UNITED NATIONS UNIVERSITY
Fisheries Training Programme

unuftp.is Final Project 2016

BIOECONOMIC MODEL FOR THE PILCHARD *(SARDINOPS SAGAX)* SPECIES IN NAMIBIA

Esther N. Piniku
Ministry of Fisheries and Marine Resources
Private Bag 13355, Brendan Simbwaye Square,
Block C Corner of Uhland & Goethe Streets Windhoek,
Namibia
Esther.Piniku@mfmr.gov.na

Supervisor:
Professor Ragnar Arnason
Department of Economics
University of Iceland
ragnara@hi.is

ABSTRACT

Achieving sustainable, profitable fisheries is a major challenge facing developing fishing nations that depend on fisheries for income and food security. Namibia is still under threat of certain species collapsing after they have failed to recover from overfishing in the past in spite of the stock-rebuilding policy measures implemented in recent years. The aim of this paper is to develop a bio-economic model for the Namibian pilchard, a small pelagic species, to identify the optimal levels of utilization for this stock over time and in the long run. The biological and economic aspects of the situation are modelled and represented by different indicators such as the biomass, effort, prices, harvests, revenue and costs. Model parameters are estimated with the help of data obtained from the Ministry of Fisheries and Marine Resources and the pilchard subsector. On the basis of the estimated bio-economic model, an optimal harvesting rule is developed and used to identify the appropriate policy for this fishery and its most beneficial long term sustainable state.
Key words: Sustainable fishery, pilchard fishery/subsector, optimal yield

This paper should be cited as:
Piniku, E. 2018. *Bioeconomic model for the pilchard (Sardinops sagax) species in Namibia.* Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/esther16prf.pdf

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

EEZ Exclusive Economic Zone
FMS Fisheries Management System
GDP Gross Domestic Products
HC Harvest Control Rule
IQs Individual Quotas
ITQs Individual Transferable Quotas
MCS Monitoring Control and Surveillance
MEY Maximum Economic Yield
MRAC Marine Resource Advisory Council
MFMR Ministry of Fisheries and Marine Resources
MSY Maximum Sustainable Yield
NPV Net Present Value
NSA Namibian Statistic Agency
OLS Ordinary Least Square
OSY Optimal Sustainable Yield
SST Sea Surface Temperature
TAC Total Allowable Catches
FOA Fisheries Observers Agency
TC Total Costs
TR Total Revenue

1 INTRODUCTION

1.1 Background of the study

The major fisheries for small pelagic fish off Namibia include those for sardine also known as Pilchard (*Sardinops sagax*). The species is of key importance in the Namibian marine ecosystem. The species plays an important role as both the controller of the abundance of both predator and prey species (Curry *et al.*, 2000) and a major composition of the predators' diets (MFMR, 2016).

Since its discovery in 1950s, the pilchard fishery has been a major source of income to the Namibian fishing industry. The fishery's landed value has doubled since independence, from the N$ 49 million in 1991 to N$ 103 million in 2015 respectively. Despite comparatively low biomass and TAC, the fishery continues to employ approximately 12% of total in the marine sector (MFMR, 2016). Approximately 85% of the final product is exported to other countries within the Southern African Development Community (SADC) (MFMR, 2016).

The fishery was almost driven to extinction as a consequence of ill-management that occurred in the 1950s to the 1980s, with no sign of improvement since then. Poor recruitments and high catches led to the first episode of the stock collapse in the 1970s followed by many more similar events afterward (Boyer & Hampton, 2001). The pilchard biomass has continued to decline steadily with no sign of recovery. In 2002, the Ministry of Fisheries and Marine Resources (MFMR) announced a zero Total Allowable Catch (TAC) that left the Pilchard industry in distress (Elago, 2009). The following years the TAC has been set at an average of 25000 mt reflecting what has been referred to as socio-economic sustainable (MFMR, 2016) rather than an environmental sustainable.

1.2 Problem Statement

Pilchard in the Namibian waters was once in abundance alongside the hake and horse mackerel during the 1960s (Boyer & Hampton, 2001). However, over the years, the pilchard has shown a worrisome trend regarding low recruitments, low biomass, low catches annually. Since the stock collapsed in the 1970s, it has not fully recovered. The pilchard abundance remains low in comparison to its initial biomass of 11 million mt estimated during the 1960s.

Low abundance has resulted in low social-economic benefits derived from the fishery i.e. income receivable, employment created, food security etc. Reasons for the declines of the stock is still not clear, but could partly be overfishing that occurred in the 1970s (MFMR, 2016). The underlying problem statement of the study is to determine approaches that can restore the depleted stock to its initial level. The applications of these approaches are key factors to maximising net benefits that can be derived from the utilisation of the resources to end-users.

1.3 Objectives of the study

The main goal of the study is to formulate a fisheries bio-economic model for the Namibian pilchard. The model shall guide sectoral stakeholders to adequately consider the biological aspects of the fishery while maximising the economic benefits that can be derived from utilising the resource. The model shall assist to define the optimal level of sustainability that ensures effective and efficient resource management in the long run.

In line with this, the objectives of the research are as follows:

- ✓ To determine the optimal economic biomass and the associated level of net benefits that can be derived from a sustainable fishery.
- ✓ Identify different management regimes that can be practiced on the pilchard subsector and the associated implications.
- ✓ Provide recommendations for different stakeholders on managing the resource sustainably.

Based on its historical importance, and the likelihood to regain its reputation of becoming once again a fishery of main economic and social importance, reconstructing the Pilchard stock is an uppermost priority for the fishing sector and Namibia as a country.

1.4 Justification of the study

The study will be used to merge the existing gap of empirical studies focusing on bio-economic analysis of sustainable use of fishery resources in Namibia; since independence, there has been no record of a bio-economic model carried out on the pilchard species. Furthermore, the information will assist policy makers and interested parties to make informed decisions regarding fisheries management. The recommendations can be extended to similar settings of over-exploited marine resources and other renewable resources in general.

2 THE NAMIBIAN FISHERIES

Namibia has a highly productive sea, and abundance of pelagic and demersal fish populations. Its coastline is located in the Benguela Current system, one of the four eastern boundary upwelling systems in the world (ATLAFCO, 2012) and one of the richest and most productive systems in the world (Paterson *et al.*, 2013). The current is characterised by a strong upwelling with higher primary production. The northern and southern Benguela are separated by the stout recurring upwelling off Lüderitz (26-28ºS), (Boyer & Hampton, 2001).

The Namibian coastline is uniquely defined by the Namib Desert that stretches along its entire length. It is characterised with harsh weather conditions, subjecting the Namibian fishing industry to large scale commercial exploitation with limited artisanal or small scale fisheries. The structure of the sector is simplified by the limited number of landing harbours along the coastline: Lüderitz and Walvis Bay. The Lüderitz harbour is located in the south, while Walvis Bay at the central coast. The latter being Namibia’s main commercial port, due to its strategic location. Figure 1 below display the Benguela upwelling system that supports the large marine ecosystem.

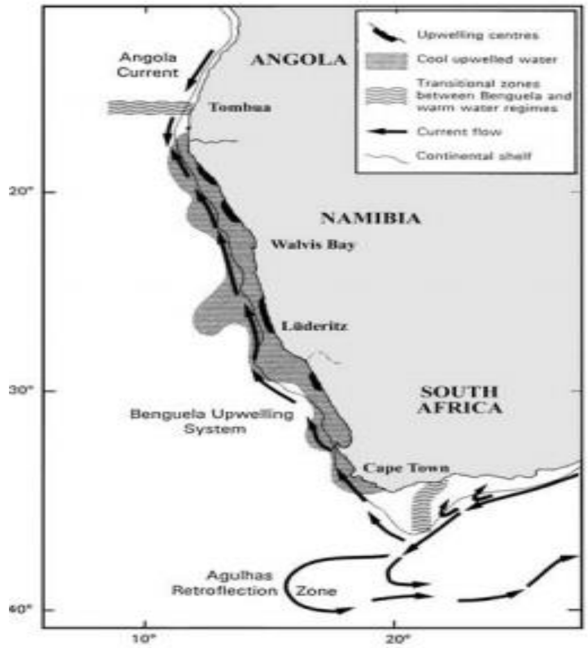

Figure 1: Major oceanographic features off the Namibian coastline (modified from (Bianchi, 1993))

The richness of the Namibian fishery is characterized by a variety stock of demersal and small pelagic species (Boyer & Hampton, 2001). Nearly 20 different species are commercially exploited in Namibia, with the majority being TACs regulated. The primary species are the small pelagic species sardine *(Sardinops Sagax)*, anchovy *(Engraulis encrasicolus, E. japanicus)*, Cape horse mackerel and mackerel (*Trachurus capensis)*; rock lobsters (*Jasus lalandi*) as well as the large pelagic species including adult mackerel, demersal hake (Merluccius capensis, M. *paradoxus* and *M. Pollis*), Monk (Lophius Vaillanti, L. vomerinus) and other deep-sea species red-crab (*Chaceon maritae*) that live further in the continental shore (Sumalia & Vasconcellors, 2000).

Like in many African countries, Namibia's fishery resources had been exposed to an open access regime and was over-exploited by companies from Asia, Europe and Russia, South Africa that flocked to Namibia. (Belhabib *et al.*, 2015). The lack of a fisheries management regime attracted more fishermen to Namibia. Although fishing activities increased, limited benefits were returned to the Namibian community. After gaining its independence in 1990, the new government of the Republic of Namibian declared its Economic Exclusive Zone (EEZ) of 200 nm along its coastline. The introduction of the Fisheries Management System (FMS) was aimed at restoring, protecting and sustainably managing the living aquatic marine resources of Namibia (Kashindi, 1999).

The fisheries management regime brought improvements within the fishing industry, such as a reduction in the number of illegal, unregulated and non-compliant operations within the sector. Furthermore, the quota allocated to right holders became more moderate and in line with the species biomass, while catches and landings were monitored. Most of the fish stocks have been revived to their normal stock level, in the process retaining their economic values over the years. Unfortunately, some of the commercial species are yet to recover from the over-exploitation that occurred pre-independence (Zyl, 2001).

The implementation of the fisheries management system increased the yield from the fishing industry. Fish caught within the Namibian EEZ is landed at its ports, reducing illegal transhipment. This generates employment, creates income and increases food security both locally and on a national level. Figure 2 below indicates the annual value of fish and fish products exports from Namibia. The value of the final products has been around N$ 200 million since 2000 but rose to N$ 500 in 2014. The decline experience in 2015 was due to a 5.7 percent decline registered in the real value added of fish and fish products processed on board during its third quarter. Further factors that have influenced the performance of the sector in recent years but not limited to include in the devaluation of the Namibian currency and low input costs. More value-added initiatives emerged, and the product shelf life has extended. The fishing sector is also moving away from exporting fish in primary conditions.

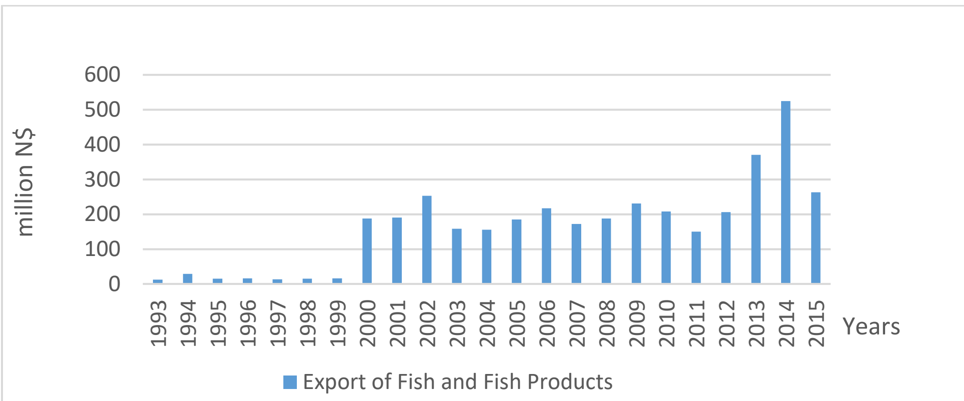

Figure 2: Exports of fish and fish products from 1993-2015 (NSA, 2015)

Namibia's economy is based on the tertiary and primary industries, with annual contributions of 58.3% and 18.7% to total Gross Domestic Product (GDP) respectively. The most sizeable industries are the mining sectors (12% of GDP), agriculture (5% of GDP) and fisheries (3.9% of GDP) (NSA, 2015). The average annual growth rate of the economy is approximately 4.6%.

2.1 The Pilchard Fishery

2.1.1 The fishery before independence

The Namibian Pilchard is a small pelagic schooling species that is part of the Southern African Pilchard (*Sardinops sagax*) family. The fish is caught using purse seiners net along the Namibian seashore, often found close inshore and within 200 m depth, just beyond the surf zone (MFMR, 2016). Over the years, the fishery has had high economic values alongside hake and horse mackerel i.e. employment, value addition and GDP contribution.

The problems associated with open access regime (common property) are over exploitation, over capacity, illegal and unregulated fishing activities, as well as high economic wastes. After Germany lost all its colonies during the World War I, the Deutsch-Südwest Afrika (now Namibia) was given as a trustee to Great Britain in 1920 by the League of Nations. Great Britain, unable to occupy its new territory, requested the Union of South Africa to administer Deutsch-Südwest Afrika as a mandate territory on its behalf. When South Africa gained supremacy and political administration over Namibia in 1915, they took over the fisheries resources. However, South Africa failed to enforce appropriate fisheries management regimes that could sustain the resources. The Namibian pilchard was an untapped species until the late 1940s. In 1960 the fisheries picked up and peaked in 1968 (1.4 m. tons). After 1970 the catches decreased and in 1978 the catch was just a fraction of what it used to be (Figure 3).

Following the collapse of the Californian Pilchard in 1949, the event caused a great wave among the fishing nations. This lead to an immense number of fishermen flocking to the Namibian coastline, beginning to exploit the pilchard stock (Midgley, 2012). The first experimental cannery that opened in Walvis Bay was of the Oven-Stone Family from South Africa in the late 1940s, with catches as low as 2000 mt annually. The catches increased from 2000 mt in the 1940s to 260 000 mt in 1953 (Elago, 2009).

