APPRAISAL OF THE ECONOMIC POTENTIAL FOR THE ROCK LOBSTER *(Jasus lalandii)* FISHERY IN NAMIBIA

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ABSTRACT

Successful fisheries management considers both biological and economic aspects. This study is aimed at directing Namibia towards developing effective fisheries policies and providing management tools that have the potential to increase economic benefits from the rock lobster fishery. Operational costs in this sub-sector were found to be relatively high with a cost per unit effort of 20.37 from the Gordon Shaefer model. Inefficiencies in maximising net sustainable revenues in the rock lobster fishery are coupled with high levels of effort, namely, effective effort strategies and cost cutting mechanisms such as extended time of baited trap settings and decommissioning of underutilised vessels, respectively. Maximising total net revenue rather than maximising the total catch per year gives a marginal improved management strategy (Roos, 2004).

Key words: Namibia, rock lobster, maximum economic yield, effort, sustainable

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ACRONYMS

FAO	Food and Agriculture Organisation
MFMR	Ministry of Fisheries and Marine Resources
MITSMED	Ministry of Industrialisation, Trade and Small and Medium Enterprise Development
MEP	Ministry of Economic Planning
NDP	National Development Plan
BCC	Benguela Current Commission
NAMPORT	Namibia Ports Authority
NAMFI	Namibia Fisheries Institute
NSI	Namibia Standards Institute
NAMROCK	Namibian Rock Lobster Packers (Pty) Ltd
WWF	World Wildlife Fund
SASSI	South African Sustainable Seafood Initiative
ICLARM	International Centre for Living Aquatic Resources Management
IUCN	International Union for Conservation of Nature
BCLME	Benguela Current Large Marine Ecosystem
UNDP	United Nations Development Programme
EEZ	Exclusive Economic Zone
TAC	Total Allowable Catch
MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
CL	Carapace Length
CPUE	Catch per unit of effort
MCS	Monitoring Control and Surveillance
TFD	Trap Fishing Days

1. INTRODUCTION

Namibia has one of the most productive fishing grounds in Africa. It contains some of the most abundant marine life concentrations in the world and provides livelihoods and food security for many (FAO, 2017). Namibia's 200 nautical miles EEZ contains about 20 different species consisting primarily of small pelagic species (pilchard, anchovy, juvenile horse mackerel and mackerel), lobster along the continental shelf, large pelagic species including adult mackerel, demersal hake and other deep-sea species (monkfish, sole and crab) in the waters further offshore (FAO, 2007).

The Namibian coastline stretches for about 1,500 km from the Kunene River in the north down to the Orange River in the south. The marine ecosystem is driven by the Benguela Current system that flows along the west coast, in the south, meeting the warm Anghulus Current, and in the north, it interacts with the warm Angolan Current. The interaction of these currents causes highly productive upwelling and thus provides ideal conditions for fish production.

This study examines potential economic gains based on the management of the Namibian rock lobster *(Jasus lalandii)*. This is an important fishery for the Lüderitz community in Namibia as evidenced by the employment created for 218 people (MFMR, 2018). In addition, the town celebrates its rich seafood culture by presenting the annual Lüderitz Crayfish Festival which focuses on the rock lobster. According to the Lüderitz Town Council (2018), this event has resulted in a boost for retail, tourism and provided much-needed job opportunities for about 15,000 inhabitants.

Rock lobster fishery was first developed in Lüderitz in Namibia in 1925 (MFMR, 2004) and currently consists of nine right holders. There are two processing plants specialising in live, cooked and frozen products. However, only one was operational during the 2017/18 fishing season and this resulted in a reduction in the number of onshore employees from 97 in the prior season to 52. The other factory was not operating due to non-renewal of the leasing contract (MFMR, 2018).

The population of rock lobster was severely depleted in the late 1960s due to overexploitation and showed a further decline in the mid-1970s which was reportedly a consequence of adverse environmental conditions. In the 1980s, landings ranged from 1,100 tonnes to 2,900 tonnes with a mean of 1,700 tonnes which is only 20-25 percent of the 7,000-8,000 tonnes of the 1960s (MFMR, 1991). The 2018 stock assessment report suggests that the current rock lobster fishery management system has resulted in the increase of fishable biomass, however, rock lobster have become smaller in size.

Namibia's main strategic objectives for its fisheries sector are to: rebuild overexploited fish stocks, establish an effective fisheries MCS system and viable national fishing and processing industries with maximum Namibianisation[1] of jobs and empowerment of previously excluded people (MFMR, 2004). The development of the Namibian fisheries sector is further explained to entail meeting the objectives of creating employment and income, ensuring multiplier effects in the economy, optimising revenues from profits of the industry, earning foreign exchange, improving domestic food supplies, food security and self -sufficiency.

[1] Namibianisation means greater involvement, participation and benefits for Namibians from the sector through share-ownership in fishing companies, employment at all levels, managerial control of fishing companies, involvement in processing and marketing.

Rock lobster is a shared species with South Africa and different management strategies are implemented by the two countries. South Africa manages its fisheries sector to develop and sustain the utilisation of marine and coastal resources; maximising the economic potential of the fisheries sector; and protecting the integrity and quality of the country's marine and coastal ecosystems (RSA, 2013).

The flexibility of introducing additional measures or regulations may be common for improvement in fisheries management. Despite potential gains from changes in fisheries management, one needs to be aware of the risks and the shortcomings of possible changes. Therefore, caution need to be taken as there are risks associated with fisheries management that may result in the collapse of some stocks (Seijo, Defeo, & Salas, 1998) and ultimately loss of socio-economic benefits.

1.1 Problem Statement

The Lüderitz community in Namibia depends heavily on the local fishing industry particularly hake, tuna, rock lobster and mariculture, which provides more than 80% of the employment.

Lüderitz inhabitants are accustomed to harvesting rock lobster for employment and income. The latest trend by fishing companies is to operate from Walvis Bay, rather than Lüderitz, to reduce the operational costs (Luderitz Town Council, 2017). These costs include; fuel, harbour fees and services such as repairs and maintenance. Walvis Bay is the main harbour and highly developed; providing better logistical and other services. Due to the proximity of Lüderitz to South Africa, services are often sought there and are expensive.

The socio-economic analysis in the TAC report of rock lobster is based on section 39 (3) and 33 (4) of the MRA, 2000 (MFMR, 2000). These sections refer to conditions pertaining to the Namibianization policy by involving Namibians in the operations of the quota allocated through the entire fisheries value chain. The analysis also considers the measures of maximising the utilisation of quotas allocated in terms of employment, corporate social responsibilities, value addition and statutory payments, amongst others. However, these analyses do not deliberate on optimising revenue from profit for the industry as per the policy statement by MFMR (2004). Therefore, managing the rock lobster fishery without this evaluation would not enable the MFMR to meet the developmental objectives of rock lobster.

The MFMR (2018) stock assessment report for rock lobster revealed that only 23% of all lobsters sorted during 2017/18 were of legal size, a trend which is of concern. Sequentially, a reduction is detected in the average size of lobster exports from 72.2 mm CL in 2016/17 to 71.3 mm CL in 2017/18. On the economic front, profit by the sub-sector declined from US$ 951 000 (47% of turnover) in 2014/15 to US$ 202 997 (14% of turnover) in 2017/18. Ultimately, this affects policy objectives of employment creation, income and foreign exchange earnings as mentioned earlier.

1.2 Rationale

In line with the Marine Resources Act no. 27 of 2000 and Namibian Constitution (Namibian Government, Chapter 11, Article 95), Namibia is committed to manage fisheries based on the principle of optimum sustainable yield in the exploitation of marine resources. To estimate optimal harvest levels, it is vital to quantify the consequences of different management strategies and corresponding levels of TAC on stability, economic yield, sustainability and risk (Steenkamp, 2002).

Limited literature is available on the impact of fisheries policies and management on optimisation of fisheries in Namibia. Therefore, the study will assist the MFMR, as suggested by Padilla & Charles (1994); by providing a framework which helps to bridge the gap between biologists, economists and other stakeholders. Furthermore, it will enable them to capture the dynamics of both fish stocks and its economic relations for management consideration.

Finally, the research intends to create a basis for contribution to the National Development Plan (2017/18 to 2021/22) which committed Namibia to implement a Blue Economy governance and management system that sustainably maximises economic benefits and ensures equitable marine wealth distribution to all Namibians by 2020 (MEP, 2017).

1.3 Research Objectives

The goal of the study is to develop a bio-economic model that allows for comparison between the present state of the fisheries and a more optimal policy, based on maximum sustainable yield (hereafter MSY) and/or maximum economic yield (hereafter MEY). The goal is to direct Namibia in developing effective fisheries policies and provide management tools that have the potential to increase economic benefits from this resource. Therefore, the specific objectives are to:

- Estimate the MSY and MEY, with corresponding effort on the rock lobster fishery for better utilisation of the resource.

- Assess the costs of fishing and economic output from the resource associated with different levels of effort in support of efficiency strategies.

- Examine fisheries management measures that optimise the Namibian rock lobster economic returns.

2. LITERATURE REVIEW

2.1 Biology of rock lobster

Rock lobster is a cold-water, slow growing, long lived crustacean making it susceptible to overfishing. According to MFMF (2018), it takes between 4-6 years to reach the legal minimum size limit of 65 mm CL. Females reach sexual maturity between 51-59 mm CL, depending on the fishing grounds. Female age at maturity is estimated at five years (Pollock, 2011) and longevity of the species are approximately 30-40 years (MFMR, 2018). The diet of these species includes a mix of mussels, barnacles, small molluscs and crustaceans (Mayfield, Atkinson, Branch, & Cockcroft, 2000), while the predators are mainly large fish, octopus and monkfish. Rock lobsters are important to the flow of energy in deep and shallow water ecosystems (MacArthur, Hyndes, & Babcock, 2007) and therefore a loss of these species can negatively affect the whole ecosystem.

The peak egg bearing season is during the months June to October, and spawning occurs during October to November. Moulting occurs frequently in juvenile lobsters, but once they become mature, they enter a cycle of only one moult per year. Mature males tend to moult during September to December and females in February to March/April (MFMR, 2018).

2.2 Distribution of rock lobster

Rock lobster are distributed from 23°S North of Walvis Bay in Namibia, to 28°S near East London on the South African east coast (DAFF, 2016). However, commercial densities are encountered only along the west coast of southern Africa from 25°S to Cape Point (34°22'S) in South Africa (Pollock, 2011) (Fig.1).

