initiated in the year preceding fishing activity. The recursive exponential decay model, merely as a function of natural mortality, explains the initial age-structure of the stock. This is described as

$$N_{0,a} = \begin{cases} R_0 & \text{if} \quad a = 0 \\ N_{0,a-1}\, e^{-M_a} & \text{if} \quad 0 < a < \max \\ N_{0,\max-1}\, e^{-M_{\max-1}} \Big/ \left(1 - e^{-M_{\max}}\right) & \text{if} \quad a = \max \end{cases} \tag{21}$$

Catches and estimation of fishing mortality

Annual catches are described by the catch equation as follows

$$C_y = \sum_{a=0}^{\max} w_{a+1/2}\, N_{y,a}\, \frac{S_{y,a}\, F_y}{M_a + S_{y,a}\, F_y} \left(1 - e^{-M_a - S_{y,a} F_y}\right) \tag{22}$$

where $w_{a+1/2}$ is the weight-at-age of a fish during the middle of the year.

The estimates of F_y are obtained by solving for C_y which represents the observed annual catch. This is conducted by using an iterative linear bisection method (Press *et al.*, 1989).

Yield projections

The estimate of MSY is obtained from the sustainable yield vs. fishing mortality curve as

$$C(F) = YPR(F) \times R(F) \tag{23}$$

where $C(F)$ is the equilibrium catch corresponding to fully-selected fishing mortality F, $YPR(F)$ is the yield-per-recruit as a function of fishing mortality and $R(F)$ is estimated recruitment as a function of fishing mortality.

The yield-per-recruit vs. F relationship (Butterworth *et al.*, 1990) is defined as

$$YPR(F) = \sum_{a=0}^{\max} w_{a+1/2} \frac{S_a F}{M_a + S_a F} \tilde{N}_a \left(1 - e^{-M_a - S_a F}\right) \tag{24}$$

where the relative number of fish at age a, $\tilde{N}_a$, is calculated as

$$\tilde{N}_a = \begin{cases} 1 & if \quad a = 0 \\ \tilde{N}_{a-1}\, e^{-M_{a-1} - S_{a-1}F} & if \quad 0 < a < \max \\ \tilde{N}_{\max-1}\, e^{-M_{\max-1} - S_{\max-1}F} + \tilde{N}_{\max}\, e^{-M_{\max} - S_{\max}F} & if \quad a = \max \end{cases} \tag{25}$$

The equilibrium recruitment corresponding to a fishing mortality of F is

$$R(F) = a - \frac{b}{SBR(F)} \tag{26}$$

where $SBR(F)$ is the spawner biomass-per-recruit as a function of F where

$$SBR(F) = \sum_{a=0}^{\max} W_a\, \tilde{N}_a\, \Psi_a \tag{27}$$

The likelihood function

Catch-per-unit-effort and survey estimates assumed to be indices of relative abundance (Chapter 3) were used to tune the model. For example, assume each CPUE estimate to be log-normally distributed about its expected value.

$$O^i_j = q^i\, E^i_j\, e^{e^i_j} \qquad\qquad e^i_j \sim N\left[0;\left(s^{\,i}\right)^2\right] \tag{28}$$

where O^i_j is the actual CPUE estimate for year j and series i, q^i is the constant of proportionality for series i, E^i_j is the model estimate corresponding to O^i_j and e^i_j is the residual error.

$$E^i_j = \sum_{a=0}^{\max} w_{a+1/2}\, N_{y,a}\, e^{-\left(M_a - S_a F_y\right)/2} \tag{29}$$

The contribution that each CPUE series i has to the likelihood function is

$$L^i = \prod_j \frac{1}{O_j^i \sqrt{2p\, s^i}} e^{-\left(\frac{\left(\ln\left(O_j^i\right)-\ln\left(q^i \mathrm{E}_j^i\right)\right)^2}{2\left(s^i\right)^2}\right)} \tag{30}$$

where the summation is over the years for which CPUE estimates were available, namely 1991 to 1998.

Maximum likelihood estimates of q^i and s^i can be obtained by differentiating Eq. (30) with respect to the parameter of interest and solving the resulting equation

$$\hat{q}^{\,i} = \exp\left(\frac{1}{n^i}\sum_y \ln O_j^i - \ln E_j^i\right)$$

$$\hat{s}^{\,i} = \sqrt{\frac{1}{n^i}\sum_y \left(\ln O_j^i - \ln \hat{q}^{\,i} E_j^i\right)^2}$$

where n^i is the number of data points in CPUE series i.

Substituting the maximum likelihood estimates of q^i and s^i into Eq. (30), taking the natural logarithm, negating, and dropping the terms independent of the model parameters gives the quantity minimised to find the maximum likelihood estimates for R_0 and h.

$$-\ln L = \left(n^i \ln \hat{s}^{\,i} + n^i/2\right) \tag{31}$$

A similar procedure was followed for the survey estimates.

Values for model parameters

The values for the model parameters for the 'base case' assessment are listed in Table 8.4. Values for only two parameters of the population dynamics model were estimated by maximising the likelihood function using a non-linear minimisation algorithm. These were R_0 (pristine recruitment) and h (the 'steepness' parameter) (see Eqs. 19 and 20). The rationale for selecting a plus-group at age 11 is that no monkfish reached this age in the age estimation procedure using hard structures (see Chapter 4). The estimation of the instantaneous rate of natural mortality M is discussed in Chapter 5. The choice of a_{50} is somewhat arbitrary. Monkfish caught in the XXS size category, range between 10 and 16 cm TL (see Chapter 3) and the age-at-50% selectivity was chosen as 1 yr. This was due to the high harvesting levels of juvenile fish by the monkfish and sole and hake directed fleets and, either directly, or indirectly the clogging effect of the nets due to the heavy gear and tickler chains used.

Table 8.4: Values of the fixed parameters of the population dynamics model for the 'base case' assessment. The values used in the sensitivity tests are in parenthesis.

Parameter	Estimate	Source
L_∞ (cm)	95.04	See Chapter 4
K (year^{-1})	0.10	See Chapter 4
t_0 (yr)	-0.31	See Chapter 4
q (g cm^{-1})	0.011	See Chapter 4
b	3.06	See Chapter 4
M (year^{-1})	0.15 (0.09, 0.20)	See Chapter 5
x (yr)	11	See Chapter 4
a_m (yr)	4 (3)	See Chapter 5
a_{50} (yr)	1 (2)	This Chapter

Management-related quantities

The ten management-related quantities used to assess the status and productivity of the monkfish stock are:

K^s	Spawning biomass at unexploited equilibrium (SB_{73}) in 1973
SB_{98}	Spawning biomass at the start of 1998
SB_{98} / K^s	Current 'depletion' in 1998 or the ratio of the spawning biomass at the start of 1998 to that at the start of 1973
$MSYR$ (%)	Ratio of MSY to the spawning stock biomass at which it occurs (i.e., C_{MSY} / SB_{MSY})
F_{SB50}	Fully-selected fishing mortality at which C_{SB50} occur
$C\left(F_{SB50}\right)$	Equilibrium catch at F_{SB50}
$F_{0.1}$	Fishing mortality rate at which the slope of the Y/R curve is 10% of its value near the origin
$C\left(F_{0.1}\right)$	Equilibrium catch at $F_{0.1}$
$F_{\max}$	Fishing mortality rate giving the maximum yield on a Y/R curve
$C\left(F_{\max}\right)$	Equilibrium catch at $F_{\max}$
$-\ln L$	Negative of the natural logarithm of the likelihood function (see Eq. (18))

The quantities K^s, SB_{98} and SB_{98} / K^s are related to the current status of the monkfish resource relative to its pristine level, whereas $MSYR$, F_{SB50}, $C\left(F_{SB50}\right)$, $F_{0.1}$, $C\left(F_{0.1}\right)$, $F_{\max}$ and $C\left(F_{\max}\right)$ are related to the status and potential yield from the monkfish fishery. The negative log-likelihood ($-\ln L$) statistic, describes how well the model fits the abundance indices.

Variance estimation

The option to estimate variability of the parameters of interest was available under the assumption that the errors of the observed data were governed by some statistical distribution other than the Normal distribution. The rationale for this is that we can use Normal distribution theory to easily estimate the variability of Normally distributed parameters. For the other distributions we can use bootstrapping (Efron, 1985; Punt and Butterworth, 1993; Punt, 1994).

Coefficients of variation for the management-related quantities were estimated using the conditioned parametric bootstrap method with 200 replicates. The bootstrapping procedure is described as follows:

By bootstapping we refer to the generation of a large number of pseudo-data sets, with each pseudo-data set point being resampled from the predicted data point, which has some associated error.

For example this can be demonstrated with the assumption of log-normally-distributed CPUE data. For example the pseudo datasets would be calculated as follows:

$$O_j^{i,U} = q^i \, E_j^i \, e^{e_j^{i,U}} \qquad\qquad e_j^{i,U} \sim N\left[0;\left(s^{\,i}\right)^2\right] \tag{32}$$

where $O_j^{i,U}$ is the abundance index for year *j* in the CPUE series *i* and in bootstrap dataset *U*, E_j^i is the abundance index for year *j* in CPUE series *i* obtained from fitting the data to the actual data, and $s^{\,i}$ is the estimate of standard deviation for year *j* in CPUE series *i*.

The assessment model was fitted to the each bootstrap pseudo-data set in turn and statistical properties of the parameters of interest, including standard errors, coefficients of variation and confidence intervals, are calculated using the percentile method (Buckland, 1984).

