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AN ASSESSMENT OF THE *Sardinella maderensis* STOCK OF LIBERIA COASTAL WATERS USING THE LENGTH BASED SPAWNING POTENTIAL RATIO (LBSPR)

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ABSTRACT

S. maderensis is an economically important species with high demand in Liberia. Due to over exploitation, this species is experiencing a collapse in the region. Consequently, it is imperative to understand more about its status. This study aimed to assess the status of *S. maderensis* in Liberia coastal waters using the length-based spawning potential ratio (LBSPR) approach. The study sampled length frequency data of *S. maderensis* from eight landing sites. The data were collected from April 2013 to September 2013, and March 2014 to October 2014. Length-frequency distribution was plotted together with key life history parameters L50, Lopt, Lmax, Linf to classify the length frequency sample into juvenile, mature, and mega-spawners. The results showed that in 2013, the maximum size of fish captured was 42 cm. The sample comprised 81.88% juveniles, 4.66% matured fish and 13.47% mega-spawners. Similarly, in 2014, the maximum size of fish captured was 42 cm, 82.22% of the captured fish were juveniles, while 8.25% were matured and 9.52% were mega-spawners. The estimated SPR was 0.23 for 2013 and 2014, and relative fishing mortality, F/M, was 0.97 and 0.99 for 2013 and 2014, respectively. The SPR values were estimated to be slightly above the target SPR of 20%, which indicates that this population is at risk of recruitment overfishing. The study recommended the use of monofilament gill nets to be replaced with multifilament gill nets; and to enforce the fisheries regulation to ban all gears with mesh sizes less than 50 millimetres.

This paper should be cited as:
Yokie, A. 2020. *An assessment of the Sardinella maderensis stock of Liberia coastal waters using the Length Based Spawning Potential Ratio (LBSPR)*. UNESCO GRÓ Fisheries Training Programme, Iceland. Final project.
http://www.grocentre.is/ftp/static/fellows/document/Anthony19prf.pdf

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1 INTRODUCTION

Liberia is located on the west coast of Africa between latitudes 4^{o} and 9^{o}N, and longitudes 7^{o} and 12^{o}W. The estimated population is 4.8 million with a yearly growth rate of 0.4% (LISGIS, 2008). The country is bordered by Atlantic Ocean to its south-southwest with relatively warm waters. The coastline is approximately 570 kilometres in length and the exclusive economic zone (EEZ) is 200 nautical (Bureau of National Fisheries, 2014).

Fisheries plays an important role in terms of providing livelihood for both fishermen and fish processors located in the nine coastal counties of Liberia (Bureau of National Fisheries, 2014). Marine small-scale fisheries of Liberia operate within the Inshore Enclosure Zone (IEZ) which is the area within six nautical miles from shore. A majority of those working in the sector are Liberians, and 60 % are female (Sherif, 2014).

Small-scale fishermen target mainly small pelagic species including Sardinella Spp. (bonny), *Chloroscombrus chrysurus (*Porjoe*), Ethmalosa fimbriata (*bonga*)* and *Engraulis encrasicolus (*anchovy/gbato*).* These species are mostly targeted by the semi-industrial Fanti canoes using ring-nets, driftnets, set-nets and gillnets (Belhabib, 2016). Additionally, the smaller non-motorized Kru vessels target the demersal species that mostly constitute *Pseudotolithus spp. (*Cassava fish*), Galeoides Decadactylus (*butternose*), Cynoglossus Spp (*Sole fish*), Arius latiscutatus & A. Heudeloti (*Catfish*).* These vessels use cast-nets, beach-seines, set-net, gillnets, traps and hook and line gear.

Among the species are that are exploited, *Sardinella spp* is caught in the largest amount and is considered to be the most important by the local fisherman (Wehye, 2017). *S. maderensis* and other clupeids species constitute a major portion of the capture for small-scale coastal vessels. Sardinella, Barracudas, Croakers, Sharks and *Ilisha africana* constituted 83% and 59.06% of the total local fish supply in 2004 and 2005 respectively (Wehye, 2017). The population of *S. maderensis* is currently undergoing pressure from the high demand for sardines (Wehye, 2017).

1.1 Rationale

The Liberian small-scale fishery is exploited through deployment of a variety of fishing gears (Belhabib, 2016). However, within IEZ, many stocks are being exploited by the small-scale fleet and some stocks are harvested close to maximum sustainable yield (MSY) (Bureau of National Fisheries, 2014).

The exploitation is done by the semi-industrial, artisanal and the subsistence sub-sectors targeting multiple species and as a result, some are displaying signs of over-exploitation (Wehye, 2017). The marine small-scale fisheries of Liberia have also battled with severe IUU fishing in the absence of monitoring during the civil war, the cost of which is estimated at USD 75 million annually (Bureau of National Fisheries, 2014).

In Liberia, the small-scale fisheries have always been the greatest source of domestic fish intake (Bureau of National Fisheries, 2014). Small pelagic fish have become the most important marine resource, accounting for about 80% of annual catches (Bene, 2004). Of these, sardinella has been understood to play a significant role in the food supply for local communities. *S. maderensis* are quite cheap and the fishery is profitable for many local fishermen, fish processors and traders within Liberia. In addition, since 2006, *S. maderensis* stocks have been exploited by some large foreign fishing vessels operating within the inshore waters as well as national fishers (Bureau of National Fisheries, 2014).

Due to lack of monitoring by the National Fisheries and Aquaculture Authority, the landing data for small-scale fisheries are rather poor, which makes sustainable management of *S. maderensis* fishery challenging in Liberia. A previous length-based assessment done by Wehye (2017) has estimated growth and mortality parameters from length data collected in 2013. These parameters were further used to estimate current and maximum exploitation rates. The study concluded that the exploitation of *S. maderensis* is at the maximum sustainable yield and shows signs of recruitment overfishing.

Given its importance and signs of potential overfishing, it is desirable to examine the status of the *S. maderensis* stock, which will be the focus of this study. It is anticipated that this analysis will provide a basis for management decisions to be taken for this fishery to ensure its sustainable contribution.

1.3 Study Objectives

The aim of this study is to assess the status of *S. maderensis* in Liberia coastal waters using the length-based spawning potential ratio (LBSPR) approach. The LBSPR method has been developed for data-limited fisheries that have to rely on length measurements. The method can be applied to stocks where few data are available, such as a representative sample of the size structure of the targeted portion of the population (i.e. the catch). This information can be combined with an understanding of the life history of the species to estimate the spawning potential ratio (Hordyk, 2015).