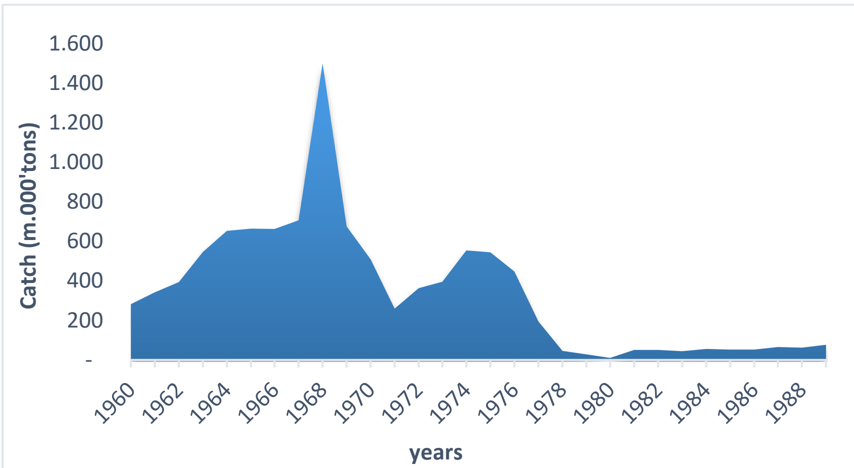

Figure 3: Development of the harvesting of pilchard by the purse seiners, during the 1960-1998, when no fisheries management was in place.

The economy of Walvis Bay started developing rapidly as the exploitation of the pilchard increased, which gradually attracted more fishermen around the mid-1950s, as the profits increased. And for many years, the species constituted as the backbone of the Namibian pelagic fishing industry. The foundation of the town was based on the richness and abundance of pilchard. As the fishery production and technology intensified; various canneries and fishmeal plants were opened in Walvis Bay. There was an alarming increase in resource exploitation as the number of vessels increased to more than 100 purse seiners catching the pilchard.

In 1954, a series of control measures were imposed on the fishing industry and a system of individual quotas was established, along with a TAC of 200 000mt that was closely linked to the California Pilchard catches of 1936. This was meant to limit the quantity of harvests. These events of the California Pilchard led to the adaptation of the sealing and fisheries ordinance that limits the capacity of the factories catches although it was done without any scientific guidance. The highest biomass of pilchard ever estimated was approximately 11 million mt in 1964, and during 1968, the industry caught roughly 1,5 million mt of pilchard (MFMR, 2014). This continuously high rate of catches contributed to the fast deterioration of the fish stock (among other factors). Catches drastically declined over the years and the stock finally collapsed in the early 1970s.

2.1.2 The fishery after independence

After Namibian independence in 1990, the implementation of the fisheries management regime was aimed at rebuilding the depleted fisheries stock. Species such as hake showed positive recovery signs, however pilchard has not yet recovered. The introduction of TAC and individual quota system lowered the catches relatively, in comparison to those before independence. The trend of high catches persisted from 1990 to 1996, till to a point when there was no sign of the stock recovery (Figure 4).

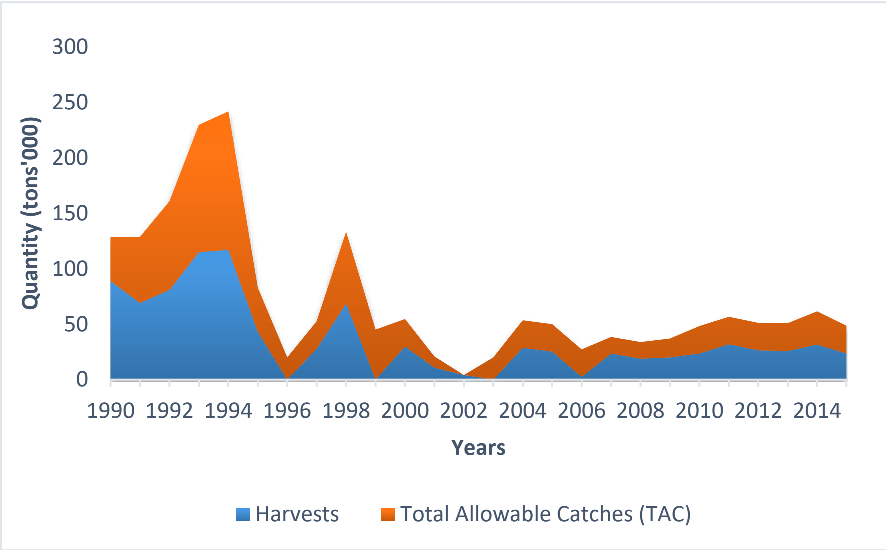

Figure 4: Pilchard catches and TAC from 1990 to 2016 (MFMR, 2016)

Initially, pilchard landings were more than those of horse mackerel and hake. The landings increased slightly during the years of 1990-1994, after some recovery of the fish biomass in the early 1990s. However, the fishery collapsed in 1996, due to but not limited to environmental aspects such as the occurrence of the Benguela El~nino event in 1996, that negatively affected the pilchard stock. The fishery collapsed again, closed in 2002 after a series of continuous low catches from 1998. The set of a low TAC as a management measure and scarcity of the fish led to a reduction in fishing effort, a reduction by 80%, from 40 to 7 in 1990 to 2015; contributing to a reduction in catches.

The highest set TAC since independence was 120 000mt in 1994, the lowest was 14 000mt in 2016 and never set above 40 000 mt annually since 1999. Following series of stock collapse in the early 1970s (Boyer & Hampton, 2001) and 1990s, including occasions of the fishery being closed in 2002, continuous low catches, the stock has is at the lowest level and is on the verge of collapsing again.

Despite the low level of biomass and TAC, the fishery contributes to local employment as other fisheries with abundant resources. The highly industrialised sub-sector employs on average 12% of the fisheries employees. Figure 5 below makes a comparison of the fisheries employment in the hake, horse mackerel and pilchard fishery during the period of 2004-2015. The sub-sector managed to maintain a positive level of employment at par with those of horse mackerel and relative to those of hake although there is a clear distinction in terms of magnitude. The fluctuations in employment within the pilchard sub-sector are a result of a reduction in overall fishing vessels and other changes in the fishery's associated with the TACs and quota allocated. However, it should be noted that most of the employees in the pilchard sub-sector are temporarily employed in the processing factories during the pilchard fishing seasons. In 2015 alone, the fishery employed about 1918 workers while operating on an economic TAC of 25 000 mt.

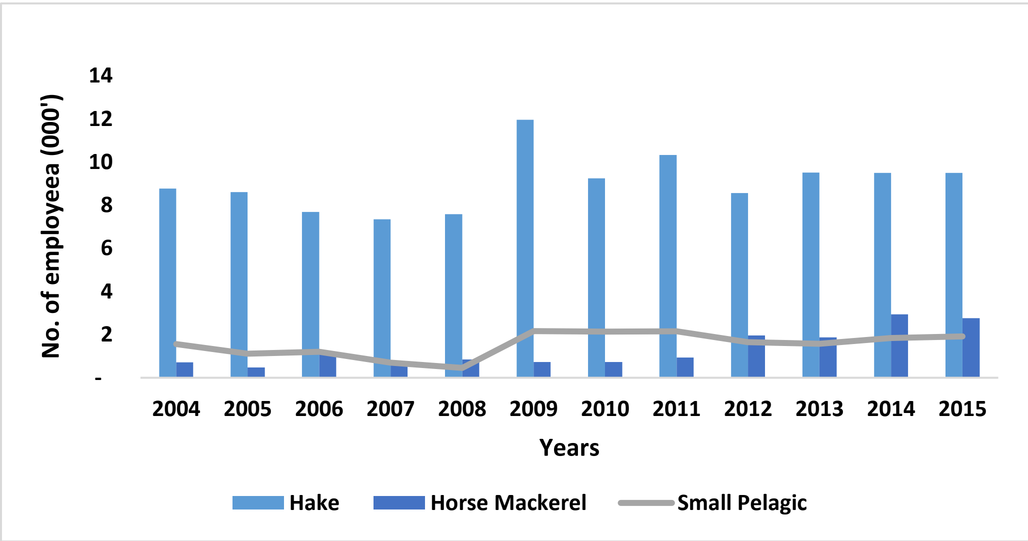

Figure 5: Hake, Pilchard and Horse Mackerel total employment (MFMR, 2016)

In terms of GDP contribution, approximately 85% of the final product is exclusively exported to the regional market, such as South Africa, Zambia, Congo and Mauritius. Approximately 10% of the final product is consumed locally and the remainder is exported to the rest of the world (MFMR, 2016).

2.1.3 Biological characteristics of Pilchard

i. Biological and Ecological Features

Pilchard (*Sardinops sagax* **)** (Figure 6) is coastal species that forms large schools and are commonly distributed along the Northern and Southern Benguela Current System. They caught in depth range from 0-200 m. Max length is measure at 25.5 cm while the mode has decrease to 22 cm over the years, the length at 50% maturity (L_{50}) is 17 cm with an average weight of 486.00 g. pilchard was indicated to have a life expectancy of up to 11 years, however this has been reduced to less than 5 years on average (MFMR, 2016).

Figure 6: The Namibian Sardinops sagax.[1]

The species is both a primary and secondary consumer; Juveniles feed mainly on zooplankton such as copepod while adults feed on both on zooplankton (Boyer & Hampton, 2001). The Pilchard is mainly prayed on by the Monk, penguin, dolphins, seals, seabirds, albacore and snoek. The predator-prey relationship in marine ecosystems is complicated, some predators i.e. gannets in the southern Australia are able to switch to other prey in the absence of the dominant prey, while others simply suffers at the hand of fate following the mass mortality of pilchards.

ii. Spawning

Pilchard spawn over a wide range of environmental variables (Van Der Lingen, 2002) and they tend to spawn in the greater variety of suitable habitants i.e. SST, salinity, dissolved oxygen (Twatwa *et al.*, 2005). In the northern part of the current, spawning is mostly among the young adults during the late summer/autumn in water temperature of 19-20°C. While further in the south of the Benguela in cooler water close to the Lüderitz upwelling zone, spawning is by older fish during the summer (Boyer & Hampton, 2001). The main spawning areas of pilchard in the northern Benguela are within the Walvis Bay district and in Spring and Palgrave Point (to the south of Cape Frio) (Lingen & Durholtz, 2003). The spawning habitats of the Benguela Pilchard is driven by large scale ocean processes and the population dynamics are dominated by low frequencies variability (Daskalov, 2003). Fertilities range around 10,000 eggs in 13 cm long females to about 45,000 eggs in females of about 18 cm.

---

[1] http://www.fishbase.org/photos/PicturesSummary.php?StartRow=1&ID=1477&what=species&TotRec=8 (assessed on 02/03/2017)

iii. Populations

The dense-concentrate of the larvae occur within 100 km of the coast off Walvis Bay and the other further north, in the mixing zone of the Benguela and the Angola Current systems (O'Toole, 1977). The pilchard larvae float south, however close to the coast and ended up recruiting fish as young as 0-group fish into the fishery. This occurs down steam of the principal upwelling (Lüderitz), (Bakun, 1996). The dynamics of the species population is directly influenced by the spawning of habitants i.e. spawners and larvae (Tjizoo, 2008), in addition to the adjustment in food i.e. plankton and good sea temperature. It has been found that spawning increase during the years of positive temperature and abundance food supply (Kawasaki and Omori, 1988) along the Namibian seashore.

The successful productivity and survival of the small pelagic depended primarily on the ocean triangle a process of enrichment, concentration and retention. (Daskalov, 2003). The triad emphasizes that the enrichment in nutrients induce (primary and secondary) productivity; eggs and larvae are to be retained to favorable and stable environment where there is concentration of fish larvae and food (Bakun, 1996). The triad is highly valued because it comprehends both physical and biological features of the ocean. Different literatures indicated that the Benguela system does satisfy all the component of the triad, (Bakun, 1993). In an upwelling system, supporting processes, vertical stability of the water column temperature, food production and turbulence are important influencers of a successful recruitment (MFMR, 2016).

v. Sea Surface Temperature

A negative relationship between the abundance of the Namibian pilchard and sea surface temperature (SST) was found in the north while the southern Benguela indicated a positive correlation. On a contrary, a positive correlation between the SST and the California pilchard population decline and a negative correlation during the period of growth (Bakun, 2003). The Namibian pilchard is said to be the similar if not the same as the Western America (Parrish & Grant, 1989). With a few exceptions when the sea surface temperature has been either above or below average; the wind anomalies have been consistent (15-25ºS), indicating that the Lüderitz upwelling cell has been in a relaxed phase for more than a decade (MFMR, 2016). Wind below the average tends to make the upwelling weaker than usual, therefore reducing the productivity of the system.

vi. Stock variation

The Benguela has relatively small, less predictable frequent inter annual variability as compared to the Pacific upwelling systems, (Shannon & O'Toole, 2003). However, the occasional but extreme variation that occurred in the system have impacts on the fishery. i.e. the pilchard biomass declined sharply after the Benguela Nino events in 1963, 1972 and 1974 both in the North and South of the Benguela. The reduction in stock size as noted, has been directly linked to the lack of oxygen from Angola that was experienced in 1993 and 1994, that was further induced by the Benguela Niño in 1995/1996.

The Benguela Niño events are associated with warm saline water from Angola and low level of oxygen concentration and reduction in productivity. The El Niño events both in South-East Pacific and the Benguela Niño in the South-East Atlantic are responsible for a shift in the distribution of Pilchard (Crawford *et al.*, 1995). The upwelling systems that are influenced by the global teleconnections, global fluctuations in pilchard catches seems to be synchronized because the variations of the ocean occurred at the same time in these systems. Pilchards are more migratory and tend to shift their geographic center in respond to climate change (Crawford *et al.*, 1995).

3 THE FISHERIES MANAGEMENT REGIME FOR PILCHARD

Environmental processes that are believed to be important for the survival and recruitment of early life stages of pelagic fishes have been synthesized through Bakun's fundamental triad as enrichment, concentration and retention processes (Bakun, 1996). The idea is that from favourable spawning habitats, eggs and larvae would be transported to and/or retained in places where food originating from enrichment areas would be concentrated. These three processes are particularly relevant as they have implications from both a physical and a biological viewpoint. The biological and environmental indicators for Pilchard continue to change over time. The physical features of the fish have evolved as well over the years.

Despite 26 years of active stock management, there seems to be no sign of recovery as the fishing mortality and environmental factors continue to influence the fish stock among others. The fishing mortality is recorded to be very high with great variations in the stock recruitments over the last six years. The low or zero recruitment negatively influences the recovery of the stock. There has been a record of changes in the fishing seasons as the fish migration pattern is suspected to have changed. It appears late in the Namibian waters and leaves late in the season. The fishing season used to start in April and run until August, however for the last two years the season commenced in late June and ran until late September. Concerns are raised as fish biomass has dropped significantly; right holders only caught 46% of the low allocated TAC during the 2016 fishing season.