Risk analysis

Risk analysis is a technique by which the effects of a future catch or fishing mortality trajectory on a resource, in terms of risk and reward, may be determined (Punt and Butterworth, 1990). The impact of future catches can be assessed by projecting the estimated age-structure at the start of 1999 ahead under a variety of possible future catch scenarios. Future catch levels 5 000, 6 000, 7 000, 8 000, 10 000, 12 000, 14 000 and 16 000 tonnes were considered.

Results

‘Base case’ assessments

Point estimates for ten management-related quantities for a range of fixed values for the 'steepness' parameter h and three choices of natural mortality M are given in Tables 8.5 to 8.7. The range considered (0.2 - 1.0) encapsulates the entire spectrum of possibilities from no compensation (h = 0.2) to no reduction in recruitment even if the spawner biomass level drops to very low levels (h = 1.0).

Table 8.5: Estimates of ten management-related quantities for $M = 0.09$, and five choices of the 'steepness' parameter h.

Quantity	h = 0.2[a]	h = 0.4	h = 0.6	h = 0.8	h = 1.0
$K^s\ (\times 10^3 tonnes)$	289.01	198.73	174.12	158.68	150.71
$SB_{98}\ (\times 10^3 tonnes)$	157.36	100.36	86.75	76.86	74.90
SB_{98}/K^s	0.54	0.51	0.50	0.48	0.50
$MSYR$ (%)	-	5.31	8.54	11.83	14.06
F_{SB50}	-	0.04	0.06	0.07	0.08
$C(F_{SB50})\ (\times 10^3 tonnes)$	-	5.16	6.29	6.62	6.95
$F_{0.1}$	-	0.04	0.06	0.08	0.09
$C(F_{0.1})\ (\times 10^3 tonnes)$	-	5.16	6.29	6.90	7.22
$F_{\max}$	-	0.05	0.08	0.11	0.13
$C(F_{\max})\ (\times 10^3 tonnes)$	-	5.41	6.66	7.20	7.62
$-\ln L$	12.45	12.43	12.49	12.52	12.53

[a] $h = 0.2001$ was used in the analysis as the stock-recruitment relationship is undefined when $h = 0.2$.

Table 8.6: Estimates of ten management-related quantities for $M = 0.15$, and five choices of the 'steepness' parameter h.

Quantity	h = 0.2^a	h = 0.4	h = 0.6	h = 0.8	h = 1.0
K^s $(\times 10^3 tonnes)$	281.19	192.58	163.85	154.56	143.69
SB_{98} $(\times 10^3 tonnes)$	152.64	97.85	80.42	77.71	70.39
SB_{98}/K^s	0.54	0.51	0.49	0.50	0.49
$MSYR$ (%)	-	6.47	9.80	13.24	15.59
F_{SB50}	-	0.04	0.06	0.07	0.08
$C(F_{SB50})$ $(\times 10^3 tonnes)$	-	5.26	6.24	6.79	6.99
$F_{0.1}$	-	0.04	0.06	0.08	0.10
$C(F_{0.1})$ $(\times 10^3 tonnes)$	-	5.26	6.24	7.13	7.53
$F_{\max}$	-	0.06	0.09	0.12	0.14
$C(F_{\max})$ $(\times 10^3 tonnes)$	-	5.62	6.77	7.61	7.92
$-\ln L$	12.41	12.40	12.43	12.44	12.47

[a] $h = 0.2001$ was used in the analysis as the stock-recruitment relationship is undefined when $h = 0.2$.

Table 8.7: Estimates of ten management-related quantities for $M = 0.20$, and five choices of the 'steepness' parameter h.

Quantity	h = 0.2^a	h = 0.4	h = 0.6	h = 0.8	h = 1.0
K^s $(\times 10^3 tonnes)$	273.58	184.89	158.73	158.74	138.03
SB_{98} $(\times 10^3 tonnes)$	148.47	94.57	80.02	88.81	69.26
SB_{98}/K^s	0.54	0.51	0.50	0.56	0.50
$MSYR$ (%)	1.08	6.59	11.19	14.79	18.53
F_{SB50}	-	0.04	0.07	0.08	0.08
$C(F_{SB50})$ $(\times 10^3 tonnes)$	-	5.32	6.74	7.76	7.09
$F_{0.1}$	-	0.04	0.07	0.09	0.11
$C(F_{0.1})$ $(\times 10^3 tonnes)$	-	5.32	6.74	8.06	7.92
$F_{\max}$	0.01	0.06	0.10	0.13	0.16
$C(F_{\max})$ $(\times 10^3 tonnes)$	0.23	5.84	7.09	8.48	8.30
$-\ln L$	12.38	12.35	12.37	12.50	12.42

[a] $h = 0.2001$ was used in the analysis as the stock-recruitment relationship is undefined when $h = 0.2$.

The historical spawner biomass and ‘depletion’ trajectories for three choices of natural mortality M and four choices of the 'steepness' parameter h are illustrated in Figures 8.6 to 8.11.

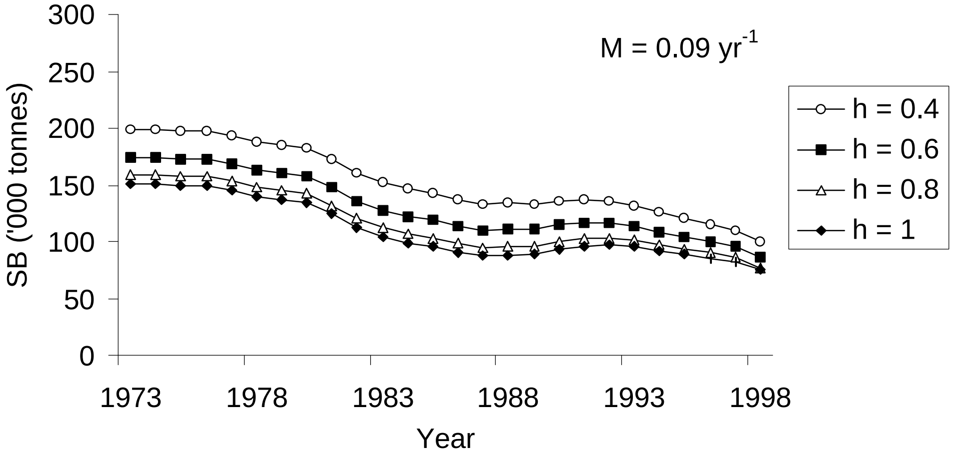

Figure 8.6: Historical spawner biomass (SB) for monkfish off Namibia for four choices for the 'steepness' parameter h and an instantaneous natural mortality rate of M = 0.09 yr^{-1}.

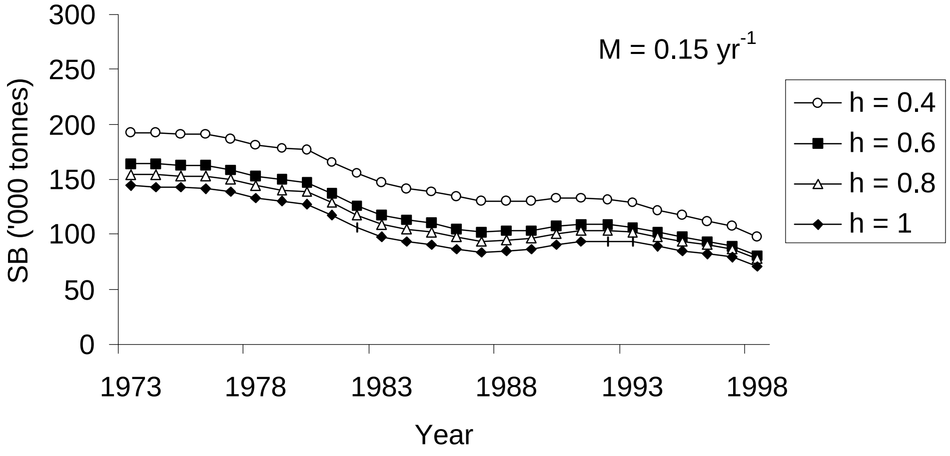

Figure 8.7: Historical spawner biomass (SB) for monkfish off Namibia for four choices for the 'steepness' parameter h and an instantaneous natural mortality rate of M = 0.15 yr^{-1}.

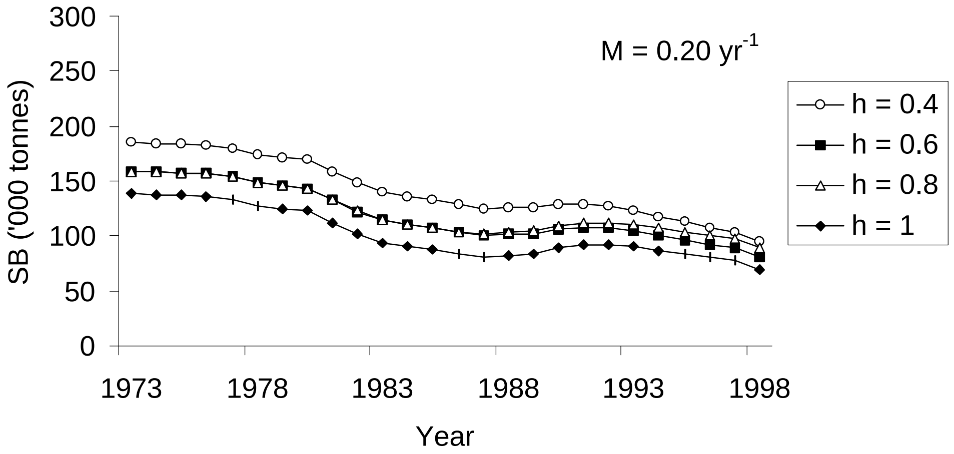

Figure 8.8: Historical spawner biomass (SB) for monkfish off Namibia for four choices for the 'steepness' parameter h and an instantaneous natural mortality rate of M = 0.20 yr^{-1}.