The available length frequency data from 2013 and 2014 were used. These data were collected by the National Fisheries and Aquaculture Authority. The life history parameters required were compiled from existing literature.

2 LITERATURE REVIEW

2.1 The history and importance of fisheries in Liberia

Fishing in the coastline of Liberia started long ago with the earliest records dating from 1960 when a little over 44 canoes were reported fishing along the coast. The fisheries developed when the Kru of the Liberian decent, the Fanti from the Ghanaian decent and other Togolese fishermen, referred to as *Popoh*, became involved in coastal fishing.

In the 1970s, a fleet of around 20 industrial vessels began fishing in Liberian waters for shrimp and demersal fish. They operated larger vessels, taking crew of up to 10 and regularly going to sea for several weeks at a time. Those vessels caught about 3,000 tonnes of finfish and 2,000 tonnes of shrimp annually. All through this period, the Bureau of National Fisheries (BNF) believed that the fisheries had opportunities for growth to an envisioned total size of some 50,000 tonnes annually, a degree notably above the mentioned catches at that time. For a long time, Liberia suffered the effects of profound civil conflict and at some point, over these years, the fisheries regulatory framework became obsolete. Tracking of fishing activities and research came to a halt, resulting in a situation where little or no knowledge about fishing events or the condition of the stocks were required (Bureau of National Fisheries, 2014).

The civil war created an atmosphere for unlawful fishing activities with overseas vessels fishing within Liberian waters. In past years, the Bureau of National Fisheries has taken a strong action in opposing illegal vessels fishing in Liberian waters and over 40 vessels were monitored and brought to justice. These days, the fisheries sector provides about 12 % of Liberia's agricultural gross domestic product (GDP) and 3% of the national GDP. Income to the government from license costs, vessel registration costs, inspection expenses, observer fees, import and export fees, and fines totalled four hundred thousand United States dollars in 2011 and rose steeply to almost six million by mid-2013, because of the fines collected from effective actions taken against foreign vessels fishing illegally in the Liberian waters. Furthermore, a greater portion of the Liberian populace is anticipated to live near coast, supported partly by fisheries for activities, along with several rural communities including females and youth. Fish offers an estimated 65% of animal protein intake in Liberia, mainly due to the fact it is notably inexpensive compared to meat or chicken and is conveniently accessible. The per-capita consumption of fish in Liberia is 4kg per year (Bureau of National Fisheries, 2014).

2.1.1 Overview of Small-scale fisheries

The Liberian marine small-scale fisheries are comprises the semi-industrial, artisanal and subsistence sub-sectors (Bureau of National Fisheries, 2014). Catches are landed at 114 fish landing sites along the coastline.

2.1.2 Semi-industrial sector

In the semi-industrial sector, fishermen use bigger motorized vessels that target mainly small pelagic species and a few larger pelagic species. The gears used include ring-nets, driftnets, set-nets, and gillnets. There are around 500 of these vessels registered to fish in Liberia and they are generally described to as the Ghanaian-design or 'Fanti' craft (Figure 1). They are constructed with a mixture of entire logs and planks, have a group of 12 to 20 crew and operate with outboard engines starting from 10 horsepower.

Figure 1. Semi-industrial bigger motorized vessels at beach landing sites in Monrovia (Wikipedia, 2020).

2.1.3 The Artisanal sector

The artisanal fishers operate the 'Kru-style' wooden dug-out non-motorized vessels (Figure 2). They generally target shallow water demersal species such as *Pseudotolithus spp. (*Cassava fish*), Galeoides Decadactylus (*butternose*), Cynoglossus Spp (*sole fish*), Arius latiscutatus & Heudeloti (*catfish*)* using a variety of fishing gears, such as cast-nets, beach-seines, set-net, gillnets, traps and hook and line (Bureau of National Fisheries, 2014).

Figure 2. Kru-style wooden dug-out non-motorize vessels in landing site of Robertsport. (Wikipedia, 2020).

2.1.4 Subsistence Sub-sector

The subsistence fishers are the smallest group. They also operate the dugout non-motorized vessels, but less than six metres in length, with a depth of approximately 60 centimetres and mostly operated by one to three men. The gears used include cast-nets, beach-seines, set-net, gillnets, traps and hook and line (Bureau of National Fisheries, 2014).

2.2 Status of small-scale fisheries in Liberia

One of the recent studies conducted on the status of small-scale fisheries in Liberia includes the MRAG (2014) report. It was determined that total landed catch in 2013 and 2014 were 341.8 and 1,638.9 tonnes for a registered 55 and 75 species, respectively. The big difference in the monitored total catches was attributed to a significant rise in the sampling effort in 2014 compared to 2013, for instance 14,290 catch records are logged for 2014, whereas 5,460 catch records are logged in 2013 (MRAG, 2014). The Fanti vessels landed 79% and 89% of the observed catch in 2013 and 2014 and catches were accumulated across all species. Fanti vessels landed more pelagic and offshore species including bonny *(Sardinella)*, blood fish *(tuna)*, cassava fish *(Pseudotolithus elongatus)*, red grouper, grunter, porjoe, sharks, sand cavalla in comparison with Kru vessels. Kru vessels appeared to target inshore species including Cassava croaker, pikefish (Barracuda), penten (halfbeaks), gbakpelleh (West African ilisha), lobster and snapper (Bureau of National Fisheries, 2014). On the average, Fanti vessels are two times the length (44’ compared to 22’) and have on average twice the engine horsepower of Kru vessels (35 hp compared to 17 hp) and hence catch more. The sardinella spp made the largest contribution (49 % - 69 %) to the predicted catches (MRAG, 2014).

2.3 Biology of *S. maderensis*

S. maderensis is from the family *Clupeidae,* and genus *sardinella*. It is classified as a small ray-finned fish and is usually found in the Eastern Atlantic and southern Mediterranean (Ba, 2016). It is a silvery fish like other sardinella species (Figure 3). It has a prominent characteristic of grey caudal fins with black tips. It feeds on phytoplankton and fish larvae and is a pelagic species that forms schools in coastal waters, often mixed with *S. aurita* (Pascual, 2012). *S. maderensis* species have a main breeding period in summer, showing a single peak during the summer period (Pascual, 2012). According to Baali (2017), *S. maderensis* males reach sexual maturity at a size smaller than females (20.75 and 21.76 cm, respectively). According to Ba (2016), the spawning of *S maderensis* species happens all throughout the year in Senegal. The body length of sexually mature females varied from 12 cm to 26 cm in Senegal while that of mature males ranged from 13 cm to 23 cm (Mosepele, 2003). The aggregate occurrence curve of individuals that had surpass the maturity stage 3 suggested that nearly 50% (L50) of females were mature at 17.50 cm while 50% of males were mature at 16.60 cm (Ba, 2016).

