FISHERIES TRAINING PROGRAMME

P.O. Box 1390, Skulagata 4
120 Reykjavik, Iceland

Final Project 2006

THE NAMIBIAN HORSE MACKEREL FISHERY: JUVENILES OR ADULTS?

Rauna Mukumangeni
Ministry of Fisheries and Marine Resources
Brendan Simbwaye Square Uhland St
Private Bag 13355
Windhoek
rmukumangeni@mfmr.gov.na

Supervisor
Dr Vilhjalmur Wiium
Icelandic International Development Agency (ICEIDA)

ABSTRACT

Bio-economic analysis of the horse mackerel fisheries off Namibia was undertaken with the purpose of defining sustainable management measures to support the decision-making process available to fisheries managers for the development of the fishery. A bio-economic model was applied to carry out projections, starting from the current situation and projecting into the future with the purpose of analysing the behaviour of the fishery under different conditions/management measures. Three scenarios are presented: Scenario1: reduction of the TAC for horse mackerel adults and juveniles from 272,432 mt to 250,000 mt and 45,000 mt to 40,000 mt respectively; Scenario 2: reduction in the juvenile allocation by 20,000 mt; Scenario 3: increase in the juvenile allocation to 50,000 mt. Two fishing fleets harvest horse mackerel. Purse-seiners target juveniles and mid-water trawlers target adult horse mackerel. This paper focuses on the biological and economical characteristics of the two different fishing methods. The Beverton and Holt stock recruitment model was applied. For each of the three scenarios, a projection was carried forward through a 12 year period. The results from the model analysis suggest that an increase in the juvenile allocation leads to reduced stock and reduced recruitment as well as reduced profitability of the fishery for adult horse mackerel. The increase results in the fishery being unsustainable and if the current management of the fishery is not changed, the stock will be depleted in the future according to the model.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

EEZ	Exclusive Economic Zone
GDP	Gross Domestic Product
MFMR	Ministry of Fisheries Marine Resources
NatMIRC	National Marine Information and Research Centre
SADC	Southern Africa Development Cooperation.
TAC	Total Allowable Catch
UFE	United Fishing Enterprise

1 INTRODUCTION

South African and foreign fleets heavily exploited the fish resources off Namibia from the 1960s onwards, which led to depleted stocks of small pelagic species, in particular pilchard. Pilchard is one of the three main pelagic species in Namibia. The others are anchovy and horse mackerel.

Since 1995, a quota of juvenile horse mackerel has been allocated to the small pelagic fishery following a collapse of the pilchard stock due to unregulated fishing before independence in 1990. The juvenile horse mackerel allocation was originally seen as a relief measure to keep the small pelagic fishery viable. The juvenile horse mackerel catch is all reduced into fishmeal and fish oil. Adult horse mackerel is caught by mid-water trawlers while the juvenile horse mackerel is targeted by the small pelagic fishery using purse seines (MFMR 2006). In this paper the horse mackerel fishery will be referred to as such, while a distinction will be made on the small pelagic fishery which mainly targets two different species, juvenile horse mackerel and pilchard. Therefore, reference with regards to the small pelagic fishery will be split into small pelagic - horse mackerel fishery which targets juvenile horse mackerel and small pelagic - pilchard fishery which targets mainly pilchard. In practical terms, however, the aforementioned two small pelagic fisheries are one and referred to as the small pelagic fishery.

As the stocks of small pelagic species do not seem to show any improvement, the small pelagic right holders demand increased allocation of juvenile horse mackerel. An increased allocation of horse mackerel juveniles to the small pelagic fishery may have subsequent economical or biological impact. This is an issue of concern for the ministry and needs to be addressed. One of the issues of concern is the impact of the prospective increase of juvenile horse mackerel allocation on the adult horse mackerel fishery and the other issue is the economic yield from fisheries targeting juvenile and adult horse mackerel.

A Beverton-Holt (1957) model is used, with costs and revenue functions added. Information was collected from the Ministry of Fisheries in Windhoek, as well as from the NatMIRC in Swakopmund.

1.1 Problem statement

Juvenile fish catches threaten future populations and catches (Sullivan 2005). It makes little sense to catch undersized fish fit only for fishmeal when the same fish could be caught when larger and more valuable (BCLME 2004). The increased demand for allocation of juveniles and its prospective impact needs to be studied.

1.2 Objective of the study

The main aim of this paper is to analyse the economic yield of an increased allocation of juvenile horse mackerel and the consequent impact on the horse mackerel fishery.

1.3 Goals

The goals of the study are:

- To identify sustainable strategies for the allocation of the horse mackerel stock using biological data and comprehensive socio-economic data on processing and marketing.
- To undertake an economic assessment of the small pelagic - horse mackerel and horse mackerel fisheries and analyse the potential of the resource in biological and economic terms.
- To investigate whether the juvenile horse mackerel allocation has biological and economical long term effects on horse mackerel stock and to establish a sustainable harvesting strategy which will contribute to the socio-economic development of the country.

1.4 Research questions

- Is it economically beneficial to shift horse mackerel exploitation from juveniles to adults?
- What are the effects of an increased juvenile allocation on the horse mackerel fishery?

1.5 Rationale

The fishmeal and fish oil industry is of global importance to livestock production, fish farming and human health (Ronald 2006). The increased demand for fish feed in aquaculture will most likely result in increased pressure on stocks harvested for fish meal production. It is unlikely that supply of commercially available fishmeal and oil will be able to keep pace with the projected increase in worldwide demand of aquaculture and terrestrial animal feed. In recent years, aquaculture has made up approximately 46% of the total annual fishmeal production, a figure that is expected to rise as demand for aquaculture products increases in the next decade (Miles *et al*. 2006).

With no evident improvement in the small pelagic stocks, the status of the fishmeal industries worldwide and considering the small pelagic fisheries needs, this study will provide important information to the design and evaluation of sustainable management strategies for the small pelagic - horse mackerel and horse mackerel fisheries in Namibian waters, with the main aim of benefiting Namibia economically (and biologically) from the resource.

2 DESCRIPTIVE BACKGROUND

2.1 Namibian fisheries

The Namibian fishing industry is based on the Benguela current system, one of the four eastern boundary upwelling systems in the world (the others are off northwest Africa, off California and off Peru). These systems support rich stocks of demersal and small pelagic species (MTI 1999).

Due to unregulated fishing before independence in 1990, fish stocks off Namibia were severely exploited by foreign vessels leading to a near collapse of many stocks. The Namibian pilchard stock targeted by purse seines was depleted, and has not recovered since then, despite low (and sometimes zero) Total Allowable Catches (TACs). The collapse has occurred in both the southern and northern Benguela pilchard stocks (BCLME 2004). At independence, the new government called upon Norway to assist in establishing and enforcing a 200 mile Exclusive Economic Zone (EEZ), a system of fisheries research, appropriate legislation and a monitoring, control and surveillance system (Nansen 2005). Several other nations were also involved i.e. Germany, Spain, and Iceland.

In 1968, estimates place the pilchard catch at 2 million tonnes. Hake catches peaked in 1972 at 800,000 mt. Horse mackerel catches were reported to be 570,000 mt in 1982. These catch levels were not sustainable. Since independence, most stocks have recovered as a result of the implementation of a resource management system that is a model for many other nations. Policies that encourage on-shore processing have seen the contribution of the fisheries sector to the Gross Domestic Product (GDP) grow annually since 1990, with a corresponding increase in employment at sea and ashore for Namibians (FAO 2002).

More than 20 commercially important species are landed. Total commercial landings were 588 405 mt in 2005. A total of 279 vessels were licensed for commercial fishing in 2003 (MFMR 2006). Some vessels have multiple licences allowing them to target more than one species. Foreign flag vessels can only operate with a local right holder and all fish caught by such vessels must be landed in Namibia, at either Walvis Bay or Lüderitz, and counted against the local right-holder’s quota for that species. Any species catch taken by foreign flag vessels are ascribed solely to Namibia’s landings (FAO 2002).

The fishing sector can be divided into the following main fisheries:

Demersal fisheries: Demersal trawlers (19-77 m length) are licensed and mainly target hake (*Merluccius capensis* and *M. paradoxus*), caught in deeper water (trawling is not permitted in less than 200 m depth). Smaller trawlers fish closer inshore for monkfish (*Lophius spp*.), sole and kingklip. Demersal long-liners (19-55 m) also target hake, with smaller quantities of highly valuable kingklip and snoek (FAO 2002). Hake catches were 188,300 t in 2005, and monkfish contributed about 8,200 t to the total catch (MFMR 2006).

Horse mackerel fishery (mid-water fishery): This sub-sector has the largest number of foreign flag vessels, about 12-15 operating at any one time. Twenty mid-water trawlers in the 62-120 m length range were licensed in 2006. The total horse mackerel (*Trachurus capensis*) catch in 2005 was 279 841 mt (MFMR, 2006).

Small pelagic fishery (purse-seine fishery): A fleet of 13 purse-seiners (MFMR 2006), (21-47 m length range) target pilchard (*Sardinops ocellatus*) for canning. Juvenile horse mackerel and anchovy (*Engraulis capensis*) which occurs sporadically in Namibian waters and are also taken for fish meal. Namibia's pilchard stock has not responded as well as others to measures designed to re-build stocks, and there is concern for recruitment levels which appear to be largely influenced by environmental factors (FAO 2002). Caches have declined in recent years from 68,600 mt in 1998 to 25,128 mt in 2005. A zero TAC was set for the 2002 season (MFMR 2006).

Orange roughy fishery (deep-water fishery): This fishery targets orange roughy (*Hoplostethus atlanticus*) and alfonsino (*Beryx splendens*). Trawlers with a length ranging between 31 m and 92 m are used to catch orange roughy. The fishery commenced in 1994 but low catch levels have since reduced the value and importance of the fishery. Total catch reported in 2000 was 1,600 mt for the two species (FAO 2002) and 451 mt in 2005 (MFMR 2006).

Tuna fishery: A fleet with the length range of 19-49 m utilising long-line and pole-and-line gear are licensed to target albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), swordfish (*Xiphias gladius*) and skipjack (*Katsuwonus pelamis*). Some 2000 mt of tuna species and 290 mt of swordfish were landed in 2000. The total tuna landings were 9356 mt in 2005 (MFMR 2006).

Rock lobster fishery: The fishery for rock lobster (*Jasus Ialandii*) is based in the southern port of Lüderitz. Crafts in the length range of 7-21 m are licensed and use lobster traps. The 2000 catch was 365 mt (FAO 2002). The landings have declined to 248 mt in 2005 (MFMR 2006).

Deep-sea red crab fishery: Deep-water traps are used to target red crab (*Chaceon maritae*). Only two vessels were licensed in 2000 in this small but valuable fishery. Being a shared stock, Namibia has initiated joint research activities with neighbouring Angola. Catches since 1998 have been close to the TAC of 2000 tonnes set for the fishery (FAO 2002). Landings for 2005 were reported to be 2408 mt (MFMR 2006).

Line fish fishery: During the year 2006, a fleet of 14 boats in the line fish sector was licensed; nine are larger vessels of which four are freezers and five ski boats. The most popular fish species include snoek (*Thyrsites, atun*), kabeljou or kob (*Argyrosomus inodorus*), blacktail (*Diplodus sargus*), galjoen (*Dichistius capensis*), and West Coast steenbras (Lithognathus aureti), and they form part of the multi-species catch of the commercial line fish sector. The fishery landed 1637 mt in 2006 (MFMR 2006).

Recreational fishing occurs along the coastline using beach-cater rods. Species targeted include blacktail, also known as dassie, (*Diplodus sargus*), galjoen (*Dichistius capensis*), kob, also known as kabeljou (*Argyrosomus spp*.), snoek (*Thyrsites atun*), West Coast steenbras, also known as white fish, (*Lithognathus aureti*), barbel (*Galeichthys feliceps*) and sharks (principally cow shark (*Notorynchus cepedianus*), bronze whaler (*Carcharhinus brachyurus*), spotted gullyshark (*Triakis megalopterus*) and smooth hound (*Mustelus mustelus*) (MFMR 2006).

Cape fur seals (*Arctocephalus pusillus*) are also harvested around Cape Cross, Wolfs Bay and Atlas Bay, with 40,000 seals culled in 2005. Seaweed, predominantly kelp, is harvested at a number of locations. Production in 2005 was 820 mt (MFMR 2006).