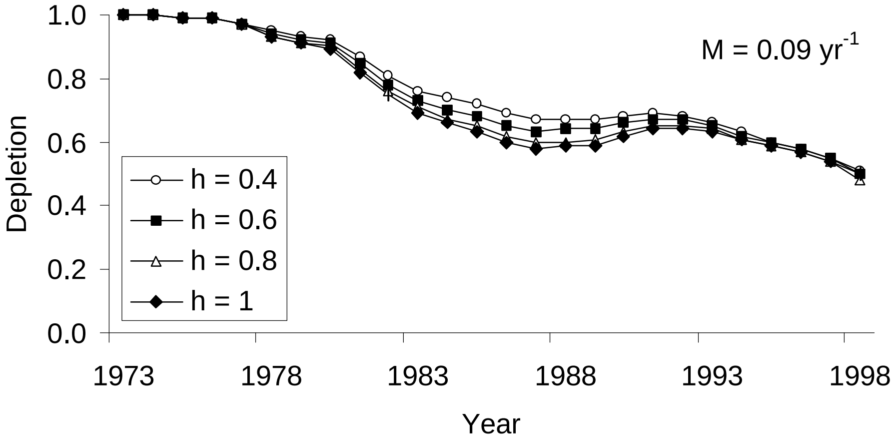

Figure 8.9: Historical spawner biomass as a fraction of its pristine level ('depletion') for monkfish for four choices for the 'steepness' parameter h and an instantaneous natural mortality rate of M = 0.09 yr^{-1}.

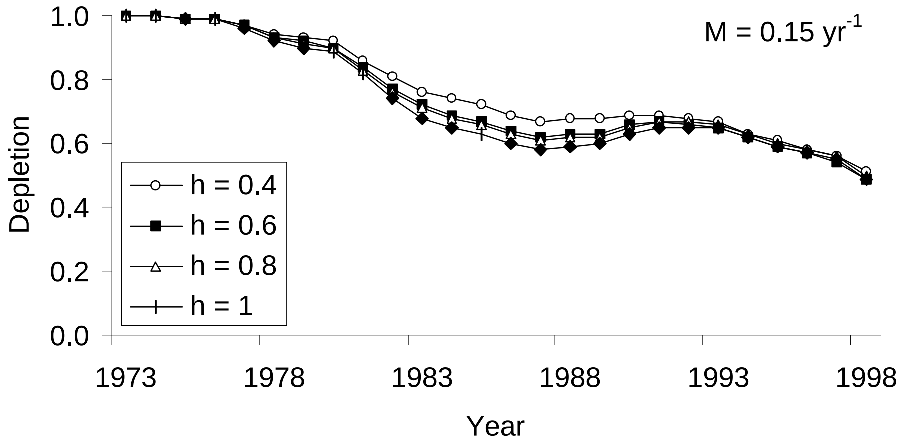

Figure 8.10: Historical spawner biomass as a fraction of its pristine level ('depletion') for monkfish for four choices for the 'steepness' parameter h and an instantaneous natural mortality rate of M = 0.15 yr^{-1}.

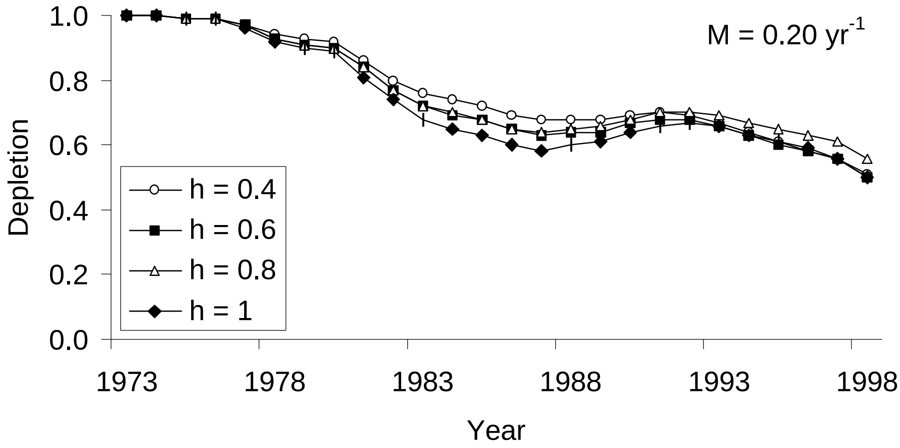

Figure 8.11: Historical spawner biomass as a fraction of its pristine level ('depletion') for monkfish for four choices for the 'steepness' parameter h and an instantaneous natural mortality rate of M = 0.20 yr^{-1}.

Table 8.8: Point estimates, bootstrap CVs and percentile method 95% confidence intervals for ten management-related quantities. The form of estimator applied here fixes the 'steepness' parameter h at 1.0.

Quantity	Estimate	CV	95% CI
$K^s \ (\times 10^3 \ tonnes)$	144.84	122.50	[37.26; 1 242.44]
$SB_{98} \ (\times 10^3 \ tonnes)$	71.55	122.5	[0.40; 1 179.10]
SB_{98} / K^s	0.49	63.20	[0.01; 0.95]
$MSYR$ (%)	15.59	96.04	[1.82; 60.60]
F_{SB50}	0.08	-	-
$C(F_{SB50}) \ (\times 10^3 \ tonnes)$	7.05	122.50	[1.81; 60.46]
$F_{0.1}$	0.10	-	-
$C(F_{0.1}) \ (\times 10^3 \ tonnes)$	7.59	122.50	[1.95; 65.13]
$F_{\max}$	0.14	-	-
$C(F_{\max}) \ (\times 10^3 \ tonnes)$	7.98	122.50	[2.05; 68.48]
$-\ln L$	12.47	-	-
h	1.00	-	-

Table 8.9: Point estimates, bootstrap CVs and percentile method 95% confidence intervals for ten management-related quantities. The form of estimator applied here estimates the 'steepness' parameter h using a non-linear search algorithm.

Quantity	Estimate	CV	95% CI
$K^s \ (\times 10^3 \ tonnes)$	143.56	98.44	[108.34; 1 236.67]
$SB_{98} \ (\times 10^3 \ tonnes)$	70.16	98.44	[24.87; 1 173.01]
SB_{98} / K^s	0.49	38.20	[0.23; 0.95]
$MSYR$ (%)	15.59	132.97	[0.04; 20.49]
F_{SB50}	0.08	71.66	[0.00; 0.08]
$C(F_{SB50}) \ (\times 10^3 \ tonnes)$	6.98	154.52	[0.00; 60.05]
$F_{0.1}$	0.10	77.55	[0.00; 0.10]
$C(F_{0.1}) \ (\times 10^3 \ tonnes)$	7.51	158.90	[0.00; 64.68]
$F_{\max}$	0.14	72.88	[0.00; 0.14]
$C(F_{\max}) \ (\times 10^3 \ tonnes)$	7.89	151.75	[0.00; 67.99]
$-\ln L$	12.47	-	-
h	0.99	56.27	[0.20; 1.00]

Point estimates, bootstrap CVs and percentile method 95% confidence intervals for ten management-related quantities are presented in Tables 8.8 and 8.9, either fixing the 'steepness' parameter h or by estimating h using a non-linear search algorithm.

Sensitivity analysis

The results of the sensitivity analysis are summarised together with those of the 'base case' analysis in Table 8.10. The results are more optimistic when age-at-50%-selectivity is increased. In terms of the 'depletion' levels, results from the 'base case' compared to when age-at-50%-maturity is decreased, were quantitatively similar.

Table 8.10: Estimates of ten management-related quantities from the 'base case' analyses and the two sensitivity tests.

Management-related quantities	'Base case' analysis	$a_m = 3\,yr$	$a_{50} = 2\,yr$
K^s $(\times 10^3\ tonnes)$	143.56	166.68	132.31
SB_{98} $(\times 10^3\ tonnes)$	70.16	83.99	67.55
SB_{98} / K^s	0.49	0.50	0.51
$MSYR$ (%)	15.59	10.01	17.98
F_{SB50}	0.08	0.07	0.10
$C(F_{SB50})$ $(\times 10^3\ tonnes)$	6.98	6.67	7.47
$F_{0.1}$	0.10	0.07	0.12
$C(F_{0.1})$ $(\times 10^3\ tonnes)$	7.51	6.67	7.91
$F_{\max}$	0.14	0.10	0.17
$C(F_{\max})$ $(\times 10^3\ tonnes)$	7.89	7.15	8.30
$-\ln L$	12.47	12.43	12.39

Risk analysis

Deterministic projections from the 'base case' point estimates of spawner biomass and 'depletion' between 1998 and 2003 and 1998 and 2008 for eight scenarios of future catches equaling 5 000, 6 000, 7 000, 8 000, 10 000, 12 000, 14 000 and 16 000 tonnes are presented in Table 8.11. Results are based on the results of bootstraps that consider uncertainty about the 'steepness' parameter h. 'Depletion' in five and ten years time and the probability that the spawner biomass in 2003 and 2008 drops below the current level were the statistics used to quantify catch scenario performance.

Table 8.11: Performance measures for a variety of possible future time sequences of catches (tonnes) from the year 1998 to the year 2008. Results are shown for the case in which M = 0.15 yr^{-1} and the 'steepness' parameter h was estimated using a non-linear search algorithm.