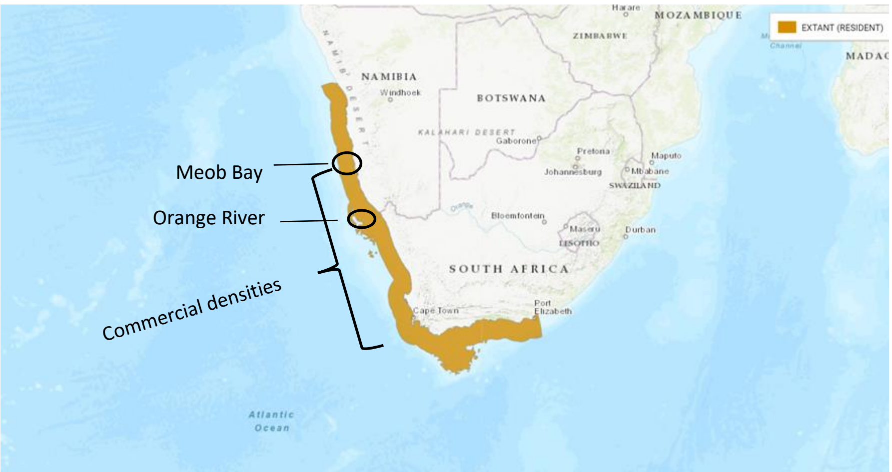

Figure 1. Distribution of rock lobster along Southern African coast IUCN, 2011.

The stock is shared with South Africa through a common larval pool. In Namibia commercial abundance occurs between the Orange River mouth (28°35´S,16°28´E) and Meob Bay (24°31´S,14°35´E) (Fig.1). Rock lobster is found at a depth range of 5-200 m on rocky bottoms, typically in deep crevices (Pollock, 2011).

There are two lobster sanctuaries, one off Lüderitz and one at Ichaboe Island (MFMR, 2015) (Fig. 2). These areas are opened for fishing based on the state of egg bearing lobster distribution during the fishing season. The main lobster fishing grounds in Namibia are divided into four areas (Fig. 2).

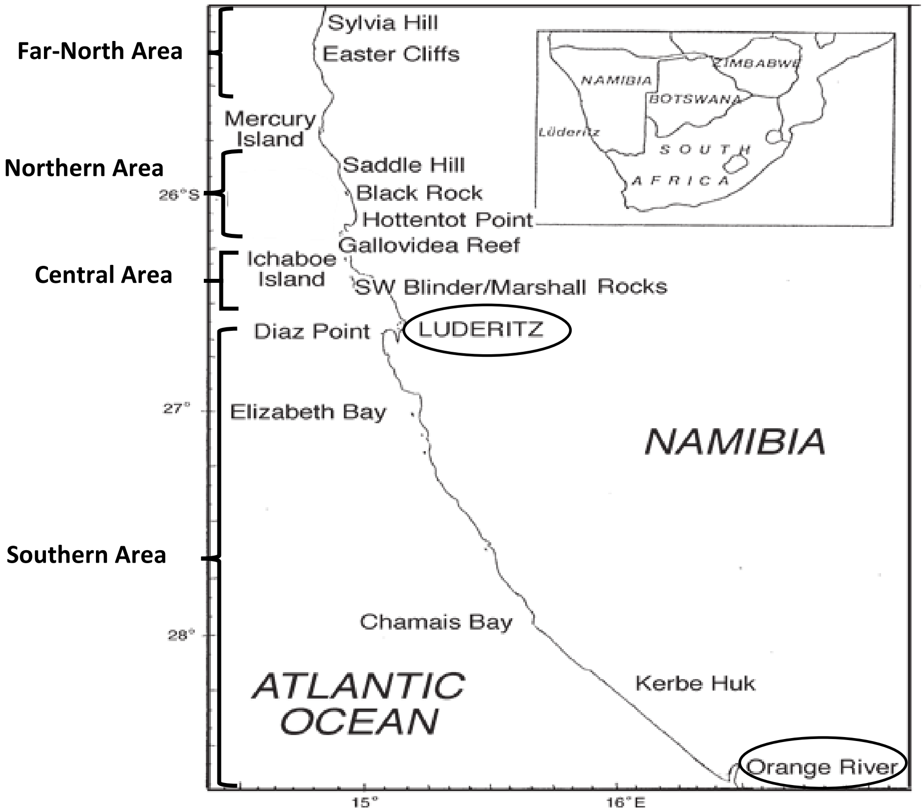

Figure 2. Rock lobster fishing grounds along the Southern Namibian coast *(Beyers & Wilke, 1990)*.

The Namibian lobster stock is commercially exploited between the Orange River mouth in the south and Easter Cliffs/Sylvia Hill north of Mercury Island. The lobster distribution range is divided into various fishing areas; southern area (Diaz Point - Orange River border); central area (between the Lüderitz and Ichaboe sanctuaries) and northern and far-northern areas (including Gallovidea, Hottentot Point, Black Rock, Saddle Hill, Mercury, Easter Cliffs).

2.3 Management

2.3.1 Management in Namibia

(i) Management tools

The rock lobster fishery is managed through setting of TACs and quota allocation. The determination of TACs are based on the best scientific evidence available and having considered advice from the Marine Resources Advisory Council (MFMR, 2000). This is done through thorough discussions of the biological status of the stock and economic performance of the sub-sector. Considering the assessed level of TAC and performance, the MRAC provide advice to the Minister who then makes a recommendation and seeks approval from the Cabinet for the level of TAC.

The fishing season is from 1 November to 30 April and no fishing takes place from June to October. The Southern fishing grounds are opened on 1 November because female lobsters release their eggs much earlier than in the northern and central fishing grounds. The northern and central fishing grounds are opened on 1 January – since females only release their eggs round about this time in these areas.

Fishery management measures adopted to ensure sustainability of rock lobster are size limitation of 65 mm CL and no berried (egg bearing) females are to be landed. Furthermore, there are two sanctuaries declared as closed areas for commercial fishing.

Effort restrictions of exploiting rock lobster is the utilisation of ring nets or traps with no minimum mesh size or escape mechanisms. The number of traps per fishing vessel is limited to 100 while there is no limit for dinghies (small motored vessels). This gear type is selective with minimal bycatch and impact on the benthic environment (MFMR, 2015).

The rock lobster catch needs to be graded immediately when brought on board the vessel and small lobsters returned to the sea. Offloading is restricted to jetties in Lüderitz for ease of monitoring. Recreational fishing of rock lobster is done through free diving, ring nets, hook and line and no harvesting is allowed between sun-set and sun-rise. The limit is seven lobsters per person per day which fishermen find to be too little (MFMR, 2017).

(ii) Taxation

Resource rent is extracted from all quotas allocated whether landed or not. Right holders may return the quota to the Ministry before a pre-determined time for reallocation to others. Otherwise, they are liable for paying all fees and levies associated with the quota. The fees and levies are;

- Quota fees: These are fees paid per tonnage of fish allocated. However, if the quota is not fully landed and returned to the Ministry only the landed quotas are paid. Rock lobster right holders allocated 10 tonnes were initially exempted to pay quota fees on the first two tonnes. This measure was introduced to assist the right holders due to the cost of operation. However, since the revision of fees and levies in 2015, there is no exemption.

- Fund levies: The levy is paid on all lobster landed.

- Observer fees: All vessels are required to carry an observer onboard for monitoring and controlling of activities at sea. A fee is paid for this service to the Fisheries Observer Agency a parastatal under the Ministry of Fisheries and Marine Resources.

- License fees: Vessels are required to be licensed before going to sea and thus pay a license fee for the vessel license.

2.3.2 Management in South Africa

There are several fishery management measures for rock lobster in South Africa including a closed season from 1st June to 15th November. A minimum size limit of 75 mm CL is set for commercial fishermen and 80 mm CL for recreational fishermen. It is prohibited to retain berried females. All landings are inspected, recreational fishing has bag limits, a Total Allowable Catch is set and there are restricted fishing zones. The difference in management of this species in South Africa and Namibia is the size limit set.

2.4 Total Allowable Catch and Landings

The total allowable catch of rock lobster is set for the duration of the fishing season. There has been a reduction from the highest ever set TAC of 405 tonnes in 2004/05 to 230 tonnes in 2017/18 (Fig.3.).

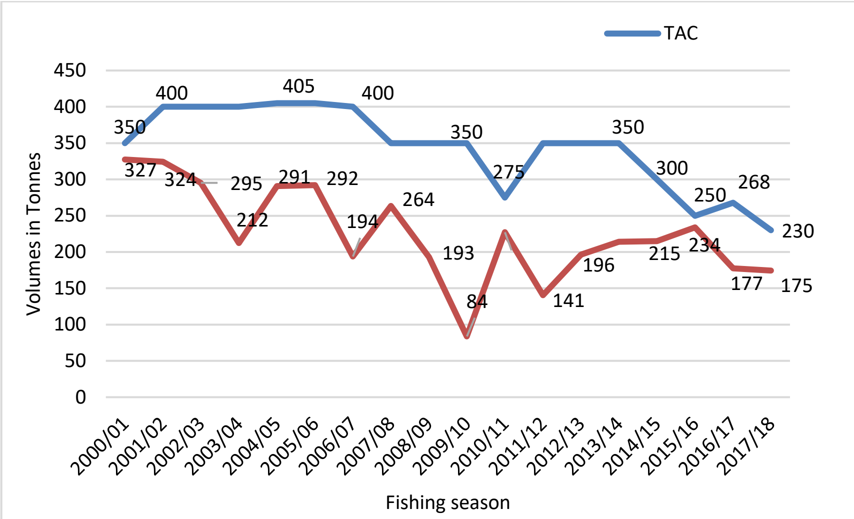

Figure 3. Rock lobster Total Allowable Catch and Landings, 2000/01 - 2017/18 *(MFMR, 2018).*

For the period under review, the TAC of rock lobster was never fully landed. Right holders find it difficult to operate due to the cost of operations. Vessel breakdowns and the windy conditions off the Lüderitz harbor also contribute to the non-operation of vessels.

As may be deduced from the figure above, there is no apparent relationship between the TAC and landings of rock lobster. Landings referred to in figure 3 are for the combined fishing rounds, which averaged 225 tonnes for 18 years since 2000/01. Effort also reduced from 113 thousand TFD to 74 thousand TFD during the same period (Fig.4). The rate of catch has increased from 24% of the TAC being landed in 2009/10 to 76% in 2017/18.

It is important to note that for the past four fishing seasons, the bulk of landings were recorded in the northern and far-northern fishing grounds accounting for 60% on average, 39% in the south and about 1% in the central grounds (although it is not to be exploited). This suggests a need of strengthening monitoring, control and surveillance (MCS) activities at the central fishing grounds.

2.5 Fishing vessels and effort

The rock lobster fishery operates trap boats and dinghies geared with traps or hoop-nets respectively. These boats are small and accommodate on average 12 crew members. In turn, it makes the rock lobster operations capital intensive, coupled with high operating cost. In total, the sub-sector has a fleet of 20 vessels, however, not all are licensed and operated as evident when only 14 were utilised during the 2017/18 fishing season.

Although the fishing season commences on the 1 November, delays are often encountered such as bad weather conditions or vessel breakdowns, and as such vessels do not all go to sea at the same time. During 2017/18, vessels started fishing operations eight days after the opening of the season. February to April is the most active period for vessels.

The effort for rock lobster is measured as "Trap-Fishing-Day" (TFD). It is assumed that catch efficiency of traps becomes insignificant after two days of no bait replenishment (MFMR, 2018). The CPUE for the rock lobster fishery fluctuates (Fig.4), with the highest recorded at 5.3 Kg/TFD in 1993/94. This has since decreased to 2.4 kg/TFD in 2017/18 representing a 55.3% reduction for the past 24 years.