3.1 Legal framework and legislation

The overall aim of fisheries management regime is to control and regulate the fisheries activities (Arnason R. , n.d), to maximize the flow of benefits from utilizing the resources, and to attain the highest and most sustainable possible profits. A lack of fisheries management mechanisms paves away for an open access regime (Arnason R. , 1999), during which members of a society purely take as much as they can without considering the next fishermen. This creates negative externalities for the community which no one is willing to pay for.

A lack of restriction to access the Namibian fishing grounds destructively affected the stock, and signs of fishery collapse were visible (Huggins, 2011). A young nation after independence, Namibia is considered to be a global model in fisheries management. Most of the stock previously over exploited are in the process of recovery. The implementation of a fisheries management and EEZ has limited if not reduced the problem of common property.

The Ministry of Fisheries and Marine Resources in its capacity as the authority mandated to manage the resources adopts appropriate regimes to sustainably manage the resources. Fisheries in Namibia are managed under three mechanisms i.e. Fisheries Management System (TAC, IQs, gear restrictions, closed seasons, protected areas etc.), Monitoring, Control & Surveillance (Monitoring landings, air, sea & shore patrol, on-board observers etc.), as well as the Fisheries Judicial System that prosecutes fishery offences (MFMR, 2013).

MFMR practices various legal instruments and regulations that correspond to the conduct of fisheries management. The Marine Resources Act No. 27 of 2000 provides 'the conservation of the marine resources ecosystem and the responsible utilization, conservation, protection and promotion of the marine resources on a sustainable basis; for that purpose, to provide for the exercise of control over marine resources; and to, provide for matters connected therewith'. The Policy Statement for "The Granting of Rights to Harvest Marine Resources and the allocation of Fishing" 2013, is a guideline that is provides assistance to applicants in their quest to acquire rights to harvest the marine resources and quota in Namibian Marine Waters. The policy eliminates any discrimination of applicants as they are treated on its virtues in every respect.

3.2 Fisheries Management System (FMS)

Pilchard is managed using a combination of harvesting rights, total allowable catches (TACs), individual quotas (IQs), a system of fees and a monitoring control and surveillance (MCS) system.

3.2.1 *Granting of fishing right*

Rights are a mean of controlling capacity and ensuring solidity within the fishery. The pilchard fishery is exclusively commercial and it is a "Right Based Management System" applied under the property right regime. Fishing rights are allocated to legal entities, because the sector is highly industrialized. These rights are granted in accordance with the criteria as stipulated in the Marine Fisheries Act No. 27 of 2000, section 33 (4). The rights are granted for various durations of 7, 10, 15, and 20 years. There are currently 22 right holders in the fishery and during 2017, 2018 and 2020 fishing seasons some rights are expected to expire upon evaluation by the Ministry as means of managing the fishery.

3.2.2 *Quota Allocation Criteria*

Thus, since Independence, the Ministry of Fisheries and Marine Resources policy on pilchard aimed to limit catches in order to promote recovery of the stock to its sustainable optimal levels. The pilchard right holders are allocated individual quota that are percentages (quota share) of a set TAC. The annual TAC is scientifically determined and the National Marine Institute Research Centre is responsible for undertaking scientific research on marine resources. The individual quotas are allocated under the same criteria as the fishing right[2].

3.2.3 *Fisheries payable fees*

For the exploration and utilisation of the resources, it is mandatory for the right holders to pay fees such as quota fees, fund levies at a sum of N$ 62.50 per mt and N$ 110 per mt respectively.

[2] Allocated quota are only transferable through official request and by the approval of the Minister of Fisheries and Marine Resources.

Additionally, harvesting of unpermitted species is punishable through a by-catch fee. All vessels entering and operating with the Namibian EEZ 200 nm should be licensed at a payable fee.

3.2.4 *Conservations Measures*

The MFMR uses different regulations on the fishing industry as measures to protect and preserve the resources and the surrounding marine environment. Harvest for commercial purposes is restricted to specific fishing gear. All licensed vessels entering and leaving the Namibian port are cleared off by the relevant authorities. Restrictions and measures are imposed on the fishing nets, mesh sizes to avoid catching of prohibited species. Throughout different fishing seasons, specific areas are closed off and inaccessible, to allow spawning, recovery or simply to protect the species.

3.3 Monitoring, Control and Surveillance

Namibia has a robust Monitoring, Control and Surveillance (MCS) system in place, which maps Namibia's fisheries to be relatively effective as compared to most of fishing nations (Bergh & Davies, n.d). The Namibian MCS practices all four dimensions of the system: air, land, sea and remote sensing.

3.3.1 Sea

This measurement allows for appropriate sea inspections, monitoring, and ensures that all catches and fisheries activities are within the pronounced regulations. There are fishery observers on board for vessel that goes to sea, mainly on the larger vessels. The observers enforce compliance with the regulations and aid in collecting scientific data. Random inspections are carried out at sea, tracking down of offenders and illegal activities using the Ministry's patrol vessels.

3.3.2 Land

The land MCS vary upon fisheries, However, all fishing vessels undergo inspections and clearance at the Namibian port. Fisheries inspectors at the harbours monitor and record all landings. This provides accurate data; the data is compared with the log book entries recorded by the captains on every vessel. The information is used for revenue calculations, scientific assessments and fisheries management. The fisheries inspectors are mandated to enforce compliance with the law and regulations. Transhipment in the Namibian water is strictly prohibited. Inland inspections by the fisheries inspectors are done at random.

3.3.3 Air

Namibia has invested highly in the modern Aerial Surveillance, a method used to monitor, locate and track all fishing vessels within 200 nm of its EEZ. Aircrafts identify and disconcert the illegal movement and operations of the unlicensed vessels roaming in the Namibian water. After inspection, the aircraft is mandated to arrest offenders, although operations are not as smooth as expected. Furthermore, the aircraft monitors the activities of the licensed vessels within the EEZ of Namibia.

3.3.4 Remote sensing

The remote satellite tracking system remotely monitors the movement of the licensed vessels with the EEZ. The system convenes information such as the position (longitude and latitude) of the vessel, date, time, identifies vessels and photographically records violations i.e. fishing in a closed area or poaching. This allows patrol vessels to be deployed more effectively.

3.4 Fisheries Judicial System

The Namibian Fisheries Judicial System is part of the general Judicial system. The fisheries court cases are treated like any other case by the Namibian Judicial System, in which they are categorized as criminal cases. The main objective of the FJS is authorizing the enforcement part of the MCS activity and apply the necessary sanction to the offenders. However, the legal process of fisheries cases is very long, although fisheries cases and offences are considered urgent. Before the amendment of the fisheries legislation, fisheries transgressions were considered minor offences, and the court had been hesitant to issue penalties for fisheries violations

However, after the revised Sea Fisheries Legislation, the issues of low fines were improved. Although there were no minimum fines set under the revised Legislation, serious offenders were fined penalties up to N$2 million depending the extent of their violation. In some rare cases, the offending vessel is forfeited to the state. Namibia is one of the countries in the world with a strong fisheries management system, however due to the weakness in the FJS, this to some extent, creates a loophole in the system. Offenders can easily get away with offenses by paying a simple fine. The manners in which fisheries offenses are treated, this does not allow the sector to fully carry out its mandate and operate to its full potential.

4 MODEL

4.1 Choice of Model

Fisheries modelling contains both the economic and biological components that are joined through harvesting the resources using the available fishing effort (Arnason R. , 2008) and to sustainably manage the renewable natural resources. Historically, modelling the efficiency of fisheries management had been measured through bio-economic models, therefore in determining the suitable model for the Namibian pilchard species, the classic Gordon-Schaefer Model (1956) will be used as a single species model. The model includes the consideration parameters such as biomass, fisheries efforts, biomass, harvests, and profit attained from the fisheries.

Fisheries Management aims at minimizing the externalities and maximising the net benefit that can be derived from utilising the resources. These net gains are directed to improving the standard of living. Disordered fisheries are commonly those exposed to a common property regime. In the common property regime, the fishermen have unlimited equal access to the limited resources as they try to maximise their benefit (Hardin, 1968). In a fisheries where a functioning management system is absent, fundamentally, the problem of overcapacity in effort and fleet, reduced fish stock, and quite low profitability are frequently experienced (Warui and Arnason, 2009). To further explain this development, Figure 7 below gives an illustration of the fisheries problem as a result of a common property regime.

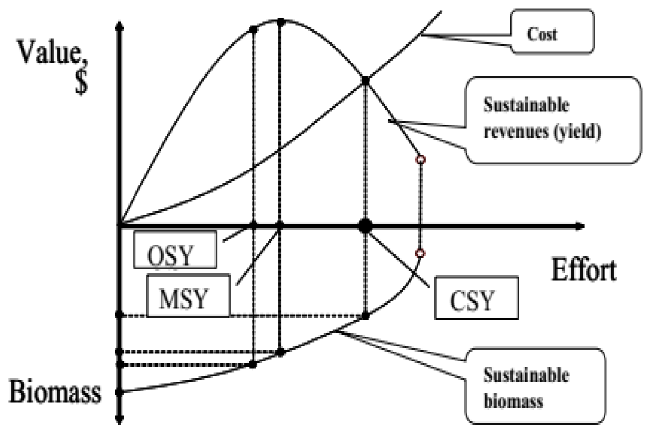

Figure 7: Unmanaged Common Property Fisher

In a fishery that is unmanaged, entry of fishermen is not controlled and the harvesting depends on the individual effort and capacity to fish. At the Optimal Sustainable Yield (OSY), the revenue made is higher than the cost, therefore profits are good. At the same point effort is very low and the biomass is at the highest point. As fishing activities become more profitable, more fishermen are encouraged to enter the fishing industry. This will increase the effort and revenue until the Maximum Sustainable Yield (MSY) is reached, although the biomass has begun to decline.

The MEY and MSY will continue to rise as revenue falls and costs begin to pick up. They will converge towards a point where revenue and costs are equal (equilibrium) and it is no longer profitable to operate in the fishery. At this point, no economic benefits are transformed from the fishery to the economy, consequently resources are wasted. Beyond the Critical Sustainable Yield (CSY) fishermen will be discouraged and begin to exit the industry, this will reduce the overall effort. Any persistent activities and effort will lead to the collapse of the fishery. Therefore, the lack of a fisheries management regime makes the economic waste inevitable in a community of property regime. Every fisherman works in complete isolation and strictly aims to maximise their utility without considering the next person (Warui and Arnason, 2009).

However, in a fishery that is managed by a well-defined and efficient system, the biomass is assumed to be at a sustainable level. Again the revenue, costs and the biomass are functions of efforts. Figure 8 below shows the best scenario of a fishery that is managed sustainably.

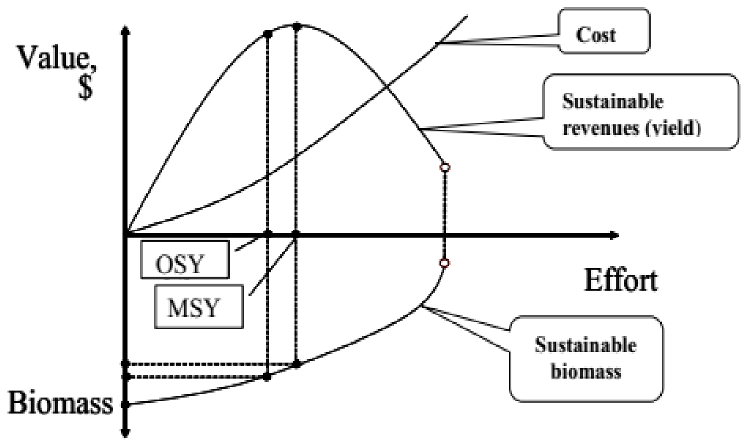

Figure 8: A Sustainable Fisheries Model

An increase in fishing activities will simultaneously increase effort as revenue increases as well. The biomass is higher at MSY and lower than any point below the OSY. A managed fishery is encouraged to remain at OSY where revenue, cost, and biomass are optimal and effort is low. If fishing activities further continue, revenue and costs converge toward the MSY, where the biomass is lower, while revenue and effort are higher. The fishery is optimally sustainable in the long run if fishing effort remains at OSY (Warui and Arnason, 2009). MSY is not optimal as costs are higher as well, therefore not as profitable as at OSY.

Furthermore, at OSY the economic gains are higher, and the risk of the biomass collapsing is relatively lower (Arnason R. , 2008). Additional effort will drive the fishery to a point where costs and revenue are equal, at it is no longer profitable to operate. Any point after the equilibrium is considered critical for the resources, where costs are higher than revenue received, and increase in effort will be highly costly and with high chances of driving the stock into extinction.

4.2 Biological Model

The basic fishery bio-economic functions generated for the Namibian Pilchard fishery are:

(i) Biomass growth

$$\dot{x} = G(x) - y$$

Where $\dot{x} = \frac{\partial x}{\partial t}$ represent the change in biomass over the course of time, *G(x)* is the biomass growth as a function of biomass, while *y* is the fish harvest.

(ii) Harvest function

$$y = Y(e, x)$$

Total harvest is a result of fishing effort, *e* and biomass, *x*

(iii) Profit function

$$\pi = p.Y\ (e,\ x) - C(y,\ e) + fk$$

Profit, π is a function of revenue (*R*) minus total cost *C;* whereby revenue is a function of a constant price, *P* multiplied with the total harvest (*y*), as given by the equations $R = P * y(e, x)$. While the aggregate cost is a function of different costs i.e. real costs that are dependent on the harvest (*y*) and effort (*e*) as well as on fixed costs (fk) that are autonomous of fishing effort and harvest given by the equation $TC = C(y, e) + fk$

4.2.1 *Biomass Growth Function*

The Namibian pilchard was modelled through the adaptation of the Schaefer Surplus Production Model:

$$G(x) = rx\left(\frac{x}{k}\right)$$

Where *r* is the inherent growth rate of the species, *x* is the biomass and *k* is the limited carrying capacity of the virgin biomass. In order to change the model into a dynamic evolution, discrete time and the harvest factors were incorporated in the above equation:

$$G(x) = rx_t\left(\frac{x}{k}\right) - y_t$$

Where y_t is the harvest at a certain time period and the above equations can be simplified into a logistic function.

$$\dot{x} = \alpha.x - \beta.x^2 - y_t$$

And coefficients α is the inherent growth rate *r* while β is $\left(\frac{x}{k}\right)$ respectively. In discrete time, the biomass changes over time, as indicated in the equation below:

$$x_t - x_{t-1} = \alpha.x - \beta.x^2 - y_t$$

Where biomass growth is measure by subtracting biomass x_{t-1} of previous year from biomass in year x_t less the amount harvested in period y_t. The model derives the desired sustainable yield (equilibrium) when $\dot{x}$=0 so that *G(x) -y = 0* where there is no change in the biomass.