Catch ('000 tonnes)	5	6	7	8	10	12	14	16
'Depletion' (5 yr)	0.56	0.52	0.49	0.46	0.39	0.33	0.27	0.21
'Depletion' (10 yr)	0.67	0.61	0.55	0.49	0.35	0.21	0.07	0.01
$P(SB_{2003} > SB_{1998})$	0.51	0.50	0.47	0.42	0.36	0.34	0.30	0.33
$P(SB_{2003} > SB_{MSY})$	0.60	0.60	0.55	0.52	0.46	0.37	0.35	0.34
$P(SB_{2008} > SB_{1998})$	0.57	0.53	0.47	0.41	0.34	0.26	0.25	0.27
$P(SB_{2008} > SB_{MSY})$	0.62	0.64	0.54	0.49	0.38	0.27	0.30	0.28

Discussion

Length-based methods can be satisfactory and useful for stock assessment, but these methods are usually less ambitious than catch-at-age methods (Hilborn, 1992; Gallucci *et al.*, 1996). One of the major limitations is the restrictive assumption of a steady state condition or constant parameter system (Sparre and Venema, 1998). The model is, therefore, critically dependent on having a length frequency distribution from a population at an equilibrium state. It is assumed that the length frequency distribution of a catch is representative of the catch from one cohort over the years in the fishery, i.e. recruitment and exploitation rates have been stable with no significant trends in either (Lai and Gallucci, 1988; Hilborn and Walters, 1992).

Recruitment to the monkfish resource varied considerably between 1994 and 1998. Substantial variation can also be observed in the exploitation rates (Figures 1.1 and 3.7) and a declining trend is evident in the biomass estimates of monkfish as obtained from data collected by the *RV Dr. Fridtjof Nansen* between 1994 and 1997 (Figure 3.4). Results obtained should, therefore, be interpreted with caution.

The length-based cohort analyses were sensitive to changes in natural mortality. As natural mortality increases, the mean population number ($\sum \overline{N}$) and biomass ($\sum \overline{B}$) increase, whereas the mean fishing mortality, F decreases. Hilborn and Walters (1992) state that if the value for natural mortality (M) is chosen too high, the estimated cohort sizes will be larger than they should be and if the estimated M is smaller than the true value, the cohorts will be too small. These biases may, however, not be serious provided that the estimates of abundance are not regarded as absolute values, but indices to reflect trends in abundance (Lai and Gallucci, 1988; Addison, 1989).

Length-based cohort analysis is, however, insensitive to changes in the terminal fishing mortality (F_t) as indicated by Addison (1989). Low values of F_t had most effect on the population number ranging between 75.3 and 78.1 million for values between 0.10 and 0.16 compared to population numbers of between 73.7 and 74.7 for values of F_t ranging between 0.18 and 0.24.

Similar results were obtained applying the mean number of monkfish caught between 1994 and 1998 (size category data) and the mean number of monkfish caught as calculated from the observer data (1997 to 1998) (Table 8.1). The mean population number and biomass were somewhat higher for the size category data (1997 to 1998) compared to the observer data for the same period.

According to the LCA, the length groups most heavily exploited were 37 to 59 cm (size category data, 1994-1998), 26 to 59 cm (size category data, 1997-1998) and 31 to 50 cm (observer data, 1997-1998).

Small differences in prediction estimates of current yield, MSY and $\overline{B}_{current} \times \Delta t$ were evident when comparing the size category and observer data sets for the period between 1997 and 1998. The estimate of $\overline{B}_{MSY} \times \Delta t$ was, however, somewhat higher when the analysis was carried out using the size category data between 1997 and 1998. Results from the Thompson and Bell prediction model for all three scenarios, however, show that the monkfish population is exploited above MSY -levels. A reduction of approximately 40% in fishing effort would provide a higher yield. The yield-per-recruit (Y/R) curves (Figure 8.5 and Table 8.2) show that, for the three analyses, Y/R ranged between 10 000 and 14 000 tonnes. A 50% reduction in effort would result in a 25% increase in the current yield ($Y_{current}$) using the mean number of monkfish caught between 1994 and 1998 and 1997 to 1998 (size category data) and a 7% increase by using the data collected by the observers between 1997 and 1998. The current biomass $\overline{B}_{current}$ multiplied by Δt would more than double if effort is reduced by 50% for all three scenarios (Table 8.2).

Estimates for ten management-related quantities using three choices of natural mortality M, were sensitive to the value assumed for the 'steepness' parameter h (Tables 8.5 to 8.7). As the value of h increased, the estimate of K^s decreased whilst the estimates of F_{SB50}, $C\left(F_{SB50}\right)$, $F_{0.1}$, $C\left(F_{0.1}\right)$, $F_{\max}$ and $C\left(F_{\max}\right)$ increased. Higher estimates of the ‘steepness’ parameter h imply that the stock is more productive with little reduction in annual recruitment, even if the spawner biomass drops to very low levels. ‘Depletion’ decreased at M = 0.15 yr^{-1} ('base case' scenario) as the value of h increased and the status of the stock was assessed to be below (49%) the target harvesting spawning biomass of 50% of pre-exploitation levels when h = 1.0. Estimates of 'depletion', when M = 0.20 yr^{-1}, ranges between 54% (h = 0.2) and 50% (h = 1.0) and those for M = 0.09 yr^{-1} between 54% (h = 0.2) and 48% (h = 0.8). Of the various values of h considered, $h = 1.0$ provided the best fit to the data.

The results were quantitatively sensitive to the value chosen for M. When h = 1, the estimates of spawning biomass and equilibrium catch at F_{SB50} for M = 0.15 yr^{-1} were lower than those for M = 0.09 yr^{-1}. As expected, the results for M = 0.20 yr^{-1} suggested a more productive stock due to yield-per-recruit effects.

If the parameter h was estimated using the search algorithm (Table 8.9), the confidence intervals for the estimate ranged between 0.2 and 1.0 (CV = 56.27%). The best-fit estimate of h was, however, the maximum possible. Lower CVs were expected when the ‘steepness’ was fixed (Punt and Japp, 1994; Booth and Punt, 1998). Bias was possibly included during the bootstrap estimation procedure (Punt and Japp, 1994).

Point estimates of approximately 7 000 and 8 000 tonnes were obtained for $C\left(F_{SB50}\right)$, $C\left(F_{0.1}\right)$ and $C\left(F_{\max}\right)$ respectively. These estimates were incorporated into the risk analysis to assess tradeoffs of various catch scenarios to stock sustainability.

The 'depletion' level of the monkfish resource is currently calculated to be 49%. This is primarily due to unsustainable catches since 1992. In addition, large numbers of juvenile monkfish are currently harvested, which may lead to growth overfishing (see Chapters 3 and 5). Another important issue was addressed by Butterworth and Bergh (1993) and O'Boyle (1993) that stated "Below what level of B_{sp}/K should one become concerned about recruitment overfishing?" and "To date, there has been no quantification of a minimum spawning stock biomass to prevent recruitment overfishing", respectively. The question remains unanswered.

Estimates of overall productivity ($MSYR$) for the monk stock were found to be higher than the longer-lived kingklip *Genypterus capensis* (Punt and Japp, 1994) (approximately 10%, age 30 years) and similar to both the panga *Pterogymnus laniarius* (Booth and Punt, 1998) (17-19%, age 20 years) and hake *Merluccius spp.* (Punt, 1994; Payne and Punt, 1995) (15-20%, age 15 years) stocks. The overall productivity of the monkfish population was estimated to be approximately 16%, ranging between 7 and 13% for lower values of the ‘steepness’ parameter h in the ‘base case’ analysis. Results of the sensitivity analysis revealed that productivity of the monkfish resource increased even further as the age-at-50% selectivity increased, principally due to the increased spawner biomass.

Estimated CVs (98%) for K^s were lower (estimated 'steepness' parameter h) than that obtained by fixing the ‘steepness’ parameter but higher for $C\left(F_{SB50}\right)$, $C\left(F_{0.1}\right)$ and $C\left(F_{\max}\right)$. This was due to the lack of a defined trend within the abundance indices used to tune the model. The results of the risk analysis suggest, as expected, that under a scenario of future catches above the current estimates of yield, the spawner biomass would continue to decline. As a result, catches in excess of 7 000 tonnes are unsustainable. If a future catch of 5 000 or 6 000 tonnes is considered, the risk of stock collapse would be decreased with possible evidence of stock recovery.

As far as length-cohort analysis and prediction models are concerned, Hilborn and Walters (1992) stated that length-based analysis has very seldom lead to useful management advice. Limits of the ASPM framework are, first, that recruitment is deterministically related to spawner biomass by the application of the stock-recruitment relationship via the 'steepness' parameter h and second, the model assumes similar selectivity and exploitation patterns throughout the period under review. Finally, the model estimates total mortality instead of fishing mortality in the calculation of annual catches. This is due to the correlation between fishing and natural mortality in Equation 9.

A Bayesian statistical approach may be an option for future stock assessment work on monkfish. Bayesian methods can be used to account for and convey the full range of uncertainties related to the models and parameter values used (Punt and Hilborn, 1997), thereby offering an elegant and theoretically consistent framework within which to provide policy advice (McAllister *et al*., 1994). Punt and Hilborn (1997) concluded that a need exists for the implementation of a variety of stock assessment models, since more confidence is attained, if results are insensitive to model and estimator choice.

To further complicate issues, it has been established that fisheries management and stock assessment is a decision problem on how to make the best choice in the face of biological, economic and political uncertainty, given certain constraints on data (Hilborn, 1992). Considerations for the development of a management procedure for Namibian monkfish, with reference to the results obtained by this study, will be discussed in the Chapter 9.

CHAPTER 9 - Towards the development of a management procedure for monkfish in Namibia

Introduction

Fisheries management is faced with three distinct and often, conflicting considerations. First, adequate spawner biomass needs to be maintained within safe biological limits to ensure maximum recruitment to the fishery under favourable environmental conditions. Second, the economics of the fishery needs to be considered, as managers and industry alike wish to achieve high and sustainable revenue from stock resources. Finally, social aspects need to be taken into consideration to ensure that adequate employment is provided and maintained (Payet, 1997).