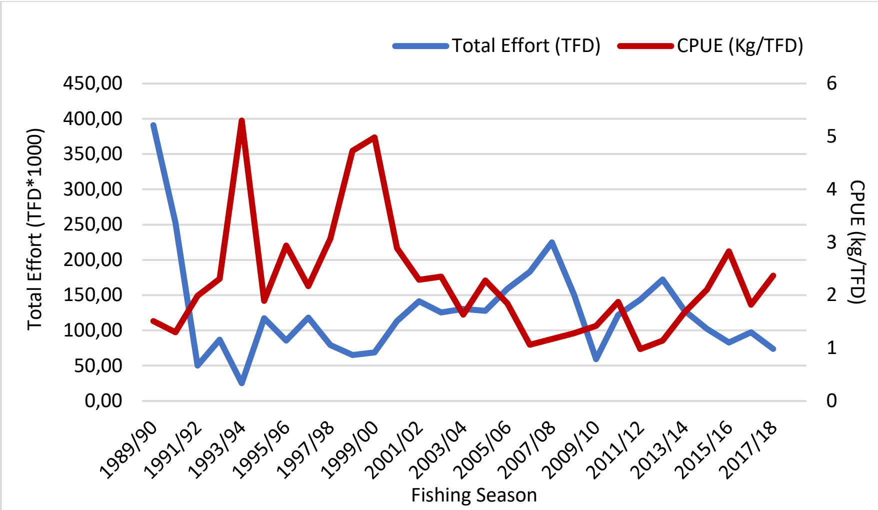

Figure 4. Effort and CPUE data, 1989/90 - 2017/18 *(MFMR, 2018)*.

During the 2017/18 season overall effort decreased from 97,452 to 73,789 TFDs (24.3%) from that of 2016/17. The reduction in the overall effort and the constant catch during the 2016/17 and 2017/18 seasons resulted in an increase from 1.8/kg to 2.4/kg (22%) in the seasonal CPUE.

2.6 Status of the rock lobster stock

The Food and Agriculture Organisation (FAO) estimated that out of the 600 marine fish stocks they monitor about 17% are overexploited[2] which includes rock lobster species in Namibia and South Africa. It is important to note that decreased productivity of a fishery resource impacts on the livelihoods in small communities such as Lüderitz and leads to a reduction in the economic returns from commercial fisheries at a national scale (BCC, 2017).

2.6.1 Stock status in Namibia

Before independence (21 March 1990),"tag and release" research formed the basis for estimating lobster numbers for the recommendation of a TAC since then, the DeLury model, a retrospective model that uses CPUE as the only abundance indicator and is based on a stock depletion, has been used to estimate fishable biomass. Input data include commercial catch, effort, estimated natural mortality, catch selectivity at the legal-size limit and the definition of two size classes loosely defined as "New Recruits (lobsters in the smallest size class, i.e. 65-69 mm CL)" and "Full Recruits (lobsters above 69 mm CL)" (MFMR, 2018). The stock assessment model adopted for the rock lobster species does not consider the effect of

[2] Defined as a fishery being exploited at above the level which is believed to be sustainable in the long term, with no potential room for further expansion and a higher risk of stock depletion/collapse (FAO, 2003).

environmental factors on fishing effort, therefore, a decline in CPUE due to adverse weather conditions is interpreted as a decline in the biomass.

Over fishing of rock lobster has led to a decrease in both male and female average sizes since 1993/94. The male sizes reduced from 65 mm CL to 63 mm CL and females 59 mm CL to 56 mm CL respectively (Fig.5).

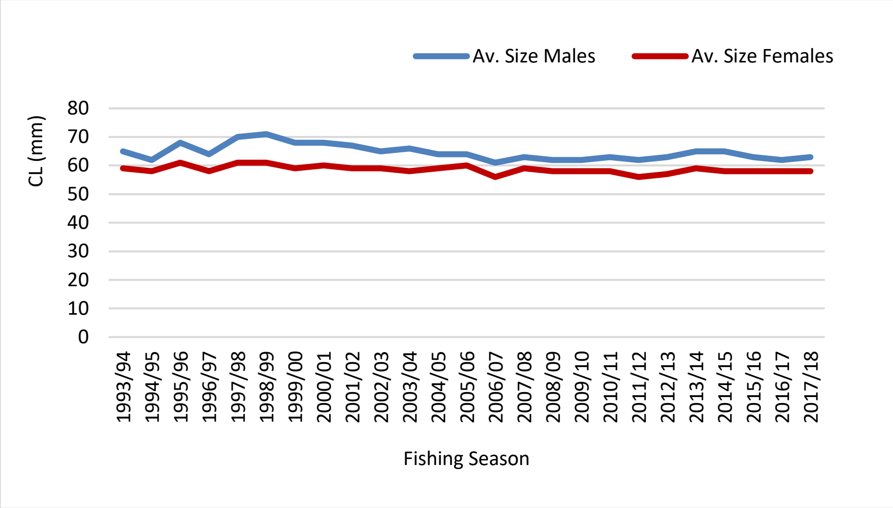

Figure 5. Rock lobster male and female average sizes, 1993/94 – 2017/18 *(MFMR, 2018)*.

The highest frequency of female average sizes was recorded at 58 mm CL for 10 years, whilst that of male lobster is recorded at 62 mm CL and 63 mm CL for five years each during the period 1994 – 2018. This shows that on average the rock lobster stock has an overall mean size that is less than 65 mm CL. This has led to a concern by MFMR (2018) suggesting that the stock is under pressure due to 72% of the lobster caught being under sized.

Fishable biomass estimates from the DeLury model is for the four commercial fishing grounds mentioned earlier because those are the only parts of the stock for which data is available. The number of new recruits and full recruits (combined for the four fishing grounds) has increased since 2007/08 from 1.7 million and 1.5 million to 4 million and 3.9 million respectively (Fig.6).

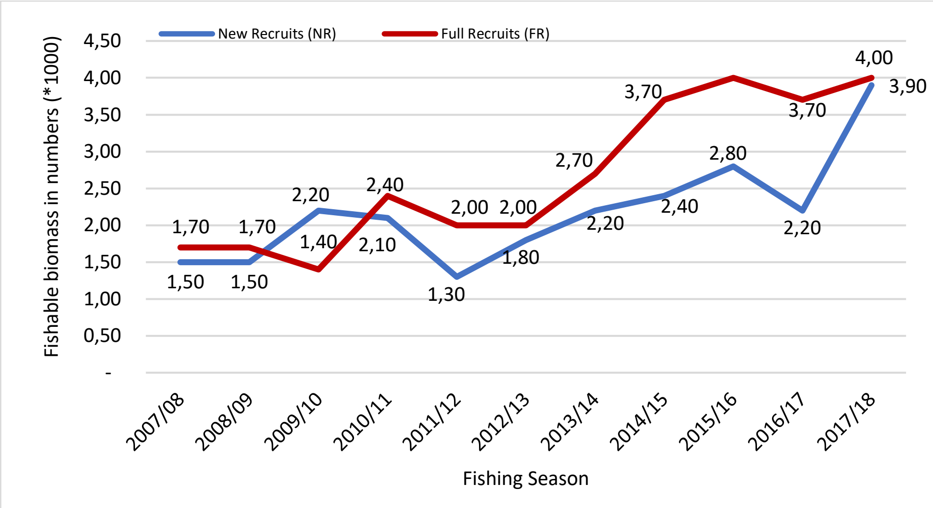

Figure 6. Fishable biomass of new and fully recruited lobsters, 2007/08 – 2017/18 *(MFMR, 2018)*.

A notable increase was observed in 2017/18 of lobsters (ranging 65 - 69 mm CL) by 77% from 2016/17 this represents the highest number of new recruits for the past decade. This is directly proportional to the increase in the fishable biomass from 1,302 tonnes to 1,711 tonnes during the same period (Fig.7). It is worth noting that the highest fishable biomass recorded was 2,460 tonnes 18 years ago in 1999/00.

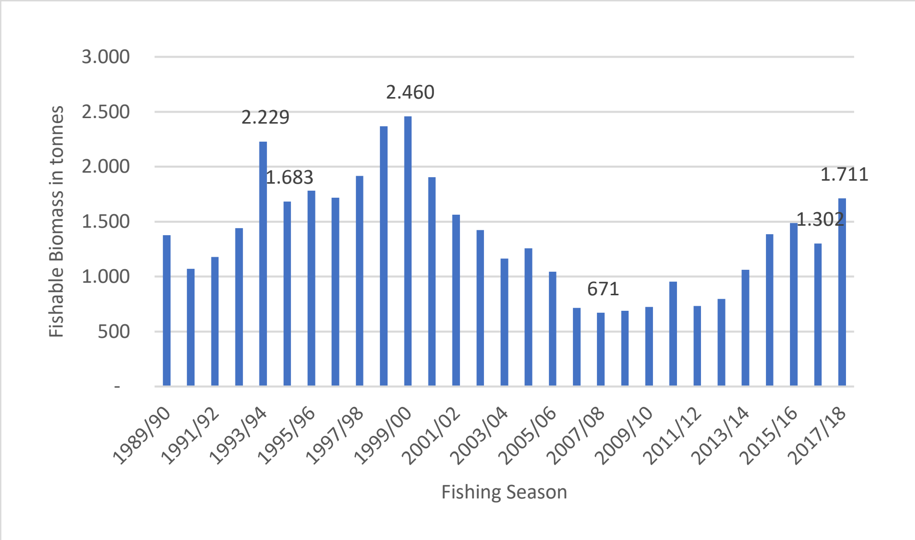

Figure 7. Estimated Fishable Biomass, 1989/90 – 2017/18 *(MFMR, 2018).*

2.6.2 Stock status in South Africa

The west coast rock lobster stock in South Africa is said to be worse off than when it was in 2013 (WWF-SASSI, 2016). Sizes of the stock are reported to have decreased, in certain areas the species is said to have reached or is close to the threshold level required to close all fishing (WWF-SASSI, 2016).

The west coast rock lobster is regarded as endangered, the most recent stock assessment indicated the stock to be heavily depleted at only 2% of its pre-exploitation levels (Aquarium, 2016). According to WWF-SASSI, 2016, this is largely a result of overfishing and increasing levels of illegal harvesting. There has been growing concern from all sides that the resource is facing a complete collapse. In addition, there is growing concern regarding increasing levels of illegal harvesting of the west coast rock lobster resource (DAFF, 2016). This may impact Namibia, the concern being that South Africans may find a way to target the rock lobster in Namibia due to a depletion of their own stocks.

2.7 Value chain of the rock lobster fishery

The value chain concept was initially proposed by Porter (1985) as a collection of activities that are performed by a company to create added value for its customers which leads to and ultimately creates high profitability for an organisation. The value chain approach can be a useful tool in the management of natural resources such as fisheries and aquaculture. It provides an analytical framework for crafting cohesive and inclusive strategies to guide the orderly development of the industry such that it benefits the environment and local business development (Parke, 2014).

