Agricultural Sciences, 2022, 13, 1136-1150
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Fishing of the Flat Sardinella (*Sardinella maderensis*, Pisces, Lowe 1838) in Benin (West Africa) Nearshore Waters: Production, Typology of Fishing Gear and Current Status of Its Stock

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How to cite this paper: Sossoukpe, E., Hoto, G., Djidohokpin, G. and Fiogbe, E.D. (2022) Fishing of the Flat Sardinella (*Sardinella maderensis*, Pisces, Lowe 1838) in Benin (West Africa) Nearshore Waters: Production, Typology of Fishing Gear and Current Status of Its Stock. *Agricultural Sciences*, **13**, 1136-1150.
https://doi.org/10.4236/as.2022.1310070

Received: September 12, 2022
Accepted: October 24, 2022
Published: October 27, 2022

Abstract

Sardinella maderensis is one of the fish species well appreciated in Benin. In recent years, this species has experienced a decrease in its production in the coastal waters of this country. To search for the causes of this decline in production, a standard survey was carried out using Computed Assisted Personal Interviewing with the 38 artisanal fishermen at the artisanal fishing port of Cotonou who targets this species in order to inquire about the fishing gear and techniques of production. The current stock status of this species was determined using FiSAT from a sample of 1240 specimens collected randomly in commercial catches from January to December 2021. The typical survey revealed a massive use of non-regulatory fishing mesh gear (86.85%). The fishing effort is also sustained and results in a fishing mortality rate (F = 2.88 yr^{-1}) higher than the rate of natural mortality (M = 2.22 yr^{-1}) suggesting overfishing of the stock. Sustainable management through capacity building of fishermen and application of regulations in terms of gear mesh size and respect for fishing seasons could be stated.

Keywords

Sardinella maderensis, Artisanal Fishermen, Unconventional Gear, Overfishing, Benin

1. Introduction

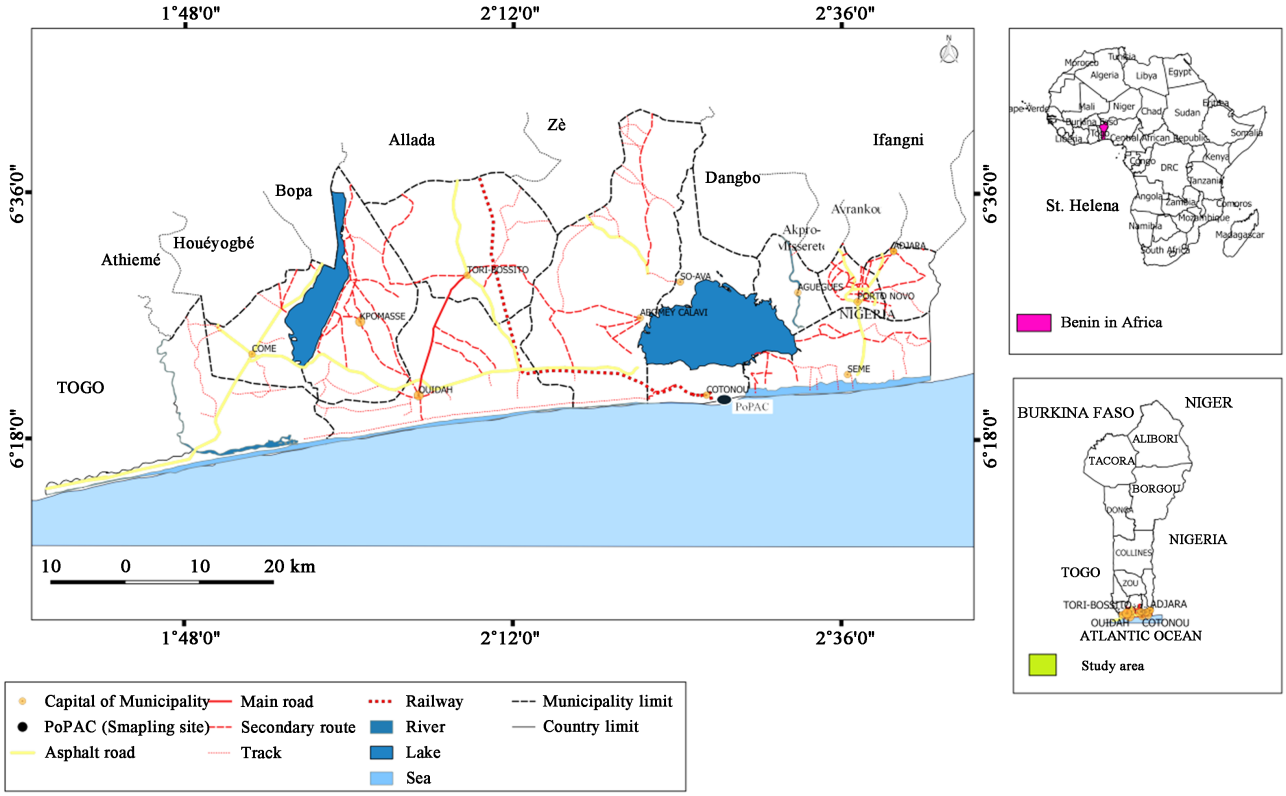
Fisheries remain a resource of primary importance for hundreds of millions of