The current crisis in world fisheries (FAO, 1995; Garcia and Newton, 1997) reflects some of the weaknesses of fisheries management (Cochrane *et al.*, 1998; Cochrane, 1999). These weaknesses include biological uncertainty, multiple and conflicting objectives that are poorly specified, social and economic objectives that override the sustainable utilisation of fisheries resources, and the failure to include all stakeholders in the process of decision-making (Cochrane, 1999). However, the development and implementation of management procedures may provide a framework in which to address some of these problems (Cochrane *et al.*, 1998). Some fisheries in South Africa (the pelagic, hake and West Coast rock lobster fisheries) and Iceland (Icelandic cod) (Butterworth and Bergh, 1993; Baldursson *et al.*, 1993; Payne and Punt, 1995) have been managed by well considered management procedures for a number of years. Similar procedures are being developed in Australia, Greenland and New Zealand (Cochrane *et al.*, 1998).

The aim of this chapter is three-fold. First, to provide an overview of monkfish fisheries and their management on a global scale. Second, to provide an overview of management procedures, including management measures, and finally, using the findings of this study, to provide options for the development of a management procedure for monkfish in Namibia.

Global monkfish fisheries and management

Monkfish are caught off the coast of the Northeastern United States southward to North Carolina (*L. americanus*), and off the coasts of Norway (*L. piscatorius* and *L. budegassa*), France (*L. piscatorius and L. budegassa*), Spain (*L. piscatorius* and *L. budegassa*), Portugal (*L. budegassa* and *L. piscatorius*), the United Kingdom (*L. piscatorius* and *L. budegassa*), South Africa (*L. vomerinus*) and Namibia (*L. vomerinus* and *L. vaillanti*).

Markets for monkfish products exist in both Europe and Asia. Tails are sold mainly in France, Portugal and other European countries. During the late 1980s and early 1990s a market for whole monkfish was developed in Korea. Since the early 1980s, Japan has been importing monkfish livers, which are used for stews and flavouring (Idoine, 1998). In addition, monkfish cheeks (from fish > 75 cm TL) are well developed and considered by some as the most favoured consumable monkfish product (Churchill, 1994).

The reported world catch of monkfish during 1990 exceeded 75 000 tonnes. The Northeast Atlantic and European catch accounted for approximately 50 000 tonnes while the Northwest Atlantic accounted for 10 000 tonnes (Churchill, 1994).

On the East Coast of America, monkfish catches off the Scotian shelf and northeastern Georges Bank, increased from 96 tonnes in 1964 to 18 000 tonnes in 1975 with the USSR as the dominant harvesting nation (Beanlands and Annand, 1996). The USSR landing statistics are, however, not considered to be reliable (Beanlands and Annand, 1996). In 1978, landings declined to 300 tonnes. Between 1978 and 1985, it was assumed that no significant exploitation of the resource took place as reported catches of monkfish were low. It is, however, unknown whether monkfish was actually caught and used for fishmeal or discarded. The scallop fleet reported the highest landings (monkfish bycatch) off Western Bank (ICES area 4VW) during 1986 and 1987 (1 900 tonnes) and off

Georges Bank (5Zc) between 1989 and 1991 (1 200 tonnes). Monkfish landings in ICES areas 4VW and 5Zc declined since then, whereas the landings in area 4X increased. Landings in this area increased from 300 tonnes in 1991 to over 1 100 tonnes in 1994. To prevent possible over-exploitation, the mobile gear fleet in this area was restricted to a 20% bycatch of monkfish and a 10% monkfish bycatch limit on the Georges Bank in 1995. As a result of the latter, monkfish catches have declined to around 930 tonnes per annum. These restrictions were, however, not extended to the scallop fleet that landed between 74 and 146 tonnes for the period 1990 to 1995. A gradual decline in the mean size of fish was noted between 1970 and 1995. An increase in landings during 1993 and 1994 resulted in a joint industry / Department of Fisheries and Oceans (DFO) program to collect data for stock assessment purposes (Beanlands and Annand, 1996). During 1996, scientists indicated that monkfish biomass in ICES areas 4VWX was declining, exploitation rates were high and that the fish were mostly immature. It was, therefore, recommended that catches be limited to less than 800 tonnes per annum, which is reflected in the average landings since 1988 (Anon., 1996b).

"As groundfish in the Northeast became depleted, fishers turned to other 'underutilised' species such as monkfish, which now, in turn, are being overfished" (Anon., 1997d). Monkfish landings in New Bedford rose from 2 359 tonnes in 1992, to about 3 357 tonnes in 1996. It was estimated that the port of New Bedford accounted for 30% of all monkfish tails, 40% of livers and 30% of all whole monkfish landed in the United States. The increase in catches led to a decision by the New England Fishery Management Council (NEFMC) and the Mid-Atlantic Fishery Management Council to manage the monkfish caught by the groundfish and scallop fisheries (Stewardson, 1998). The immediate goal of the management plan was to reduce monkfish landings by more than 50% and ultimately to rebuild the stocks to sustainable levels over a 10-year period. This would involve the imposition of access limits, management zones, minimum size limits, and bycatch levels that would restrict monkfish landings in most cases to 136 kg per day over the next three years.

The 'corrected' monkfish landings by U.K. vessels in England and Wales between 1974 and 1986 increased from about 1 600 tonnes in 1974 to a maximum of 5 700 tonnes in 1983 (Elson *et al.*, 1989). A marked decline in landings has, however, occurred since then. Smaller vessels (less than 40 feet) catch monkfish with otter trawls and various tangle and gillnets, whereas vessels over 40 feet, use beam and otter trawls. In some years significant monkfish catches have been made by scallop dredgers, gill and tangle nets, seine nets and 'hook and line' (Elson *et al.*, 1989).

Ireland's landings have increased from 100 tonnes in 1977 to more than 2 000 tonnes in recent years (Fahy and Gleeson, 1992). The fisheries council of the European Union agreed to allocate 81.4% of the North Sea monkfish quota (almost 18 000 tonnes) to the United Kingdom (Anon., 1998b). This was the first time that the U.K. monkfish fishery has been subject to quotas.

Norwegian catch statistics of monkfish date back to 1935. Catches increased from 880 tonnes in 1991 to over 4 000 tonnes in 1993. During the same period, gillnet fishery landings increased from 304 tonnes to 3 470 tonnes. Currently monkfish is caught by gillnets and as a bycatch in the trawl fishery (B.I. Staalesen, IMR Norway, pers. comm.). In 1992, monkfish catches in ICES sub-area VI were 4 600 tonnes (mostly *L. piscatorius*). An additional 12 200 tonnes of *L. piscatorius* and 8 000 tonnes of *L. budegassa* were landed in ICES areas VIIb-k and VIIIa, b (west of Ireland and in the Bay of Biscay along the French coast). Catches have decreased by 50% since 1988 in the ICES sub-areas VIIIc and Ixa, (along the Atlantic coast of Spain and Portugal), indicating a decrease in stock abundance. Catches in these areas were 3 400 tonnes for *L. piscatorius* and 2 100 tonnes for *L. budegassa* during 1992 (B.I. Staalesen, IMR Norway, pers. comm.). During 1993, landings of *L. piscatorius* increased to over 4 400 tonnes, but declined to approximately 1 300 tonnes in 1997.

From global catch statistics it appears that the Namibian monk fishery is currently among the biggest and most valuable monkfish fisheries in the world. However, increasing worldwide demand for monkfish could make the Namibian as well as other monkfish fisheries ‘short-lasting adventures’. Given the notable decline in all monkfish fisheries, it is not surprising that all the harvesting countries have called for the development and implementation of management plans for their monkfish resources.

Management procedures and measures

A management plan is “a written plan for managing a resource encompassing legal, enforcement, social, economic and natural scientific considerations (natural scientific considerations could, for example, be in the form of an operational management procedure)” (Anon., 1997e). An operational management procedure (OMP) is “a scientifically evaluated process defining the manner in which the available data on a resource are used to determine the level of a control measure such as a TAC, thereby incorporating a harvesting strategy” (Anon., 1997e). The procedure must, therefore, set the rules, which specify the data to be collected, the analysis of such data, the management actions to be taken as a result of such analysis, and the means of analysing the results of such actions. Cochrane *et al*. (1998) defined a management procedure (MP) as “a set of rules, derived by simulation and normally implemented for three to five years, specifying how the regulatory mechanism is set, the data collected for this purpose and how these data are to be analysed and used”. For example, the process involves the setting up of an operating model to represent reality and then examining the implications of managing the resource over the next x years (under a range of assumptions about the present stock status and future dynamics of the resource). Considerations for ‘extreme events’ or ‘exceptional circumstances’ should be included and finally, performance statistics should be compared.

Butterworth and Bergh (1993) identified three principal aims for the long-term management of a renewable marine resource. First, to maximise the total catch to be made over a period of time. Second, to minimise the chance that harvesting unintentionally depletes the resource, that is, the resource collapses and third, to minimise variation in, for example, TACs from one year to the next for reasons of industrial and social stability.

Before a harvesting strategy can be adopted, there should be some risk or decision analysis to assess its expected performance (Butterworth and Bergh, 1993). Hilborn (1992) suggests that the key elements of risk analysis are: (i) defining alternative possible states of the fishery (biological, economic and/or social), (ii) estimating the relative probability of the different states of the fishery being the true state, (iii) considering alternative management actions for each possible state of the fishery and (iv) evaluating which action has the best outcome given the possible states of the fishery and their relative probabilities.