Value addition has been a concern to Namibian policymakers since independence, and the government’s white paper set out objectives for value capture. In order to grow export earnings and to create employment, promoting value addition features as a key objective in the paper, with a focus on onshore processing (MITSMED, 2013). In consultations by MITSMED (2013) with the fishing industry it was argued that by processing certain species, value is reduced rather than added. Rock lobster is no exception, as whole cooked or frozen lobster tend to fetch a higher price than when processed into tails.

The draft Namibia Fisheries Policy (2015) will become an important framework update for the continued governance of the Namibian fishery sector. It details the marine resource processing industry, with chapters dedicated to investment, marketing and value addition. The key areas targeted for this industry in the growth at home strategy are greater industrial value addition to marine resources, product diversification to satisfy market demands, continued creation of jobs, broadening of Namibia's economic base and raising of government tax revenues. The rock lobster fishery value chain starts with right holders having access to exploit the resource and quota holders allocated quotas. The process is controlled by quota holders or operators that have catching and processing capacity, however, the marketing is done jointly through a marketing body (Fig. 8):

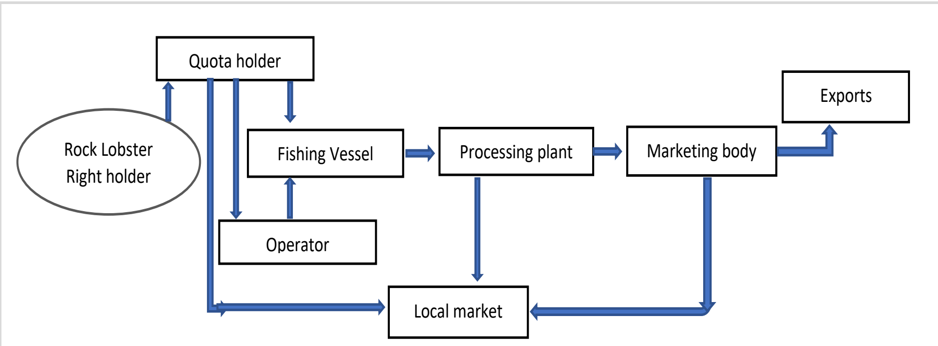

Figure 8.Value chain in the rock lobster fishery.

Primary production and input supply: Quotas in the rock lobster fishery are consolidated for operations to increase efficiency. The current draft fisheries policy of 2015 states that quota allocations may vary depending on the performance of right holders against predetermined criteria such as employment, investment and value addition (MFMR, 2018).

Transformation and technology: Rock lobster landings go through the basic value addition process onshore which entails careful handling and the highest standards of hygiene, to ensure that products reach their market destination in perfect quality. The main products produced are whole cooked, whole frozen, raw tails and live lobster. The MFMR (2016), encourages local value addition of rock lobster to create employment and increase investment.

Product distribution and trade: Rock lobster is traded under two brands namely; Gaston and NAMROCK. The driving force behind international business development and growth of Namibian rock lobster is NAMROCK the marketing organisation that sells Namibian rock lobster worldwide. The bulk of rock lobster produced is exported while local sales are minimal targeting restaurants.

The Namibian rock lobster industry is disadvantaged by the geographical positioning of Lüderitz and lack of appropriate infrastructure in and around the town. The lack of a large airport in Lüderitz means that the industry is deprived in terms of export logistics. There have been attempts to undertake special cryogen freezing of lobsters so that they can be exported to the sashimi market in Japan. This procedure requires expensive equipment and there is no financial capital in the industry to invest in this equipment (MFMR, 2010).

Service delivery: The service providers for the rock lobster fishery are mainly public institutions such as MFMR NAMFI, NSI, NAMPORT and the Fisheries Observer Agency. The Namibian Confederation of Fishing Associations and Rock Lobster Association provides skills, knowledge and bargaining power to its members.

Business environment: Operations in the rock lobster fishery is highly affected by its location, due to the high cost of doing business in Lüderitz as compared to Walvis Bay (Luderitz Town Council, 2017). Quota usage agreements between right holders and operators to catch their quota and receive quota usage fee are very common. These agreements are usually for the duration of the fishing season and differ across right holders, despite the difference in content, the right holder remain liable for all obligation of the quota to MFMR. The fluctuations in the status of the rock lobster fishery and unpredictability on the supply of raw material creates uncertainty to operators. Investment in the sub-sector is in vessels and two processing plants. Average prices for all Namibian rock lobster products have recorded a marginal increase since 2013 to 2017 (MFMR, 2018). During 2016/17 over 3,385 Namibians benefited from corporate social responsibilities by rock lobster fishing companies. Positive financial performances are recorded for the sub-sector to a tune of at least US$ 620 000 per fishing season since 2015/16 (MFMR, 2018).

2.7.1 Landed Value

The landed value is a concept applied to all fisheries in Namibia to determine the amount of fees and levies to be paid. It is defined as the value of fish in the form in which it is landed. The landed value of rock lobster was determined through industry consultations like for any other fisheries and set at US$ 16/kg (MFMR, 2017).

2.7.2 Export sizes

The main market for Namibian rock lobster is Japan to which 94% is exported, competing with South Africa and major suppliers of lobster such as Canada and USA (MFMR, 2018). The Japanese market prefers smaller sized lobster, despite low volumes of exports as compared to other suppliers Namibia offers a competitive edge in this regard. The sizes of the numbers of individual rock lobsters exported whole for minimum 65 mm and median 76 mm shown a decreasing trend since 1993/94 (Fig.9).

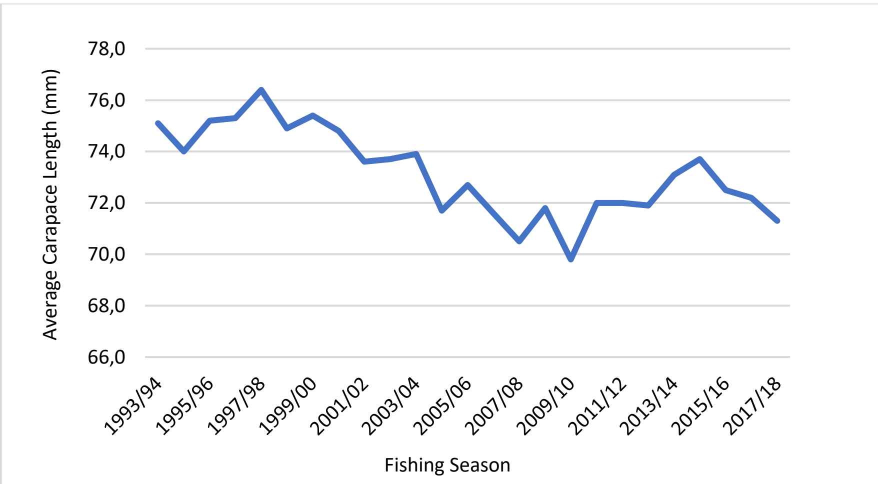

Figure 9. Average size of rock lobster exports, 1993/94 – 2017/18 *(MFMR, 2018)*.

The export sizes fluctuated since 1997/98 from 75.1 mm CL to 71.3 mm CL in 2017/18 representing a 5% reduction.

2.7.3 Export prices

Rock lobster is a luxury product mostly consumed in high end restaurants and exported as whole cooked, whole raw frozen, live or frozen tails. The price for whole cooked and raw lobster is the same and thus one figure showing the fluctuation. There has being a decrease observed in the average whole lobster price since 2011/12 from US$ 61.27/kg to US$ 23.46/kg (Fig.10).

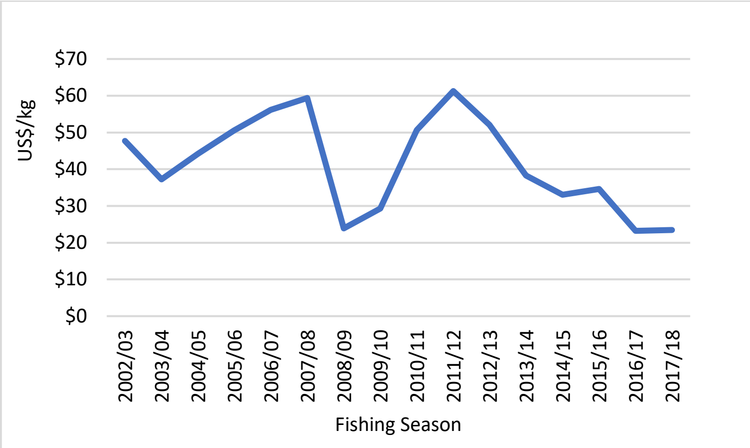

Figure 10. Average whole cooked and raw lobster prices, 2002/03 -2017/18.

The rock lobster tail prices show a decreasing trend, although, it is highly priced when compared to the whole lobster. The average price decreased from US$ 89.28/kg in 2011/12 to US$ 41.94/kg in 2017/18 (Fig.11).

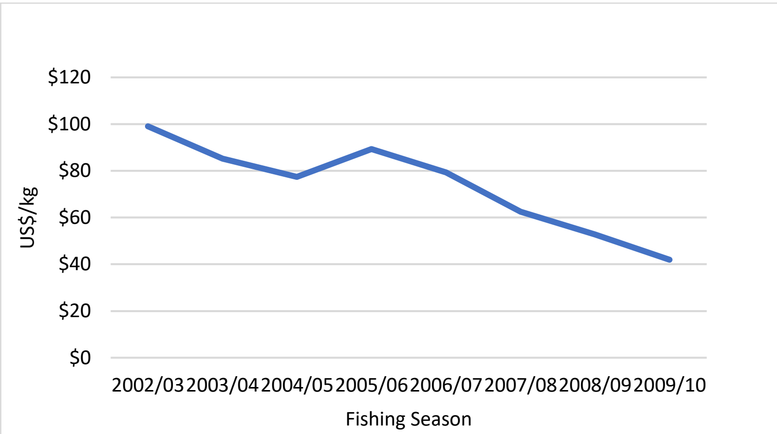

Figure 11. Average lobster tail prices, 2002/03 - 2017/18.

Similarly, compared to the other rock lobster products, the live lobster prices decreased from US$ 86.70/kg in 2002/03 to US$ 40.24/kg in 2017/18.

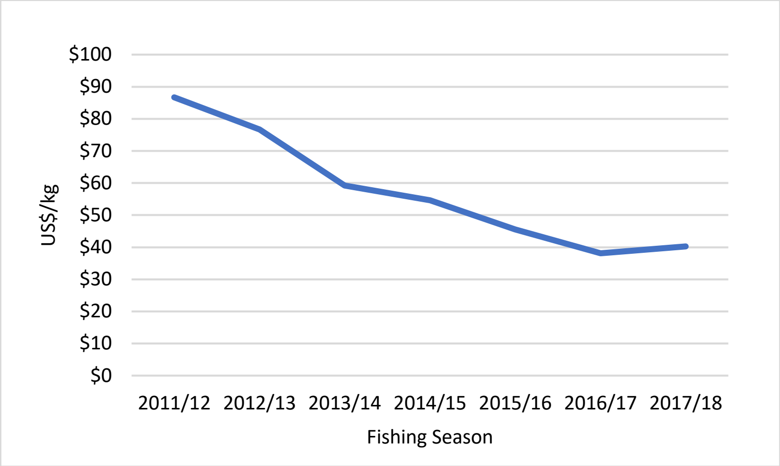

Figure 12. Live rock lobster prices, 2011/12 - 2017/18.