The distribution of the *S. maderensis* species are closely related to the dynamics of the upwelling system and usually adapt to environment where different upwelling intensity are expected (Ba, 2016).

Figure 3. Image of *S. maderensis* (Wikipedia, 2020).

2.4 Length Based Spawning Potential Ratio (LBSPR) Approach

For tropical species where age data are not available, length data can be useful in length-based stock assessment (Pauly, 1987). Assessment based on length data are also cost effective because length data are easily obtained, whereas aging process for tropical species can be time consuming and difficult because growth rings are hard to identify from otoliths of such species (Pauly, 1987).

An assessment technique based on spawning potential ratio using length data was proposed by (Hordyk, A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries, 2015). The spawning potential ratio (SPR) is a well-established biological reference point and estimates of SPR can be used to inform management decisions for data-poor fisheries. The LBSPR uses the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio to estimate the SPR of a stock directly from the size composition of the catch (Hordyk, A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries, 2015). The method utilizes maximum likelihood methods to find the values of relative fishing mortality (F/M) and selectivity-at-length that minimize the difference between the observed and the expected length composition of the catch, and calculates the resulting SPR. Hordyk (2015) has successfully demonstrated the LBSPR as a tool for cost-effective assessment of data-poor fisheries. One key advantage of LBSPR is that information on recruitment is not directly required.

Some studies have used the LBSPR method to analyse the status of their stocks and inform management decisions for data-poor fisheries. Princea (2015) describes its first application to 12 species of Indo-pacific coral reefs in Palau. Another study applies LBSPR to assess the status of Atlantic bonito exploited in the southern Atlantic coast of Morocco. The results showed that most of the fish were caught before they reached maximum growth. The study concluded that there might be indications of overfishing (Baibbat, 2019). Ernawati (2019) also use the LBSPR method to assess the status of one of their economically important fish species the *Lutjanus malabaricus* in Western of South Sulawesi, Indonesia.

2.5 Fishing regulations for *S. maderensis* in Liberia

In the Fisheries regulation of Liberia, gears with the mesh size less than 50 mm are illegal. However, some studies have looked at the type of gears and mesh size used by fishermen to catch *S. maderensis* and other species in the small-scale sector of Liberia. Dunbar (2015) reveals that the key factor affecting the sustainable use of small-scale fisheries in Liberia was the use of illegal monofilament gill nets, accounting for 52.8% of gear used, while the use of legal multifilament net was 47.2%. The monofilament gill nets can be used by purse seine and cast net and beach seine, and their mesh sizes are usually 38.1 mm (1.5 inches) to 44.5 mm (1.75 inches), 25.4 mm (1 inch) to 50.8 mm (2 inches) and 25.4 mm (1 inch) to 50.8 mm (2 inches)

This study also shows that fishermen measure mesh sizes of gears with the number of fingers that fit in a mesh. One finger is roughly equal to one inch. Regardless of the ban on the use of gears with mesh sizes less than 50 millimetres (2 inches), the study revealed that the highest mesh size of gear used by fishermen in Liberia ranges from 1-3 inches with most of the nets being doubled to reduce the mesh sizes. In these findings, 2 inches of mesh were the highest in use which constitute (38.2%), followed by 2.5 inches (15.3%) and 3 inches (11.4%) respectively.

Subah (2010) also shows that in the small-scale fisheries sector, *S. maderensis* are mainly caught by three gears, cast net, purse seine and beach seine. The report further explains that *S. maderensis* and Atlantic flying fish are mainly caught with purse seine with the mesh size of 38.3mm (1.5 inches) to 44.5mm (1.75 inches). Additionally, *S. maderensis* along with mullet and grunter are also caught with cast net with mesh size of 25.4mm (1 inch) to 50.8mm (2 inches). Furthermore *Sardinella*, croakers, bonga are caught by beach seine with mesh size of 25.4mm (1 inch) to 50.8mm (2 inches) and the dimension of 1-5 meter.

Figure 4. Monofilament Gill net used in one of the eight landing sites in Westpoint (Dunba, 2015)

3 MATERIAL AND METHODS

3.1 Study area

The project region includes the nine coastal counties of Liberia along the entire coastline of 570 kilometres (Figure 5). The continental shelf extends from Côte d'Ivoire to Robertsport in Liberia, with an average width of 34 km and the widest part in the central region of Liberia. An inshore exclusion zone (IEZ) reserves the six nautical miles closest to shore for the sole use of subsistence, artisanal and semi-industrial fishing activities. Trawling is not allowed inside the IEZ.

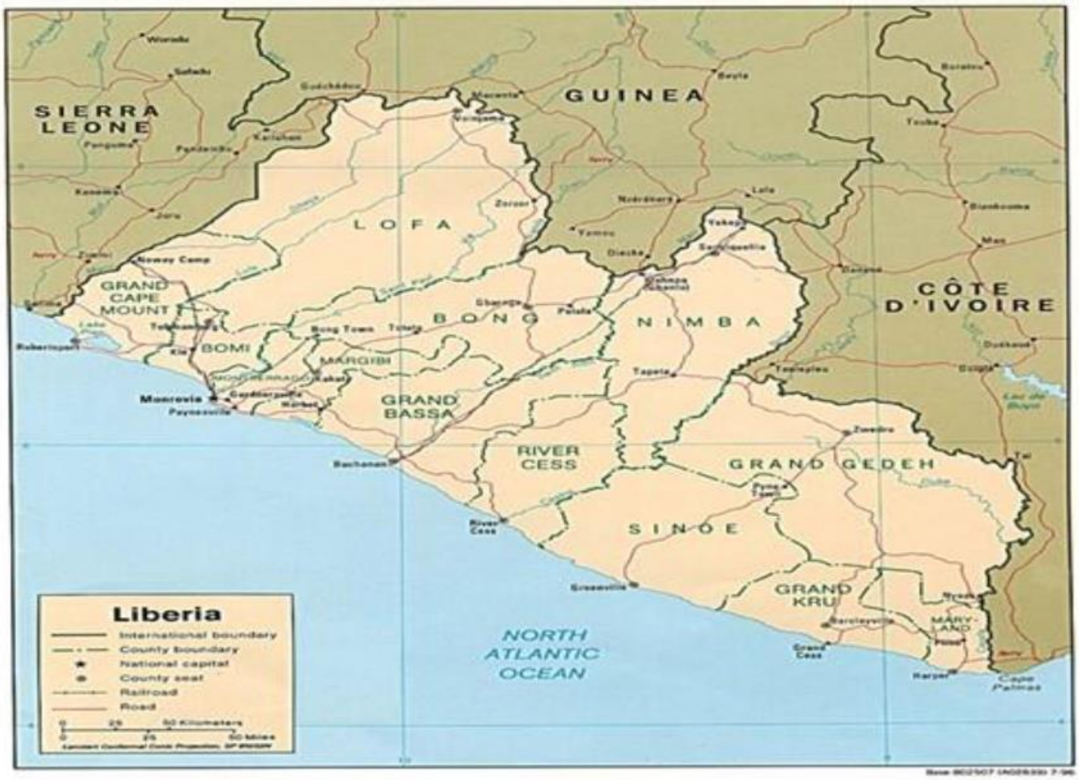

Figure 5. Map of Liberia showing the nine coastal counties.