Punt (1992b) also indicated that there are at least three phases in the process of selecting management methodologies for a resource. First, there should be an agreement between the decision-makers, in consultation with scientists, on what the objectives are and how these are most appropriately quantified. Scientists should then quantitatively determine the trade-offs associated with a set of candidate alternative methodologies. Finally, the decision-makers should make the final selection between these methodologies.

Butterworth and Bergh (1993) maintain that the selection of a trade-off between risk to the resource and reward in terms of catches made, is ultimately the responsibility of the politicians and not the scientists. Scientists should, however, attempt to ensure that this selection is made on an *a priori* basis related to longer-term concerns, rather than being dominated by short-term considerations such as the total allowable catch (TAC) level for the forthcoming season. Francis (1994) used the phrase “Think five years, act one year” in equivalence to the environmental assertion “Think global, act local”. In addition, Butterworth and Bergh (1993) stated that management procedures should be implemented by means of simulation-tested management procedures, and not by linking annual ‘best’ assessments of resource status to equilibrium-state based biological reference points.

Dealing with uncertainty

Risk, or ‘the probability of something undesirable happening’, arises from uncertainty. The latter is one of the dominant features of fisheries management worldwide (McAllister *et al.*, 1994; Hilborn, 1997). Francis and Shotton (1997) specified six types of uncertainty: (i) process uncertainty that arises from natural variability (e.g. variability in recruitment), (ii) observation uncertainty that arises in the process of data collection, (iii) model uncertainty (all conceptual models used by fisheries scientists and managers are ‘approximations’), (iv) estimation uncertainty (a secondary type of uncertainty that arises from the three above types), (v) implementation and (vi) institutional uncertainty.

Cochrane (1999) recognised the management system to be the mechanism through which to consider the residual uncertainty, as well as to reduce uncertainty at all levels. Cochrane (1999) stated that there is a general awareness of what an imprecise science fisheries risk assessment is. Managers, however, frequently attempt to push catch limits further and further and by ignoring some of the uncertainty in a management system, higher catch rates are allowed in that they are mistakenly justified by reduced risk.

Implementation uncertainty refers to the extent to which management policies are successfully implemented, while institutional uncertainty arises from interactions between different groups, and institutional processes within management. For example, various problems were experienced during the implementation of the management procedure for the pelagic fishery in South Africa, and implementation uncertainty was also one of the major problems contributing to the collapse of the Canadian cod resource (Walters and Maguire, 1996; Cochrane *et al.*, 1998). TACs were overruled or adjusted for socio-economic reasons, whereas illegal landings and discards were suspected in the cod fishery. The primary purpose of joint decision-making between industry and the management authorities to reduce uncertainty was, therefore, defeated. Rice and Richards (1996) stated that effective implementation requires that objectives of management and fishers are essentially the same. Ill-defined social, economic, and political objectives in fisheries management are associated with institutional uncertainty (Francis and Shotton, 1997). Stephenson and Lane (1995) relate part of the reason for fisheries failures in the past decades to the fact that "objectives have been broad, ill-defined, and in many cases not operationally feasible".

Cochrane (1999) identified three characteristics of an ideal management system. First, the management system should reflect, where cost-effectively possible, a reduction of all types of uncertainty. The system must also be robust to the remaining uncertainties while allowing the extraction of an appropriate proportion of the realisable yield. Second, the management system, where relevant, must be effective for multispecies fisheries, keeping in mind that most fisheries are in fact multispecies fisheries. Finally, the management system should be able to provide opportunities for the involvement of all stakeholders.

Cochrane (1999) also presented four additional features of an ideal management system. First, the monitoring and enforcement of management measures must be feasible and cost effective. Second, no unnecessary social and/or economic distortions should be introduced. Third, opportunities and enticement for sustained pressure on fisheries managers to allow increased exploitation of a resource for short-term benefits must be minimised and finally, management costs must be minimised and the procedures must be frequently reviewed and revised to adjust for changes in the status of the resource.

Industry involvement in decision making and conservation

The Canadian Department of Fisheries and Oceans (DFO) after consultation with fishers and industry managers recognised that: "The challenge that lies ahead in most fisheries of the world is for fisheries administrations to move into a new era of co-operation between government and industry. The partnership must be real. …Direct industry participation should lead to a sense of ownership, which will foster a greater sense of responsibility" (Anon., 1998c). Consultation between industry and fisheries scientists during the development of a management procedure for the South African pelagic fishery has lead to the critical re-examination and re-evaluation of objectives and new insights were gained by both parties (Cochrane *et al.*, 1998). The FAO Code of Conduct for Responsible Fisheries states that: "… States should seek to identify relevant domestic parties having a legitimate interest in the use and management of fisheries resources and establish arrangements for consulting them to gain their collaboration in achieving responsible fisheries" (FAO, 1995). Furthermore, countries like Australia, Chile and New Zealand have developed or are in the process of developing mechanisms to involve all users in fisheries management (Pikitch *et al.*, 1997). Cochrane (1999) concluded that successful collaboration would only be achieved once: (i) the objectives and achievable desires of the major stakeholders can be identified and agreed upon, (ii) decisions on management measures are well supported and reflect and contribute to the objectives established, (iii) improved regulatory compliance takes place that would in turn result in lower enforcement costs and fewer violations and conflicts.

Benefits to be derived from a management procedure

A management procedure requires that all parties agree on a set of rules (Butterworth *et al*, 1997). All stakeholders, including fishing industry, management and scientists would, therefore, have the incentive to carefully consider, present and discuss their long-term objectives and plans with other interest groups (Cochrane *et al.*, 1998). Actual changes in the biological understanding of a fishery, normally occur on a scale closer to five years and management procedures are, therefore, usually implemented for a period of three to five years. Major annual assessments would, therefore, not have to be undertaken, thus reducing the workload generated by such assessments (Cochrane *et al.*, 1998). The process of developing a management procedure is also an educational process for all stakeholders and facilitates a greater degree of trust between the affected parties. During the process in South Africa, scientists became aware of the problems facing the industry as well as their operational requirements. Industry, on the other hand, acquired a greater insight into the dynamics and probable variability of the resources as well as the different management scenarios and their biological and socio-economic implications (Cochrane *et al.*, 1998).

Management measures

The key to successful fishery management lies in limiting the impact of the fishery on the resource (Anon., 1996a). Management tools to limit the harvesting of a resource can be divided into *output* controls, *input* controls and technical measures or the ‘how’, ‘when’ and ‘where’ of fishing activities (Anon., 1996a; OECD, 1997). *Output* controls, such as a total allowable catch (TAC), individual quotas and individual transferable quotas (IQs and ITQs) and vessel catch limits, limit the output from the fishery, namely the catch (OECD, 1997). *Input* controls, on the other hand restrict the intensity of fishing activities (Anon., 1996a) and include limited licenses, individual effort quotas and other gear and vessel restrictions (OECD, 1997).

Quota management has the theoretical benefit that it ensures that only the desired amount of fish is removed from the biomass each year. Direct effort control, on the other hand, has the theoretical advantage of directly limiting fishing mortality (Anon., 1996a).

Effort limitation requires that a range of *inputs* to fishing be limited, i.e. the number of vessels in the fleet, the dimensions and hold capacity of the vessels, the amount of gear used and fishing days at sea (Anon., 1996a). It is then assumed that search is random and that the area occupied by the stock and the distribution of fish within the stock remains constant (Beverton and Holt, 1957). With random search and fixed fishing technology the area swept is proportional to fishing effort. Thus with the same effort expended each year a constant fishing rate is imposed. In theory, high catches at constant levels of effort would indicate a healthy stock and low catches a decline (Anon., 1996a). Walters and Pearse (1996) stated that it is, however, evident that assumptions of random search and constant technology have proven to be untenable. If, for example, only limited entry is imposed, efficiency could increase enormously due to the use of larger and more powerful vessels. Effort controls should, therefore, make provision for changes in the types and sizes of vessels and in the technical efficiency (catching power) of the fleet (larger engines, electronics and more efficient harvesting). In addition, effort controls must also take into account changes in the seasonal allocation of fishing effort and changes in the catchability of the fish (Anon., 1996a). An anonymous author stated: "Due to administrative simplicity, licensing systems restricting entry are one of the most prevalent types of input control used in fisheries both within and outside the EU. Where no charges are made, licensing systems have generally proved ineffective in preventing input growth of national fleets and achieving fisheries management objectives, owing to capital stuffing and input substitution" and "Effort can only ever be defined incompletely in terms of measurable characteristics of vessels, gear, fishermen and activity" (Anon., 1997c). An advantage of effort control, when compared to TAC management, is that fishers tend to land everything caught as long as it is marketable and the hold capacity of the vessels has not been reached (Anon., 1996a). Discarding of fish in Namibia is prohibited and fisheries observers and inspectors oversee that fishers comply with the regulation.

Effective TAC management, on the other hand, requires precise annual assessments of the size of a resource in terms of biomass. Only then can TACs be set at the right level as it will ensure that pressure on stocks will not increase dramatically if stock levels decline. In the past, excessive TAC levels due to the over-estimation of biomass have had disastrous outcomes (e.g. cod). Over-exploitation in TAC managed stocks may, however, also be a consequence of non-compliance (OECD, 1997). Quota management also creates an inherent incentive to ‘beat the quota’ by landing too much or by landing as many valuable fish as possible and discarding the rest. Good quayside monitoring and observer programmes could however, eliminate these problems and dumping or discarding at sea. Another consideration within a quota control system is that when TACs are reduced, it may create the desire to ‘fish harder’ and to spend more time at sea selecting the most profitable fish to land. The actual pressure on the various resources may, therefore, be excessive as stocks decline (Anon., 1996a). "Experience of TAC and quota systems worldwide shows that they have generally been inadequate to prevent stock decline" (Anon., 1997c) and "TAC management clearly results in overcapacity, shortened fishing seasons and fluctuating landings" (OECD, 1997).