2.7.4 Profitability

Income and expenditure surveys are conducted on an annual basis to obtain an overview of the financial performance of the industry. During 2012/13, the income of the sub-sector could not cover the expenditure incurred, therefore a negative profit (after tax) margin was recorded (Fig. 13).

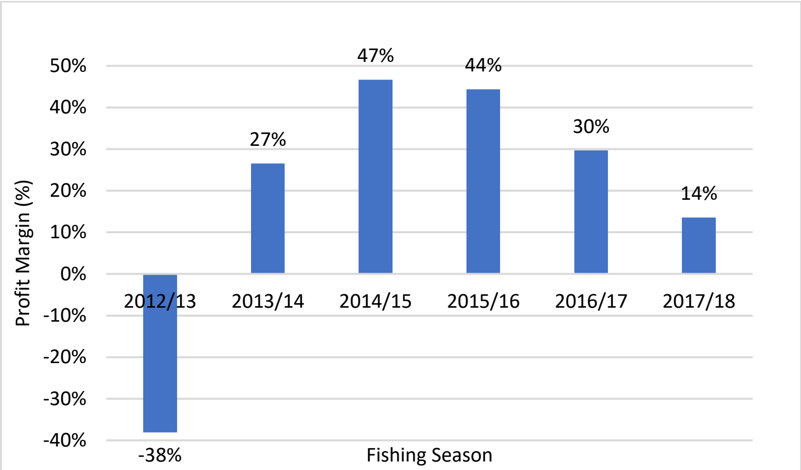

Figure 13. Profit margin in the rock lobster sub-sector 2013/14 - 2017/18 (MFMR, 2018).

The sub-sector was more effective in converting revenue received during 2014/15 into profit, the profit margin for this period was the highest at 47%. A reduction was recorded since 2015/16 from 44% to 14% in 2017/18. This was mainly due to expenditure increasing faster than income.

2.8 Cooperative management of shared fishery resources

This section reflects on work done on co-management of shared fishery resources. The significance of cooperative fisheries management is dependent on the importance of the shared fishery resource and management goals of the countries that may be affected. However, if there are divergent objectives, there would be a burden of developing mutually acceptable compromise resource management programmes (FAO, 2003).

Cooperative fisheries management considers at least two levels of cooperation (Gulland, 1980); cooperation in research alone, without coordinated management programmes – as all parties may benefit from improved information and data. It provides a foundation for more extensive cooperation in resource management in future. This was seen to have existed between Kuwait and Iran in the Persian Gulf. The secondary level of cooperation is 'active' management which involves the establishment of coordinated joint management programmes; as Gulland (1980) suggested will require allocation of harvest share; determination of optimal management strategies and implementation and enforcement of coordinated management agreements.

In achieving the levels of cooperation as discussed by Gulland (1980) a cooperative management authority is vital (FAO, 2002). Namibia, Angola and South Africa, through the establishment of the Benguela Current Commission works towards an integrated, science based and regional approach for the conservation, protection and sustainable use and management of the Benguela Large Marine Ecosystem. The focus is on the management of shared fish stocks, environmental monitoring, biodiversity and ecosystem health (BCC, 2013). Therefore, the foundation of cooperative fisheries management for species such as rock lobster may be initiated through this multi-sectoral, inter-governmental initiative by the three countries.

(i) Caribbean Large Marine Ecosystem (CLME) and Adjacent Regions

The living marine resources of the Caribbean LME are often shared between countries and thus, the management and recovery of depleted fish stocks require cooperation at various geopolitical scales. The UNDP (2008) found that at present there is inadequate institutional, legal and policy frameworks for managing shared living marine resources across this region.

The CLME lacks capacity at the national level and particularly with relation to the transboundary distribution, dispersal and migration of these organisms (UNDP, 2008). Therefore, a major barrier to sustainable management of these shared main resources is lack of knowledge; even if an adequate mechanism for effective region-wide ecosystem-based management was in place (like the one between Namibia, Angola and South Africa).

Establishment of an effective mechanism is the major challenge for management of transboundary resources. There is considerable spatial and seasonal heterogeneity in productivity throughout the CLME region. Even for those countries with substantial capacity at the national level, the regional institutional network required for Caribbean-wide integrated management is lacking and many fragmented institutional arrangements must be sorted out on regional and national scales. Conclusively, this refers to the importance and need for primary level cooperation as defined by Gulland (2008) and establishment of a management authority as suggested by FAO (2002) and as done in BLME.

2.9 Optimisation of sustainable economic yield from fisheries

Over the last decade, there has been an increasing interest in the use of economic instruments in the management of fisheries (Grafton, et al., 2006) and benefits from achieving economically optimal levels of harvest (Grafton, Kompas, & Hilborn, 2007). This has been encompassed into the MEY concept defined as the sustainable catch or effort level for a commercial fishery that allows net economic returns to be maximised (Norman-Lopez & Pascoe, 2011).

The best means to achieve the bioecological component of sustainability is debatable. The maximum economic yield occurs at a fishing mortality rate that is lower than that providing the maximum sustainable yield. Thus, aiming for MEY instead of MSY would have a higher probability of achieving the bio-ecological component of sustainability (Bodiguel , Gréboval , & Maguire, 2009).

Internationally, while most fisheries management policies aim to achieve a wide range of objectives, economic objectives are gaining increasing importance in determining fisheries management strategies. However, recent critics of MEY as a management target have argued that a decline in the level of fishing activity necessary to achieve the target will result in a subsequent loss of economic activity elsewhere in the economy and, potentially, a net loss to society (Norman-Lopez & Pascoe, 2011). This ultimately results in short term gains and long-term losses.

Norman-Lope and Pascoe (2011), noted that since 2007, MEY has been considered as the primary target reference point for Commonwealth fisheries. Namibia has not determined comprehensive management strategies to address consequences of achieving the optimal economic yield for the rock lobster fishery. This research paper could be used for development of such strategy.

3. BIO-ECONOMIC MODELLING

Bioeconomics is related to the development theories in fisheries economics initiated by Gordon (1954). It is a field that integrates resource biology and ecology with the economics of fisher behaviour, considering space, time, and uncertainty. The relative importance of including these dimensions in the bioeconomic modelling and analysis of fisheries depends on the fishery-specific management questions. The degree of stock mobility, sensitivity to environmental factors and the likely behaviour of fishers over time and space also plays a vital role. It is important to note that Gordon (1954) showed that bMEY would always be greater than the biomass that maximises the sustained yield bMSY.

3.1 Model choice

In determining the bio-economic model for the rock lobster fishery in Namibia, the Gordon-Schaefer model (1956) was applied. The model was used to compute MSY and MEY that may be taken from the rock lobster stock. Successful fisheries management considers both biological and economic aspects. Therefore, the model accounts for biological growth rates, the carrying capacity, total and marginal costs and revenues.

The limitation of the model is that it does not consider the time it takes for the stock to adjust as effort and harvest are changed depending on the implication. It suggests that as effort is reduced, harvest increases in the long term, but in the short-run it is expected that it leads to a decreased harvest, while the stock recovers. Thus, harvest may need to be more restricted than the model results imply while the stock size is adjusting toward the MEY levels. The optimal adjustment path could be explicitly estimated in more complex models, but that is beyond the scope of this study. The following analysis and equations are adopted from the book *Fundamentals of Fisheries Bioeconomics* by Anderson and Seijo (2010).

3.2 Biological analysis

The biological analysis hereunder discusses the interactions between effort, harvest, and stock size. However, the operation of a commercial fishery, entails understanding the levels of effort that is produced under specified circumstances. Populations of organisms cannot grow infinitely, they are constrained by environmental conditions and food availability. They thus strive to stabilise at the highest possible size for a given set conditions (Anderson & Seijo, 2010).

(i) Logistic growth model

The growth of a fish stock is the net effect of the weight of new individuals entering (recruitment), the weight of individuals leaving the stock (natural mortality) and increase in weight due to growth of individuals in the stock. A biological population with plenty of food, space to grow and no threat from predators, tends to grow at a rate that is proportional to the population (Lipkin & Smith, 2004). The Schaefer model assumes that recruitment, individual growth, and natural mortality can be represented simultaneously by a logistic growth equation.

Growth (G) in the stock biomass (X_t) is given by the intrinsic growth rate (r), the rate at which the stock would typically grow with no external effect and carrying capacity of the environment (K), which represents the largest size that can be achieved given food supplies, habitat etc.

$G(X_t) = rX_t\,(1 - \frac{Xt}{K})$ ……………………………………… (Eq.1)

Stock growth is estimated to be proportional to stock size, but decreases with stock density, and when the stock size equals the carrying capacity, growth will fall to zero. The combined effect is an inverted U-shaped growth curve where growth initially increases with stock size but ultimately falls to zero. The maximum growth of the stock biomass is derived by setting the first derivative of Eq.1 to zero:

$r - \frac{2rXt}{K} = 0$………………………………………………… (Eq.2)

therefore, $X_{MSY} = \frac{K}{2}$ ………………………………………(Eq.3)

At lower stock sizes growth varies directly with stock size because recruitment increases, and the more individuals there are in the stock, the greater the effect on individual growth. However, in the long run stock begin to push against environmental carrying capacity, which reduce recruitment and individual growth and increase natural mortality. The net growth then becomes inversely proportional to stock size and eventually fall to zero. A critical issue in fisheries management is what happens to stock size over time. It is worth noting that the size of an unexploited fish stock will change overtime as follows:

$X_{t+1} = X_t + G(X_t)$ ………………………………………... (Eq.4)

Thus, with no harvest, stock size next year is the sum of the stock size this year and growth generated. According to the Schaefer model the stock during the period of observation will reach equilibrium when X_t equals K.

(ii) Logistic growth with harvest

Harvest affects population dynamics of the fish stock, whereby the stock size the following year will be equal to stock size this year plus growth this year minus catch this year. The stock thus reaches an equilibrium when the stock growth is equal to the harvest. The adjustment of stock size until growth equals harvest is the factor that causes the time path of stock size to move toward an equilibrium:

$X_{t+1} = X_t + G(X_t)$ - Harvest………………………………... (Eq.5)

If the harvest rate is changed, there will be a different equilibrium. It will occur at a stock size where growth equals the new harvest level and will take varying amounts of time to achieve a new equilibrium stock size. The management of fisheries needs to be considered in a dynamic sense.