2.2 Horse mackerel fishery

Horse mackerel (*Trachurus trachurus/capensis*) also locally known as maasbanker is one of the pelagic species found in abundance off the Namibian coast in the waters of both the Benguela systems (BCLME 2004). It is found in highest abundance mostly as juvenile fish in the Benguela ranging in distribution from Luanda in Angola through Namibia and past the Cape in South Africa. The abundance of the horse mackerel stock increased greatly in the late 1970s possibly as a result of the collapse of the sardine. The yield of horse mackerel will, however, to a large extent depend on the proportion of juveniles caught (Strømme and Sætersdal 1991).

Horse mackerel is caught using one of three main fishing methods: purse seine (targeting juveniles, used in the small pelagic fishery), mid-water trawlers (targeting adult horse mackerel used in the horse mackerel fishery) and by the demersal trawlers (as a by-catch while targeting hake). Adult horse mackerel taken by the mid-water trawl fleet is processed at sea (FAO 2002). The horse mackerel fishery started in 1961. Its catch increased during the 1970s and reached a peak in 1982 with more than 600,000 mt of horse mackerel landed. The fishery produces mainly whole round fish, dried fish and fishmeal (Krakstad 2001). There are 12 right holders in the horse mackerel fishery. In 2005, 20 vessels were licensed to catch adult horse mackerel. Russian freezer trawlers chartered by Namibian companies as well as Namibian-owned mid-water trawlers are used to catch horse-mackerel (NAMPORT 2006). Thus the fishery employs mainly foreigners with few Namibian employees because of the utilisation of the foreign owned vessels.

The annual catches by the horse mackerel fishery of horse mackerel fluctuate between 280,000 mt and 300,000 mt (Figure 1 and Table 1) and it is the largest fishery in terms of TAC allocated and volume landed. The total horse mackerel TAC has fluctuated between 350.000 mt and 410,000 mt and has been constant at 350,000 mt since 2002 (MFMR 2006). Due to low market value, its contribution to final value of production is second to hake accounting for on average 30% of the total final value of production. In 2005, the fishery contributed N$ 637.6 million to the final value of fish and fish products (MFMR 2006).

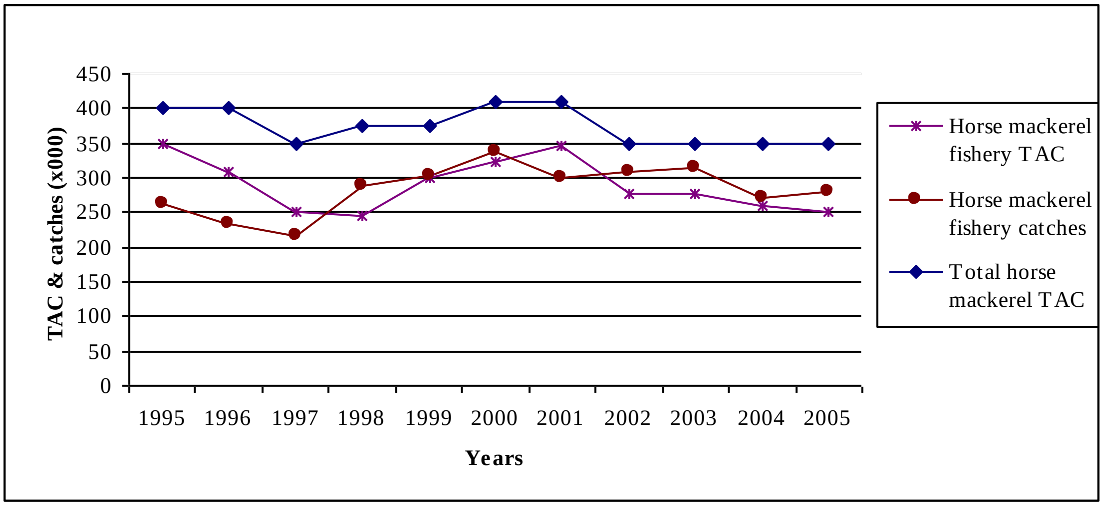

Figure 1: Horse mackerel annual TAC and total catches (10^3 mt) of the horse mackerel fishery, 1995-2005 (Ministry of Fisheries 2006, unpublished)

The contribution of the horse mackerel fishery to the total value of fisheries in Namibia in the period 2000-2005 fluctuated between N$ 502.5 and N$ 928.1 million. Government revenue has significantly decreased from 48 million in 2004 to 24.5 million in 2005. The decrease in government revenue is attributed to a decrease in TAC.

Table 1: Horse mackerel fishery TAC, government revenue, landings and values, 2000-2005 (Ministry of Fisheries 2006*, unpublished)

Years	**Horse mackerel fishery**			
	TAC (mt)	**Landings (mt)**	**Total value of production (N$ mil)**	**Government revenue (N$ mil)**
2000	321,999	322,697	597.6	60.5
2001	347,500	291,357	842.4	53.8
2002	276,000	297,108	928.1	53.5
2003	292,500	308,128	743.0	55.5
2004	260,000	267,230	502.5	48
2005	250,000	272 432	637.6	24.5

*The landings in Table 1 are solely of the horse mackerel resource and exclude the by-catch of the fishery.

Recent stock assessment indicates that the overall horse mackerel stock is low compared to the 1990 level, with indications of low recruitment of the stock (Katoma 2006).

The markets of the Namibian horse mackerel are located in Africa, in particular in the Democratic Republic of Congo, Ghana, Zambia, South Africa and other SADC countries. A small portion is exported to Asia and the Caribbean region (INFOSA 2004). Namibia also faces global competition in this fishery from Mauritania and Chile and Peru.

2.3 Small pelagic fishery

The small pelagic fisheries are particularly important in Namibia and South Africa, and the stocks are closely monitored in both countries, making extensive use of hydro-acoustic surveys. The sardine population, occurring in Namibia and Angola, has been estimated to have declined from approximately 800,000 mt in 1992 to less than 100,000 mt at the end of 1995 (FAO 1997). The most important of the small pelagic fish are the round and flat sardinellas (Strømme *et al*. 1986). In recent years shoals seem to have shifted from the west to the south coast and the resource has declined (BCLME 2004). The small pelagic fishery started during the early 1950s targeting mainly pilchard. Catches of horse mackerel in the fishery were recorded from 1971. There has been a decline from 38 boats in 1990 to 10 active boats in 2001. This is mainly due to the low biomass of pilchard in the last few years. Catches of horse mackerel in this fishery are mainly dependent on market prices of fishmeal and availability (shoaling behaviour) of the juvenile horse mackerel (Krakstad 2001).

The small pelagic fishery targets small pelagic species i.e. horse mackerel, anchovy and sardines. The main target is pilchard, which is also quota regulated. The other pelagic species are not in abundance hence the absence of quota regulation and the focused discussion on pilchard. Due to lower catching of small pelagic species because of unregulated fishing in the 1990s, a quota of juvenile horse mackerel was given to the small pelagic right holders since 1995. The allocation was initially given as a relief measure, in order to sustain the operations of the small pelagic right holders.

The small pelagic fishery has 22 right holders. Fourteen vessels were licensed to the small pelagic sector in 2006, an increase compared to 10 boats in 2001. The fishery had a final value of production of N$ 205.9 million in 2005 with a total catch of 25,128 mt (MFMR 2006). The fishery has a tendency of exceeding its quota (Figure 2).

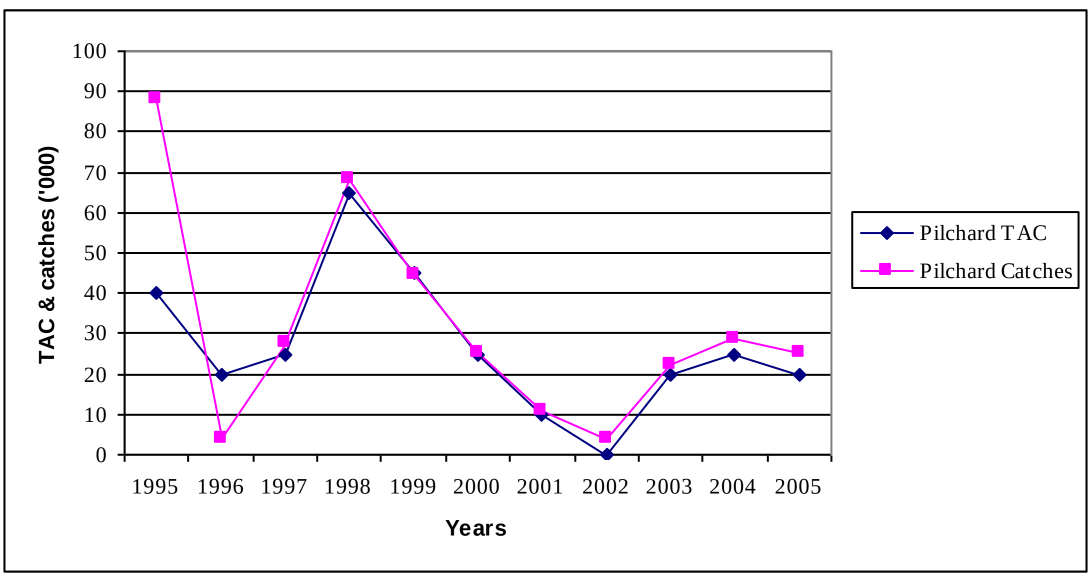

Figure 2: Annual TAC and total catches (10^3 mt) of pilchard in 1995-2006 (Ministry of Fisheries 2006, unpublished)

In the period 2000-2005, the TAC for pilchard has fluctuated between 10,000 mt in 2001 and 25,000 mt (in both 2000 and 2005). Stock collapse resulted in a zero TAC being declared in 2002 as shown in Figure 2 above.

Table 2: Small pelagic -pilchard fishery government revenue and values, 2000-2005 (Ministry of Fisheries 2006, unpublished)

Years	**Total value of production (N$ mil)**	**Government revenue (N$ mil)**
2000	103.9	4.2
2001	66.8	4.21
2002	153.7	11
2003	220.6	3.7
2004	228.5	4.8
2005	205.9	4.6

Offshore employment in this fishery in 2006 was estimated to be 169 employees. This number was calculated using the number of vessels licensed in the fishery in 2006 with an average of 13 crew members on each vessel. The pilchard fishing season is from 1 January-30 August.

2.4 The small pelagic - horse mackerel fishery

The small pelagic fishery targeting juvenile horse mackerel is fairly small with an approximate total value of N$ 9.5 million per year (MFMR 2006). The small pelagic right holders who are catching juvenile horse mackerel are, however, highly reliant on the resource of juvenile horse mackerel for the sustainability of their operations, as the pilchard stock is not doing well, and the anchovy is also limited.

The fishery has invested in two fishmeal plants owned by United Fishing Enterprise (UFE) and Etosha Fishing Corporation (Pty) Ltd respectively. Of the 13 vessels licensed to catch small pelagics, six offload at Etosha and the other seven offload at UFE where their juvenile horse mackerel catches are processed into fishmeal and fish oil.

The amount of juvenile horse mackerel allocated to this fishery has fluctuated between 40,000 mt and 100,000 mt in the period 1995-2005 (Figure 3). The allocation has been constant at 40,000 mt since 2002 to date. The purse seine fleet tends to target juvenile horse mackerel between January and March each year. They then switch to pilchard at the start of the pilchard season in March. The number of people employed in the small pelagic (horse mackerel) fishery at fishmeal plants is said to be fixed on a year to year basis. The two fishmeal plants in total employ 119 people, but the catch of juvenile horse mackerel is seasonal and the employment is mostly on a temporary basis (Table 3).

Table 3: Employment at fishmeal plants in 2002-2005 (MFMR 2006, unpublished)

	United fishing enterprises (since 2004)	Etosha fishing (since 2002)
Permanent	9	10
Temporary	55	45
Total	64	55

The horse mackerel quota was exceeded in 2002 to 2005. The purse seine fleet thus does not only exceed its pilchard allocation but also its horse mackerel allocation (Table 2 and Figure 3).