TACs and technical controls on 'how', 'where' and 'when' fishing takes place cannot properly control total fishing effort. These management tools are, however, important in determining the impact of fishing on the resource (Anon., 1996a). Restricting the 'how' of fishing is done through gear restrictions e.g. cod-end mesh size regulations and gillnet effort can be curtailed by limiting soak time and the number, mesh size and lengths of the nets.

Closed seasons control the 'when' of fishing activities with the aim to keep exploitation rates within desirable levels and to protect the spawning biomass. From an economic perspective, closed seasons could be implemented to ensure that the fishery operates at the most opportune time for markets, that quality problems are minimised or that high bycatch is avoided.

The 'where' of fishing is controlled by means of closed areas. Closures could be short- or long-term or permanent, and are usually implemented to protect juvenile and/or spawning fish. The applicability of this technical measure is, however, influenced by distribution and migration patterns of fish (Cochrane, 1999).

Considerations for a Namibian monkfish management procedure

Management of monkfish and the process of decision making in Namibia

In 1994, 'monk and sole' fishing rights were allocated. These rights entail that such vessels may catch monkfish and sole, while their hake catches are limited by quota. Hake vessels on the other hand, land monkfish as a bycatch, although occasionally monkfish were targeted. To curtail the monkfish bycatch by the hake fleet, bycatch levies were increased in January 1998 from N$ 2 000 to N$ 4 300/tonne (see Chapter 1).

The decision making process in Namibia involves the following steps: scientists from the Stock Assessment Group of the Ministry of Fisheries and Marine Resources (*MFMR*) provide recommendations on the status of a resource to the Director of the *MFMR.* On consideration and approval by the Director, the recommendations are presented to the Sea Fishery Advisory Council. The latter provides a set of independent recommendations to the Minister of Fisheries and Marine Resources, by whom the final management decision is made.

In January 1998, the Director of the *MFMR* called for the development of a management procedure for monkfish, and a Monkfish Working Group (*MWG*) was established. The aim of the *MWG* was to facilitate the utilisation of the monkfish stock to its full potential, through scientifically based management strategies, while ensuring its long-term sustainability. The *MWG* was constituted to be representative of all interested parties that are directly involved in the utilisation, research, development and management of Namibia's monkfish resource. This included representatives from the Ministry and the industry (including members from the 'Monk and Sole Association' that was established in May 1996), and other interested parties as determined by the Minister of Fisheries and Marine Resources. The *MWG* (including the Director of Fisheries and Marine Resources) was to provide the necessary inputs for consideration by the Sea Fishery Advisory Council to provide the Minister with alternatives upon which to make the final decision (Figure 9.1).

However, because of conflicts in another working group, the Minister of Fisheries and Marine Resources imposed a moratorium on the activities of working groups in January 1999. As a result, the formation of the working group for monkfish has been delayed and neither of the parties was able to partake in any discussions on the way ahead. During September 1999, the Minister indicated that working group activities should continue. Activities may, however, only involve discussions of a scientific nature, i.e. no management recommendations by working groups are permitted.

Summarised Data, Knowledge of Life-history and Model Parameter Estimates

Management Procedure

Final Decision

Figure 9.1: A possible management procedure for Namibian monkfish. Note that the Monk Working Group only deals with biological aspects. Socio-economic implications of management decisions are considered within the Directorate of Policy, Planning and Economics.

The implications of a management procedure for monkfish in Namibia

Management procedures include scientific, social, economic and political issues. At this point in time, political and socio-economic implications cannot be predicted and neither can process uncertainty (natural variability, e.g. variability in recruitment). This study has, however, provided a significant proportion of the scientific information required by the procedure as input parameters for decision making.

The data used in this study, of which the bulk was collected after Namibian Independence in 1990, were obtained from a variety of sources. These included fisheries independent (research survey data), dependent (commercial) as well as historical data from the literature. The data were used to identify trends in monkfish abundance and the exploitation pattern of the industry, as well as to provide information on the reproductive biology, growth patterns and mortality of the species. Finally, the status of the monkfish resource was assessed using length-based as well as age-structured production models.

Abundance indices obtained from both the survey and commercial data (standardised and GLM estimated catch-per-unit-effort) were used to tune the age-based stock assessment framework, but these indices should be considered as relative and perceived with caution. Even though both the survey and catch-per-unit-effort (CPUE) indices exhibit a similar pattern over time (decrease between 1994 and 1996 and an increase in 1997/98), considerable variability is evident, aggravated by the short length of the time series. Problems arise when abundance data are relatively uninformative about the dynamics of the stock. The term "relatively" can be defined in this context when the abundance data series is either too short (normally the data series are < 5 - 10 years in length) and/or the abundance indices do not reflect the response of the stock to harvesting pressures. Examples include a constantly declining trend in abundance data, also referred to as "one-way downhill trip" data (Polacheck *et al*. 1993) that can lead to negatively biased estimated levels of stock productivity or temporally invariant indices that do not increase or stabilise when harvesting levels are reduced or fail to illustrate a decreasing trend in abundance when harvesting levels are increased. As monkfish reaches at least 10 years of age, a time series longer than 10 years is required to identify informative trends in both abundance and catch levels, crucial to obtain meaningful results though the population modeling process.

Total biomass indices as well as indices of recruitment and spawner biomass should be considered as under estimates (and hence relative indices), the reasons being that these surveys are directed at catching hake and fishing operations (gear used and trawl speed) differ considerably from that used by commercial fishers. It was also established that the recruitment index obtained from data collected during these hake surveys, are questionable as juvenile fish seem to be severely under represented in the catches. Fisheries independent biomass estimates of the monkfish resource are a desirable option and commercial trawlers could possibly be contracted to undertake this task under the control and supervision of scientists.

Examination of the commercial CPUE data revealed a distinctly seasonal pattern, in all probability instigated by environmental factors beyond the scope of this study. Estimates of CPUE using Generalised Linear Modeling, however, need to be refined by incorporating environmental data.

Furthermore, commercial catch data were analysed to gather information on the size structure of the population as well as to identify changes in the fishing effort of the monkfish and sole fleet in terms of area, depth and vessel size. Data used were the size category and ‘daily’ size category data, as well as length frequency data collected by fishery observers. In addition, these length-based catch data were used as input in the length-based assessment modeling.

Through the analysis of the above data, it was found that the monkfish and sole and hake directed industries currently harvest large numbers of juvenile monkfish. This is of concern as this pattern of harvesting may lead to growth overfishing. It was concluded that certain areas and/or depth zones could not realistically be closed to prevent catches of juvenile monkfish. Industry members indicated that by not compensating vessel operators and crew for monkfish in the smaller size classes, vessel operators are forced to move away from areas where large proportions of juvenile monkfish occur. The success rate of this practice is, however, debatable as juvenile monkfish are still landed in large proportions. Two possible solutions were identified to reduce the harvesting of juvenile monkfish. These were firstly, the use of highly size-selective gillnets opposed to trawling gear and secondly, the testing of rigid sorting grids to select and release monkfish below a certain size.

Gillnet fishing for monkfish in Namibia demonstrated that the harvesting of juvenile monkfish could be reduced substantially. The mean length of the monkfish caught in gillnets (67 cm TL) was significantly larger than the monkfish landed by the trawlers (38 cm TL) and less than 1% of immature fish were landed. However, this method of fishing turned out to be controversial for the same reasons as those identified by Northridge (1991). First, there were several competitive conflicts between gillnets and other gear types and second, gillnet fisheries may have a detrimental impact on commercial species and the environment. If gillnet fishing for monkfish in Namibia were to be reconsidered, the advantages and disadvantages of gillnet fisheries (as listed in Chapter 6) should be carefully weighed against each other and the recommendations provided, taken into account. Finally, it was concluded that as the effect of trawling on the monkfish resource is still not fully understood (indicated by the results obtained from the stock assessment frameworks), the introduction of another full-time or permanent fishing method or gear type should be approached with caution.

On the other hand, experiments testing grid sorters showed promising results in that specific rigid grid sorters were highly effective in releasing juvenile monkfish and it has been suggested that experiments testing grid sorters should continue to receive priority. Once a suitable grid design for monkfish has been identified, studies need to be designed and undertaken to quantify the survival of monkfish released by the grids as well as testing the feasibility of using these grids on a permanent basis in the commercial monkfish and sole fishery.

The need for a biologically based management strategy prompted an investigation into the growth patterns, reproductive biology and mortality rates of the species. Information about these aspects was fundamental as input parameters in both the length- as well as age-structured population models. Monkfish were aged using both otoliths and illicia and the latter was found to be the most suitable structure to determine the age of this species. Length- and weight-at-age as well as maturity- and selectivity-at-age (in conjunction with the results obtained from the investigation on reproductive biology) relationships were constructed from this data and were later used as input in the age-structured production model. However, the optical nature of the illicia margins did not always indicate whether the last annulus was complete, making it impossible to validate growth zone periodicity. It is crucial that the nature of the illicium-margin and the position of the first annulus be studied in greater detail in the near future, as the age related relationships and growth parameters form the underlying framework of both the length- as well as age-based assessment models. Instantaneous natural mortality was inferred as 0.15 year^{-1} or a range of between 0.09 and 0.20 year^{-1} through the application of two different methods. As the growth parameters (L_∞ and K) obtained though age estimates using the illicia are used as input in both methods, amongst other parameters such as temperature, the importance of accurate age estimates are once again stressed. However, in both the stock assessment frameworks, sensitivity analyses were carried out to assess the sensitivity of the models to the value of this parameter.