In many cases it is not very useful to think in terms of equilibrium stock sizes, or of changes in the equilibrium with changes in harvest levels. The time path of the stock size as it moves towards an equilibrium tends to be more critical. This is an important concept of long-run optimal management. Fisheries utilisation is better understood by considering how decisions to fish are affected by various rules and regulations, this is dealt with through fishery yield or production functions:

$y_t = qX_t\,E_t$………………………………………………… (Eq.6)

The short run yield (y_t) is dependent on the catchability (q) and fishing effort (E_t). This function assumes that it does not obey the law of diminishing marginal production. Each additional unit of effort or stock adds the same amount to catch. The shortfall is that with a high enough level of effort, catch may be greater than the actual stock size. However, it may still apply as industry participants make decisions in the context of the current stock, which may or may not be an equilibrium stock size.

The yield from a given stock size for different levels of effort is important for understanding the current operation of a fishery, the concept of sustainable yield is also useful for long-term analysis. The sustainable yield curve shows the relationship between the level of fishing effort and the level of sustainable yield. A sustainable yield can be maintained indefinitely because catch is equal to growth. To achieve a sustainable harvest, growth must equal short-run yield:

$$rX\,(1 - \frac{X}{K}) = qXE \text{ or } r - \frac{rX}{K} = qE$$

$$\text{therefore, } X = K - (\frac{qK}{r})\,E \text{ ……………………………… (Eq.7)}$$

The population equilibrium equation (Eq.7) shows that equilibrium stock size varies inversely with effort. Each level of effort is associated with a level of harvest, and so over a range, each level of effort will be associated with an equilibrium stock size (Anderson & Seijo, 2010). When E equals zero, the equilibrium stock size is equal to K, the ecological carrying capacity. Substituting the equation seven into the short-run yield equilibrium (Eq.6) produces the sustainable yield function (Y):

$$Y = aE - bE^2 \text{…………………………………………… (Eq.8)}$$

Where $a = qK$ and $b = q^2\frac{K}{r}$, stock size is a function of effort. Therefore, when plotted the curve will show the yield produced for a given level of effort after the stock comes into equilibrium for that level of effort. Growth increases with decreases in stock size, however, further increases will decrease sustainable yield. The sustainability curve ignores the time it takes for stock to adjust.

3.3 Economic analysis

Commercial fishing is an activity undertaken for profit, data on prices, costs and how profits vary with output, is used to formulate a model that predict the likely levels of effort and output. The economic/Gordon model (1954), is derived from the Schaefer model.

(i) Total sustainable revenue

A "monetised" version of the sustainable yield (Total Sustainable Revenue (TSR)) and the growth curves is derived from fish prices, cost per unit (C_E) and effort which shows how cost and revenue vary with effort or stock size, respectively:

$$TSR_E = P\,(aE - bE^2) \text{ ………………………………… (Eq.9)}$$

The TSR shows the amount of revenue that will be generated for any level of effort after the stock has adjusted to that effort.

(ii) Total cost

Fish on a deck has value, but it does not get there for free. The opportunity cost of inputs for the fishing operations produces the effort to catch the fish. Cost is considered as the inputs to fishing operations and is made up of fixed and variable costs, the representation is an expression as a function of effort:

$TC_E = C_E E$ …………………………………………………… (E.q10)

Total cost will increase linearly with effort as per E.q 10.

(iii) Sustainable net returns

The profit function depends on fish price, sustainable yield and costs:

$NR_E = P\ (aE – bE^2) - C_E E$ ……………………………………….. (E.q11)
Maximizing NR_E, therefore, $P\ (a – 2bE) = C_E$

The static maximum economic yield is based on the net returns and expressed formally as follows:

$C_e = p(a\text{-}2bE)$

where a=qk and $b=\frac{q\hat{}2K}{r}$ and thus,

$E_{(mey)} = \frac{\text{pa}-\text{Ce}}{2pb}$

It is important to increase the production of effort if the value of the extra harvest is greater than the cost of taking that harvest. However, the optimal balance of production in the fishery and the rest of the economy is critical and not just maximising the net value of harvest.

3.4 Data description

The data relevant for this study was received from the Ministry of Fisheries and Marine Resources; Directorate of Policy, Planning and Economics and Directorate of Resource Management. These secondary data are collected from the fishing industry by economists and through scientific research conducted by biologists on an annual basis.

3.4.1 Biological and economic data

The biological data that will be utilised for the estimation of the rock lobster model parameters is for the period 1989/90 to 2017/18; this is namely biomass and catch data. Effort data is for the period 1994/95 – 2017/18. Whilst economic variables such as prices and cost will only cover the period from 2012/13, due to unavailability of verified data earlier than this period. The data available would take a longer time to be verified. Data was received in kilograms or Namibian Dollars (N$) and converted for uniformity to tonnes or US$.

3.4.2 Fishable biomass

The rock lobster fishable biomass is an estimation from the DeLury model that only considers the commercial component lobsters larger than the legal size 65 mm CL. Therefore, only fishable biomass is utilised in this study.

3.4.3 *Effort and CPUE*

The seasonal effort statistic is calculated by multiplying the total number of baited lobster traps deployed (i.e. traps) and the period for which those traps were deployed (i.e. soak time). The "traps-soak-time" or effort variable is then standardised to a 24-hour period which produces a unit of effort and is thus commonly referred to as a 'Trap-Fishing-Day' (TFD). The effort is proportional to the number of traps and time for which they are set. Therefore, the number of operational vessels may not necessarily be a good indicator of variation in effort for the rock lobster sub-sector.

When the catch of any given period is divided by its corresponding effort it yields catch per unit effort (CPUE) and quantified as 'Kg/TFD' (MFMR, 2018).

3.4.4 *Average prices*

The price data for rock lobster was adjusted for changes in inflation during the period under review. An average price was calculated based on whole cooked and raw frozen whole lobster and live products. This is because these two products were produced for the time for which income and expenditure data is assessed in this study 2012/13 to 2017/18. While the frozen tails prices were treated as outliers to the time series and thus excluded.

3.4.5 *Cost variables*

The cost of operations in the sub-sector is derived from the income and expenditure survey and were categorised as fixed or variable costs (Table.1). This survey is mandatory for all quota applications and accompanied by audited financial reports.

Table 1. Main Variable and Fixed cost items for rock lobster sub-sector *(MFMR, 2018)*.

Variable Costs	Fixed Costs
Salaries and emoluments	Fishery fees and levies: quota, observer, fund and license
Employee contr. to social welfare	Fuel and lubrication
Food and crew provisions	Foreign exchange losses
Repairs and maintenance	Insurance
Electricity, water, gas	Depreciation
Payment on loans	Other Fees: processing, professional, charter, harbor
Bank charges	Rent equipment, land and building
Inputs to processing	Storage and freight

The operational costs of the rock lobster sub-sector are primarily recorded in N$, however, for this purpose it was converted to US$ based on the average of the various years exchange rates as per the Bank of Namibia (Central Bank) records.

3.5 Results

There are two different functional forms that may be used to estimate the relationship between biomass and biomass growth for the rock lobster fishery; Logistic and the Fox functions. The main difference between the two functions is that Fox function exhibits higher estimates relative to low biomass levels and is more resilient to high levels of fishing effort than the logistic function (Arnason, Kelleher, & Willmann, 2008).

3.5.1 Estimation of biological parameters

The biological parameters for the rock lobster fishery were estimated on the fishable biomass for the four commercial exploited fishing grounds in Namibia. The natural growth function was estimated with OLS regression and resulted in the following:

$$G(x) = 0.54X(1- \frac{X}{2{,}390})$$

As table 2 shows there is a high degree of uncertainty of the carrying capacity estimation of 2,390 tonnes. When the intrinsic growth rate is calculated at 95% confidence interval the carrying capacity is deemed probable to be somewhere between 1,467 to 6,436 tonnes.

The current level of biomass is estimated to be at 1,711 tonnes, according to the Delury model, which is 72% of the estimated carrying capacity. This is an indication that at least 28% is non-fishable biomass, suggesting an undersized stock of 679 tonnes.

The rate at which the rock lobster stock would grow without external effect is 0.54 which is relatively high for this slow growing stock. It follows that a unit increase in biomass would lead to a 54% increase in biomass when the biomass is low. In comparison, the average rate of increase of biomass for the rock lobster stock has been 3% for the period under review.

The regression output shows a R^2 of 0.53. However, it is important to note that the regression was made with a suppressed constant, thus giving a higher value than would be the case otherwise. This R-squared implies that 53% of variation in the biomass growth is explained by the model. The output table two below was based on 28 biomass data observations for the period 1990/91 to 2017/18.

Table 2. Parameter estimation for biomass growth function.

$R^2 = 0.53$						
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
r	0.540773	0.123753	4.369768	0.000177	0.286395	0.795152
-r/K	(0.000226)	0.000069	(3.269331)	0.003032	(0.000369)	(0.000084)
K	2,389.59				1,467.15	6,436.27

Given the parameter estimates, the MSY for the rock lobster stock is 323 tonnes. The catches for the sub-sector is recorded at 230 tonnes on average since 1990/91. However, the catches for 2016/17 and 2017/18 were 177 tonnes and 175 tonnes which is 55% and 54% of MSY. This shows that the current catches are within the largest long-term steady catch possible for rock lobster.

The biomass at MSY was estimated at 1,195 tonnes, while the highest fishable biomass was 2,460 tonnes in 1999/00. If that is the true carrying capacity, then, X_{msy} translates into 1,230 tonnes of biomass at the maximum sustainable level. This is higher than the biomass at MSY from the model and is much lower than the current biomass of 1,711 tonnes (Fig.14). As a result, it could be established that the current biomass level has grown above the point of maximum growth rate of 323 tonnes. The 2017/18 natural growth of the biomass is recorded at 587 tonnes.

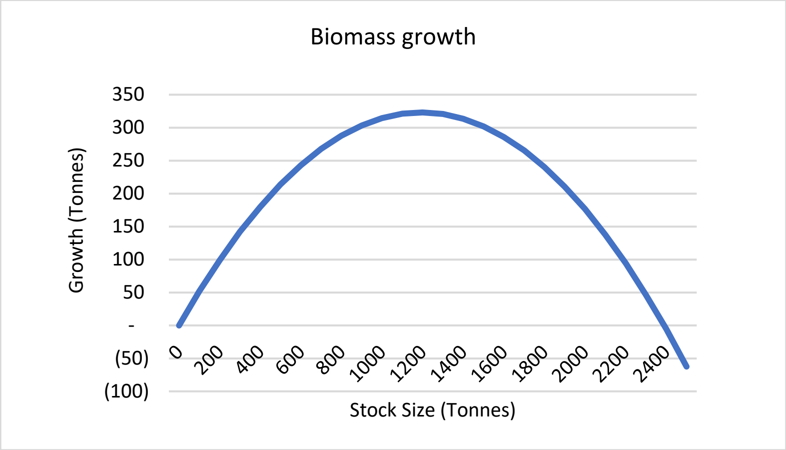

Figure 14. Biomass growth and stock size of rock lobster.

3.5.2 Harvest function parameter estimation

The yield for the rock lobster was subjected to biomass and effort, which resulted into an estimation of the function:

$$Y_t = 0.0000014XE$$

The model estimation shows that the catchability of rock lobster is almost insignificant as 10,000 increase in effort affects the catch by less than 1%. However, there were no direct proportional changes in catches relative to the effort. Because, there were years when effort was recorded at low levels while the catches were higher and vice versa.