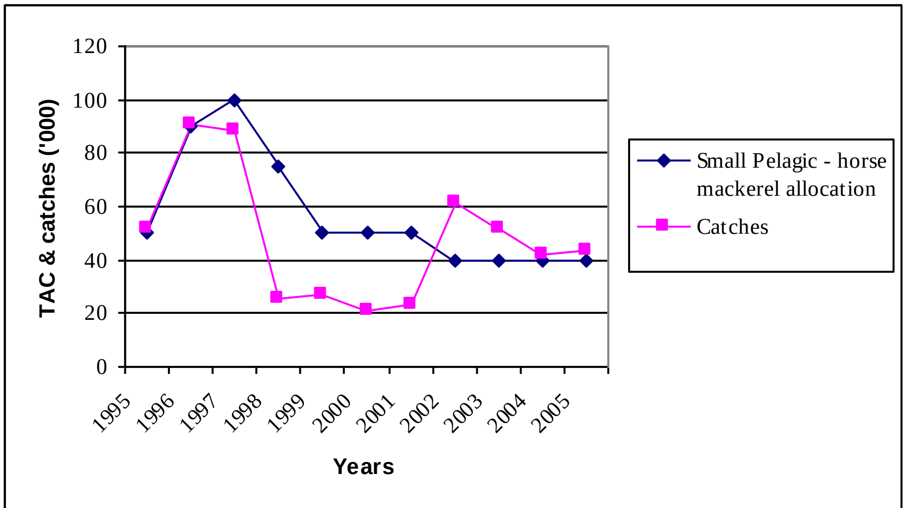

Figure 3: Annual TAC (10^3 mt) and total catches of the juvenile horse mackerel 1995-2005 (MFMR 2006, unpublished)

Government revenue decreased form N$ 11 million in 2002 to N$ 4.6 million in 2005 (Table 4). This could partly be attributed to the number of licensed vessels in the fishery which decreased from 26 vessels in 2005 to 13 vessels in 2006.

Table 4: Small pelagic - horse mackerel fishery government revenue and values, 2000-2005 (Ministry of Fisheries 2006, unpublished)

Years	Total value of production (N$ mil)	Government revenue (N$ mil)
2000	5	3.7
2001	5.1	4.2
2002	13.4	11
2003	11.3	9.3
2004	9.2	7.6
2005	9.5	4.6

Catches of juvenile horse mackerel depend highly on the price of fishmeal and the availability of the juvenile horse mackerel (Krakstad 2001). Fishmeal prices went up steadily in the course of 2005, due to persistent strong demand. Fishmeal prices reached a record level in early 2006, a level that had never been reached in recent history at US$ 880/mt (INFOSA 2006).

The markets for Namibian fishmeal are South Africa, Japan, Spain, Korea, China and Taiwan. Competition is faced from large fishmeal producing nations including Chile and Peru who are among the top 10 fishmeal producing nations in the world. Other countries on the list include China, Thailand, USA, Denmark, Iceland, Norway, Japan and South Africa (Miles *et al*. 2006).

3 LITERATURE REVIEW

The capture of important quantities of small immature fish is a common worldwide problem, threatening the integrity of fish stocks and thus seriously undermining the sustainability of fisheries (Tudela *et al*. 2006).

Far too many young fish of target and non-target species are being caught before they can mature. Worldwide losses, as a result of juvenile fish failing to reach marketable maturity, are thought to run into billions of dollars a year (FAO 2006).

Any type of fishing has some effect on the stock, but the effect of catching large quantities of immature fish is probably proportionally even larger. Fishing activity, even if sustainable always results in the complete reshaping of the age structure of the exploited wild population. In a virgin, non-exploited population, the different age classes in the population are represented in a proportion resulting from the different recruitment strengths (the incorporation of young of the year individuals into the population resulting from each annual reproductive episode and the rates of natural mortality, i.e. predation and other natural causes). In a fish population exploited by a fishing fleet, a new mortality the one inflicted by fishing, called fishing mortality, is added to the population (Tudela *et al.* 2006).

For most exploited fish populations the mature stock would benefit from proportional reductions in juvenile mortality. The results will be based on the fishes' population identity, distribution, migration, the intensity of fishing, the behaviour of the fisherman, and the other management systems in place (Horwood *et al.* 1998). Reduction of mortality of younger fish boosts recruitment to the adult stock Jennings (1999) and the cycle continues; leave more adult fish in the water today and you increase the odds of having more young fish in the future. Take more of the breeding age fish out of the water, and you decrease the chances that stocks will be abundant in the near future (NOAA 2001b).

In Peru, for example, the fishing industry which is primarily export-oriented is undermining the sustainability of fish stocks, mainly due to uncontrolled fishing to supply the fishmeal industry. Peruvian fishers indiscriminately harvest fish regardless of species or size to service the fishmeal industry. This adversely affects marine biodiversity (Sueiro 2005). According to this report the Peruvian fishing industry is in a serious financial crisis. The collapse of the fishery would severely affect the economies of coastal cities and have a negative impact on the national economy given that fishing is such a key element of the economy. In the same report it was revealed that a high catch of juveniles led to decrease of stock.

Juvenile catching, pirate fishing among others were said to be the reasons for dramatically depleted stocks in the Mediterranean region, especially the tuna stocks, leading to an alarming state of the fish stocks. The depletion was also because of the markets, which play a big role. Protection of juvenile fish in populations is critical to the sustainable management of these fisheries. Rather than targeting undersized fish that have not even had a chance to breed, spawning and nursery areas of fish species should be protected (Greenpeace 2006).

Capture of juvenile fish leads to biological impact: recruitment failure, biodiversity change, and collapse of fisheries (FAO 2000). A key issue in securing the future of commercial fisheries is the ability to catch target species of marketable and legal size while minimising the level of discards of smaller or juvenile fish. The objective of this harvesting strategy is to let juvenile fish escape so that they can grow to maturity, help replenish stock and reach a marketable size. Catch of juveniles threatens stocks, thus the problem of limiting juvenile fish catches continues to be a major one in fisheries management world wide. Most juvenile fish catches are a result of by-catches (Cinneide *et al*. 2002).

According to Myer and Merts (1998), if all undersized fish are allowed to spawn and to grow through the fast growth phase to optimum length for harvesting the fishery's landings and revenue will increase despite the fact that some juveniles will die from natural mortality before reaching optimum length. NOAA (2001b) disagrees, however, arguing that as allowing the fish to spawn may seem like obvious propositions, no one had produced compelling evidence that an increase in spawning fish is the key to rebuilding depleted fish stocks. In fact, some scientists and fishermen argue that when it comes to some fish, the most important factor is not the number of spawners, but rather one or more environmental conditions that spawners, eggs and larvae encounter. A single adult female can produce thousands and even millions of eggs depending on the species, over a lifetime. However, a few individuals survive to become juvenile fish. Juvenile fish suffer a high rate of mortality, but the highest and most variable mortality is suffered during the earliest stages, i.e. during egg and larval stages. Mortality of older juveniles is much lower (NOAA 2001b). It is thus not easy to predict the effect on adult stock, as the odds of going from egg to juvenile can vary from year to year. However, until we find out how to predict the effect on the adult stock it makes sense to leave a large enough biomass of spawners in the sea in order to maintain healthy, sustainable fisheries.

Clearly, increasing or decreasing the spawning biomass does not result in a proportionate change in the amount of recruitment it is able to produce. However, as fishing reduces the adult population size of a fish species, the total number of juveniles produced per time decreases (Walters *et al*. 2003). Some fisheries are managed under long-term rebuilding programs because they are long-lived species and do not mature and spawn for a decade or more. The timeframes of rebuilding programs are directly tied to the biology of the fish in question and allow the fisheries to remain viable while the numbers of fish grow to stable stock levels (NOAA 2001a). In the ground fish fishery off the north-eastern U.S for example whose fleet has curtailed its effort since 1994 under a management plan designed in part to protect and increase spawning stocks. Some stocks, but not all of the depleted ground fish stocks, have had increases in spawning stock followed within a few years by increases in numbers of juvenile fish (NOAA 2001a).

Arguments of Beverton *et al.* (1957) agree with some literature referred to above, that if fish are harvested before they have a chance to reproduce, recruitment can be seriously impacted. However, some species of fish do not become sexually mature until well after the time when they are large enough to be of interest to commercial fishing therefore, if unlimited, decreasing likelihood of recruitment. Even if the adults are cannibalistic, it is likely that the remaining fish will grow more rapidly and that a higher percentage of the juveniles will survive and grow up to become adults since many fish populations are resource limited meaning that the availability of food, shelter, and desirable habitat limit the fish distribution and biological productivity. Thus in the absence of competitors for these same resources, when the size of the population is reduced, more resources become available to the remaining fish, reducing the rate of natural mortality. Other writers like Barkai *et al.* (2001) argue that the natural mortality of most marine organisms is very high when they are very young and vulnerable to predation. The rate of natural mortality normally declines as individuals grow older. They argue that the fish caught by fishermen may otherwise have been killed by other predators. For example, substantial amounts of fish which are removed annually from the sea by fishermen are bound to die anyway, even if no fishing takes place. Therefore, it is logical and correct to conclude that a high fishing mortality should be maintained when natural mortality is high, to avoid the loss of potential harvest to predators. Therefore, the potential of juveniles to survive and grow up to become adults depends on the decline in the number of adult fish causing the fish population to abandon marginal habitats, making more resources available. Freshley (2004) agrees that juvenile stocks may have an influence on the adult stock in the long run but that this also depends on their habitat. Juvenile fish may rely heavily on bottom types providing easily accessible cover from larger predators, whereas older individuals might use a wider range of areas because their larger size makes them less vulnerable to predation.

Moran and Kangas (2006) studied the effects of the trawl fishery on the stocks of pink snapper using alternative method of assessing the impact of pre- adult fishing mortality on yields to the fishery on adult snapper. They found that the impact of pre-adult fishing mortality on yields to the fishery on adult snapper played a significant role in depletion of the adult stock. They also looked into the number of juveniles that would become adult stock taking into account the growth and natural mortality rates, by-catch of the juveniles by other fisheries and concluded that the juvenile stock has an impact on the adult stock, even though the natural mortality rate of snapper like the young of most fish species is high.

4 MODEL DESCRIPTION

In this section, a short description underlying the Beverton-Holt model used in this research is presented. A harvest function and economic parts including prices and costs are included.

A bio-economic model was used to calculate fishing mortality, stock in numbers, recruitment, total stock, spawning stock, and fishing effort. In addition, it was also used to calculate costs, revenues, and profits. Catchability was assumed.

The model was constructed with eight year classes and from 2006 to 2018. Fishing mortality rates for three different scenarios were calculated while natural mortality, maturity of fish and weight of fish for the eight year classes were kept constant through the 13 years for the three scenarios. The provided initial data of stock in numbers for 2006 was acquired from NatMIRC. Calculations were made from the year 2007 onwards.

The following is a brief description of the model.

1. Stock in numbers

Data for the first year were acquired from NatMIRC. From the year 2007 onwards stock composition and abundance were calculated.

Stock in numbers is calculated using the following formula:

$$n_2(t) = n_1(t\text{-}1) \cdot e^{-(f1(t)+m(t))}$$

For example, if n_2 is stock in numbers for year class 1 in 2007, then n_1 is stock in numbers of the previous year, 2006, for year class 0. n_1 always represents the year before which is then used in the formula to calculate n_2, stock in numbers for the year after.

The letter *e* represents exponential, which is constant at 2.718 while *f*, is the fishing mortality, *t* represents the year class and *m* is the natural mortality. The procedure is repeated for all years until stock in numbers for all year classes 0-7 are calculated.

2. Recruitment

Recruitment is calculated using the Beverton-Holt recruitment function:

$$R = \frac{\alpha * X}{\beta + X}$$

where α and β are constants and X is the spawning biomass. The values for α and β were acquired from NatMIRC.

3. Total stock

This is calculated by using the following formula:

$$= \sum [n_1(t\text{-}1) \cdot e^{-(f1(t)+m(t))}] * w$$

Where $n_1(t\text{-}1) \cdot e^{-(f1(t)+m(t))}$ is the number of individuals of the specific year (as above) and *w is* the average weight of the same year class.

Total stock is given by the summation of stock in biomass for different year classes of a specific year.

The average weights of different year classes (0-7) used in these calculations were provided by NatMIRC and were fixed throughout the different years. The calculation is repeated for all the years and year classes.

4. Spawning stock

Spawning stock is the summation of stock in biomass of the mature part of the stock (year classes 2 to 7) for a specific year. The maturity of each year class is assumed fixed from 2-7 year classes, and was acquired from NatMIRC.

The spawning stock was calculated using the following formula:

$= \sum [n_1 (t\text{-}1) \cdot e^{-(f1(t)+m(t))}] * w$ for year class 2 to year class 7

The calculations were repeated for all 13 years.