Finally, the current abundance, harvesting rate and productive potential of the monkfish resource were estimated using length- as well as age-based population models. Both frameworks have limitations and these are discussed in Chapter 8. However, given the uncertainties in the input parameters (natural mortality, the various relationships involving the age of the species and the growth parameters) and the indices used to tune the age-structured production model, both models provided evidence that the monkfish resource was fully to over exploited. Further work would, however, involve the development of an adequate and appropriate database for further age-based as well as Bayesian stock assessment modeling to obtain independent estimates of resource status.

To conclude: process (e.g. variability in immature and mature monkfish biomass indices), observation (through measuring variables such as stock biomass), model (length- and age-based modeling and input parameters) and estimation uncertainties are clearly evident in the assessment of the monkfish resource. The results obtained are the current best estimates of the status of the Namibian monkfish resource and the biological information provided by this study and the preliminary modeling of the data, may be the first step towards the reduction of observation, model and estimation uncertainty. The data presented in this study can also contribute towards creating awareness amongst industry and fisheries managers of uncertainty, and thus the need for all stakeholders to jointly seek solutions for the management of the resource on a sustainable basis.

The concept of a successful industry-government partnership in Namibia has in some quarters been described as 'wishful thinking', 'over-optimistic' and 'naïve'. This common belief is the consequence of previous antagonistic encounters between industry and fisheries managers/scientists. The monkfish and sole industry consists of ten companies. During this study, a good rapport has been established and the industry has become a key player in the collection of data. This was necessitated by the fact that monkfish has been regarded as a minor resource in comparison to the pilchard, hake, horse mackerel and orange roughy resources. During this project a great deal of trust has been created between industry and scientists, and this bodes well for the development of a procedure to manage this small but valuable resource.

Even though the management of the Namibian monkfish resource seems less easy to resolve, a number of options do exist. However, these options should be carefully considered, taking all the advantages and disadvantages into account and involving all stakeholders in the selection process. The first option is to do away with the current monkfish and sole directed fishery and classify all monkfish catches as bycatch (L. Clark, Fishery Economics Advisor *MFMR*, pers. Comm). The second option is maintain *status quo*, meaning limited access and a restriction of 800 HP on vessel capacity. The final option is to implement a TAC (with or without an effort limitation).

The easiest solution would be to abandon the monkfish and sole directed fishery, classify all monkfish taken as bycatch and manage monkfish catches solely by bycatch fees. The hake fleet would benefit in being able to catch more monkfish, if desirable and management would not need to face the problems associated with managing a resource harvested by two different fleets. However, what would be the fate of the current monkfish and sole right holders, including their various employees? An option would be to grant these right holders exploitation rights in other fisheries, for example the hake fishery. Monkfish catches are, however, likely to fluctuate depending on market price, i.e. as monkfish prices increase, these fish will be targeted once again and it would thus defeat the purpose of the initial implementation of rights to catch monkfish and sole. The questions that arose were: how much monkfish bycatch are ‘unavoidable’ by the hake trawlers and would there be enough monkfish (if the TAC for hake was increased) to sustain a designated monk fishery (V. Wiium and L. Clark, Fishery Economics Advisors *MFMR*, pers. comm). While monkfish catches in the monkfish and sole fishery have been increasing since 1996, catches of monkfish by the hake trawlers have been decreasing. This was the result of a bycatch fee implemented on the monkfish taken by the hake trawlers in 1994. In 1998, this fee was increased from N$ 2 000 to 4 300/tonne with wet and freezer trawlers exempted from paying bycatch fees on monkfish catches less than 4 and 2% of the volume of their hake catches respectively. As a result, there was a significant reduction of monkfish bycatch taken by the hake trawlers (from 2.8 to 2.1%) (V. Wiium, Fishery Economics Advisors *MFMR*, pers. comm). It is believed that the bycatch of monkfish by the hake trawlers could be even further reduced, possibly to 1%. Gear modifications such as the use of bobbin gear in stead of ground ropes, adjusting the length of the bridle sweeps, the type of trawl used and possibly the use of semi-pelagic nets may reduce the monkfish bycatch taken by the hake trawlers below 2%. Also, as the increase in the bycatch levy significantly reduced monkfish bycatch, this fee may even be doubled and the exemption limit reduced to 2 and 1% for the wet and freezer trawlers respectively. However, economic costs of deterring monkfish bycatch by the hake trawlers may be high (the use of semi-pelagic trawl gear are likely to reduce hake catches) and will have to be considered. Whether a bycatch of monkfish of 1% by the hake trawlers is too ambitious due to cost considerations, remains to be seen (V. Wiium and L. Clark, Fishery Economics Advisors *MFMR*, pers. comm).

The second option is to maintain *status quo* i.e., limited access and a restriction of 800 HP on vessel capacity. Namibian monkfish and sole fishers have been reluctant to move away from effort control and towards a TAC imposed management measure, for obvious reasons. Industry members have nevertheless indicated that the monkfish catch of almost 17 000 tonnes during 1998 was ‘abnormal’ and have expressed concern about the ability of the resource to sustain catches of this magnitude. An option would be to reduce the number of licenses, but this option would only solve the problem temporarily, as license holders would soon invest in larger and more efficient vessels. Jentoft (1989) correctly stated: “Experiences with indirect regulations are primarily negative: they have scarcely obtained the intended results and often produced unintended consequences” and that “they close the door to new entrants, and, as a consequence, they establish privileges which make the fishery a ‘rich man’s club’”. In view of the uncertainties in the assessment of the monkfish resource and the absence of robust recommendations it is recommended that a precautionary approach (FAO, 1996) be followed and that the *status quo* scenario not be considered as a future management option. Monkfish is a long-lived species and natural mortality is low, therefore, the long term loss (if any) by applying the precautionary principal until more information is available, would be small.

Based on the information provided by this study, the most suitable option for managing the Namibian monkfish resource appears to be the implementation of the third option, i.e. TAC in conjunction with effort control. This would provide an upper limit on fishing effort (input control) as well as on catches (TAC). If the allowable effort were set too high, the TAC would be the limiting factor and *vice versa*. A combination would overcome some of the problems with quota management and also deal with the shortcomings of effort controls alone, e.g. incentives to invest in unregulated inputs, to 'fish harder' and to concentrate fishing during a time when a unit of effort may be more productive. Also, such a combination control measure would reduce the number of effort components that would have to be dealt with if the fishery was controlled by effort alone.

The technical detail of implementing a joint TAC and effort control system would, however, require attention. The process can be done flexibly to meet the needs of each sector of the fishery. One control can be used as the limiting factor whereas the other can function as a 'safeguard'. Experience suggests that, neither TAC, nor effort control can be relied upon alone and by implementing a combination of the two, a ‘double-check’ safeguard is provided (Anon., 1996a).

Another concern of the monkfish and sole industry is how quotas (non-transferable or transferable) would be allocated (equally or based on past performance) if a TAC were to be implemented. Introducing non-transferable quotas can be done by, either implementing quotas in the monkfish and sole fishery and managing monkfish bycatch through levies in the hake fishery, or by allocating monkfish quotas in both the monkfish and sole and hake fisheries (V. Wiium, Fishery Economics Advisors *MFMR*, pers. comm). The first option would require that monkfish bycatch in the hake fishery is limited to the minimum and can be achieved by increasing the existing bycatch levies and/or through gear modifications as mentioned previously. The second option, i.e. quotas for both fisheries would mean that vessels would be operating with double quotas (hake and monkfish). Problems associated with this option are that firstly, a vessel may run out of monkfish quota, but still have hake quota at hand and secondly, the consequences of an increased TAC for hake. The latter may require that, either monkfish quotas for hake vessels are increased to allow for increased monkfish bycatch, or that if the monkfish quota is unchanged, the monkfish quotas for the monkfish and sole vessels be reduced. This option would, however, also mean that the hake vessels would not have the incentive to reduce their bycatch of monkfish (V. Wiium, Fishery Economics Advisors *MFMR*, pers. comm). An option to be considered is that of transferable quotas where quota transfers can take place between the two different fishing sectors. For example, if the hake sector catches monkfish, these fish could be exchanged for hake caught by the monkfish sector (who has hake quotas) and *vice versa*. Such a system should, however, include a substantial bycatch fee to prevent monkfish catches above quota when, for example a hake quota holder runs out of monkfish quota and cannot find any monkfish quota for sale, (V. Wiium, Fishery Economics Advisors *MFMR*, pers. comm).

Jentoft (1989) presented various examples of co-management studies. A system that has proved to work well is one that exists in the U.K. In the early 1970s, producers' organisations were formed to organise raw fish sales and administer the EEC prime support scheme. In 1984, the Government decided to decentralise the management function by transferring regulatory responsibilities to the producers' organisations and instead of dividing the TAC among individual fishers, sectoral quotas were allocated to the producers' organisations for distribution among their members. The question arises whether a TAC could be allocated to the Namibian 'Monkfish and Sole Association' for equal and fair distribution among its members. Jentoft (1989) stated that fishermen's organisations are in a better position to determine the relevant equity considerations based on needs, demands and interests of individual fishers. Governments, on the other hand, follow principles of 'universalism', guaranteeing equal (e.g. quotas allocated on the basis of past performance), but not necessarily fair treatment ('rich'/investors vs. 'poor'/operators).

The development and implementation of a management procedure may be a lengthy process. However, as outlined in the above chapter, such a procedure offers several major advantages. This study has identified some of the uncertainties in the assessment of the monkfish resource, but has also provided a good foundation for further work, upon which to base such a management procedure. Three options by which to manage the monkfish resource were identified and it is anticipated that the most feasible and cost effective solution will be chosen. The final implementation of a Namibian monkfish management procedure rests upon open dialog between scientists, government and industry to prove that it is possible to co-manage a resource using relevant scientific information in the fate of economic and environmental uncertainty.

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