3.2 Length frequency data collection

Monthly samples were gathered by fisheries enumerators of the Bureau of National Fisheries (BFN) from small-scale fishers at eight designated fish landing sites from April 2013 to September 2013 and March 2014 to October 2014. Acquired samples were identified using identification keys by Fischer et al. (1981). A total of 6,000 samples of *S. maderensis* were sampled and measured in 2014 and 1,804 in 2013. Morphometric measurement of length was done using the 100 cm measuring board at the landing sites. Total length was measured and recorded based on the closest 0.1 cm and the weighing of the sample was done with an electronic weighing scale. Identification keys were used to classify each specimen to species level (Wehye, 2017). There was no sexual differentiation made between samples.

3.3 Plotting length frequency distribution with key life history indicators

Length-frequency distribution was plotted following the methods developed by Froese (2000; 2004). This method recommends plotting key life history indicators together with the distribution. This simple perspective can be used to assess the quality of the sample and the status of the stock (Froese & Binohlin, 2000). The following key parameters were plotted:

- L50 – Length at 50% maturity
- Lopt - Length at which the maximum yield is obtained
- Lmax – Maximum length observed in the sample
- Linf – Asymptotic length

A representation of the length data together with key parameters can be used to classify the length frequency sample into juvenile, mature, and mega-spawners. These were marked on the plot per year, and a percentage of each group was calculated. Juveniles are fish that are smaller than L50, mature fish are between length L50 and Lopt, and mega-spawners are defined as fish that are Lopt plus 10% in size (Froese, 2004).

3.4 Estimating spawning potential ratio

The LBSPR method requires as input length composition data of the catch, as well as some biological parameters for the stock. To setup a simulation model the following inputs are required: natural mortality (M), growth rate (K), von Bertalanffy asymptotic length (Linf), parameters for the size-at-maturity (L50 and L95, which correspond to the lengths at which 50% and 95% of the stock are expected to be mature), length at 50% selectivity (SL50) and length at 95% selectivity (SL95), F/M ratio, and width of the length classes.

Growth parameters of *S. maderensis* were taken from a study conducted on the stock in Liberia (Wehye, 2017). In this study length frequency data from Apr – Sep 2013 (same data set as analysed here) were used. A von Bertalanffy growth model was fitted to estimate K and Linf. Length converted catch curve was used to estimate natural mortality and fishing mortality. The selectivity parameters (SL50 & SL95) were also taken from the Wehye (2017) study.

The length at 50% and 95% maturity were calculated as follows using the maturity ogive parameters from Pascual-Alayoy et al (2012):

$$L95 = (1 / b) * \log (1/0.05 - 1) - a/b$$

$$L50 = -(a/b)$$

The length at maximum yield-per-recruit (Lopt) was estimated using Beverton (1992).

$$Lopt = Linf * (3 / (3 + M/K)) \text{ (Beverton, 1992)}$$

The analysis was conducted in R using package LBSPR (Hordyk, 2019)

Table 1. The biological and selectivity parameters for the *S. maderensis* species used as inputs for the LBSPR model.

Parameters	Symbols	Values	Reference
Von Bertalanffy asymptotic length	L∞	44.46	Wehye et al. 2017
Natural mortality	M	0.81	Wehye et al. 2017
Von Bertalanffy coefficient	K	0.38	Wehye et al. 2017
Length at 50% maturity	L50	24.46	Calculated Pascual-Alayoy et al 2012
Length at 95% maturity	L95	30.36	Calculated Pascual-Alayoy et al 2012
Length at 50% selectivity	SL50	13.99	Wehye et al. 2017
Length at 95% selectivity	SL95	19.5	Wehye et al. 2017
F/M ratio	SPR	43	Wehye et al. 2017
Width of the length classes	Bin Width	1	Wehye et al. 2017
Natural mortality/VB coefficient	M/K	2.1	Wehye et al. 2017

Slope of maturity ogive	a	12.204	Calculated Pascual-Alayoy et al 2012
Intercept of maturity ogive	b	0.499	Calculated Pascual-Alayoy et al 2012
Length at which the maximum yield is obtained	Lopt	26.15	Beverton, 1992

4 RESULTS

4.1 Length frequency distribution with key life history parameters

Figures 6 and 7 show the length frequency distribution for *S. maderensis* for 2013 and 2014 respectively. The lengths were grouped in 1 cm length bins. The mean length in 2013 was 21.2 cm and in 2014 decreased to 20.5 cm. Plotting the data in this framework with the life history parameters showed that for year 2013 (Figure 6 and 7):

- The maximum size of fish captured was 42cm.
- 81.88% of the sampled catch were juveniles.
- 4.66% of the catch were matured.
- 13.47% were mega-spawners.

For 2014, the following were observed:

- The maximum size of fish captured was 42cm.
- 82.22% of the sampled catch were juveniles.
- 8.25% of were matured.

9.52% were mega-spawners.

The analysis showed that majority of the fish are caught before becoming mature.

4.2 Estimating spawning potential ratio

To understand the life history and the targeted portion of the population of *S. maderensis*, the LBSPR model was used to simulate the expected length composition of *S. maderensis*, growth curve, SPR and yield curves. These simulations were based on the life history parameters compiled for the species as delineated in Table 1. The simulations are given in Figure 8, which show:

a) the expected (equilibrium) size structure of the catch and the expected unfished size structure of the vulnerable population

b) the maturity and selectivity-at-length curves

c) the von Bertalanffy growth curve, and

d) the SPR and relative yield curves as a function of relative fishing mortality. After the simulation, the empirical length data were fitted to provide an estimate of the spawning potential ratio (SPR).