5. Fishing mortality and effort

In the model, a TAC is determined externally by the policy makers. It is assumed that the TAC is fully caught each year. Fishing mortality can therefore be derived for each fishery as the portion of the total stock harvested. Fishing mortality is a function of the effort level of the fishing industry. For each fishery a simple function is used to express this relationship, i.e.

$$F_m = q \cdot E$$

where F is fishing mortality, E is effort and q is the catchability coefficient. The data for the first year allows a calculation of q for each fishery, which is then considered fixed throughout all the years.

6. Revenues

The following equation was used to determine revenue for the horse mackerel and small pelagic (horse mackerel) fisheries respectively:

$$TR_{df} = p_{df} * h_{df} \qquad df = hm,sphm$$

where df stands for different fisheries, hm for horse mackerel fishery, $sphm$ for small pelagic (horse mackerel) fishery, TR is total revenue, p is price, and h is harvest.

Multiplying the price of fish (p) by harvest (h) for the different fisheries (df) gives the total revenue (TR).

It is worth noting that a conversion factor of 4.25 applies to juvenile horse mackerel produced into fishmeal. Therefore, for each 1 metric tonne of juvenile horse mackerel caught, only 0.24 mt of fishmeal is produced

Prices are assumed constant throughout. Price and cost information were collected from the fishing industry (explained in more detail in the next chapter).

A simple cost function is used. All vessels in each fishery are assumed identical, with costs:

$$C_{df} = FC + VC * E$$

C= Total costs
FC= Fixed costs
VC = Variable costs
E= Effort

By using the given formula, the cost of a respective fishery can be worked out by multiplying effort by the sum of fixed costs together with variable costs.

Profits

$$\prod = TR\text{-}TC$$

∏ = Total profits
TR = Total revenues
TC= Total costs

Total profit is calculated by subtracting total cost (*TC*) from total revenue (*TR*).

Using the above formulas, a Beverton-Holt stock recruitment relationship was applied to three scenarios which have different TAC levels as presented below. An initial stock and fisheries situation referred to as base year was established based on current fishing conditions. TAC for the base year was 272,432 mt for the horse mackerel fishery and 43,349 mt for the small pelagic (horse mackerel) fishery. The model projected results 12 years into the future.

Scenario 1: Reduction in horse mackerel to 250,000 mt and juvenile horse mackerel allocation to 40,000 mt
Scenario 2: Reduction in the juvenile horse mackerel allocation to 23,349mt
Scenarios 3: Increase in the juvenile horse mackerel allocation to 50,000 mt

5 DATA

The biological and economic data are presented in this chapter. In addition, estimated parameters for the base year 2006 are also presented here. The base year catches used were for the year 2005 since the 2006 catch information was not yet available. Effort data for the horse mackerel fishery sector for the base year were estimated based on the number of licensed vessels, the duration of the license period, the total number of annual fishing days, and the given average fishing days per vessel. Information from one of the largest companies was used to calculate the estimated effort of 2006.

Effort data for the small pelagic (horse mackerel) fishery were calculated based on total catches for 2005, number of licensed vessels it took to land the catch considering a trip of 2 days at most with an average catch per vessel per trip of 221 mt or 110, 6 mt per day. The data on which the calculations are based where collected from the fishing industry. Information from one of the biggest companies was used to calculate the estimated effort of 2006. The effort data calculation for the small pelagic (horse mackerel) fishery was done on the postulation that all vessels spend the same number of fishing days at sea. A total of 28 days were calculated based on the number of licensed vessels that year and the total catches recorded. The number of licensed vessels was 19 vessels.

The total effort of 3,047, 9 days was calculated based on the averages of five vessels of one of the biggest companies. The given total fishing days of the five vessels was 1,045 days. Dividing 1,045 by 5 vessels derives an average of 209 fishing days per vessel which was multiplied by the fraction of the duration of the licence of the vessel to give the effort of each vessel. The number of days the vessels were licensed were as follows: (1*156, 75+1*69, 7+ 2*17, 42+1*34, 8+2*121, 9=539, 92+12*209 =3047, 9. The fishing season for horse mackerel is from January to December, if a vessel was licensed from the 1 January to 30 March, then effort is 3/12*209. The estimated total effort of 3047, 9 fishing days for the whole horse mackerel fleet per annum was calculated. Effort is calculated by fishing mortality / catchability (FM / q).

The total effort in days, for the small pelagic (horse mackerel) fishery was calculated to be 392. It took 14 vessels 392 fishing days to catch 43,349 mt of fish, meaning that 43,349 mt divided by 14 vessels amounts to 3096, 4 mt which is annual average catches per boat. One vessel takes 28 fishing days to catch its annual average of 3096, 4 mt. The annual average catches per boat of 3096, 4 mt divided by 110, 6 (average catch per day) gives 28 fishing days per boat.

5.1 Biological data

The initial stock data of the base year 2006 used in the model to predict the Namibian horse mackerel stock state 12 years into the future is presented in Table 5.

Table 5: Stock data for the initial year 2006 (Ministry of Fisheries 2006, unpublished)

YEAR CLASS	STOCK NUMBERS (‘000)	AVERAGE WEIGHT (g)	TOTAL STOCK (‘000)	MATURITY	SPAWNING STOCK (‘000)
0	10.2	7	71.3	0	0
1	11.1	18	199.6	0.196	0
2	4.1	52	215.8	0.733	215.8
3	3.1	100	316.4	0.969	316.4
4	1.2	150	194.3	0.997	194.3
5	0.70	218	154.4	1.000	154.4
6	0.33	297	98	1.000	98
7	0.38	530	199.5	1.000	199.5
TOTAL	**31.1**		**1449.3**		**1178.4**

The model parameters M, α, and β estimated by NatMIRC are used in the model (Table 6). The same parameters were used in the evaluation of the biological state of the stock of horse mackerel of 2006. They were taken from the base case model used by the scientists to evaluate the state of the stock and on which recommendations for the 2007 Total Allowable Catches of horse mackerel were based.

Table 6: Values of parameters used in the model, natural mortality rate M, α, β, obtained from NatMIRC, mfmr biological state of the stock report (2006).

Parameters	Values
M	0.4
α	26.866 6
β	1043.66

In Table 7 (below), data used to calculate fishing mortalities for the different fisheries, horse mackerel fishery and small pelagic - horse mackerel fisheries are shown. The formula for calculating fishing mortality is given by: $F_m = q \cdot E$ or by Fm = total catches / total stock. Fishing mortality depends on the Total Allowable Catch (TAC) allocated.

Table 7: Data used to calculate the estimate of fishing mortalities

Method	**Catch (mt)**	**Total stock ('000)**
Horse mackerel fishery	272,432	1178.5
Small pelagic - horse mackerel fishery	43,379	271.0

The initial calculated estimates of fishing mortalities are presented in Table 8 below. They were calculated using the initial biomass and the total catches for the specific fisheries. The catches used were of 2005 because the catches for 2006 are not yet available. However, catches are more or less the same each year and the catches for 2006 are expected to be more or less the same as those of 2005.

Table 8: Parameter estimates of calculated fishing mortalities

Method	**Fishing mortalities**
Horse mackerel fishery	0.231
Small pelagic - horse mackerel fishery	0.159

The catchability coefficients (q) for the two fisheries, horse mackerel and juvenile horse mackerel fisheries differ, as different fishing methods are used. The initial estimated q were calculated using fishing mortality data from the model and calculated estimate of effort based on the information provided by the fishing industry see Table 9 (below). The estimates of q used in the model were fixed in the 12 year prediction into the future.

Table 9: Data used to calculate the initial q estimates of the horse mackerel and small pelagic – horse mackerel fisheries and calculated estimates of q

Method	**Effort (fishing days)**	**Fishing mortality**	**q**
Horse mackerel fishery	3047.9	0.231	0.0000758446
Small pelagic - horse mackerel fishery	392	0.159	0.000408071

In the horse mackerel fishery, fish are harvested from the age of two upwards with most catches falling in the range of 2-3 years, while the small pelagic - horse mackerel fishery harvests fish from zero to the age of one.

Prices and cost data were provided by fishing companies as described in the following sections.

5.2 Economic data: price and cost

Prices for horse mackerel differ for different sizes and from company to company. Prices used in the model were obtained from two of the biggest companies in the two fisheries. Price data used were for the year 2006. A weighted average of final product prices for horse mackerel was calculated taking into account the different prices for the different fish sizes. It was calculated to be N$ 3127/mt. Price for fishmeal is N$ 4836 per tonne.
Different costs are involved in the landing of horse mackerel in the small pelagic - horse mackerel and horse mackerel fisheries. These include repairs and maintenance of vessels, repairs and maintenance of fishing gears, fuel and lubricants, inspectors' cost, levies e.g. by-catch, quota and fund levies, salaries, depreciation, insurance, medical/pension, food and license fees.

Fixed costs in the horse mackerel fishery was derived by taking an average total fixed cost (N$ 18,899,045/5) of the five vessels used in this study to get an average per vessel. The same method was applied for small pelagic - horse mackerel fishery (N$ 3,244,846/4) using four vessels.

Variable costs were calculated by dividing the total variable costs for the five vessels by their total number of fishing days. For the horse mackerel fishery variable costs are N$ 215,347,976/1045 = N$ 206,074 and for small pelagic - horse mackerel fishery N$ 24,226,367/112=N$ 216,306.

The fixed costs for the horse mackerel fishery per boat per fishing day is N$ 3,779,809 variable costs are N$ 206,074. The fixed costs for purse-seines are N$ 811,211 and the variable costs are N$ 216,306.

The calculated fixed costs and variable costs were assumed to apply to all the vessels respectively.

6 RESULTS

The results from the bio-economic model are presented in this chapter for the three scenarios. The model assumes that the whole allocated TAC is landed. Because of the catches of 2006 that are not yet finalised, catches for 2005 were used as catches for 2006 in the model. The base year for the model is the year 2006. The model assumes a fixed TAC (equivalent to landed quota), fixed prices (revenue remains the same for a certain scenario), and fixed catchabilities. The model is, however, price change sensitive as in reality, revenues could either increase or decrease as the dollar fluctuates against other trading currencies.

The projections are carried out in three different scenarios, which are then compared to the base year to establish the implications that a change in TAC has on the biological and economic aspects of the horse mackerel stock. Projections were made over a 12 year period.

6.1 Initial situation (base year 2006)

In the initial scenario, the adult horse mackerel TAC is set at 272,432 mt and the small pelagic - horse mackerel fishery allocation is 43,349 mt. In this scenario, a sharp decrease in total stock and spawning stock (Figure 4), and decreasing recruitment (Figure 5) is observed. Costs in the small pelagic - horse mackerel fishery show an increase and profits a decrease (Figure 6). Profits in the horse mackerel fishery show a decrease while costs increase (Figure 7).

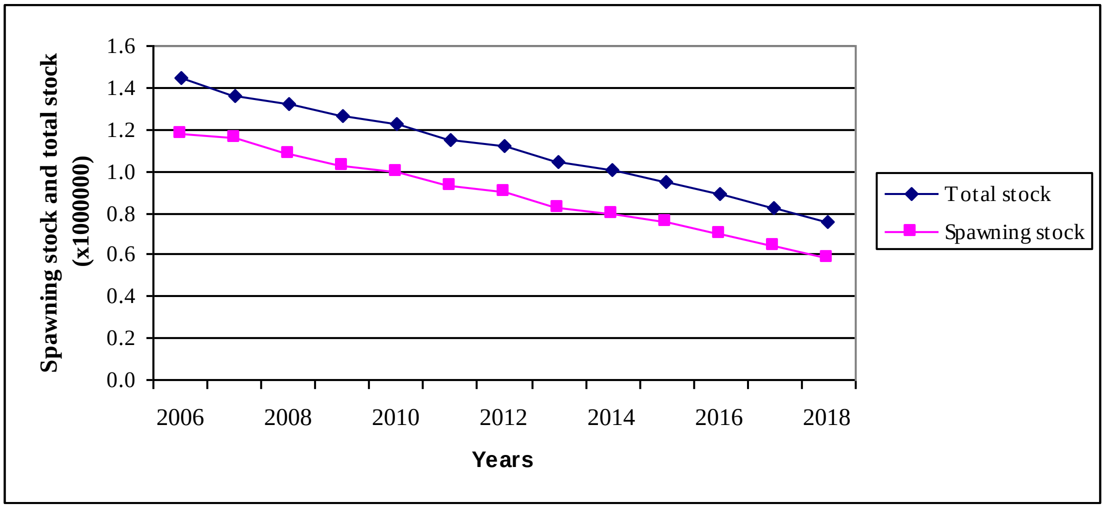

Figure 4: Initial scenario - projections, spawning stock (mt) and total stock (mt) of the horse mackerel, 2006-2018

Decreasing recruitment is attributed to the fact that spawning stock is reduced which is caused by increasing fishing mortalities of the two fisheries. Stock in numbers and spawning stock show a decrease.