4.2.2 *Harvest Function*

The harvest function for the Namibian pilchard was based on the Generalised Schaefer (1954), where total harvest, *y*, is a function of fishing effort, *e* and biomass, *x*. The volume of the fish harvested is positively related to the increase in the fishing effort at a specific biomass and the same is true. with the biomass given a specific effort (Arnason R. , 2008). The generalised harvest function can be written in full as:

$$y = q * e^{a} * x^{\delta}$$

Where the q is the average catchability coefficient of a vessel of the fleet under study; e is the extracting effort (measured by the number of days spend at sea etc.), while x denotes the available biomass. The coefficient δ indicates the degree of schooling behavior. The pelagic species are specified to be δ∈ (0.30), and δ=0 specifies strong schooling stock while a complete isolated stock is signified by δ=1. Normally, $0<\alpha\leq1$ or $0\leq\beta\leq$.

The catchability of the function can be obtained by:

$$\hat{q} = \frac{y_t}{e_t x_t^{\delta}}$$

4.2.3 *Cost Function*

The economic model makes use of the Gordon Model (1954) which is directly derived from the Schaefer Model. The model integrates in the economic aspects through total revenue which is a function of landing price (p) multiplied by the harvest (y) which is subject to biomass (x) and effort (e).

$$TR = p * y \ (x * e)$$

Total cost is a function of variable costs and fixed cost as indicated below:

$$TC = a * p * y + b * e * fk$$

Where a is the crew shares of landings commission received, p is the price of landing, y is the landings, b is the marginal cost of effort, e is the effort and fk being the fixed costs.

Therefore, profit is a function of total revenue minus total cost as given by:

$$\pi = P * (1 - a) * q * e^{a} * x^{\delta} - fk - b * e$$

In this function, fk is the fixed cost in the short run, however, it is assumed that fk becomes a variable cost in a long run.

4.3 Dynamics of Adjustment paths

Since fisheries are rarely in equilibrium (steady-state), they evolve over time, although it might take a long time to reach an equilibrium. However, they tend to dwell on a dynamic adjustment path toward an equilibrium. This will readily change as new developments emerge in the fisheries. The fishery then moves towards another sustainable state (equilibrium) on a new adjusted path (Arnason R. , 2008). Dynamics are more realistic in determining the fisheries management policy as they put into consideration variations in effort, biomass, profits as time changes.

The dynamics reference point aims to maximise the present value of the profits attained from fisheries over time. This involves controlling effort over time in order to bring the fishery to an optimal evolutionary path and therefore considered effective in determining the sustainable optimal level for fisheries management policy. It takes into consideration the rate of discount. The expression of the basic optimal equilibrium biomass is given by:

$$G_x(x) + \frac{C_e(e).Y_x(e,x)}{\pi_e\left(e,x\right)} = r$$

Therefore, at a given discount rate (*r*), the combination of biomass, effort, profit and harvest of the fish will yield a long run optimal state or the optimal equilibrium. By substituting the Schaefer model in the above equation:

$$\psi = (\alpha - 2\cdot\beta\cdot x) + \left(\frac{b\cdot\delta\cdot(\alpha-\beta\cdot x)}{p\cdot(1-a)\cdot q\cdot x^{\delta} - b}\right) = r$$

The rate discount plays an important role in the optimal dynamics; where the higher the discount rate, the lower the optimal equilibrium biomass and if the rate of discount is high enough, the optimal equilibrium may exceed the MSY- effort level (Arnason R. , 1990). Stakeholders might prefer current benefit over future benefit. The optimal sustainable biomass is obtained when $X^{*}=X_{MEY}$ and when r=0.

Subsequently, the optimal equilibrium effort E^{*} can be derived by:

$E_{eq} = \frac{\alpha-\beta.x}{q.x^{\delta-1}}$ which is expanded into:

$$E^{*}_{eq} = \frac{\alpha.\left(X^{*}\right)^{1-\delta} - \beta.\left(X^{*}\right)^{2-\delta}}{q}$$

4.4 The optimal Feed-back rule

The feedback rule can be approximated by some low order polynomials that hit optimal equilibrium

$$y(t) = a0 + a1\cdot x(t) + a2\cdot x(t)^2$$

Which is then reduced to:

$$y = a0 + a1\cdot x^e$$

Therefore:

$$a1 = \frac{y^e - a0}{x^e}$$

4.5 Net present Value

The present value is the worth of the sum of money, as opposed to its invested at a compound rate. The general present value is obtained by:

$$PV_{\pi} = \frac{R_t - TC_t}{\left(1+d\right)^t} = \frac{\pi_t}{\left(1+d\right)^t}$$

The net present value generated by this industry (NPV) is calculated as the sum of annual net benefits – gross revenues less total costs (variable and fixed costs) at a discounted rate (Larkin *et al.*, n.d.). The net present value is used as a measurement of the project profitability over time, the higher the NPV, the more profitable the project is expected to be. The net present value of the profit earned from the fishing activities is attained by:

$$NVP_{\pi} = \sum_{t=0}^{n} \frac{\pi_t}{\left(1+d\right)^t}$$

5 DATA

As explained in chapter four above, the bio-economic model employed in this study consists of three functions; a biomass growth function $G(x)$, a harvesting function, $Y(e, x)$ and a cost function, $C(e)$, where x and e denote biomass and fishing effort, respectively. To apply the bio-economic model, the parameters of these functions need to be estimated. For this purpose, data on the relevant variables has been collected. Although, these data are not extensive and likely subject to considerable errors, they can be used to obtain statistical estimates of the model parameters with the help of standard regression techniques.

5.1 Biomass Data

The study made use of time-series data of (i) annual biomass estimates (ii) annual Total Allowable Catches (TAC) (ii) aggregate annual harvest pilchard for the period 1990 to 2016 to estimate the biomass growth function. The biomass estimates are primarily based on annual acoustic survey conducted by the Directorate of Resource Management with the assistances of the pilchard subsector. On the other hand, the catch data are provided by the Directorate of Policy, Planning and Economics, division of Statistics as well as by the Directorate of Resources Management. Historical data are obtained from previous Annual Reports. The data used covered a range of 27 years from 1990 to 2016 (see Annexure 1).

5.2 Effort Data

The corresponding effort data used to estimate the harvest function for the Namibian pilchard was obtained from the pilchard subsector, to be specific from one out of the three main operators for the period 1999 to 2015. These harvest data are based on reports filed by the pilchard companies and crossed-checked with the log books completed by the captains and observations and assessments by the Fisheries Observes Agency (FOA). The effort data used consisted of total number of days spent at sea per year, and the number of vessels used to harvest the quota per year. The data used is from 1999-2015 (see Annexure 2)

5.3 Economic Data

The economic data obtained consist of information about landings price of pilchard and fishing costs. Note that there are 3 main operators in the subsector, however, the data used in this study are those from one operator only. Table 1 depicts the total expenditures used in the model. The data was extracted from the Income and Expenditure Survey which is part of the annual quota applications carried out by the MFMR to the fishing industry as means of data collection and monitoring performance. Revenue was calculated using the average landed value of N$ 4.00/kg was converted to US$ 0.316/kg using the 2015 average exchange.

Table 1: Total cost for the Namibian Pilchard subsector

Year	TVC (US$)	TFC (US$)	TC (US$)
2012	3029719	1505415	4535134
2013	2841016	1883571	4724587
2014	2907292	1818444	4725736
2015	2073337	1423763	3497100

6 ESTIMATION OF MODEL PARAMETERS

6.1 Biomass growth function

The following simple (Pella-Tomlinson) biomass growth function is adopted:

$$G(x) = a \cdot x(t) - b \cdot x(t)^c ,$$

where *t* refers to time. Note that in this formulation *a* is the intrinsic growth rate and the carrying capacity of the stock is $\left(\frac{a}{b}\right)^{c-1}$, which collapses to *a*/*b* when the Pella-Tomlinson form coincides with the logistic (i.e. *c*=2). Thus, in discrete time biomass would evolve approximately according to the process:

$$x(t+1) - x(t) = a \cdot x(t) - b \cdot x(t)^c - y(t) ,$$

where *y*(*t*) denotes harvest during the period (*t*+1).

For the purpose of statistical modelling of the parameters *a* and *b*, it is helpful to rewrite the biomass growth function in the form:

$$z(t) \equiv \frac{\left(x(t+1) - x(t) + y(t)\right)}{x(t)} = a - b \cdot x(t)^{c-1} + u ,$$

where the stochastic error term has been added to reflect the stochastic nature of the biomass growth process.
The coefficients *a*, *b* and *c* were estimated by the method of least squares. An initial non-linear regression indicated that the coefficient *c* was not significantly different from 2. A test of the null hypothesis (H0) that *c*=2 could not be rejected (asymptotic normal statistic was 0.137 far from being significant). Thus, the restriction that c=2 was imposed and the equation estimated in a linear form. Table 2 below indicates the regression results.

Table 2: Regression output for the pilchard biomass growth function

Estimated Equation: $z(t) = a - b \cdot x(t)$			
No. of observations	25		
R^2	0.07		
Variable Name	**Estimated Coefficients**	**T-Ratio**	**P-Values**
b	0.000045549	1.330	0.197
a	0.52414	1.552	0.134
Diagnostics of the residuals			
Durbin –Watson statistic		1.57	
Jarque-Bera test for normality of residuals: Chi-square (2) =3.6			

The results reported in Table 1 seem reasonable. The diagnostic checks on the residuals do not reject the ordinary least squares assumptions of independently, normally distributed error terms. A low degree of fit (R^2) is normal in these kinds of estimations indicating a high degree of variability in biomass growth process. The estimated coefficients have the right signs and reasonable magnitudes. According to them, the carrying capacity of the stock is about 11.5 million metric tonnes and the maximum sustainable yield defined by $a^2/4b$ about 1.5 million metric tonnes.

There are reasons to believe that ecosystem and environmental conditions may play a significant role in the biomass growth process of the pilchard. Indeed, further investigations indicate that the biomass growth coefficients may be time variant. Thus, the hypothesis that the intrinsic growth rate *a* was independent of time was resoundingly rejected. More precisely, it appeared that it was a monotonically falling function of time over the data period.

Alternatively, we may assume that the biomass growth function above is subject to random variations as follows:

$$x(t+1) - x(t) = a \cdot x(t) - b \cdot x(t)^c - y(t) + u(t) \cdot x(t),$$

where $u(t)$ is an identically and independently distributed normal variable with expected value zero and variance σ^2. According to the estimation results σ^2 was estimated to be close to unity.

6.2 Harvest function

The following generalised Schaefer harvest function was adopted:

$$y(t) = q \cdot e(t)^a \cdot x(t)^b,$$

where, as before, $y(t)$ denotes harvest, *e(t)* fishing effort and $x(t)$ biomass at time *t*. The coefficient *q* is often referred to as catchability. While *q*, *a* and *b* are the parameters to be estimated.

A logarithmic transformation of the above equation allows us to estimate these parameters in a liner form:

$$\ln y = \ln q + a \cdot \ln e + b \cdot \ln x .$$

The results of an OLS estimation of this equation led to the results summarized in Table 3.

Table 3: Regression output for the pilchard harvest function

Estimated equation:	$\ln y = \ln q + a \cdot \ln e + b \cdot \ln x$		
No. of Observations		14	
R^2		0.4944	
Variable Name	**Estimated Coefficients**	**T-Ratio**	**P-Values**
a	0.89237	2.443	0.33
b	0.16676	2.201	0.050
lnq	-2.2697	-1.323	0.213
Diagnostic of the residuals			
Durbin -Watson = 2.46			
Jarque-Bera test for normality of residuals: Chi-square (2) =3.6			

The statistical properties of this regression are reasonable. The fit of the estimated equation to the data as measured by R^2 is fairly good. The Durbin-Watson and Jarque-Bera statistics do not indicate that the basic assumption of normally and identically distributed error terms needs to be rejected. The t-statistics for the estimated coefficients suggests they are reasonably well determined.

An estimate of the catchability coefficient, *q*, can be obtained as $e^{\ln q}$. Carrying out this transformation yields the estimate of *q* as 0.103. Thus, the estimated harvest function is:

$$y = 0.103 \cdot e^{0.892} \cdot x^{0.167} .$$

Interestingly, according to the estimated *a*, the harvesting function is concave in fishing effort. Thus, increasing fishing effort by 1% will only lead to a 0.89% increase in harvest. The schooling parameter, *b* is estimated to be some 0.167, which indicates that Namibian pilchard is a highly schooling species (Anarson *et al.*, 2009). This, as is well known, greatly increases the likelihood of severe overexploitation of the stock (Bjorndal & Lindroos, 2004).

6.3 Cost Function

The available data on pilchard fishing costs were limited. What we managed to obtain was fairly detailed cost and operational data for one company over the period 2012-2015. On the basis of these data the following total cost function was estimated

$$C(e) = c \cdot e + fk$$

Where *c* is a parameter and *kf* represent the fixed costs. The results of an OLS estimation of this equation led to the results summarized in Table 4.

Table 4: Regression output for the Namibian Pilchard cost function

Estimated equations	*TC=c e+fk*		
No. of Observations		4	
R^2		0.867	
Variable Name	**Estimated Coefficients**	**T-Ratio**	**P-Values**
c	0.012762	3.614	0.069
fk	3.0307	7.705	0.016
Diagnostic of the residuals			
Durbin -Watson statistic		1.543	
Jarque-Bera test for normality of residual: Chi-square (2) = 0.5798			

Due to the extremely few degrees of freedom in this estimation, diagnostic statistics for the residuals don't mean much. However, they clearly do not indicate any serious deviation from the OLS assumption normal and identically distributed residuals. The R^2 of 0.87 indicates a well fitted model. However, again the few degrees of freedom should be counted against this statistic. According to the coefficient estimate of *fk* the fixed costs of this operation is about 3 million US$ while the coefficient estimate of *c* suggests that an increase of one fishing day will lead to a US$ 12.8 thousand.

7 THE PILCHARD FISHERY: THE ESTIMATED MODEL

Having obtained estimates of the basic functions of the bio-economic model for the pilchard fishery, the properties of this model may now be examined. The equilibrium or sustainable properties of the fishery according to the model is first estimated, and later the dynamic properties of the model are considered.