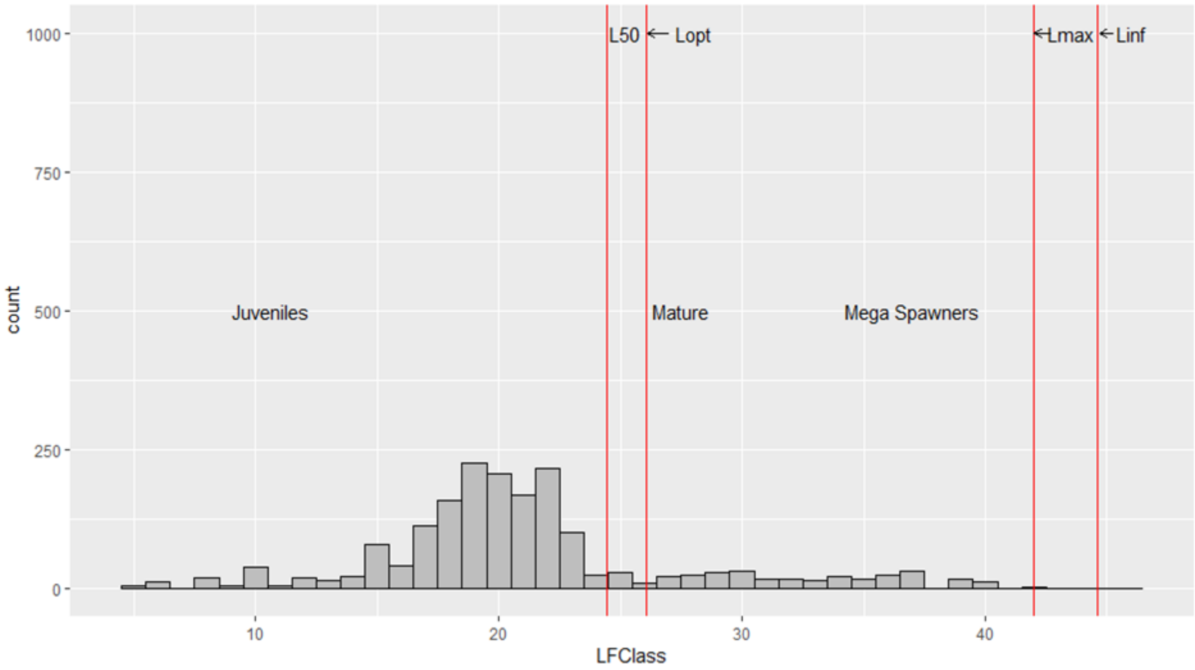

Figure 6. Length-frequency distribution of *S. maderensis* taken from Liberia coastal water in 2013 (April - September), showing juveniles, mature and mega-spawners stages with L50, Lopt, Lmax and Linf.

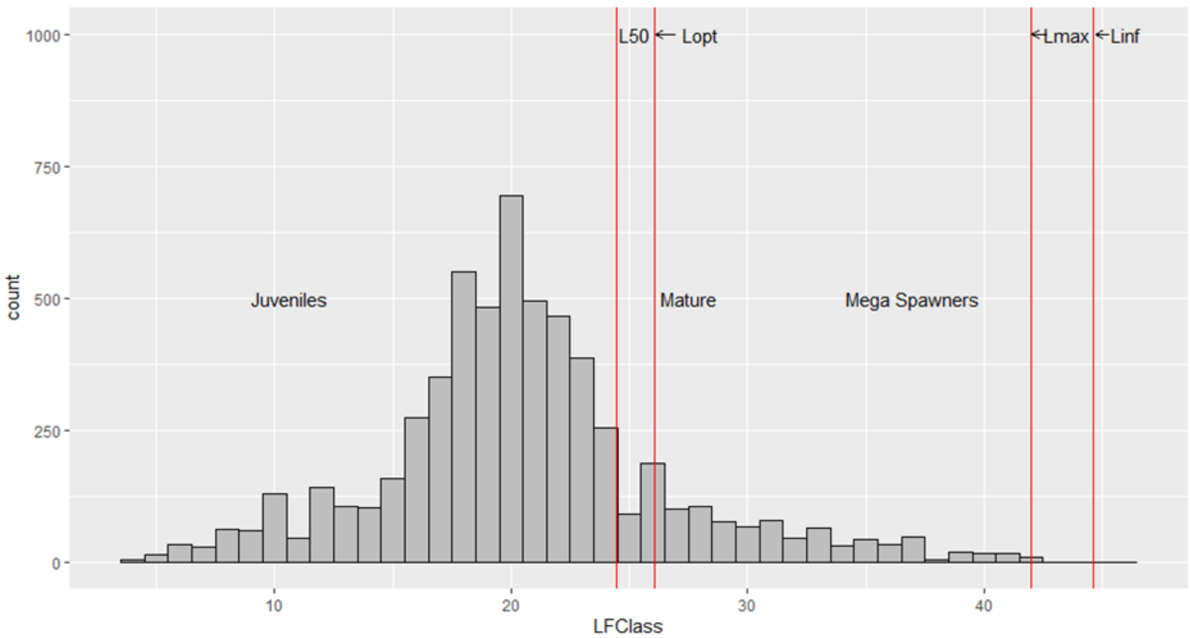

Figure 7. Length-frequency distribution of *S. maderensis* taken from Liberia coastal water in 2014 (March – August) showing juveniles, mature and mega-spawners stages with L50, Lopt, Lmax and Linf.

The length frequency distribution of *S. maderensis* together with the fit from the LB-SPR model, overlaid as a black solid line, is presented in Figure 9. The estimated selectivity curves for 2013 and 2014 are below the maturity curve (Figure 10) indicating that majority of the *S. maderensis* captured in this fishery are juvenile.

The estimated SPR was 0.23 for both 2013 and 2014 (Table 2; Figure 11). The SPR values were estimated to be slightly above the target SPR of 20%, which indicates that this population might be experiencing recruitment overfishing. The relative fishing mortality, F/M, was estimated at 0.94 and 0.96 for 2013 and 2014, respectively (Table 2; Figure 12). The estimated values for SL50 and SL95 were 17.26 & 23.8 in 2013, and 17.29 & 23.89 in 2014 (Table 2; Figure 12), which are below L50. A comparison of the observed length data to the expected (equilibrium) size structure of the catch is shown in Figure 13.

This population might be experiencing recruitment overfishing based on these results.