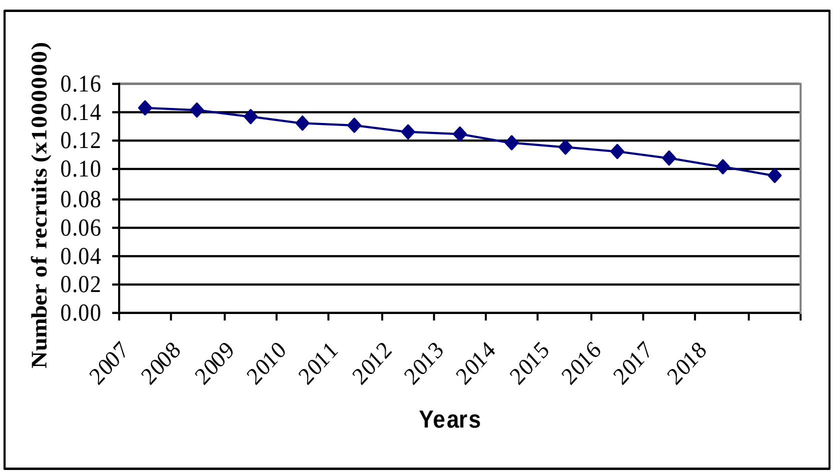

Figure 5: Initial scenario - projected number of recruits of the horse mackerel stock, 2006-2018

More effort is required to catch the fish that is now less available. Effort is increased as the stock is decreased. Effort can be changed either by increasing or decreasing the number of boats or the fishing days spent by boats at sea. When effort is mentioned to have changed, it is either an increase or decrease in the number of fishing days at sea.

The higher the effort, the higher the costs (variable costs) and the lower the profits as shown in Figures 6 and 7. Under an unchanged fishing regime, the model predicts that five years into the future the fishery will experience further negative profits because of decreasing stock that results in increased effort, and thus increased costs.

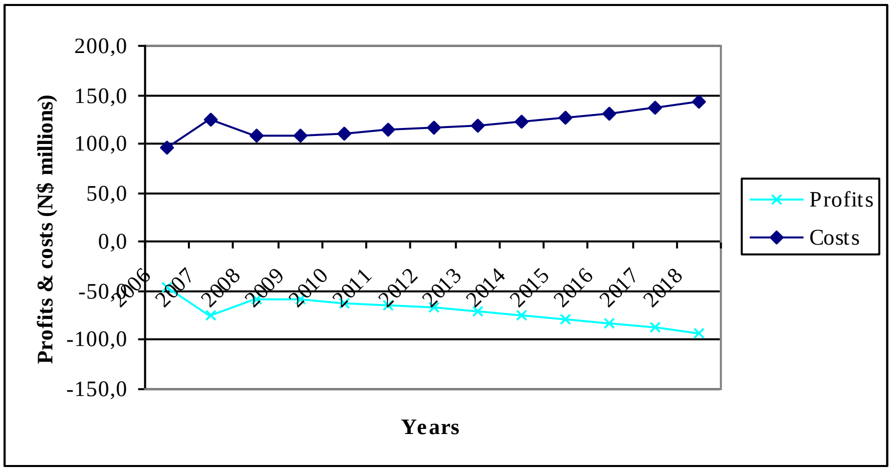

Figure 6: Initial scenario - projected profits and costs of the small pelagic - horse mackerel fishery, 2006-2018

The small pelagic - horse mackerel fishery will be profitable for about 5 years until profits become zero in year 2011 and remain negative afterwards. Profits in the small pelagic - horse mackerel fishery are negative in the base year already because of the high cost of fishing, and the little juvenile allocation not enough to cover the costs.

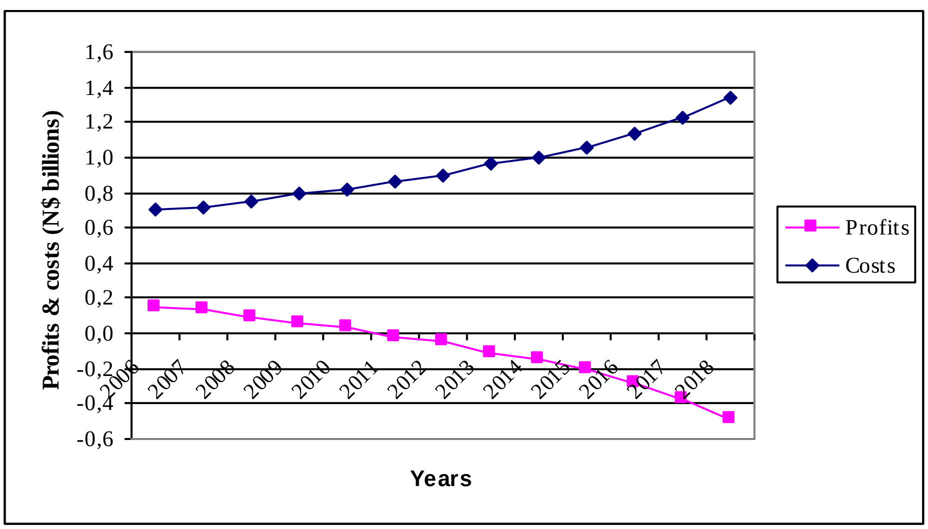

Figure 7: Initial scenario - projected profits and costs of the horse mackerel fishery, 2006-2018

6.2 Scenario 1: Reduction in TAC of horse mackerel to 250,000 mt and juvenile allocation to 40,000 mt

Scenario 1 represents only a modest reduction in the juvenile horse mackerel allocation and the TAC to the fishery from the current or initial situation. The long-term effects of the stock are similar. Reduced catches, increasing fishing mortality, reducing profits of the horse mackerel and small pelagic - horse mackerel fishery and increasing effort because less fish are available.

Under this fishing regime, fishing mortality of adults will remain high, and recruitment will decrease total stock and spawning stock (Figure 9), will decrease as a result of reduced numbers reaching maturity (Figure 8). The decrease in the horse mackerel TAC and decrease in the allocation of juveniles shows a positive impact on the stock although it still does not make the horse mackerel fishery sustainable. Although the total stock and spawning stock are decreasing in this scenario, they show a lower decreasing trend compared to the base year (Figure 8).

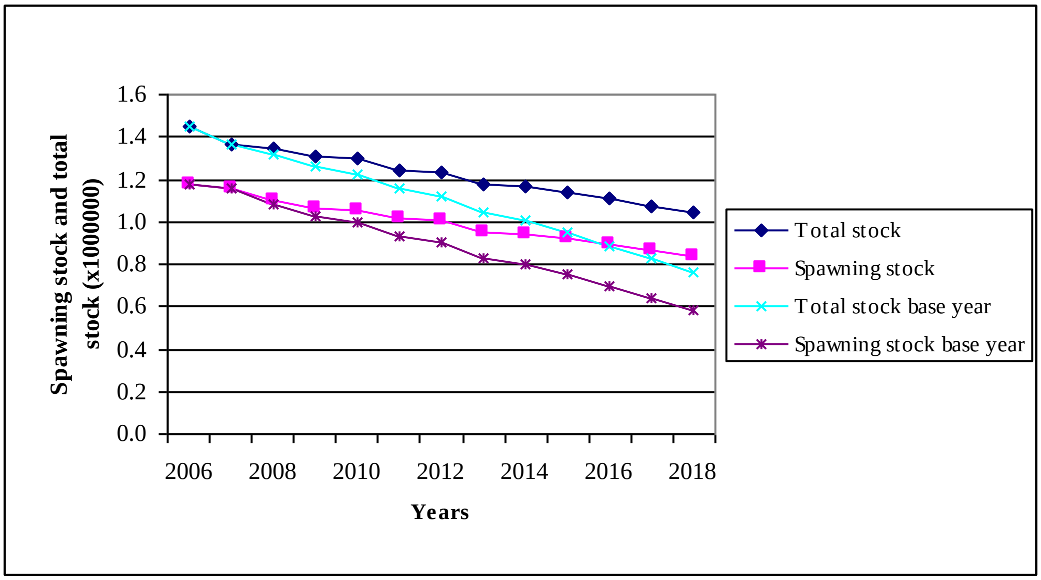

Figure 8: Scenario 1 - projections, spawning stock (mt) and total stock (mt) of the horse mackerel, 2006-2018

The impact of the reduced horse mackerel TAC and lower allocations of juveniles on the stock do not seem to show immediately. It will be visible from around the year 2009/2010 (Figure 9).

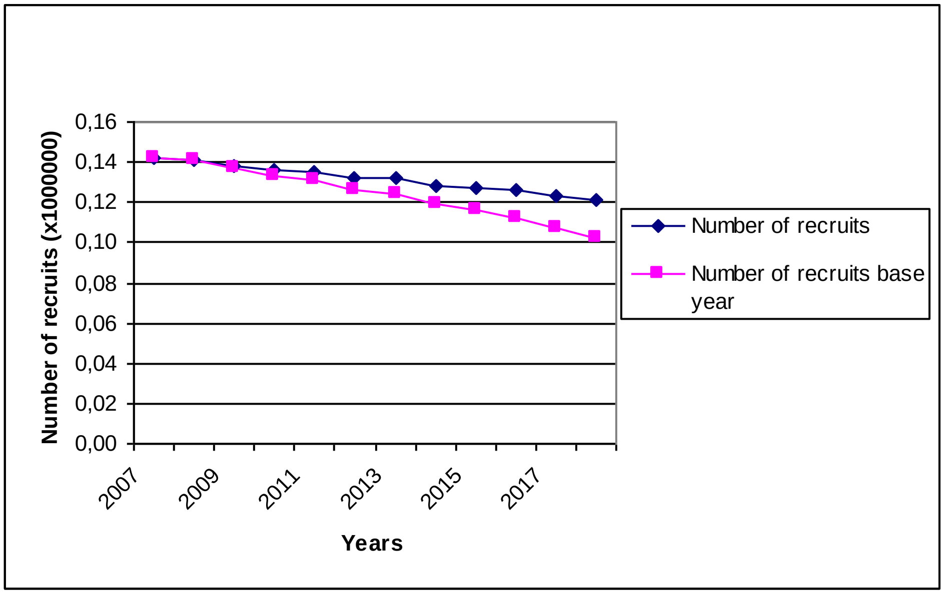

Figure 9: Scenario 1 - projected number of recruits of the horse mackerel stock, 2006-2018

Costs in the horse mackerel fishery show a reduction, while profits show an increase in the first scenario compared to unchanged regulations from the base year (Figure 10). The base year with a higher TAC shows lower profits in the horse mackerel fishery compared to scenario 1 with a lower TAC. The decreasing trend in stock and recruits leads to decreased profits of horse mackerel which become zero in 2013 and remain negative afterwards (Figure 10). The observed negative profits occur two years later in this scenario compared to the base year.