Variation in the model explain about 96% of the variation in the data, as the R^2 shows, while the confidence interval range is quite narrow as shown in table 3.

Table 3. Parameter estimation for harvest function.

$R^2 = 0.96$						
	Coefficient	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
q	0.0000014	0.0000001	24.9131357	0.0000000	0.0000013	0.0000015

3.5.3 Sustainable yield curve

The sustainable yield curve was estimated to be:

$$Y_e = 0.0034E\text{-}0.000000009E^2$$

The sustainable yield for rock lobster was estimated to increase with effort up to a maximum of 323 tonnes and effort level correspondence of 195,000 TFD and decreases as effort is further increased (Fig.15). The 2017/18 catch of rock lobster is recorded at 175 tonnes with an effort level of 73,789 TFD which is 54% and 38% of the sustainable levels respectively. At this level of effort, the estimation is that the sustainable catch should at least be 202 tonnes. The growth of biomass is not equal to the short run yield; therefore, the current catches are not at a sustainable level.

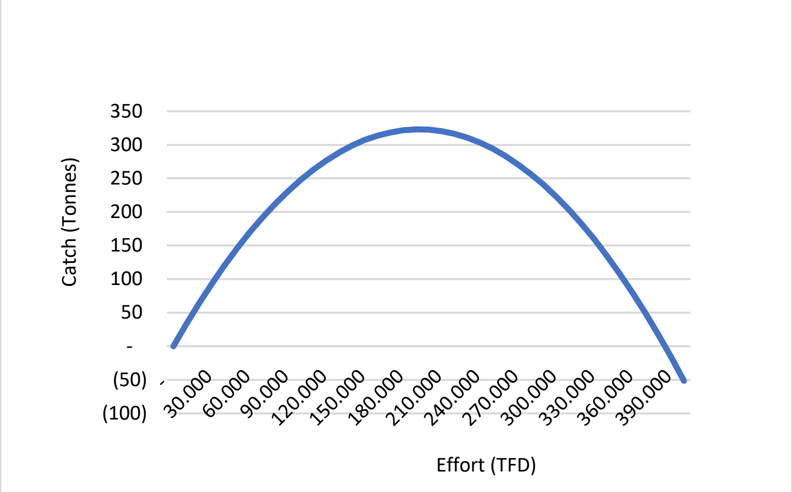

Figure 15. Sustainable yield curve.

The effort at MSY was estimated to be 192,606 TFD, which corresponds to a catch of 323 tonnes. As effort in the rock lobster sub-sector is reduced, the harvest initially decreases and then increases as stock size increase.

3.5.4 Population equilibrium curve

The equilibrium stock size of rock lobster varies inversely with effort see Figure. 13. At the highest stock size 2,234 tonnes the effort associated herein is 25,097 TFD. And the lowest stock size for rock lobster is assessed at 822 tonnes associated with 252,731 TFD of effort (Fig.16).

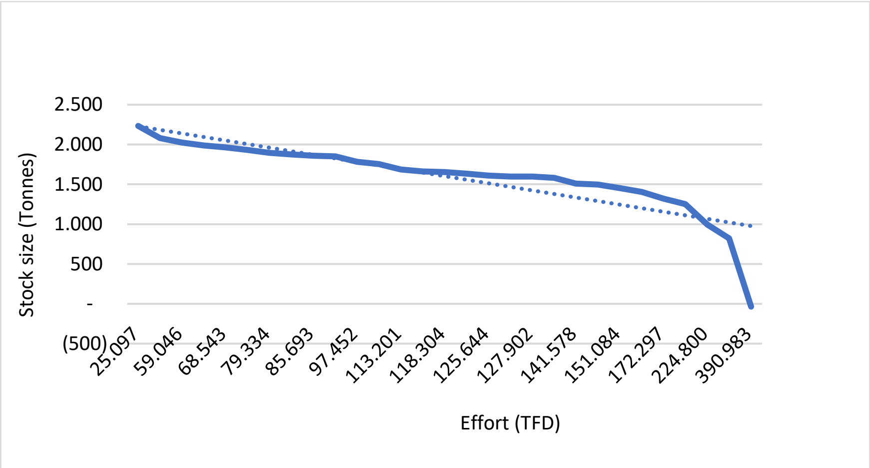

Figure 16. Population Equilibrium Curve.

The rock lobster sub-sector exerted 68,543 TFD of effort to the highest biomass of 2,460 tonnes assessed in 1999/00, while the lowest biomass for the stock was assessed at 671 tonnes with 224,800 TFD of effort. The rock lobster subsector is pushing high amounts of effort on a low biomass.

3.5.5 Cost function parameter estimation

The cost information considered for estimation of the parameters for the cost function are for the period 2012/13 to 2017/18. This resulted into the following:

$$TC_E = 20.37E$$

Cost per unit of effort was estimated at US$ 20.37. As the effort for rock lobster is increased the total cost increases by US$ 20.37, making the catching of these species quite expensive when comparing it to the price of whole lobster at US$ 40.60/kg. The model explained 97% variation in the data.

Table 4. Parameter estimation for cost function.

$R^2 = 0.97$						
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Ce	20.36594521	1.467053	13.882215	0.000035	16.594766	24.137125

3.5.6 Rock lobster as a sustainable fishery

The total cost of harvesting the sustainable yield from a given rock lobster stock size fluctuates as per the function;

$$TSC_x = 20.37(K-X)\ (0.54/0.000014K)$$

A unit increase in the cost per unit of effort leads to a decrease of costs, less effort is needed to produce the sustainable catch as the stock size is increased. The total sustainable revenue for rock lobster for any stock size can be obtained from the function:

$$TSR_x = P*[0.54X(1-\frac{X}{2,390})]$$

A positive relationship between sustainable revenue and effort is observed in the function:

$$TSR_{E\ =}\ P(0.003E\text{-}0.09\text{+}E8E\text{^}2)$$

3.5.7 Profit function estimation

The profit/net revenue function for rock lobster was estimated to increase with the proportional change of price and yield together with a decrease by US$ 20.37 and effort as follows:

$$\pi = (pY) - (20.37E)$$

The increase in effort up to a maximum of 160,000 tonnes leads to an increase of net revenue and every unit increase after this point results in a reduction (Fig.17). The highest net sustainable revenue of US$ 9 million, while the highest profit in the rock lobster sub-sector was realised in 2014/15 at US$ 951,000.

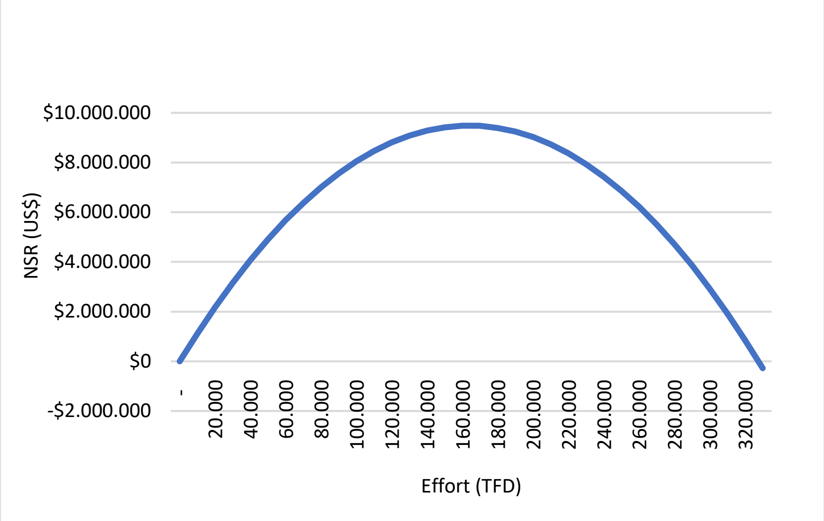

Figure 17. Net sustainable revenue and effort.

The net sustainable revenue for rock lobster is estimated at US$ 9 million with a stock size of 1,400 tonnes. Whereas, stock size in 2014/15 was 1,386 tonnes with the highest profit of US$ 951 000. The net sustainable revenue is positive and increasing for stock size of 400 tonnes to 1,400 tonnes than an increase from 1,500 results in a decreasing return (Fig.18).

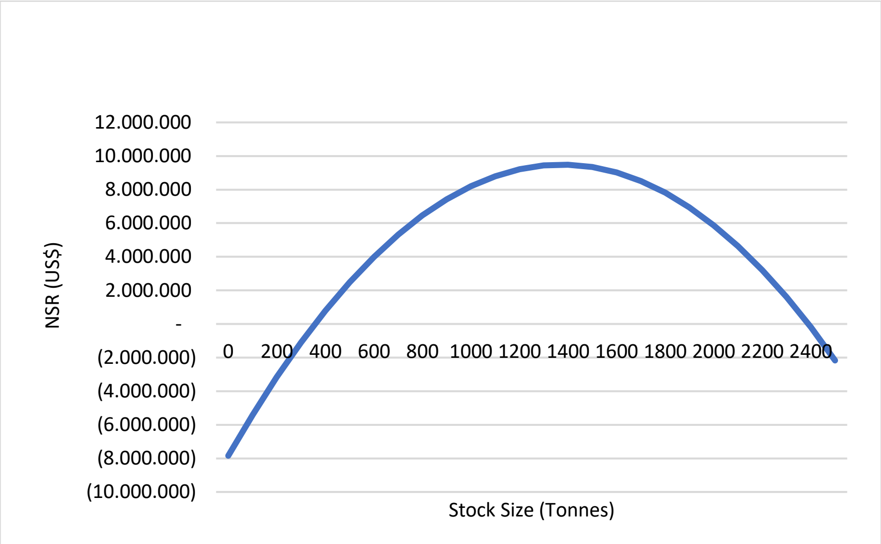

Figure 18. Net sustainable revenue and stock size.

3.5.8 Static Maximum economic yield

The level of effort for rock lobster is estimated in order to accomplish economic efficiency in the sub-sector. In addition, it is crucial to maximise the sustainable yield because the inputs that have other potential uses in the economy are used to produce the effort to catch the fish (Anderson & Seijo, 2010).

The model estimated the rock lobster total sustainable cost to increase with the increase in effort (Fig.19), which is the trend observed in the sub-sector. However, during 2017/18 total cost in the sub-sector increased with a decrease in effort from US$ 1.40 million to US$ 1.46 million and 97,452 TFD to 73,789 TFD respectively. Total revenue was estimated to increase up to US$13 million at an effort level of 210,000 TFD after which an additional unit of effort led to a decrease in sustainable revenue.