7.1 The sustainable fishery

The sustainable fishery is defined by the requirement that biomass does not change, i.e., $x(t+1)=x(t)$. In that case the essential bio-economic model is reduced to:

$$0 = a \cdot x(t) - b \cdot x(t)^c - y(t),$$

$$y(t) = q \cdot e(t)^a \cdot x(t)^b,$$
$$C(t) = c \cdot e(t) + fk,$$
$$\pi(t) = p \cdot y(t) - C(t),$$

and it is possible work out the sustainable biomass and harvest (or yield) functions as well as the sustainable profits for any level of fishing effort, *e*, that is selected.

Note that for biomass to be constant, harvest has to be constant and, therefore, also fishing effort. As a result, revenues costs and profits are also constant. Thus, the reference to time, *t*, in the sustainable variant of the bio-economic model above is actually redundant.

As, discussed above and further illustrated in section 7.3 below, there appears to be a great deal of randomness in the stock evolution of the pilchard. Therefore, first of all, the concept of a sustainable fishery is of much less practical relevance in this fishery than many others. Second, to make any sense the concept of sustainability must refer to the expected (or average) level of biomass growth where random stock growth disturbances assume their expected value (namely zero in our case). This will be further explored below.

7.2 Sustainable yield and biomass function

The Figures 9 and 10 indicate the sustainable biomass and yield as function of fishing days at sea. The MSY is approximately 1508 thousand metric tonnes and this occurs at 9246 fishing days and biomass 5754 metric tonnes as per. A notable attribute of both functions is the gap that occurs at approximately 9325 fishing days. If fishing effort is maintained above this level, the stock will, according to the estimated model, eventually collapse with the fishery. The reason why this gap occurs is as schooling behavior of pilchard as represented by the low value of the schooling coefficient, *b*.

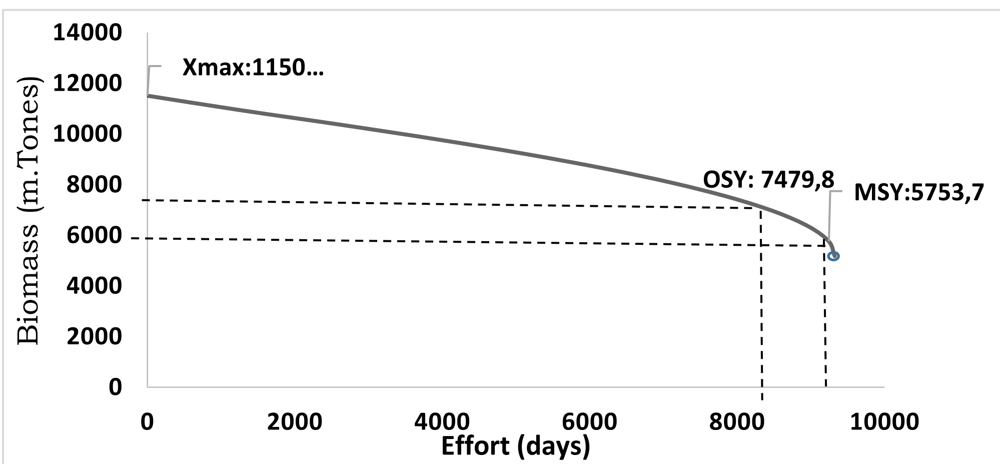

Figure 9: Sustainable biomass for the Pilchard fishery

The fishery's corresponding sustainable harvest and effort are given by Figure 10 below.

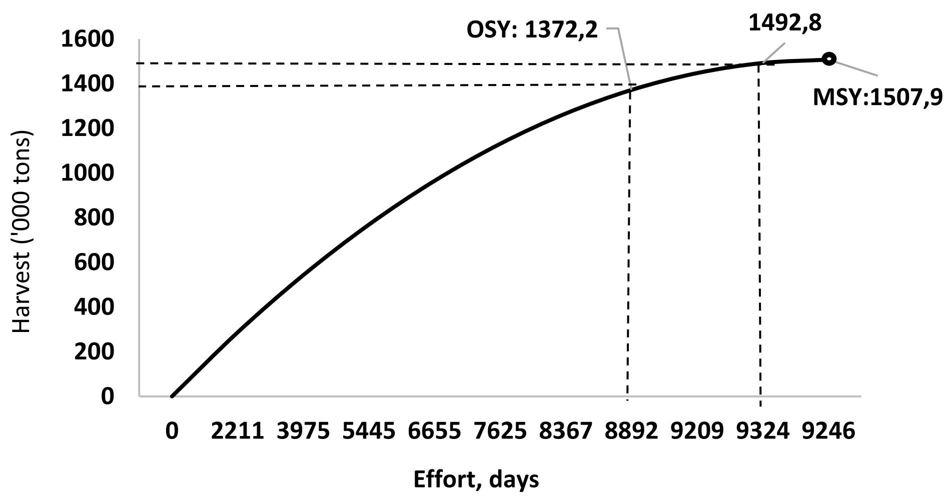

Figure 10: The sustainable yield for the Namibian pilchard fishery.

At the MSY, the fishery is taking about 26% of the biomass every year. Fishing effort above the E_{msy} is not efficient; less catch with increasing effort with the biomass declining. Note that this tendency will continue until it eventually reaches a gap in sustainable harvest and effort resulting in the collapse of the fishery.

It is interesting to note in this context that at the current depressed state of the biomass, the pilchard subsector is currently operating far below the MSY with only 12.500 tonnes landed from a total of 50 fishing days in 2015. Because the MSY does not imply any level of efficiency in terms of harvesting the fish, the study therefore considered the costs of fishing and the revenue attained from the sales of fish.

7.3 Optimum Sustainable Yield and Fisheries Economic Yield

The concept of Optimum Sustainable Yield (OSY)[3] has been widely used in the management of renewable natural resources. OSY implies the efficient harvesting of the resources where the injection of inputs, i.e. effort, aims to maximize the sustainable net benefits (often measured as profits). Figure 11 depicts sustainable annual revenue and annual fishing costs for the Namibian pilchard fishery measure per unit cost of fishing effort. The OSY corresponds to an effort level lower and biomass higher than that of maximum sustainable yield.

The revenue is increasing with level of sustained fishing effort, although at a slowing rate. The yield is also growing accordingly, i.e. up to the MSY effort level. Beyond this point, the corresponding sustainable catches and received revenue will fall. However, according to the estimates costs increase linearly with the number of days of fishing per year.

[3] This is also often referred to as the maximum economic yield (MEY)

According to the estimated model, the optimal sustainable yield of the pilchard fishery occurs at fishing effort level 7919 corresponding to sustainable harvest of 1376 thousand tonnes and biomass of 7475 thousand metric tonnes. At this point annual profits are 110.3 m. USD per year. So, obviously, according to the estimated model, this can be profitable fishery.

Interestingly, the sustainable profits at the OSY (or MEY) is not much less than at the MSY or 110.3 vs. 99.0 m. US$. Moreover, the harvest at the MSY is about 1508 thousand metric tonnes but only 1373 thousand tonnes at the OSY. However, the biomass at the MSY is considerably less or 5753 thousand metric tonnes compared to 7475 thousand metric tonnes at the OSY. The MSY, therefore, being closer to the point of collapse, is considerably riskier than that of the OSY.

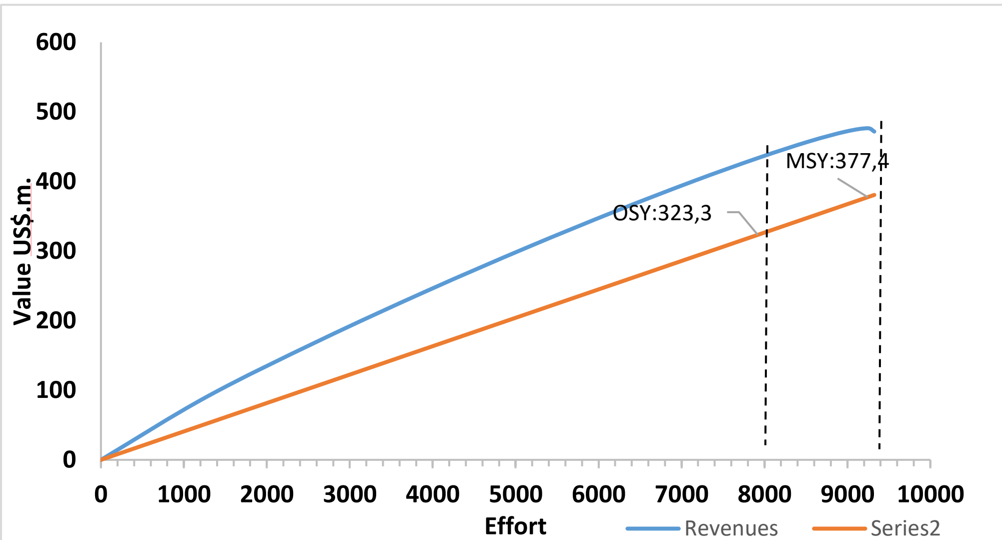

Figure 11: A sustainable fisheries model for the Namibian Pilchard derived from the logistic biomass growth model using revenue, costs and net benefits with implied effort

7.4 Dynamics of the Fishery

The sustainable relationships constitute a very special case of the fishery. In reality the fishery evolves over time. This evolution depends on the biomass growth relationship, the path of fishing effort and changes in all the exogenous variables affecting the fishery.

7.4.1 Deterministic and stochastic evolution of the biomass

According to the estimated biomass growth function, the evolution of biomass is quite regular. To illustrate this, consider the biomass and harvest evolution from a certain assumed initial level of biomass in 2018 and a certain harvest control rule (HCR). The initial level of biomass in 2018 is set at 0.05 million metric tonnes

The harvest control rule: $y(t)$=-0.450+0.3299·$x(t)$ million metric tonnes, if $y(t)>0$.
$y(t)=0$, if $y(t)>0$

Note that the initial biomass level, as estimated by biological research, is extremely depressed at less than 1% of the estimated carrying capacity. However, the HCR is close to the optimal one. Assuming the deterministic biomass growth function, the path of biomass and harvest will be as illustrated in Figure 12.

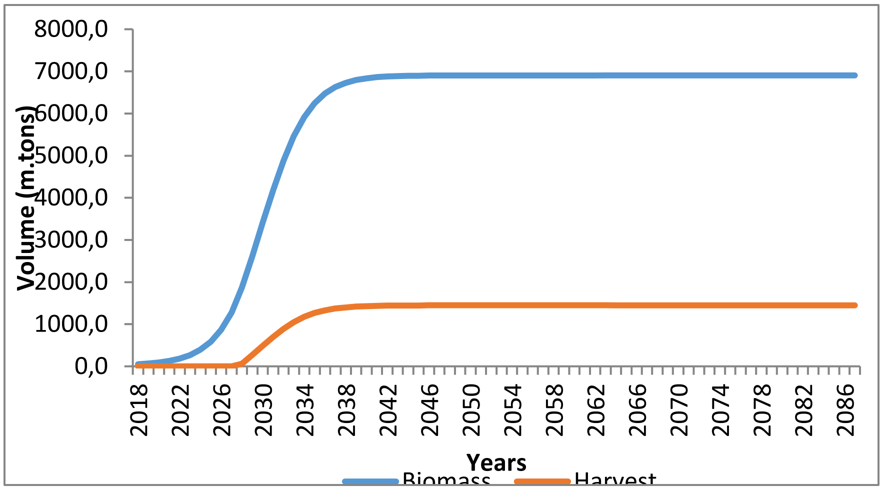

Figure 12: The Optimal sustainable yield for the Namibian pilchard under the harvest control rule management policy.

As illustrated, the HCR adopted leads to a very regular, although prolonged, recovery path of biomass. The path of harvest is similarly regular. Note that according to the harvest control rule specified, the fishery will be closed for harvests for the first 9 years to allow the stock to recover. After about 29 years the fishery has reached in long term sustainable level.

If, by contrast, we recognize that biomass evolution is highly stochastic, the predicted evolution of the fishery will be radically different. In accordance with our investigation into the biomass growth process in section 4, let us assume the following biomass growth function:

$$x(t+1)-x(t)=a\cdot x(t)-b\cdot x(t)^{c}-y(t)+u(t)\cdot x(t),$$

with $u(t)$ having a normal distribution of mean zero and variance 0.3, i.e. $u(t) \sim N(0,0.3)$.
In this case, from the same initial biomass and the same HCR, the evolution of biomass and harvest could be (i.e. for one draw from the stochastic distribution of u) as illustrated in Figure 13.

This evolution of biomass seems much more in accordance with what has been historically estimated. Interestingly from the year 2050 onward the average biomass and harvests are about 5.5 and 1.4 million metric tonnes respectively which is close to the OSY. Small pelagic species have a tendency of being unstable over time due to their short life span, higher intrinsic growth rate, and a higher schooling behavior.

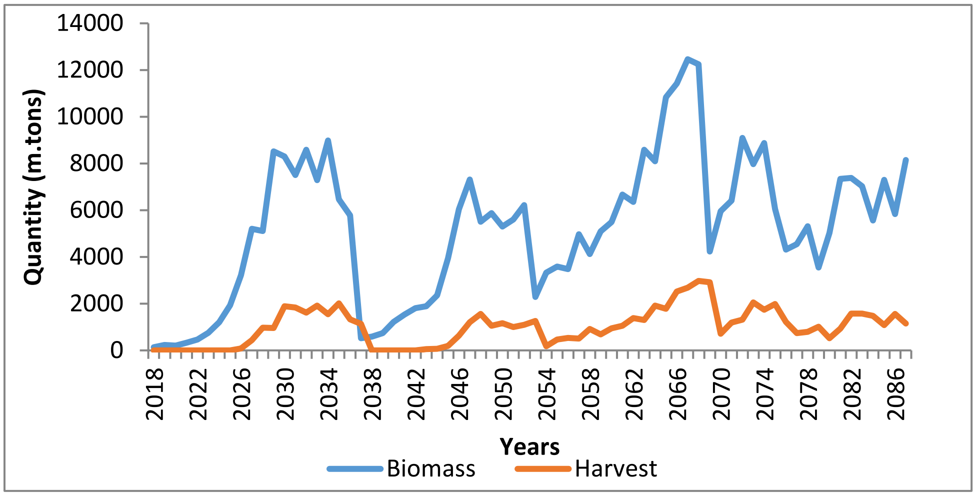

Figure 13: Evolution of the biomass and harvest of the Namibian pilchard fishery.

7.5 Optimal Fisheries Policy

The optimal fisheries policy is the level of effort (or harvest) that maximises the present value of net benefits flowing from the fishery over time. This kind of a policy normally converges to a fishery equilibrium over time (Arnason, 1990; Anderson & Seijo 2011). It is important to realize that this dynamic equilibrium differs from the static OSY if the rate of discount is positive. In that case the dynamic OSY corresponds to a higher fishing effort and lower biomass than the static OSY (Clark, 2006).