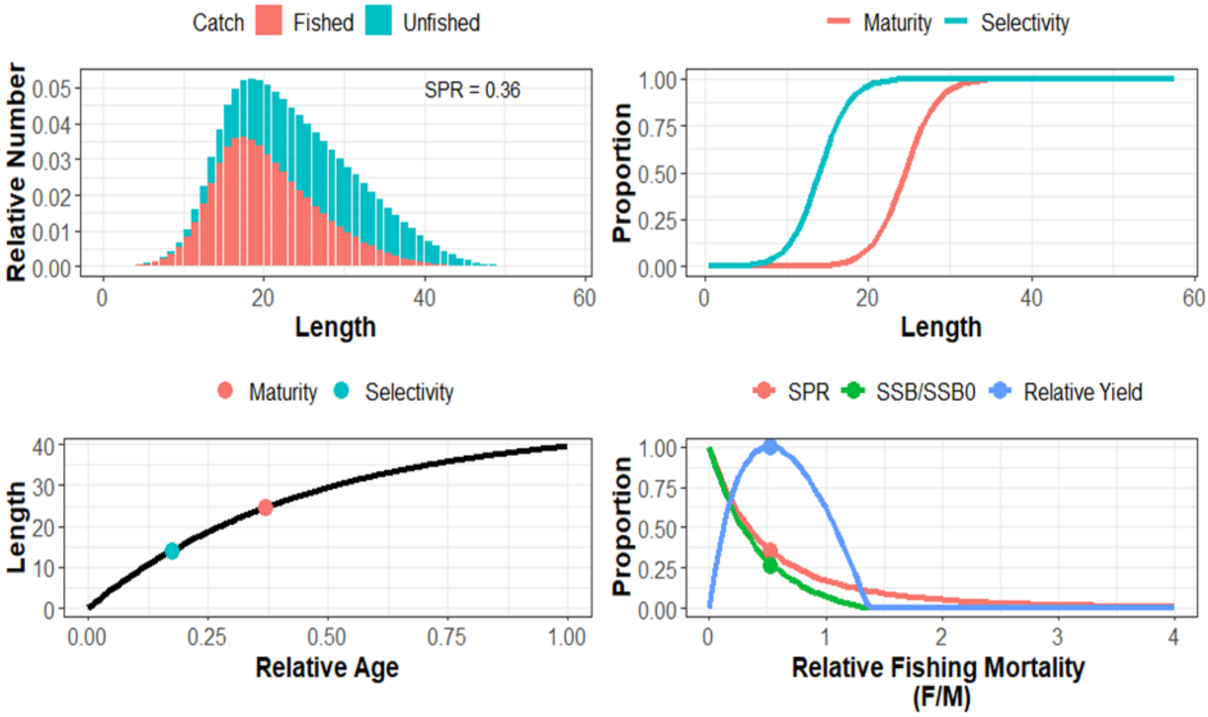

Figure 8. a) the expected (equilibrium) size structure of the catch and the expected unfished size structure of the vulnerable population, b) the maturity and selectivity-at-length curves, c) the von Vertalanffy growth curve, and d) the SPR and relative yield curves as a function of relative fishing mortality

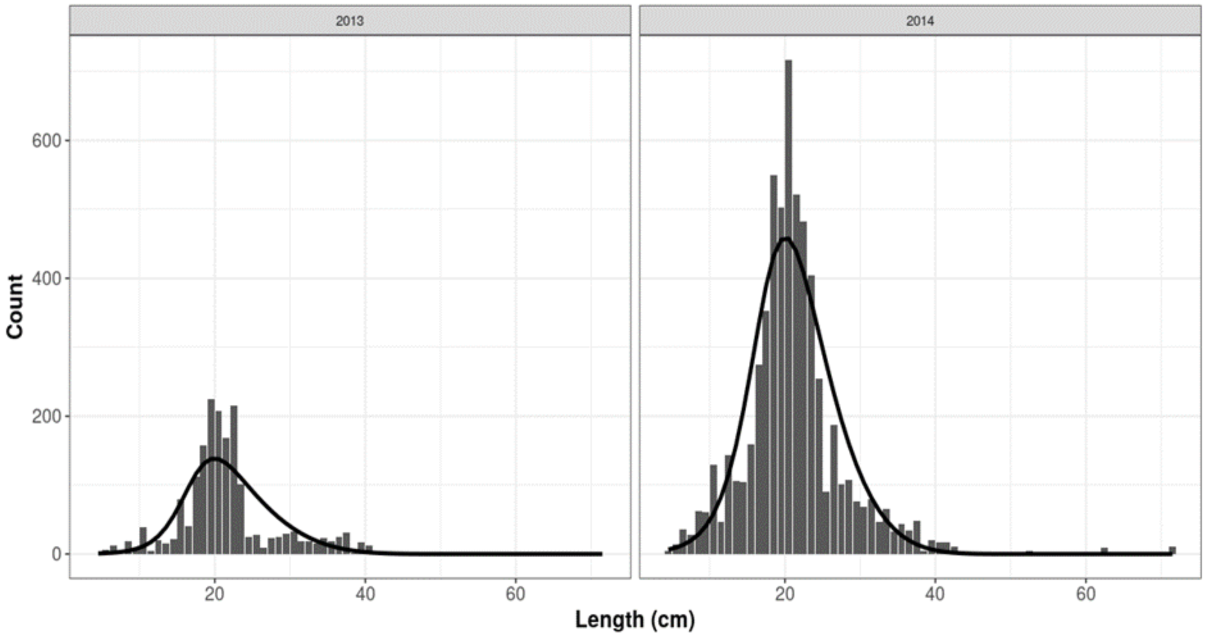

Figure 9. Length composition histograms for *S. maderensis* species in Liberia with curves fitted by the length Based SPR assessment software.