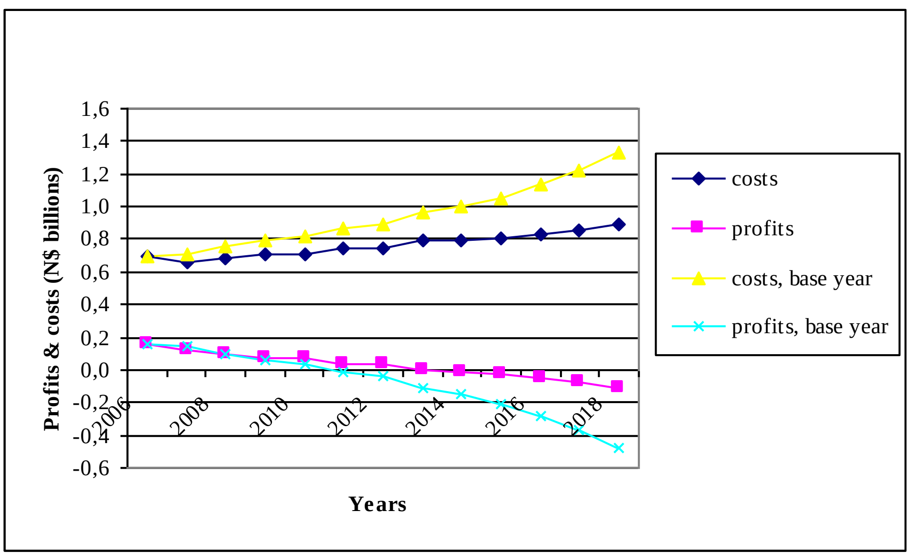

Figure 10: Scenario 1 - projected profits and costs of the horse mackerel fishery, 2006-2018

The small pelagic - horse mackerel fishery shows the same trends as the horse mackerel fishery. Costs are reduced with a lower TAC as less effort is required to catch the fewer tonnes of fish thus pushing the costs down. Scenario 1 with a lower TAC and juvenile allocation compared to base year shows lower costs. The negative profits observed in the small pelagic - horse mackerel fishery are not quite as low in the first scenario compared to the base year (Figure 11).

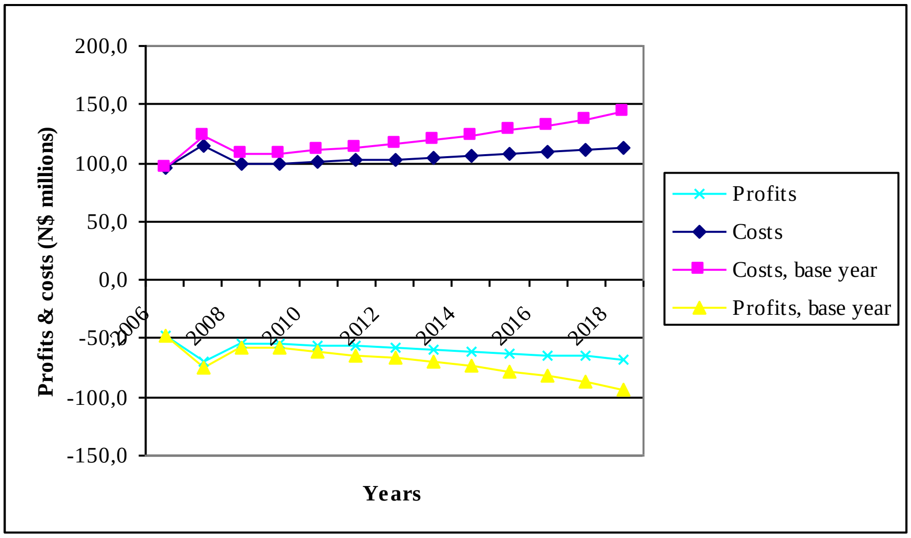

Figure 11: Scenario 1 – projected profits and costs of the small pelagic - horse mackerel fishery, 2006-2018

Although changing the fishing regime from the current to Scenario 1 would constitute an improvement, it will still remain an unprofitable and unsustainable fishery.

6.3 Scenario 2: Reduction in the juvenile allocation by 20,000 mt

Reduction in the juvenile allocation while keeping the horse mackerel fishery's TAC constant has its implications. It reduces the fishing mortality of juveniles and later that of adult horse mackerel as well. A decrease in the juvenile allocation today seems to increase the harvestable stock of adult horse mackerel in the future. This reduction in the fishing mortality leads to increased spawning stock and total stock which is to be observed from the year 2008 after the implemented reduction (Figure 12).

In this scenario, with a low juvenile allocation, total stock and spawning stock show an increase not only compared to the observed reduced total stock and spawning stock in the base year where the adult horse mackerel TAC and juvenile allocation are higher. There is also a real increase in both spawning stock and total stock at the end of the projected period (Figure 12).

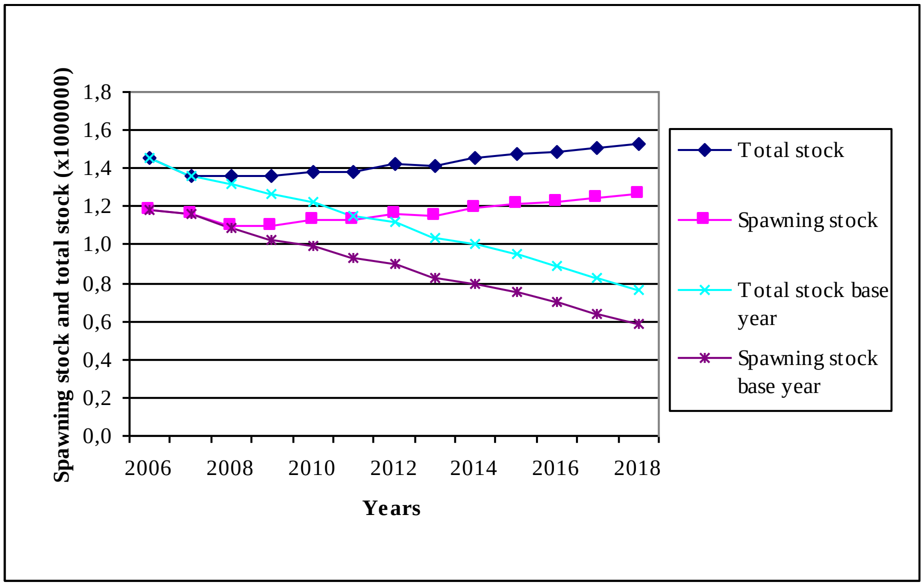

Figure 12: Scenario 2 - projections, spawning stock (mt) and total stock (mt) of the horse mackerel, 2006-2018

Figure 13 below shows the number of recruits of this scenario increasing as a result of the decrease in the juvenile allocation and TAC compared to the decreasing trend shown in the base year. In the first three years after a reduction in the allocation, the number of recruits is shown to be the same as the base year it then begins to increase in the year 2010 and continues to increase stably further. There is also a real increase in the number of recruits predicted by the model using scenario 2.

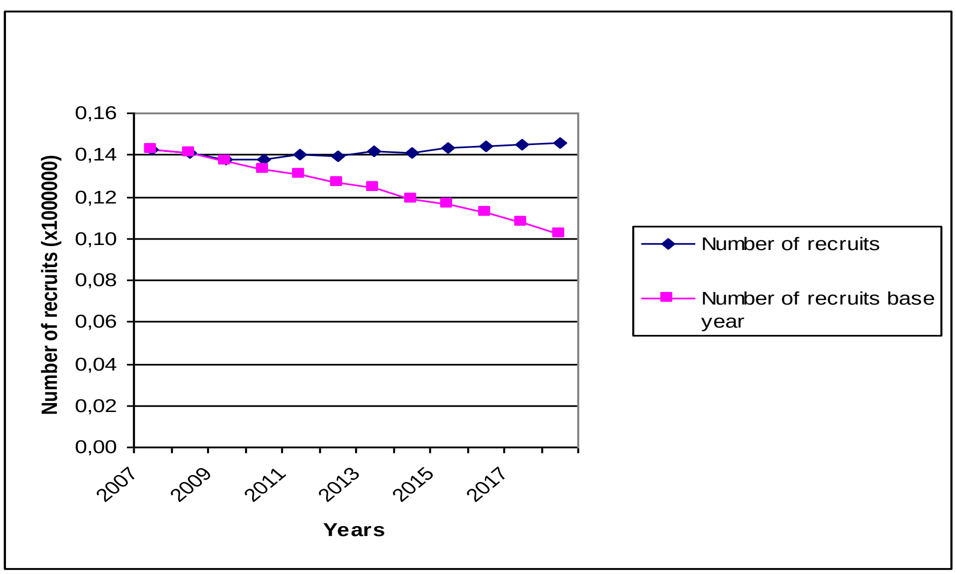

Figure 13: Scenario 2 - projected number of recruits of the horse mackerel stock, 2006-2018

The fishing regime proposed under scenario 2 shows improved profits in both fisheries (Figure 14), even though the small pelagic - horse mackerel fishery profitability is still negative, there is an improvement compared to the base year. A reduction in the juvenile allocation shows relatively stable decreasing costs in the horse mackerel fishery compared to the observed sharp increasing costs that are expected to prevail if the fishing regime remains unchanged as is reflected in the base year. Profits in the horse mackerel fishery remain positive and after a small initial reduction increase steadily during the 12 year projection. This is a major improvement compared to the base year projection, in which profits became zero in the year 2011 and became increasingly negative after that. The profits decline faster in the base year projection compared to how steadily they remain positive in scenario two.

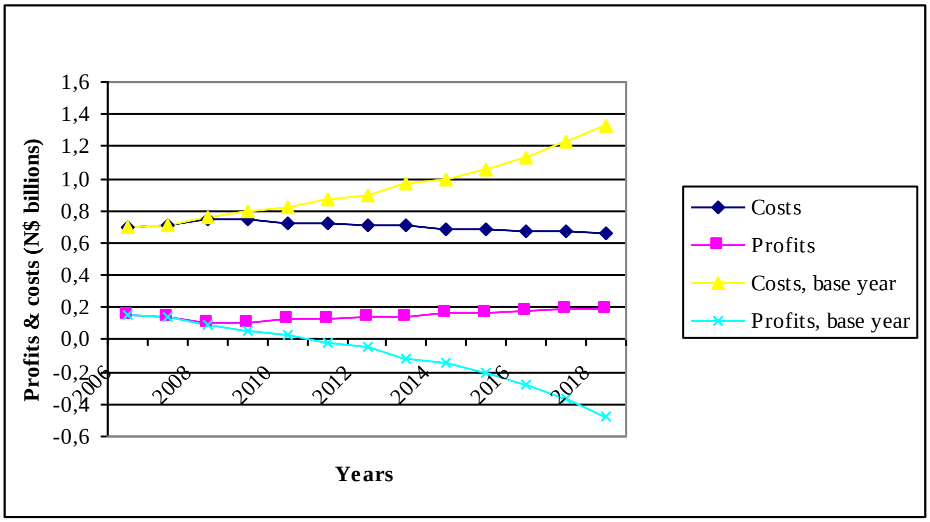

Figure 14: Scenario 2 - projected profits and costs of the horse mackerel fishery, 2006-2018

The small pelagic - horse mackerel fishery is still experiencing negative profits in scenario 2 (Figure 15). The costs show a decreasing but stable trend compared to the increasing costs in the base year. The small pelagic - horse mackerel fishery profitability show an improved, yet still negative, situation in scenario two compared to highly negative profits with a sharp declining trend in the base year.

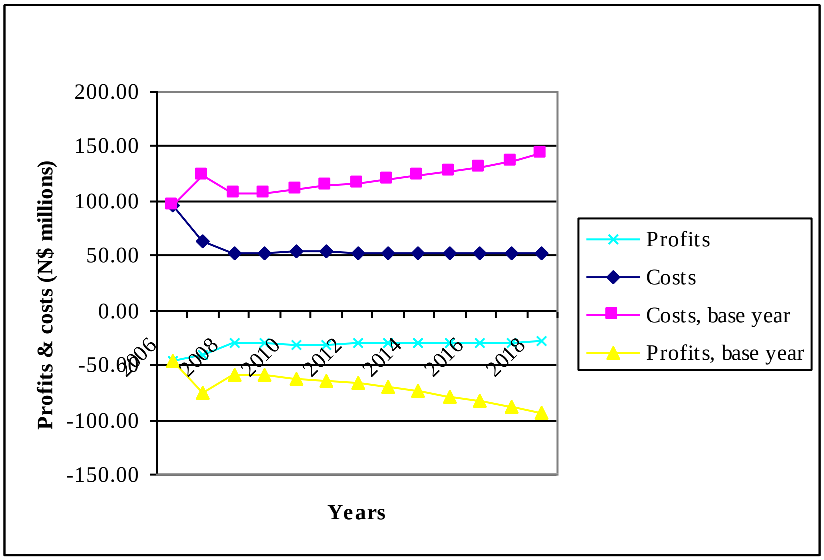

Figure 15: Scenario 2 - projected profits and costs of the small pelagic horse mackerel fishery, 2006-2018

The improved profitability of the small pelagic - horse mackerel fishery shows a trend that suggests positive profits of the fishery if a further decrease in the allocation is made (Figure 15). A further reduction in juvenile allocation would be accompanied by decreasing costs.