Additionally, increasing values of the net present value (NPV) with respect to a change in the discount rate *(d)* was analyzed at an optimal equilibrium level of the fishery. The NPV is a representation of pure profit from the fishery over time. After some experimentation, the result indicated that the following simple Harvest Control Rule (HCR) provided a good approximation to the optimal fisheries policy.

A near-optimal harvest control rule
$y(t)$=-0.500+0.0.2820·$x(t)$, if $y(t)$>0,
$y(t)$=0, if $y(t)$>0.

Applying this rule to the non-stochastic version of the bio-economic model leads to the following outcomes of the fishery (rate of discount 10% per annum) (Table 5).

Table 5: Harvest Control Rule on a non-stochastic bio-economic model

Present value of the fishery:	360 m. USD
Equilibrium	
Biomass	6.905 m. tonnes
Harvest	1.447.50 m. tonnes
Effort	8.535.20 days
Profits	108.97 m. USD

The evolution of biomass and harvest is illustrated in Figure 14.

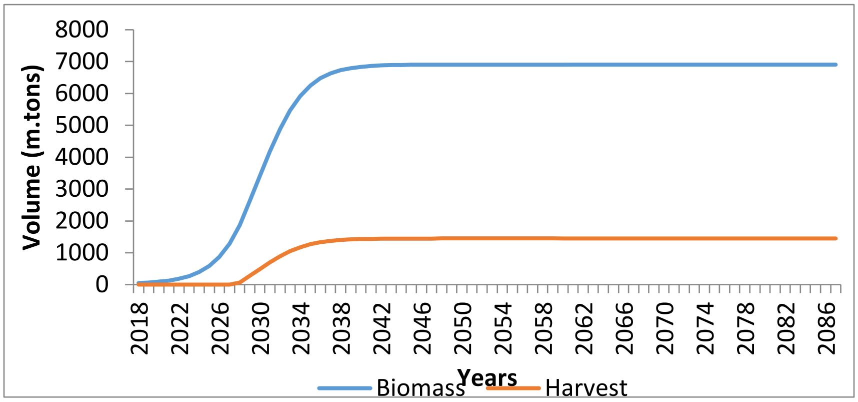

Figure 14: Optimal biomass and harvest level for the Namibian pilchard fishery.

The fishery reaches an equilibrium after 38 years where there are no fluctuations in the stock and harvest, at a given fixed amount of effort. At this equilibrium, the biomass is almost 6 million tonnes, almost 60 times the current estimated level and the harvest is almost 75 times greater. The corresponding effort level is 8535 days compared to the current level of about 50 days.
Assuming the stochastic biomass growth function (but the same initial biomass and HCR), the evolution of biomass and harvest will be as illustrated in Figure 15.

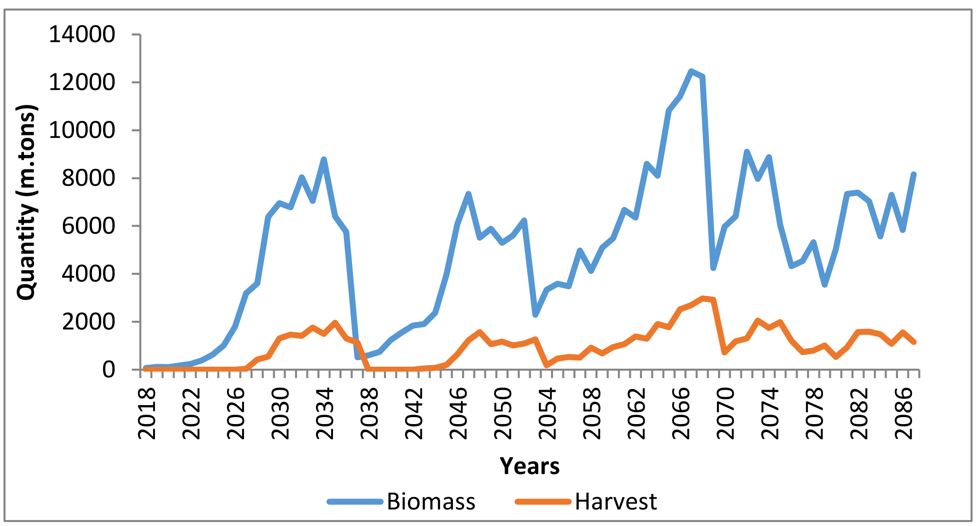

Figure 15: Optimal biomass and harvest level in a stochastic system

The corresponding evolution of fishing effort (days) compared to the no stochastic case (blue curve) will be as illustrated in Figure 16.

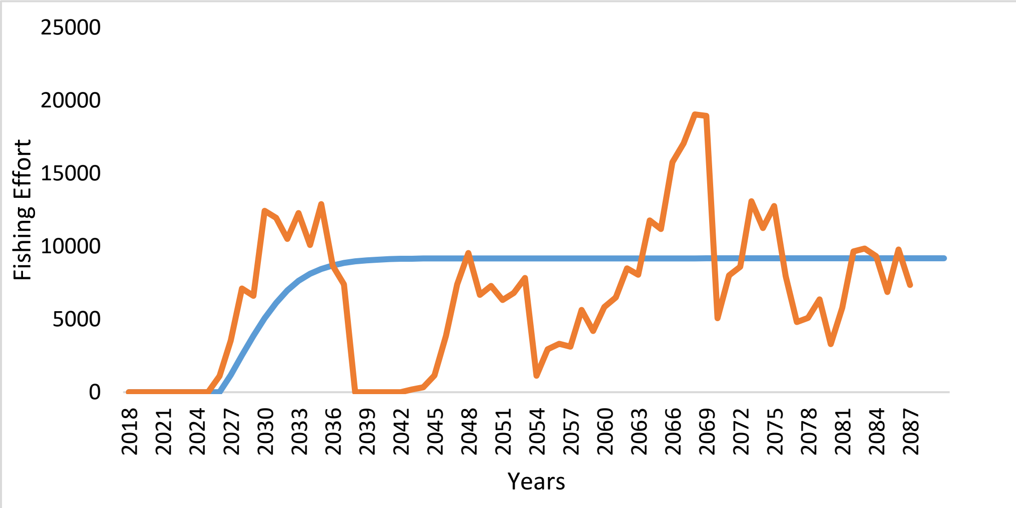

Figure 16: The evolution of the fishing effort after an optimum harvest policy was introduced for the period 2018-2087. The first years indicate the closure of the fishery for 9 years.

Obviously, the fishery is much more volatile under the stochastic biomass growth situation than it is when this randomness is ignored. This applies to all the key measures of the fishery, biomass, harvest, fishing effort and profits. It is a real question whether in fact this instability can be optimal from an economic and social perspective. The following Table 6 provides some key statistics for the fishery in the stochastic biomass growth case.

Table 6: Stochastic Biomass growth for the Namibian Pilchard

Present value of the fishery:	304m. USD
Long run average levels	
Biomass	7.475 m. tonnes
Harvest	1.372.m. tonnes
Effort	7.925 days
Profits	100.6m. USD

The reason the present value of the fishery is higher in the stochastic case is primarily that for the stochastic draw taken, biomass recovers more quickly. It also has partly to do with the ability to take good advantage of the occasional high biomass levels.

Noticeably, Figure 12 and 14 as well as 13 and 15 have identical patterns, however it is important to present them in the study; they represent different Harvest Control Rules for the Namibian Pilchard.

8 DISCUSSION

The Namibian pilchard stock has shown extreme stock fluctuations similar to those common to other sardine stocks around the world. It seems that sardine stocks are greatly sensitive to environmental and ecosystem conditions, making them vulnerable to stock fluctuations. Since the early 1940s, sardine stocks in such diverse areas such as off California in 1940s, Britany in 1970s, Peru in 1970s etc. have gone through severe stock declines closed to collapses (Parrish & Grant, 1989). However, most of these stocks have recovered or are in the process of recovery perhaps supported by the implementation of fisheries management measures (Parrish & Grant, 1989). These measures have included long term fisheries moratoria to allow the fish to recover. For instance, the California sardine was put under moratorium in 1970s and re-opened again in 1980s, with a full recovery to its original size (Parrish & Grant, 1989).

During the 26 years since 1990, according to the stock estimates, Namibian pilchard has gone through three severe stock depressions with stock highs in between (see Appendix 1). It is currently in the midst of its fourth depression and according to the somewhat variable recent statistics, the most severe phase. The level of harvest seems to play an insignificant role in stock fluctuations. From 1990 to 2014, harvesting removed less than 2% of the total biomass every year. Nevertheless, the stock went through at least three major depressions during that period. Therefore, for the Namibian pilchard, major stock variations may be expected to occur even in the absence of the fishing. It is only in 2014 to 2016 that the harvests seem to have become a significant fraction of the biomass and this is because of the greatly reduced stock level.

Even if harvesting has negligible impact on the pilchard stock evolution in normal times, it may well be the case the continued harvesting in the face of very low stock levels may lead to further stock declines and even a stock collapse. This is because when the stock is very low, even a low level of harvest may seriously reduce the life span of the remaining individuals, wipe out sub-stocks and thus, lead to altered migratory pattern in the future or to a collapse or a prolonged depression of the stock. All of these have been recorded for the California and Southern African Sardine, (Murphy, 1966). Therefore, a positive harvesting strategy can lead to a long term stock depletion if it is done during the period of poor recruitment as a result of adverse environmental conditions (Link *et al.*, 2004.).

The reasons for the current low pilchard stock level are unknown. Most likely it is primarily due to adverse environmental factors. According to biological research (Crawford *et al.*, 1995), the pilchard stock growth is greatly affected by such environmental factors as water salinity, temperature and upwelling all of which are quite variable in Namibian waters. It may also be the case that predation and other ecosystem factors have played a role.

The bio-economic model developed in this research suggests that the fishery is currently operating way below the optimal sustainable biomass and harvesting levels. The biomass needs to be restored to much higher levels in order to realize the economic potential of the fishery. The quickest way to facilitate that is to close the fishery. However, because of the existing capital investments and marketing channels, a complete closure will be difficult for the industry to deal with. This applies even more so to the labour employed in the fishery. Thus, if the fishery closure will continue for many years it seems likely that a great deal of physical and human capital will be forfeited and a great deal of general expertise in running this industry may be lost. Therefore, a more beneficial policy might be to maintain catches at some low minimum level during the period of stock depression, e.g. by allocating a minimum TAC of 10 thousand metric tonnes per year, until the stock has recovered to a level close to the MEY.

An alternative policy is to place the fishery under moratorium for a sufficiently long period for stock recovery to occur (possibly as long as 9 years) with controlled harvest immediately after re-opening. This policy minimizes the risk of a stock collapse and has a higher expected present value according to the bio-economic model. However, it suffers the costs discussed in the previous paragraph which are not incorporated in the bio-economic model.

9 CONCLUSION AND RECOMMENDATIONS

The main objective of the study was to compile an empirically-based model of the biological and economic aspects the Namibian Pilchard fishery and use this model to suggest sensible fisheries policies for the fishery. The finding of this model is that the fishery is potentially very profitable. However, to realize this potential the stock level has to be restored from its current depressed level. Another important finding is that due to the inherent stock variability, a stable fishery at a high level is probably not attainable. Therefore, the optimal fishery will almost surely exhibit a strongly fluctuating path over time with very good catches, when stocks are high, being interspersed by very low or even no catches, when the stock is low. The average catches and stock levels can apparently be much higher than they are now. In fact, the model suggests that long average catches can exceed 1.3 million metric tonnes and the stock level 5 million metric tonnes.

According to the optimal policy suggested by the bio-economic model, the fishery should be closed when the biomass is sufficiently depressed. However, due to the poorly malleable physical and human capital investments in the pilchard industry, the opportunity cost of closing the fishery, not accounted for in the bio-economic model, are very substantial. Therefore, a more optimal policy might be to set a certain minimum for annual harvests, e.g. at 10 thousand metric tonnes, even when the biomass is very low, in order to maintain the industry. In monetary terms, the opportunity cost of this policy compared to occasional closures is about worth US$ 34 million as compared to the 360 million that can be potentially attained.

The following specific policy implications are drawn:

- In terms of regulatory measures to preserve the species; the fishery should continue operating however on a conservative harvest of 10 000 tons per year, the policy should be able to strengthen, conserve the biomass as well as minimize economic/social loss to the society. At a point when the stock has recovered to its carrying capacity, the total allowable catch should be determined on a basis of a conservative HCR. However, flexibility should be allowed for appropriate response to changes in economic and biological conditions of the fishery.

- In terms of strategic management, the Ministry of Fishery and Marine Resources should consider alternative fisheries management policies i.e. Individual Transferable Quotas (ITQs) with long-term proportional rights. This allows for the harvest to maximized the economic yield from limited resources.

- The study is considered to be a pilot for the Namibian fisheries, however with a few shortcomings. It is therefore recommended that similar studies and research be carried out on other fisheries i.e. hake, however with sufficient data.

ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to UNU-FPT staff; Dr. Tumi Tomasson, Þór H. Ásgeirsson, Mary Frances Davidson and Sigríður Ingvarsdóttir, who gave me this golden opportunity to be part of this programme, which has been very enlightening and a lifetime experience for me.

The completion of this project could not have been possible without the helping hand of my supervisor Professor Ragnar Arnason, for has given me positive advice, guidance and assisted me to finalize this project within the limited time frame.

I would be indebted if I forget Mr. Pieter Greeff of Etosha Fishing Corporation Ltd (Pty), for his time and effort he put in providing me with all the necessary information I have ever requested. Special thanks to the staff members of the Ministry of Fisheries and Marine Resources for lending me their assistance and advice.

To my family and friends, I would also like to extend my great gratitude for the love, moral support and advice they have given me throughout my stay in Iceland.

Thank you all!

LIST OF REFERENCES

Anderson, L. G., & Seijo , J. C. (2011). Bioeconomics of Fisheries Managment. 1-10.

Arnason, R. (1990). Minimum Information Management in Fisheries. . *Canadian Journal of Economics.23*, 630-653.

Arnason, R. (1999). Property Rights As Means For Economic Organization. *A paper for the mini course for the right base management*, 9.

Arnason, R. (2008). *Basic Fisheries Economics (unpublished /manuscript). A paper prepared for the workshop on Policy and Planning for Coastal Fisheries Resouces.* Suva, Fiji,January 28 to February 8, : University of South Pacific.