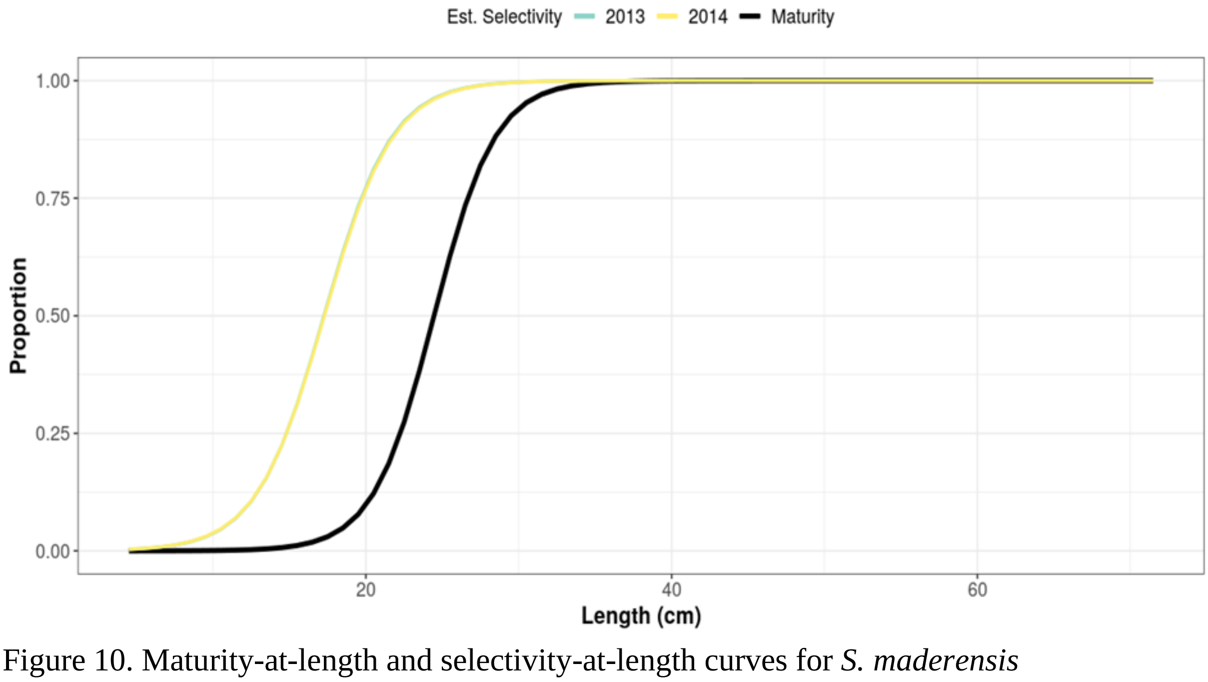

Figure 10. Maturity-at-length and selectivity-at-length curves for *S. maderensis*

Table 2. Annual estimates of spawning potential ratio (SPR), fishing pressure (F/M) and selectivity (SL50, SL95)

Years	SPR	SL50	SL95	F/M
2013	0.23	17.26	23.8	0.97
2014	0.23	17.29	23.89	0.99

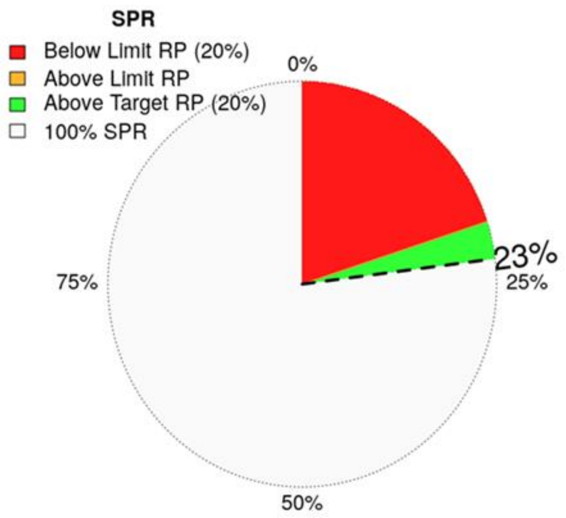

Figure 11. Estimated Spawning Potential ratio and Reference Point (RP)

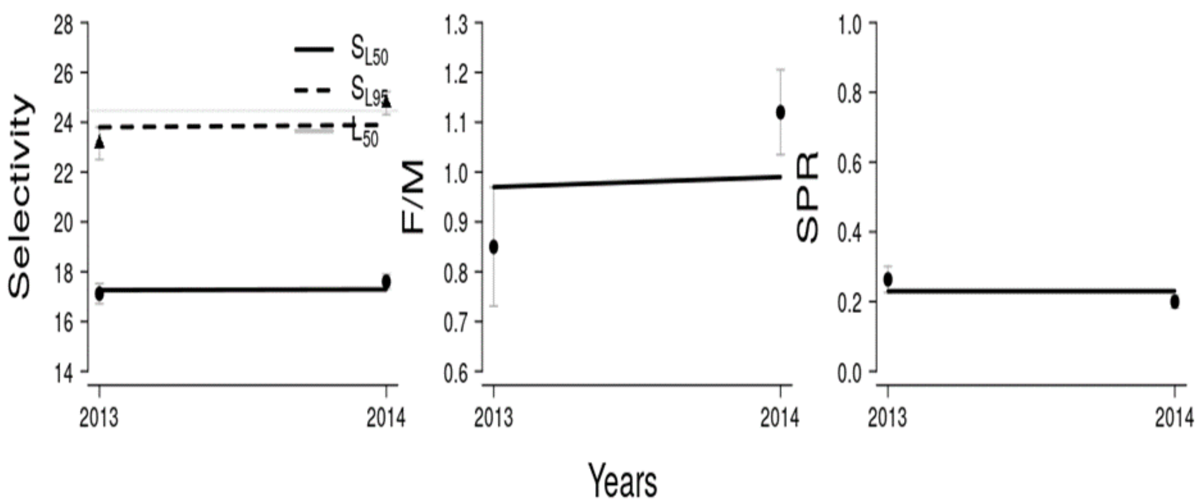

Figure 12. Visual display of estimated quantities (SPR, SL50, SL95 and F/M). The black line corresponds to the smoother line to the estimated points.