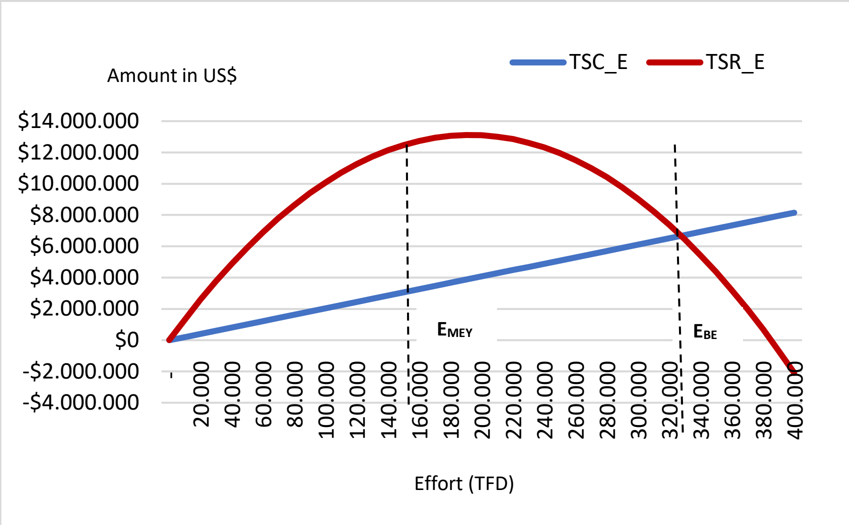

Figure 19. Sustainable cost, sustainable revenue and effort

The bioeconomic equilibrium where the net sustainable revenue is equal to zero or break-even point is estimated at effort level 327,609 TFD, after which further increases produce an efficient economic utilisation as sustainable costs are higher than sustainable revenue. The effort at the maximum economic yield is 160,000 TFD and 314 tonnes of rock lobster catches. This is lower than the 2017/18 level of effort at 73,789 TFD that yield 175 tonnes.

The sustainable cost relative to the stock size for rock lobster is showing a decreasing trend. Whilst the sustainable revenue increases up to US$ 13 million at a stock size of 1,400 tonnes (Fig.20). Thereafter, the increase in stock size leads to a reduction in sustainable revenue.

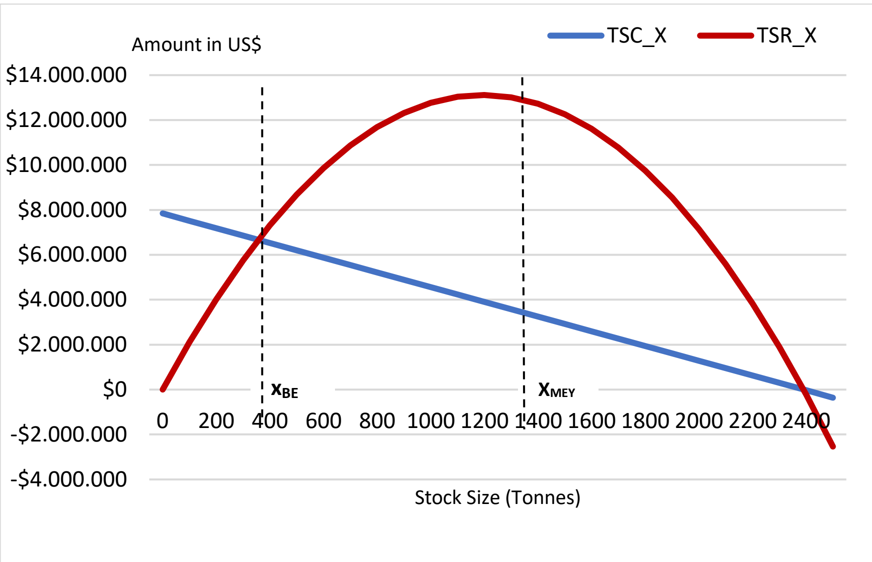

Figure 20. Sustainable costs, sustainable revenue and stock size.

Bioeconomic equilibrium for the stock size is assessed to be 358 tonnes. The 2017/18 biomass level was assessed with the Delury model at 1,711 tonnes, whilst the highest was in 1999/00 at 2,460 tonnes. This is suggesting that the 2017/18 biomass is at a level were revenues for the rock lobster sub-sector is decreasing at a fast rate.

3.5.9 Parameter Estimation

The parameters estimated for the rock lobster bioeconomic model are shown in table 5.

Table 5. Bioeconomic parameter estimation for rock lobster.

	Symbol	Value
Biological Parameters		
Intrinsic growth rate	r	0.54
Carrying capacity	K	2,390
Economic Parameters		
Price of rock lobster (US$/Tonne)	P	40,600
Cost per unit of effort	Ce	20.37
Catchability coefficient	q	0.0000014
Equilibrium values		
Maximum sustainable yield	Ymsy	323
Bioeconomic equilibrium yield	Ybe	158
Maximum economic yield	Ymey	314
Stock at maximum sustainable yield	Xmsy	1,195
Stock at bioeconomic equilibrium	Xbe	358
Stock at maximum economic yield	Xmey	1,400
Effort at maximum sustainable yield	Emsy	192,606
Effort at bioeconomic equilibrium	Ebe	327,609
Effort a maximum economic yield	Emey	160,000

3.5.10 Price Change impacts

Rock lobster prices have fluctuated marginally during the period of review. Therefore, to examine how sensitive the results on the Maximum Economic yield and impact on effort and biomass to the estimated parameters, the results were also examined if the parameters would change by 10%.

The 10% increase in price led to a rock lobster price of US$ 44,660 per tonne, the total net sustainable revenue of rock lobster increases and biomass at MEY was assessed at the same level of 1,400 tonnes. Thus, no deviation from the biomass that maximises the economic returns of rock lobster. Similarly, 10% reduction in the rock lobster price to US$ 36,539.72 per tonne retains the same level of E_{MEY} while sustainable revenue reduced.

In terms of the effort that maximise the economic returns in rock lobster, a 10% increase in price reduced the level of effort to 170,000 TFD and Y_{MEY} increased to 314 tonnes. While a price reduction maintains effort at 160,000 TFD (Table 6).

Table 6. MEY for price change of rock lobster.

		10% increase	**10% decrease**
Maximum economic yield	MEY	319	314
Stock at maximum economic yield	X_{MEY}	1,400	1,400
Effort a maximum economic yield	E_{MEY}	170,000	160,000

4. DISCUSSIONS

The socio-economic performance of the rock lobster sub-sector in Namibia is assessed by studying the amount of quota landed relative to the level of Namibianization, employment, statutory payments, food security, investment and the income and expenditure in general. This study thus focused on economic factors as important driving forces in fisheries by incorporating suitable biological models to model the dynamics of fisheries (Mackinson, Sumaila, & Pitcher, 1997).

The simple model presented in this paper provides an analysis which shows that the rock lobster sub-sector is profitable and can consequently increase its sustainable net revenue through readjusting its effort strategies. The model however estimated a high intrinsic growth rate and uncertainty is observed in the carrying capacity given a wide confidence interval.

A positive stock growth of the rock lobster species is observed which, indicates potential for growth given the current harvests. However, the model shows that at least 28% of the species are undersized. Therefore, there is a need to consider management measures that shall lead to stock recovery. The model could be further developed to segregate biomass per fishing ground to compare the results and introduce fishing ground specific measures as may be the case given the results. Further investigation may be initiated since settlement is a complex process where larval behavior, biological factors and oceanographic processes interact at different scales (Hinojosa, et al., 2016). Since, Namibia through the BCC is in the process of assessing the vulnerability and resilience of rock lobster to climate change; it would be interesting to see the model results in establishing the status in this regard. Also, due to the dire situation of rock lobster in both Namibia and South Africa, the BCC platform may be utilised for discussions on strengthening cooperation in shred stocks such as rock lobster.

Landings in the rock lobster fishery are 54% of MSY and is often considered to be poor when compared to the TAC, however, the model results suggest that the MSY is 30% higher than the TAC set in 2017/18, which may be too high. Therefore, it may be necessary to revisit inputs to the stock assessment model adopted for the rock lobster fishery in Namibia.

The rock lobster was found to be overcapitalised in terms of the effort on the species. Efficient strategies may be adopted to reduce the costs and improve effectiveness. The current catches are not at a sustainable level, a lot of effort is deployed resulting in low catches. Given illegal fishing activities of rock lobster in South Africa, and the depleting stock status, this may be a concern to Namibia. The ‘poachers’ in South Africa may venture to exploit the Namibian rock lobster stocks through recreational fishing and therefore stringent management tools should be implemented to better control this activity.

Cost of operation in the rock lobster fishery is relatively high when considering the effort levels and revenue generated. In addition, the cost items may be reduced by decommissioning vessels not utilised (as necessary) because the fixed costs attached increases the operational costs. Employment may not necessarily be affected as the vessels are not utilised. With efficient utilisation of active vessels, the sub-sector can increase value addition activities within the short value chain of the sub-sector.

The sub-sector has a potential to increase its catches to 314 tonnes in order to maximise economic returns. The duration for deploying baited traps may be increased without necessarily increasing vessels or fishing gear. Also, the sub-sector may increase baited vs non-baited traps for better utilisation. The current operations in the sub-sector are at a positive net sustainable revenue level, but lower than should be given the effort levels. The limitations to the study are that all processes affecting stock productivity (*e.g.*, growth, mortality, and recruitment) are subsumed in the effective relationship between effort and catch. The variations in the spatial distribution of rock lobster were not captured in the model. Thus, it becomes difficult to distinguish whether population fluctuations are due to fishing pressure or natural processes.

5. CONCLUSION

The model estimated a yield level 50% higher than the current catch levels of lobster. It is premature to confirm that the sub-sector can increase its catch to that level, as a catch to that magnitude 323 tonnes was recorded over a decade ago. Since then the landings have been fluctuating at a fast rate downwards.

Biomass at MSY is estimated at 1,195 tonnes less than the fishable biomass recorded for the past four fishing seasons averaging 1,472 tonnes. The total allowable catch for rock lobster for this period 2014 – 2017 was at various rates 22%, 17%, 21% and 13% of the fishable biomass. The management objective for the rock lobster fishery needs to have clear guidelines to achieve both maximum stock size and economic returns to increase its contribution to the Namibianization policy.

Since, the bulk of catches are concentrated in some fishing grounds. The review of access to the fishing grounds should be explored to reduce the pressure on the stock. Or a rotational access may be introduced. As for the fishing grounds where fishing is not allowed and is still taking place, stricter measures need to be implemented such as reduction of quotas relative to the catches in these areas.

A bio-economic approach for formulating management strategies for the rock lobster would be ideal as the economic factors do affect optimal catches. Maximising total net revenue rather than maximising the total catch per year gives a marginal improved management strategy (Roos, 2004). However, it is important to keep in mind that the high economic returns that the right holders will gain, ensure that more effort is driven for rock lobster, which accelerate the rate of stock collapse (Mackinson, Sumaila, & Pitcher, 1997).

Recreational fishing of rock lobster contributes to the stock status of rock lobster and thus, stricter monitoring and control needs to be enforced. There is a need to explore recording of the catches although a limit is set.

Further research may be initiated to examine fisheries management measures that optimise the Namibian rock lobster economic returns given the harvest in South Africa and how harvest affects the stock on the Namibian side. In addition, this study is a contribution to the bioeconomic modelling of the Namibian fisheries which is highly recommended.

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