Arnason, R. (2009). Rents Drain in Fisheries: The case of the Lake Victoria Nile Perch Fishery. 3.

Arnason, R. (n.d). Fisheries Management Theory: Background. *Fame Workshop on New Developments in Right Based Fisheries Management : Community Fishing Rights*, 2.

Arnason, R., Willmann, R., & Kellehe, K. (2009). The Suncekn Billion; The Economic Justification for Fisheries Reforms. *The International Bank for Reconstruction and Development/The World Bank, Washington, DC*.

ATLAFCO, T. M. (2012). *Fisheries and Aquaculture Industry in Namibia.States Bordering the Atlantic Ocean ; ATLAFCO member countries.* ATLAFCO.

Bakun, A. (1993). The California Current, Benguela Current and Southwestern Atlantic shelf ecosystems: a comparative approach to identifying factors regulating biomass yields. *J-P. Roux & L. J. Shannon (2004) Ecosystem approach to fisheriesmanagement in the northern Benguela: the Namibian experience, African Journal of Marine Science, 26:1,*, 79-93.

Bakun, A. (1996). Pattern in the ocean: Ocean Processes and marine population dynamics. *University of Califonia Sea Grant Program, San Diego, Califonia, USA, in cooperation with Centro de Investigaciones Biologicas de Noroeste, La Paz, Mexico*.

Bakun, A. (2003). California Current , Benguela Current and Southwestern Atlantic Shelf ecosystem: . *A comparative approach to identifying factors regulating biomass yeild. In G.M. Daskalov, D.C. Boyer and J. P Roux (*, 259-260.

BCLME. (2007). *The Changing State of the Benguela Current Large Marine Ecosystem: Expert workshop on climate change and variability and impacts thereof in the BCLME region.* Benguela Current Large Marine Ecosystem.

Belhabib, D., Willemse, N., & Pauly, D. (2015). A fishery tale: Namibian fisheries between 1950 and 2010. *Working Paper No. 2015-65*, 2.

Bergh, P. E., & Davies, S. (n.d). Against all Odds: Taking control of the Namibian Fisheries. 291.

Bianchi, G. C.-P. (1993). FAO species identification field guide for fishery purposes. *The living marine resources of Namibia. FAO, Rome.*, 2.

Bjorndal, T., & Lindroos, M. (2004). International Management of North-Sea-Herring. *Environmental & Resources Economics, 29; 89-96*, 87.

Boyer, D., & Hampton, I. (2001). An Overview of The Living Marine Resources Of Namibia: A decate of Namibia Fisheries Sciencem 23:1. *South African Journal Marine Science*, 5-6.

Clark, C. W. (2006). Fisheries Bioeconomics: why it is so widely misunderstood. Applications of dynamical systems theory to population ecology. *The Society of Population Ecology and Springer- 48: 95*, 96.

Crawford, R. J., Cooper, R. M., Dyer, J., & Chesselet, B. M. (1995). Trends of African Penguin (sphenisus demersus) population in the 20th centrury. *South Afrcan Journal of marine Science 16*, 101-102.

Curry, P., Bakum, A., Crawford, R. J., Jarre, A., Quinones, R. A., Shannon, L. J., & Verheye, H. M. (2000). Small Pelagic in upwelling systems: patterns of interactions & structure changes in "wasps-waist" ecosystem. *ICES journal of marine Science 57,*, 603-618.

D. Lluch-Delda, R., T.Kawasaki, A.D.MacCall, H.Parrish, R., & P.E.Smith, R. &. (1989). World-Wide Fluctuations of Sardine and Anchovy Stock: The Regime Problem. *South African Jouranl of Marine Science 8: 195-205,* 202.

Daskalov, G. (2003). Long-tems changes in fish abundance and environmental indices in the black sea. *Marine Ecology Progreses Series,225*, 255-270.

Elago, P. N. (2009). *Duration of Fishing Rights and Investments: An Emperical Study of Investment in Namibian Fisheries.* Reykjavik, Iceland: United Nations University-Fisheries Training Programme.

Gharibi, M. (n.d.). Dynamics of Fisheries. *Cheriton School of Computer Science, University of Waterloo, Canada*, 9.

H.Sobers, R. (2010). *Bioeconomic Analysis of the Flyingfish Fishery in Barbados.* Reykjavik: United Nation University- Fisheries Training Program.

Hardin, G. (1968). The Trategy of the Commons: Science 162. 1243-1244.

Hill, K. T. (2010). Fishery logbook data for pacific sardine. *Workshop on enhancing stock assessments of pacific sardine in the Californa*, 1-2.

Huggins, L. E. (2011). Fencing Fisheries in Namibia and Beyond:A lesson learn from Developing Nations. 2-3.

Kashindi, M. S. (1999). Management of the Deep-Sea Fishery of Namibia: Orange Roughy (Hoplostethus atlanticus). 8.

Larkin, S., Michael, H., Kate, Q., & Gil, S. (n.d.). Future Generations, Discount Rates and the Optimal Harvest of Fisheries Resources. *University of Florida, New Zealand Seafood Industry Council Limited,Oregon State University and Oregon State University*, 6-7.

Lingen, C. v., & Durholtz, M. D. (n.d). Review of Variability in Biomass, Growth and Other Characteristics of Anchovy (Engraulis encrasicolus) and Sardine (sardinops Sagax) in the Benguela Current Upwelling Ecosystem. *Marine and Coastal Management*, 3.

Link, P. M., & Schneider, U. A. (n.d.). Economic impacts of changes in fish population dynamics: the role of the fishermen's harvesting strategies. *Working Paper FNU-50*.

M, Daskalov D; Boyer, D C; Roux, J P. (2003). Relating Sardine Sardinops Sagax Abundance to Enviromental Indices in the Northern Benguela. *Progress in Oceanography*, 259-260.

MFMR. (2013). Annual Report . *Retrived from: http://www.mfmr.gov.na/*, 14.

MFMR. (2014). *Marine Resources Advisory Council , Directorate Resources Management. Management Recommendations for Sardine (Pilcahrd).* Swakopmund: National Marine Information & Research Centre.

MFMR. (2016). *Marine Resources Advisory Council, Directorate of Policy Planning & Economics. Management recomendation for sardine (pilchard).* Windhoek: MFMR.

MFMR. (2016). *Marine Resources Advisory Council, Directorate of Resources Management, Management recommendations for sardine (Pilchard).* Swakopmund: National Marine Information and Research Center.

MFMR. (2016). *Marine Resources Advisory Council, Directorate of Resources Management, Management recommendations for sardine (Pilchard).* Swakopmund: National Marine Information and Research Center.

Murphy, I. (1966). Population biology of the Pacific sardine (sardinops caerulea). prof. Calif. Acad. Sci. 4;34(1) :1-84. *In D.LLuch-Belda; R.J.M. Crawford; T.Kawasaki; A.D. MacCall; R.H.Parrish; R.A. Schwartzlose & P.E.Smith (1989). World-Wide Fluctuations of Sardine and Achovy Stock: The regime Problem. South African Journals Marine Science,8:195-205*, 202.

NSA. (2015). *Annual National Account, Retrieved from:http://cms.my.na/assets/documents/National_Accounts_2015_-_11_August_2016.pdf.* Windhoek: Namibian Satistic Agency.

OECD, O. f.-o. (2012). *Economics of Rebuilding Fisheries: Case strudies of Fisheries Rebuilding Plans.* OECD.

O'Toole, M. J. (1977). Investingation into some important fish larvaae in the South-East Atlantic. *Ph.D. Thesis, University of Cape Town*, 299 (unpublished).

Parrish, R., & Grant, R. S. (1989). The Monotypic sardine, sardina and sardinops. *Thier taxanomy, distribution, stock structure and zoogeography. Can J Fish Aquat sci 46:2019-2036*, 2032.

Paterson, B., Kirchmer, C., & Ommer, R. (2013). A Short History of the Namibian Hake Fishery. *A social Ecological Analysis*, 1-2.

Paul, L., & Parkinson, R. &. (2001). Pilchard (Sarditlops Neopilchardus) biology and Fisheries in New Zealand, and a review of Pilcahrd (Sardhops, sardina) biology, fisheries and , research in the main world fisheries. *New Zealand Fisheries Assessment Report 200U37.44 p.*, 35.

Porter, G. (2004). A matrix Approach to Analysingthe Resource Impact of Fisheries Subsidies . *Economic and Trade Brach: United Nations Enviromental Programme*, 10.

Shanghala, K. M. (1999). Management of the Deep-Sea Fishery of Namibia Orange Roughy (Hoplostethus Atlanticus(. *United Nation University-Fisheries Training Progamm, Final Project*, Pg 6.

Shannon, V. L., & O'Toole, M. (2003). Sustainable of the Benguela : Ex Africa semper a liquid novi. *In Dawit Yemane; Stephen P. Kirkman; John Kathena; Silvi E. N'siangango ;Bjørn Erik Axelsen & Toufiek Samaai. Assessing changes in the distribution and range size of demersal fish populations in the Benguela Current Large Marine Ecosystem, Rev Fish Biol F.*

Sumalia, U., & Vasconcellors, M. (2000). Simulation of ecological and economic impact of distance fleet on namibia Fisheries. *Econological Economic. 457-464*, 32.

Tjizoo, M. B. (2008). Characterising and Comapring the Spawining Habitants of the Sardine (Sardinops Sagax) And The Anchovy (Engraulis Encrasicolus) In The Northern Benguela Regions. *Master Thesis Project, Department of Zoology, Faculty of Science. University of Cape Town*, 4.

Twatwa, M. N., Van De Lingen, C. D., Drapeau, L., Moloney, C. L., & Field, G. J. (2005). Characterizing and comparing the spawning habitats of anchovy (Engraulisencrasicolus) and sardine (Sardinops sagax) in the southern Benguela upwelling ecosystem. *In C.D Van De Linger and M.D. Durholtz (u.d) REVIEW OF VARIABILITY IN BIOMASS, GROWTH, AND OTHERCHARACTERISTICS OF ANCHOVY Engraulis encrasicolus AND SARDINE Sardinops sagax IN THE BENGUELA CURRENT UPWELLING ECOSYSTEM.*

Van Der Lingen, C. (2002). Diet of sardine Sardinops sagax in the southern Benguela upwelling ecosystem. *South African Journal of Marine Science, 24;1*, 301.

Zyl, B. J. (2001). Managing Namibia's Marine Fisheries. *A Decade of Rebuilding*, 2.

APPENDICES

Appendix 1: Biomass, TAC and Harvest for the Namibian Pilchard

Year	*Biomass (m. tons)*	*TAC (000'tons)*	*Harvest (000'tons)*
1990	0.0	40.0	89.0
1991	11059.7	60.0	69.0
1992	26932.9	80.0	81.0
1993	14450.9	115.0	115.0
1994	5725.8	125.0	117.0
1995	1639.7	40.0	43.0
1996	5657.9	20.0	0.0
1997	13202.6	25.0	27.7
1998	12949.7	65.0	68.6
1999	8248.4	45.0	44.7
2000	4750.0	25.0	29.7
2001	3460.5	10.0	10.8
2002	13295.5	0.0	4.2
2003	16474.3	20.0	22.3
2004	6910.6	25.0	28.6
2005	4049.6	25.0	25.1
2006	1216.1	25.0	2.3
2007	3758.4	15.0	23.5
2008	5017.6	15.0	18.8
2009	5560.0	17.0	20.1
2010	12307.9	25.0	23.4
2011	10689.1	25.0	31.8
2012	3327.1	25.0	26.3
2013	886.1	25.0	25.8
2014	235.5	30.0	31.6
2015	44.0	25.0	23.6
2016	6.4	14.0	3.4

Source: Ministry of Fisheries and Marine Resources

Appendix 2: Total harvest, boats, days and biomass for the Namibian Pilchard

Year	Harvest	Boats	Days	Biomass
1999	44653.00	33.00	0.00	8248.40
2000	2970.00	30.00	0.00	4750.00
2001	10763.00	26.00	0.00	3460.50
2002	4160.00	25.00	0.00	13295.50
2003	22255.00	20.00	67.00	16474.30
2004	28605.00	16.00	208.00	6910.60
2005	25128.00	17.00	86.00	4049.60
2006	2314.00	16.00	51.00	1216.10
2007	23522.00	9.00	58.00	3758.40
2008	18755.00	11.00	71.00	5017.60
2009	20137.00	10.00	36.00	5560.00
2010	23424.00	8.00	108.00	12307.90
2011	31774.00	8.00	72.00	10689.10
2012	26259.00	7.00	96.00	3327.10
2013	25778.00	9.00	101.00	886.10
2014	31578.00	10.00	121.00	235.50
2015	23605.00	7.00	150.00	44.00

Source: Ministry of Fisheries and Marine resources and the Pilchard subsector

Appendix 3: Basic sustainable model for the Namibian Pilchard Fishery

Negative Biomass	Biomass	Harvest	Effort	Revenues	Costs	Profits
mt	1000 mt	1000 mt	Days	m. USD	m. USD	m. USD
0.0	0.0	0.0	#DIV/0!	0.0	#DIV/0!	#DIV/0!
-575.4	575.4	286.5	2211.0	90.5	90.3	0.3
-1150.7	1150.7	542.8	3975.4	171.5	162.3	9.2
-1726.1	1726.1	769.0	5445.0	243.0	222.3	20.7
-2301.5	2301.5	965.0	6655.1	305.0	271.7	33.3
-2876.9	2876.9	1130.9	7624.8	357.4	311.3	46.1
-3452.2	3452.2	1266.6	8367.3	400.3	341.6	58.7
-4027.6	4027.6	1372.2	8892.4	433.6	363.0	70.6
-4603.0	4603.0	1447.6	9208.9	457.4	375.9	81.5
-5178.3	5178.3	1492.8	9324.2	471.7	380.7	91.1
-5753.7	5753.7	1507.9	9245.7	476.5	377.4	99.0
-6329.1	6329.1	1492.8	8980.4	471.7	366.6	105.1
-6904.5	6904.5	1447.6	8535.7	457.4	348.5	109.0
-7479.8	7479.8	1372.2	7919.3	433.6	323.3	110.3
-8055.2	8055.2	1266.6	7139.9	400.3	291.5	108.8
-8630.6	8630.6	1130.9	6207.3	357.4	253.4	104.0
-9205.9	9205.9	965.0	5133.8	305.0	209.6	95.4
-9781.3	9781.3	769.0	3935.1	243.0	160.6	82.4
-10356.7	10356.7	542.8	2634.7	171.5	107.6	64.0
-10932.0	10932.0	286.5	1274.0	90.5	52.0	38.5
-11507.4	11507.4	0.0	0.0	0.0	0.0	0.0