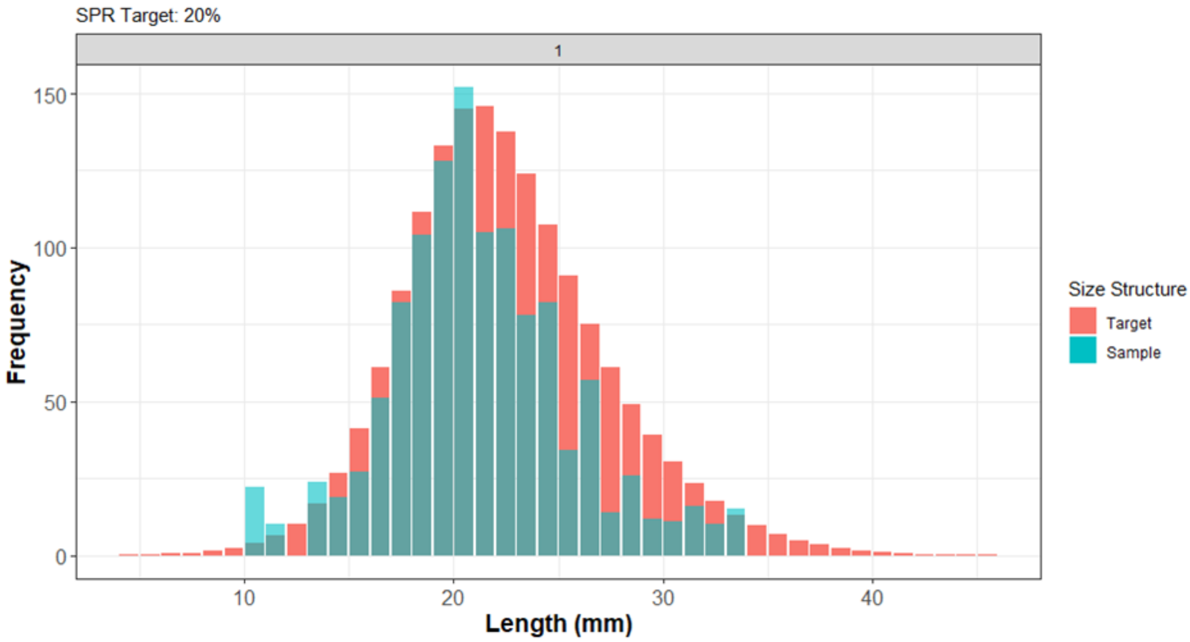

Figure 13. Comparing observed length data to target size structure

5 DISCUSSION

Sardinella maderensis is one of the main fish species that are captured and traded in Liberia. Understanding the life history and status of the stock is an important starting point for developing a management plan for its population. The results of this study suggested that the population of *S. maderensis* might be experiencing recruitment overfishing. Recruitment overfishing is when too many fish are harvested before they can be matured, which limits the replenishing capacity (Florian, 2012).

The recruitment overfishing of *S. maderensis* stock in Liberia could be related to the careless practise of gear use. The mesh size of gill nets used for *S. maderensis* fish captured was 1-3 inches with most of the nets being doubled to reduce the mesh sizes. This indicates that both gear types are likely using mesh size smaller than the minimum legal mesh size of 50mm (Dunba, 2015). Hence, it can be inferred that most fishermen have not been abiding by the fisheries regulation pertaining to minimum mesh sizes. Noncompliance might occur because fishermen are still not aware of the regulation that was issued in 2012. Alternatively, they may be aware but not understand the importance of the regulation. Therefore, increasing fishermen's awareness and education regarding the regulation is necessary, as well as continued monitoring of gear usage is required.

This study indicated that the major portion of the catch of *S maderensis* in 2013 and 2014 were juveniles, 81.88% and 82.22%, respectively. This can be seen from the comparison of the selectivity curve and the maturity curve also (Figure 10), which shows that selectivity is below the maturity line. These results are similar to that seen by Wehye (2017) in Liberia. Their study also showed that most of the harvested stock were juveniles in 2013. Recruitment is generally determined by the number of spawners, fertility, and the mortality rate of new recruits before they can reach fishable size (Suryandari, 2018). Removing most of the population before they reach maturity will negatively affect the spawning stock biomass which in turn will affect recruitment.

SPR is a reproductive relative index used to assess stock status in exploited stock (Hordyk, 2019). SPR is defined as an amount of the unfished reproductive population left in the population after exploitation by a fishery and is generally used to set target and limit reference points for fisheries management in data-poor fisheries (Hordyk, 2019). For example, $SPR_{40\%}$ is generally considered a conventional substitution for MSY, and $SPR_{20\%}$ is substitution for when recruitment rates are likely to be decreased for finfish (Mace & Sissenwine, 1993). Based on the definition of spawning potential ratio (SPR), unfished stocks have an SPR of 100% ($SPR_{100\%}$). Fishing mortality reduces SPR100% from the unfished level to $SPR_{X\%}$ (Suryandari, 2018) . Scenarios analysed in this study resulted in SPR values of 0.23 (23%). With a reference limit set to SPR 20%, this indicated *S. maderensis* stock is at near risk of recruitment overfishing. This is also indicated by the length at 50% and 95% selectivity (SL50) and (SL95) being much smaller than length at maturity (L50). An SPR of 23% indicated that the proportion of *S. maderensis* remaining to spawn were very few, because they were captured before becoming mature. A high relative fishing mortality (F/M) indicated that exploitation is quite high in Liberia.

6 CONCLUSION AND RECOMMENDATIONS

This study assessed the status of *S. maderensis* species in Liberia coastal waters using the length-based spawning potential ratio (LBSPR) approach with available length frequency data from 2013 and 2014. The results reveal that there are too many juveniles of *S. maderensis* being caught, leading to a low spawning potential ratio of 0.23. This indicates that this population might be at risk of recruitment overfishing. Caution is needed in management of the *S. maderensis* stock to prevent population decline.

It is clear that fishermen are not following the gear size restrictions as defined by the fisheries regulations, leading to a catch comprising of too many immature fish.

The following recommendations are being made:

- Better implementation fisheries regulation.
- Monitoring of illegal gear use.
- Educating fishermen about mesh sizes and minimum size of fish that can be caught and how it can support sustainability of stock.
- Gather more biological information, such as maturity data.
- Continued sampling for length frequency data because it is more cost effective and are useful for assessing the status of the species.
- The LBSPR model is very sensitive to the initial parameter estimates, especially Linf values, therefore further analysis based on a selection of parameters is recommended before drawing any solid conclusions.

ACKNOWLEDGEMENTS

Firstly, I want to acknowledge the Almighty God for life and strength in completing my research project. I would also like to express my deepest appreciation to the Fisheries Training programme under the Auspices of UNESCO for offering me this Fellowship in order to study in Iceland. My sincere gratitude to my supervisor Warsha Singh for her continuous support, guidance, patience, motivation, enthusiasm, and immense knowledge.

I also like to express my very great appreciation to Thor Asgeirsson, Programme Director, alongside Tumi Tómasson, and Mary Frances for their support. Special thanks to the Director General of the National Fisheries and Aquaculture Authority (Madam Emma Matei Glassco) and her able deputies in persons of Augustine M. Manoballah and William Y. Boeh for allowing me to join this course. I am highly indebted to my wife (Linda G. Yokie) for her endless love, moral and valuable support, patience, motivation during my six months stay in Iceland.

My deepest gratitude also goes to Robert for his efforts in compiling the needed data for my project and assistance in keeping my progress on schedule. Finally, I wish to thank all my UNESCO-FTP 2019 fellows for support and togetherness.

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