A reduction in the juvenile allocation seems to have positive biological and economical impact on the adult stock. In this scenario, the result following the reduction in the juvenile allocation brings the horse mackerel fishery to be sustainable.

6.4 Scenario 3: Increase in the juvenile allocation to 50,000 mt

Increasing the juvenile allocation while, keeping the horse mackerel TAC constant results in increasing fishing mortalities of the adult and juvenile horse mackerel. This leads to a decreasing spawning stock and total stock as is shown in Figure 16 below. The increase puts strain on the adult stock thus reducing the harvestable stock of adults and results in increased costs and reduced profits of the two fisheries.

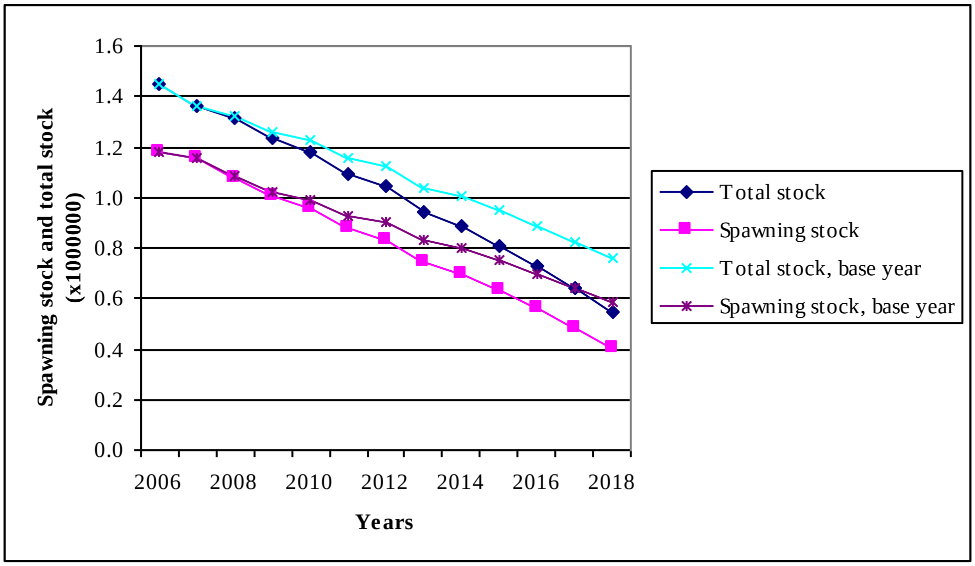

Figure 16: Scenario 3 - projections, spawning stock (mt) and total stock (mt) of the horse mackerel, 2006-2018

Figure 17 shows decreasing number of recruits as a result of an increase in the juvenile allocation. The decrease will be visible in the year 2011, four years after the increase at a higher decreasing rate compared to the base year.

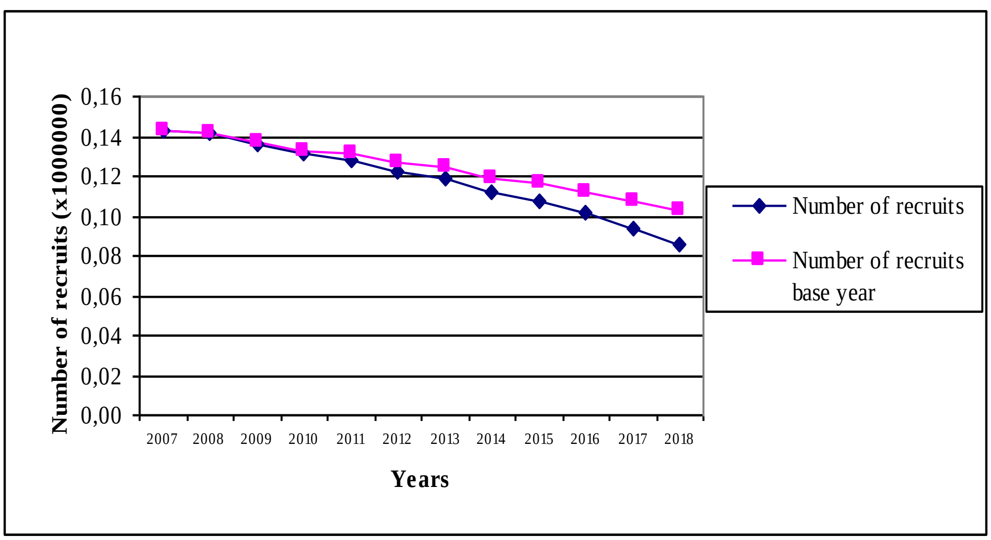

Figure 17: Scenario 3 - projected number of recruits of the horse mackerel stock, 2006-2018

Profits in the small pelagic - horse mackerel fishery show that costs are higher than in the base year and profits are lower. It shows that the higher the juvenile allocation, the higher the costs in the fishery and the lower the profits (Figure 18). Profits are still low in the fishery; an increase in the juvenile allocation does not seem to be enough to make the fishery profitable in turn it incurs more losses. Costs show to be higher and profits lower in scenario 3, compared to the base year. According to the observed results, an increase in the juvenile allocation increases the juvenile fishery's costs. The increased revenue from the increased catch is more than evened out by the increased cost. As the stock is fished down, finding and fishing the allowed 50,000 mt gets increasingly difficult which increases the cost, pushing the fishing even further away from being profitable. It thus offers little logic why the small pelagic fishery would request for an increase in the juvenile allocation given the observation.

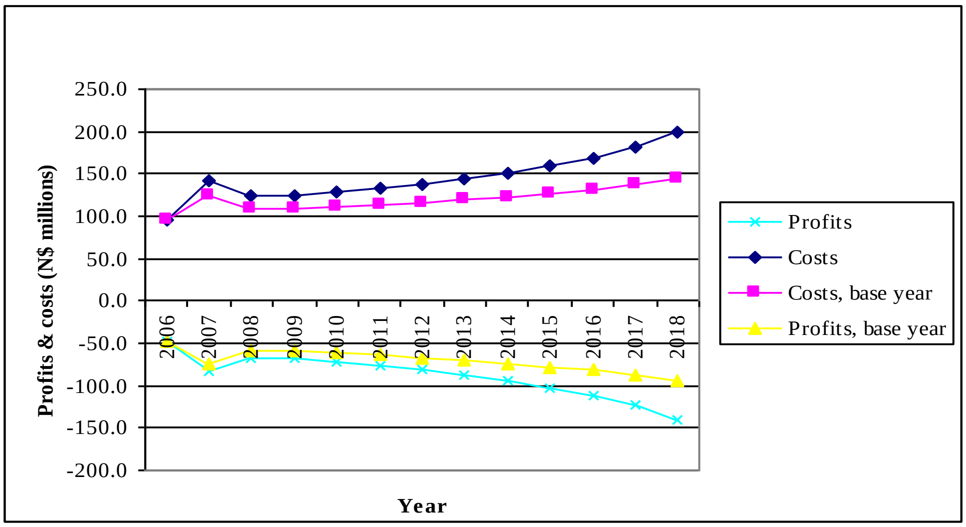

Figure 18: Scenario 3 - projected profits and costs of the small pelagic - horse mackerel fishery, 2006-2018

With increased allocation to the small pelagic - horse mackerel fishery, the stock of adults shows an accelerated reduction. Profits become negative in the year 2011 same as in the base year and continue to be negative, but at a faster rate.

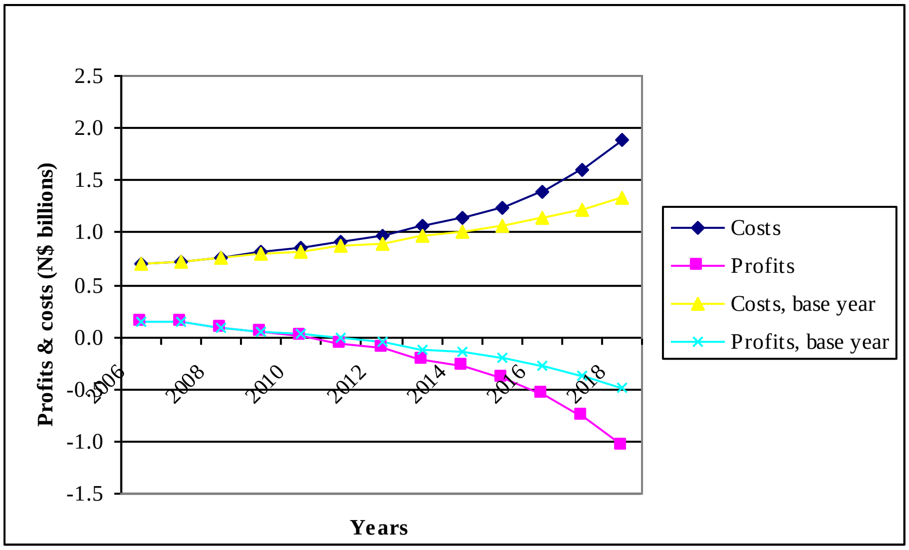

Figure 19: Scenario 3 - projected profits and costs of the horse mackerel fishery, 2006-2018

An increase in juvenile allocation shows a negative effect on the spawning stock and total stock. The impacts emerge to be low total stock, low recruitment, and high costs in the two fisheries and negative profits.

7 DISCUSSION

Economic factors are important driving forces in fisheries but they must be incorporated into suitable biological models when modelling the dynamics of fisheries (Mackinson *et al*. 1997).

The Namibian horse mackerel industry has been studied using catch, biological parameters, effort, and price and cost data for the two fishing fleets that harvest the same species at different stages. The Beverton and Holt bio-economic model was applied focusing on the impact of changing Total Allowable Catches (TAC) of adults and juveniles on total stock, spawning stock, recruitment, and costs and profits of the fisheries.

Capture of juvenile fish may lead to recruitment failure, biodiversity change, and collapse of fisheries (FAO 2000). The simulations carried out in this study indicate that reduced catches of juvenile horse mackerel will lead to increased adult stock in the future because the juvenile mortality is reduced thus boosting recruitment to the adult stock (Jennings 1999). Catch of juveniles threatens stocks and the problem of limiting juvenile fish catches continues to be a major one in fisheries management world wide (Cinneide *et al*. 2002).

Several writers are of the belief that if all undersized fish are allowed to spawn and to grow to optimum length and all spawners are excluded from the catch, the fishery's landings and revenues will increase despite the fact that some juveniles would die from natural mortality before reaching optimum length (Myer and Merts 1998). Others disagree, however, arguing that allowing the fish to spawn may seem like an obvious proposition, but no one has produced compelling evidence that an increase in spawning fish is the key to rebuilding fish stocks. In addition, they argue that other factors such as environmental conditions play a role as a single adult female can spawn producing hundreds of thousands of eggs over a lifetime and less than one in every hundred survive to become juvenile fish thus making it difficult to predict the effect on adult stock. However, they say that it makes sense to leave a large stock of spawners in the sea in order to maintain healthy, sustainable fisheries (NOAA 2001a).

The small pelagic - horse mackerel fishery fleet has high variable costs compared to the horse mackerel fishery and because the allocation of juvenile horse mackerel to them is not sufficient to allow them to cover the costs, they incur losses. Only a large increase in the allocation of juvenile horse mackerel will make the small pelagic - horse mackerel fishery profitable. Such an increase in the allocation will increase the likelihood of depleting the stock in the future. Fishermen are thought to lose hundreds of millions of dollars a year because of the loss of juveniles (Sullivan 2005). These juvenile fish catches threaten future populations and catches. It reduces the harvestable stock of adult horse mackerel. The findings of this study support the statements of Sullivan as it also showed that increased juvenile allocation impacts negatively on profits of both the horse mackerel fishery and the small pelagic - horse mackerel fishery.

The small pelagic - horse mackerel fishery fleet is currently experiencing losses with catching pilchard because of the depleted state of the pilchard stock. They are counting on the juvenile horse mackerel allocation to make their operations viable because they cannot request a TAC increase on the depleted stock of pilchard. The results are clear that increasing the juvenile allocation by a few tons will not make the small pelagic fleet profitable and it will impact negatively on the horse mackerel fishery and the horse mackerel stock in the long term through reducing total stock and spawning stock thus decreasing recruitment and profits of the horse mackerel fishery as well as of the small pelagic - horse mackerel fishery. According to Mattos *et al.* (2006) low or negative profits would usually indicate that fisheries resources are exploited in an economically wasteful way, often through excessive fishing capacity and effort.