Appendix 4: Optimal Dynamics of the Namibian Pilchard for the period 2018-2087

Year	Biomass 1.1	Effort (days)	Attempted harvest	Stochastic growth term	Biomass 31.12	Actual harvest	Revenues (m.USD)	Costs (m.USD)	Profits (m.USD)	PV-profits
2018	50.0	0	0.0	-0.1617111	68.0	0.0	0.000	0.000	0.000	0.0
2019	68.0	0	0.0	0.17833918	115.6	0.0	0.000	0.000	0.000	0.0
2020	115.6	0	0.0	-0.6002447	106.2	0.0	0.000	0.000	0.000	0.0
2021	106.2	0	0.0	0.06639186	168.3	0.0	0.000	0.000	0.000	0.0
2022	168.3	0	0.0	-0.112228	236.4	0.0	0.000	0.000	0.000	0.0
2023	236.4	0	0.0	0.10370695	382.3	0.0	0.000	0.000	0.000	0.0
2024	382.3	0	0.0	0.1209653	622.2	0.0	0.000	0.000	0.000	0.0
2025	622.2	0	0.0	0.1386336	1017.0	0.0	0.000	0.000	0.000	0.0
2026	1017.0	0	0.0	0.27391457	1781.5	0.0	0.000	0.000	0.000	0.0
2027	1781.5	8.65117	2.5	0.36998108	3227.4	2.5	0.779	0.353	0.425	0.2
2028	3227.4	2394.4	410.3	-0.1162007	3659.3	410.3	129.642	97.749	31.893	12.3
2029	3659.3	3130.16	532.1	0.56249883	6493.6	532.1	168.134	127.786	40.349	14.1
2030	6493.6	7861.9	1331.5	0.06057132	7038.4	1331.5	420.746	320.954	99.792	31.8
2031	7038.4	8752.88	1485.1	-0.0219019	6831.8	1485.1	469.301	357.328	111.973	32.4
2032	6831.8	8415.64	1426.9	0.17762773	8073.4	1426.9	450.889	343.560	107.329	28.3
2033	8073.4	10432	1777.0	-0.0621416	7057.5	1777.0	561.546	425.875	135.671	32.5
2034	7057.5	8783.94	1490.5	0.25341615	8785.9	1490.5	470.998	358.596	112.403	24.5
2035	8785.9	11578.4	1978.0	-0.1710251	6394.4	1978.0	625.045	472.677	152.368	30.1
2036	6394.4	7699.04	1303.5	-0.1293022	5753.3	1303.5	411.902	314.306	97.596	17.6
2037	5753.3	6642.29	1122.7	-0.9745709	531.5	1122.7	354.762	271.165	83.597	13.7
2038	531.5	0	0.0	-0.352132	610.1	0.0	0.000	0.000	0.000	0.0
2039	610.1	0	0.0	-0.2479176	761.6	0.0	0.000	0.000	0.000	0.0

2040	761.6	0	0.0	0.15613887	1253.3	0.0	0.000	0.000	0.000	0.0
2041	1253.3	0	0.0	-0.2030606	1584.2	0.0	0.000	0.000	0.000	0.0
2042	1584.2	0	0.0	-0.2771335	1861.2	0.0	0.000	0.000	0.000	0.0
2043	1861.2	114.932	24.9	-0.3722007	1961.3	24.9	7.879	4.692	3.187	0.3
2044	1961.3	265.93	53.2	-0.1544336	2458.0	53.2	16.798	10.856	5.942	0.5
2045	2458.0	1083.52	193.3	0.33816423	4109.1	193.3	61.070	44.234	16.836	1.3
2046	4109.1	3892.77	658.9	0.35062794	6275.6	658.9	208.224	158.919	49.305	3.4
2047	6275.6	7503.82	1270.0	0.16250783	7520.9	1270.0	401.314	306.336	94.978	6.0
2048	7520.9	9537.76	1621.2	-0.2261845	5564.2	1621.2	512.304	389.370	122.934	7.0
2049	5564.2	6329.1	1069.3	-0.0124767	5931.7	1069.3	337.912	258.380	79.533	4.1
2050	5931.7	6937.17	1173.0	-0.156586	5336.3	1173.0	370.664	283.203	87.460	4.1
2051	5336.3	5950.6	1005.1	-0.0355054	5641.7	1005.1	317.601	242.927	74.673	3.2
2052	5641.7	6457.59	1091.2	0.03649927	6263.7	1091.2	344.820	263.625	81.195	3.2
2053	6263.7	7484.33	1266.6	-0.6706177	2292.6	1266.6	400.258	305.541	94.717	3.4
2054	2292.6	805.298	146.6	0.11565669	3373.3	146.6	46.325	32.876	13.449	0.4
2055	3373.3	2643.34	451.4	-0.1580079	3638.7	451.4	142.649	107.912	34.738	1.0
2056	3638.7	3095.15	526.3	-0.2392696	3545.9	526.3	166.299	126.357	39.943	1.1
2057	3545.9	2937.33	500.1	0.20881157	5072.1	500.1	158.031	119.914	38.118	0.9
2058	5072.1	5510.4	930.5	-0.2848196	4183.6	930.5	294.053	224.957	69.097	1.5
2059	4183.6	4018.74	680.0	0.06589801	5175.0	680.0	214.868	164.061	50.807	1.0
2060	5175.0	5681.95	959.6	-0.0287422	5559.3	959.6	303.220	231.960	71.260	1.3
2061	5559.3	6320.93	1068.0	0.13506815	6748.4	1068.0	337.473	258.046	79.427	1.3
2062	6748.4	8279.18	1403.3	-0.0603605	6400.5	1403.3	443.450	337.990	105.461	1.6
2063	6400.5	7709.1	1305.2	0.32108392	8639.2	1305.2	412.449	314.717	97.732	1.3
2064	8639.2	11343	1936.6	0.0321794	8109.2	1936.6	611.974	463.067	148.907	1.9
2065	8109.2	10489.8	1787.1	0.40110353	10829.9	1787.1	564.739	428.235	136.504	1.5
2066	10829.9	14831	2554.5	0.25667737	11389.4	2554.5	807.217	605.461	201.756	2.1
2067	11389.4	15713	2712.3	0.32279809	12414.8	2712.3	857.084	641.469	215.615	2.0

2068	12414.8	17321.3	3001.5	0.26471207	12186.6	3001.5	948.474	707.125	241.350	2.1
2069	12186.6	16964.2	2937.1	-0.3823206	4213.3	2937.1	928.131	692.546	235.586	1.8
2070	4213.3	4068.81	688.3	0.24489509	5956.6	688.3	217.511	166.105	51.406	0.4
2071	5956.6	6978.26	1180.0	0.02132651	6409.6	1180.0	372.882	284.881	88.001	0.6
2072	6409.6	7724.02	1307.8	0.39213978	9103.6	1307.8	413.258	315.326	97.932	0.6
2073	9103.6	12087.3	2067.6	-0.0083202	7957.0	2067.6	653.358	493.454	159.905	0.8
2074	7957.0	10243.9	1744.2	0.17115985	8861.5	1744.2	551.169	418.198	132.971	0.6
2075	8861.5	11699.6	1999.3	-0.2141962	6032.0	1999.3	631.781	477.625	154.156	0.7
2076	6032.0	7102.75	1201.3	-0.3341233	4319.6	1201.3	379.607	289.963	89.644	0.4
2077	4319.6	4248.24	718.3	-0.1056094	4559.3	718.3	226.990	173.430	53.560	0.2
2078	4559.3	4651.67	785.9	0.02954948	5351.0	785.9	248.352	189.900	58.452	0.2
2079	5351.0	5975.08	1009.2	-0.4245207	3570.7	1009.2	318.913	243.927	74.986	0.2
2080	3570.7	2979.47	507.1	0.20139009	5073.5	507.1	160.238	121.634	38.604	0.1
2081	5073.5	5512.74	930.9	0.35208632	7415.7	930.9	294.178	225.052	69.126	0.2
2082	7415.7	9366.9	1591.5	0.02978004	7427.0	1591.5	502.925	382.395	120.530	0.3
2083	7427.0	9385.37	1594.7	-0.0225693	7045.0	1594.7	503.938	383.149	120.789	0.2
2084	7045.0	8763.66	1487.0	-0.2015337	5570.1	1487.0	469.890	357.768	112.122	0.2
2085	5570.1	6338.94	1071.0	0.23637881	7322.1	1071.0	338.441	258.781	79.660	0.1
2086	7322.1	9214.87	1565.2	-0.1795179	5838.4	1565.2	494.588	376.188	118.399	0.2
2087	5838.4	6783	1146.7	0.33691117	8166.2	1146.7	362.346	276.909	85.436	0.1

PV

(adjustment) = 303.0
PV (remainder) = 1.2
Total PV = 304.2

Appendix 5: Evolution of the Namibian Pilchard for the period 2018 to 2087.

Year	Biomass 1.1	Effort (days)	Attempted harvest	min harvest imposed	Biomass 31.12	Actual harvest	Revenues (m.USD)	Costs (m.USD)	Profits (m.USD)	PV-profits
2018	50.0	0.0	0.0	0.0	76.1	0.0	0.000	0.000	0.000	0.0
2019	76.1	0.0	0.0	0.0	115.7	0.0	0.000	0.000	0.000	0.0
2020	115.7	0.0	0.0	0.0	175.8	0.0	0.000	0.000	0.000	0.0
2021	175.8	0.0	0.0	0.0	266.5	0.0	0.000	0.000	0.000	0.0
2022	266.5	0.0	0.0	0.0	402.9	0.0	0.000	0.000	0.000	0.0
2023	402.9	0.0	0.0	0.0	606.7	0.0	0.000	0.000	0.000	0.0
2024	606.7	0.0	0.0	0.0	907.9	0.0	0.000	0.000	0.000	0.0
2025	907.9	0.0	0.0	0.0	1346.2	0.0	0.000	0.000	0.000	0.0
2026	1346.2	0.0	0.0	0.0	1969.3	0.0	0.000	0.000	0.000	0.0
2027	1969.3	278.4	55.4	55.4	2769.4	55.4	17.512	11.366	6.146	2.6
2028	2769.4	1612.6	281.1	281.1	3590.5	281.1	88.823	65.835	22.989	8.9
2029	3590.5	3013.2	512.7	512.7	4372.6	512.7	162.007	123.012	38.994	13.7
2030	4372.6	4337.5	733.3	733.3	5060.3	733.3	231.708	177.072	54.636	17.4
2031	5060.3	5490.7	927.2	927.2	5619.1	927.2	293.003	224.154	68.849	19.9
2032	5619.1	6420.1	1084.8	1084.8	6041.3	1084.8	342.802	262.093	80.709	21.3
2033	6041.3	7118.0	1203.9	1203.9	6341.5	1203.9	380.434	290.587	89.846	21.5
2034	6341.5	7612.2	1288.6	1288.6	6545.1	1288.6	407.189	310.760	96.430	21.0
2035	6545.1	7946.3	1346.0	1346.0	6678.4	1346.0	425.332	324.399	100.933	20.0
2036	6678.4	8164.8	1383.6	1383.6	6763.8	1383.6	437.218	333.318	103.900	18.7
2037	6763.8	8304.4	1407.7	1407.7	6817.5	1407.7	444.823	339.018	105.805	17.3
2038	6817.5	8392.2	1422.8	1422.8	6851.0	1422.8	449.612	342.605	107.008	15.9
2039	6851.0	8447.0	1432.3	1432.3	6871.8	1432.3	452.599	344.840	107.759	14.6
2040	6871.8	8480.9	1438.1	1438.1	6884.6	1438.1	454.449	346.225	108.224	13.3

This paper should be cited as:
Piniku, E. 2018. *Bioeconomic model for the pilchard (Sardinops sagax) species in Namibia.* Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/esther16prf.pdf

2041	6884.6	8501.8	1441.7	1441.7	6892.5	1441.7	455.590	347.079	108.512	12.1
2042	6892.5	8514.7	1444.0	1444.0	6897.3	1444.0	456.293	347.604	108.689	11.0
2043	6897.3	8522.6	1445.3	1445.3	6900.3	1445.3	456.725	347.927	108.797	10.0
2044	6900.3	8527.5	1446.2	1446.2	6902.1	1446.2	456.990	348.126	108.864	9.1
2045	6902.1	8530.5	1446.7	1446.7	6903.2	1446.7	457.153	348.248	108.905	8.3
2046	6903.2	8532.3	1447.0	1447.0	6903.9	1447.0	457.253	348.322	108.930	7.6
2047	6903.9	8533.4	1447.2	1447.2	6904.3	1447.2	457.314	348.368	108.946	6.9
2048	6904.3	8534.1	1447.3	1447.3	6904.6	1447.3	457.351	348.396	108.955	6.2
2049	6904.6	8534.5	1447.4	1447.4	6904.7	1447.4	457.374	348.413	108.961	5.7
2050	6904.7	8534.8	1447.4	1447.4	6904.8	1447.4	457.388	348.424	108.965	5.2
2051	6904.8	8534.9	1447.5	1447.5	6904.9	1447.5	457.397	348.430	108.967	4.7
2052	6904.9	8535.0	1447.5	1447.5	6904.9	1447.5	457.402	348.434	108.968	4.3
2053	6904.9	8535.1	1447.5	1447.5	6905.0	1447.5	457.406	348.437	108.969	3.9
2054	6905.0	8535.1	1447.5	1447.5	6905.0	1447.5	457.408	348.438	108.969	3.5
2055	6905.0	8535.1	1447.5	1447.5	6905.0	1447.5	457.409	348.439	108.970	3.2
2056	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.410	348.440	108.970	2.9
2057	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.410	348.440	108.970	2.6
2058	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.410	348.440	108.970	2.4
2059	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.440	108.970	2.2
2060	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.440	108.970	2.0
2061	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.440	108.970	1.8
2062	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.440	108.970	1.6
2063	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	1.5
2064	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	1.4
2065	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	1.2
2066	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	1.1
2067	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	1.0
2068	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.9
2069	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.8
2070	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.8

2071	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.7
2072	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.6
2073	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.6
2074	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.5
2075	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.5
2076	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.4
2077	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.4
2078	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.4
2079	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.3
2080	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.3
2081	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.3
2082	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.2
2083	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.2
2084	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.2
2085	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.2
2086	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.2
2087	6905.0	8535.2	1447.5	1447.5	6905.0	1447.5	457.411	348.441	108.970	0.2

PV (adjustment) = 358.2
PV (remainder) = 1.5
Total PV = 359.7