The fluctuations in the allocation of horse mackerel TAC and juveniles impacts employment. These changes arise as a result of changed effort. The change might reduce the employment period at fishmeal plants. The higher the allocation the longer will be the duration of employment and the fishmeal plant in operation. The same numbers of people are employed throughout.

In the horse mackerel fishery, reducing TAC leads to reduced fishing effort which could be reducing the number of boats and thus reducing employment which is socially undesirable. Effort reduction is, however, important when TAC is reduced to increase fish production, stock levels, productivity and profits as well. Employment in the horse mackerel fishery would only reduce should the industry decide to reduce the number of vessels licensed. This will also have a positive impact since it will reduce the costs of fishing associated with licensing too many vessels.

A reduction in juvenile allocations leads to increased effort in the horse mackerel fishery, because more fish is made available in the future. Part of the cost function is a function of effort, meaning the higher the effort, the higher the costs as was observed in the results section of the study. Any increase in fishing effort would drive stocks to an unsustainable situation. The effort will, however, decrease when the increased cost makes it unprofitable for the fishery. According to Mattos *et al*. (2006), effort must change with changes in the population size in order to keep equilibrium.

Among the three analysed scenarios, only scenario 2 appears to be sustainable. The other two scenarios are unsustainable and eventually will drive stocks to unsustainable situations leading to depleted stocks in the long run.

Reducing the juvenile allocation by 20,000 mt in scenario 2 manages to make the horse mackerel fishery sustainable but the small pelagic -horse mackerel fishery is still not profitable until a further decrease is implemented. Such a reduction will lead to reducing fishing mortalities and increasing stock. According to Mattos *et al.* (2006), reduction in fishing mortality will increase the spawning stock and thus future recruitment.

Increased TAC might be welcomed by the small pelagic - horse mackerel fishery now but is not sustainable neither for the small pelagic - horse mackerel nor the horse mackerel fishery in the long run. It could perhaps be supported if it would lift the small pelagic - horse mackerel fishery out of negative profits but since it does not as is shown by the results of scenarios 1 and 3 then it is probably not advisable. Why give a portion of the allocation to the small pelagic - horse mackerel fishery whose situation will not even improve if the same can be left to benefit the horse mackerel fishery a few years later? Or why decrease the benefits at a cost to the fishery with rights to harvest a stock and give it to the fishery that will not be better off? Increased allocation would increase losses in the small pelagic - horse mackerel fishery. It will also decrease profits in the horse mackerel fishery in the long run, which is just as undesirable as is the state of the pelagic stock now which is what prompted the ministry to give an allocation of juveniles in the first place. Increasing the allocation is like solving a problem with another because of the undesirable effects it could have.

A key issue in securing the future of commercial fisheries is the ability to catch target species fit for human consumption while minimising the catch level of juvenile fish. The objective of catching mature fish is to let juvenile fish escape so that they can grow to maturity to help replenish stock (Cinneide *et al.* 2002). Leaving the fish to the horse mackerel fishery seems quite effective, and will allow the horse mackerel fishery to be sustainably managed from the biological and economic point of view.

Some writers such as Beverton *et al.* (1957) are of the opinion that the potential of juveniles to survive and grow up to become adults depends on the decline in the number of adult fish causing the fish population to abandon marginal habitats, making more resources become available.

Allowing the small pelagic fleet to fish for this resource according to the model results will lead to unsustainability in the future with the possibility of depleting the stock. Also, contrary to what will usually be expected, according to the model results presented a decrease in the juvenile allocation increases profitability of the small pelagic - horse mackerel fishery and decreases the costs rather than decreasing the profits and increasing the costs. This is a clear indication that the resource is currently exploited in a wasteful economic way.

Another argument that would not favour the juvenile allocation to be increased is the tendency to over-catch developed by the small pelagic fleet over the years. This can be proven by the recorded catches. The fleet is not only over-catching the pilchard TAC but also the juvenile horse mackerel allocation.

7.1 Study limitations

Data is scarce for the adult fishery and small pelagic - horse mackerel fishery costs of fishing. This led the study to be limited within the framework of what data is available. The results could improve with more detailed information on the costs of fishing and the effort of the two fisheries, horse mackerel fishery and small pelagic - horse mackerel fishery. Time was also a limiting factor in this study.

8 CONCLUSION

The study aimed at analysing the economic yield of an increased allocation of juvenile horse mackerel and the consequent impact on the horse mackerel fishery and how Namibia can benefit economically and biologically from the resource in a sustainable manner. The results indicate that an increase in the juvenile allocation of horse mackerel to the small pelagic - horse mackerel fishery will decrease spawning stock, total stock, recruitment, and profits while increasing the costs in the horse mackerel fishery, as well as in the small pelagic - horse mackerel fishery. It will result in non-sustainability of the fishery likely to end in depletion of the horse mackerel stock in the long run. A decrease in allocations will have a positive impact on the fishery through increasing spawning stock, recruitment, profits and decreasing costs. It is, therefore, essential to allow a greater proportion of juvenile fish to grow and be able to spawn. The current harvesting strategy of the horse mackerel stock discussed under initial conditions shows that allocating a TAC of 272,432 mt and juvenile horse mackerel of 43,349 mt is not sustainable and may result in depletion of the stock.

In addition, the modelled increase in juvenile horse mackerel to the small pelagic - horse mackerel fishery would not create additional employment and neither will it result in job losses onshore (fishmeal plants) if decreased. An increased allocation will reduce employment in the horse mackerel fishery should the fishery license fewer vessels as a result.

It is clear from the findings that the economic and biological benefits are in favour of the adult fishery. On this basis, we should be very cautious about continuing to allocate high volumes to the small pelagic - horse mackerel fishery if horse mackerel quotas are being fully used in the adult fishery; and in the long run, we should be planning to phase out allocations limited only to the small pelagic - horse mackerel fishery.

There should be a rational and quantitative trade-off of biological risk against economic return with the overall aim of ensuring profitability for the fishery without compromising the long term productivity of the resource.

ACKNOWLEDGEMENTS

First and foremost, I thank the Almighty Father for the strength, love and protection which made it possible for me to complete this daunting task.

Other thanks extend to:

- My supervisor, Dr Vilhjalmur Wiium, for his very valuable advice, support, encouragement, and the time he took to fit me into his busy schedule
- UNU-FTP, for the wonderful opportunity and for making it possible for me to be in Iceland and study
- Dr Tumi Tomasson, Sigridur Ingvarsdottir, and Thor Asgeirsson, for the kind support and great hospitality that made me feel at home in Iceland
- Professor Ragnar Arnason, for his helpful assistance with modelling and wonderful advice on topic selection
- Konrad Thorisson, for his valuable input and referring me to relevant articles
- Dr Carolla Kirchner and Margit Wilhelm for their cooperation and timely provision of information
- Fishing companies, for their cooperation and data provision
- My family, for all that matters
- My tender loving partner and pillar of strength Luis Miguel for his endless encouragement, support, and unconditional love
- Last but not least my cute daughter, the apple of my eye, for allowing me to finish this project with limited sweet cries

LIST OF REFERENCES

Barkai, A. & Bergh, M. 2001. The relationships between the size of fish populations and their productivity. [November 28, 2006] <http://www.olrac.com/fni8> OLRAC. Cape Town

BCLME, 2004. Market analysis of major fish product markets in the Benguela current large marine ecosystem. <www.bclme.org/projects/docs/LMR-SE-03-02>

Beverton, R. and Holt, S. 1957. On the dynamics of exploited fish populations. [November 27, 2006] <http://www.soest.hawaii.edu>

Cinnéide, L; Mulligan N; O'flynn, F; Holmes, T & Officer, R. 2002 Dingle fishermen conserves their inshore fish stocks – TCMS a way forward. <www.irishscientist.ie>

Freshley, C. 2004. The rise and fall of an industry. [26 November 2006] <http://www.maine.gov>

FAO 2000 Reducing the impact of tropical shrimp trawl fisheries. FAO Fisheries Report No. 627. Rome. [3 December 2006]. <http://www.fao.org>

FAO 2002 Fishery country profile: Namibia. FAO, Rome. [November 29, 2006] < http://www.fao.org/fi/fcp/en/NAM/profile.htm>

Greenpeace 2006. http://www.greenpeace.org

Horwood, J. and Nichols J; Milligan, S. 1998. Evaluation of closed areas for fish stock conservation. <http://cat.inist.fr>

ICES, 2004 Ecosystem overview for widely distributed and migratory populations [November 25, 2006] <http://www.marine.ie>

INFOSA, 2006. FISH INFO network Market Report. INFOSA [November 28, 2006] <http://www.eurofish.dk/>

Jennings, S. 1999. Handout, CEFAS Lowestoft, 3pp. The case for no-take zones. [3 December 2006] http://www.cefas.co.uk/publications.aspx

Katoma, L. 2006. Media release from cabinet chambers. [3 December 2006] <www.grnnet.gov.na>

Krakstad, J. 2001. The Namibian horse mackerel stock. [3 December 2006] <http://iodeweb1.vliz.be/odin/handle/1834/711>

Mackinson, S. Sumaila, U.R and Pitcher, T.J. 1997. Bioeconomics and catchability: fish and fishers behaviour during stock collapse. Fisheries Research., 31:11-17

Mattos, S. Maynou, F and Franquesa, R. 2006. A bio-economic analysis of the hand-line and gillnet coastal fisheries of Pernambuco State, north-eastern Brazil. Scientia Marina: Vol 70, No 2. [November 29, 2006] <http://scientiamarina.revistas.csic.es/index.php/scientiamarina/article/viewArticle/161>

Miles, R. D and Chapman, F.A. (2006) The benefits of fish meal in aquaculture diets [November 29, 2006] <http://www.thefishsite.com/articles>

MFMR, 2006 Ministry of fisheries and marine resources [November 25, 2006] <http://www.thefishsite.com/articles>

Ministry of fisheries and marine resources (MFMR) 2006. Horse mackerel, rock lobster and deep-sea red crab geological state of the stock.

Moran, M. and Kangas, M. 2006 The effects of the trawl fishery on the stock of pink snapper, *Pagrus auratus*, in Denham Sound. <www.fish.wa.gov.au>

MTI 1999 Supply survey on Namibia's fish and fish products. <www.intracen.org/sstp/Survey/fish/fishnam.html>

Myers, R.A and Mertz, G. (1998). The limits of exploitation: A precautionary approach. Ecological Applications: Vol. 8, No. sp1 <www.esajournals.org>

NAMPORT, 2006 Equipped for cold storage. NAMPORT, Namibia [November 28, 2006] <http://www.namport.com/content/show >

Nansen, F. 2005. Results and impact review of Namibian/Norwegian co-operation in the fisheries and maritime sectors, Norad Report 2/05. [3 December 2006] <www.cdcf.no>

NOAA, 2001a. NOAA announces 2001 status of U.S. fish stocks fisheries on a path toward recovery. <www.publicaffairs.noaa.gov/releases>

NOAA, 2001b. Scientists Set Odds for Rebuilding Stocks Depending on Size of Spawning Stock. <www.publicaffairs.noaa.gov/releases2002/may02/noaa02049.html>

Ronald, W.H (2006). Aquaculture global fish outlook: International fishmeal and fish oil organization. [November 23 2006] <http://www.iffo.net/default>

Strømme, T. and Sætersdal , 1991. Surveys of the marine fish resources of Angola, 1985 – 1986 and 1989. Internal Report of Institute of Marine Research, Bergen, Norway, 119 pp.

Sueiro, J. C. (2005). On the verge of collapse: The Peruvian fishing industry is in serious financial crisis, as corporate earnings dwindle. Samudra Report no. 41 [17 December 2007] <http://icsf.net/icsf2006/uploads/publications/samudra/pdf/english/issue_41/ALL.pdf>

Sullivan, K. 2005. New solutions that reduce the accidental death of marine life reeled in by international smart gear competition. Vancouver. [3 December 2006] <smartgear@smartgear.org>

Tudela, S; Aipnjiguly, S; & Remy, A (2006). Baby fish [November 25, 2006] <www.wwf.fi/wwf/www/uploads/doc/babyfishreport.doc>

Walters D.M, Leigh D.S. and Bearden A.B. 2003, Urbanization, sedimentation, and the homogenization of fish assemblages in the Etowah River Basin, USA, *Hydrobiologia* **494** (2003), pp. 5–10.