people around the world, whether for food, nutrition, income or livelihoods (FAO, 2016) [1]). In 2018, global capture fisheries production reached a record high of 96.4 million tonnes, an increase of 5.4 percent compared to the average of the previous three years. This increase is mainly due to marine capture fisheries, whose production increased to 84.4 million tonnes in 2018 (FAO, 2020 [2]). In spite of this increase in fishing at the global level, in West Africa the situation has greatly changed into overexploitation of stocks, deterioration of the marine environment and strong growth in demand linked to demographic pressure (Ndiaye, 2000 [3]). In Benin, the fishing sector plays a significant role in the country's economy because it accounts for 2 percent of GDP, generates more than 600,000 direct and indirect jobs, contributes to reducing the unemployment rate and provides nearly 30% of the total quantity of animal protein in population consumption (FAO, 2014 [4], Hessavi *et al.*, 2019 [5]). Nevertheless, in recent years, Benin has experienced strong population growth (3.51% between 2002 and 2013) inducing an increased food needs and strong pressure on natural resources including fish stocks in Beninese fisheries (Hessavi *et al.*, 2019 [5]). Almost three-quarters of the fish consumed in Benin are imported (Hessavi *et al.*, 2019 [5]). This increase in the population combined with the use of devastating gear, independently to regulations texts, is expressed by a decline in catches in spite of the increase in fishing effort and performance of fishing gear (Lalèyè, 1995 [6], Lévêque and Paugy, 1999 [7]). Small pelagic fish, mainly the Clupeidae of the Beninese coasts (*Sardinella maderensis* and *Ethmalosa fimbriata*) experienced catch decline. *Sardinella maderensis* is a fish species well appreciated by the population due to its affordable price and several types of transformations ranging from smoking to salting passing by brining. The average economic value of its annual production between 2015 and 2020 is estimated at more than 600 million FCFA or about 907,000 US dollars per year (Hessavi *et al.*, 2019 [5]). In spite of these advantages, the IUCN status of the flat Sardinella was downgraded to "vulnerable" (Tous P *et al.*, 2015 [8]) and its production is continuously decreasing. If nothing is done, there is a risk of total depletion of its stock on the Beninese coasts. The present work aims to search for the causes of the downward trend in the production of this species.

2. Materials and Methods

2.1. Study Area, Data Collection and Fish Sampling

Current studies were conducted in Benin, an Atlantic Ocean coastal country of West Africa (**Figure 1**). *Sardinella maderensis* species is fishing in this Ocean, where occurred annually four hydrological seasons: a major hydrological warm season (January to June), a major hydrological cold season (June to October), a minor hydrological warm season (October to November) and a minor hydrological cold season (November to January). Fifty percent of the artisanal fishing resources are landing at the Artisanal Fishing Port of Cotonou (PoPAC) in southern Benin (**Figure 1**) where *Sardinella maderensis* specimens were collected.



Source: Basemap
Projection system: UTM zone 31N
Geodesy system WGS 84
Design: Gerard HOTO, June 2021

Figure 1. Geographic location of the sampling site.

Data on artisanal fishermen, types of fishing gear, production capacities, fishing seasons and difficulties encountered were collected by survey with the artisanal fishermen who target the flat Sardinella using Computed Assisted Personal Interviewing (CAPI). The assisted data collection methodology consisted of the design of a questionnaire form by the expert in charge of conducting the study who submits it to the CAPI expert. By mutual agreement, the two parties validate the form in order to allow the CAPI expert to digitize the questionnaire form on Kobocollect by creating a Kobo account. Then he goes to the test before proceeding with the deployment of the questionnaire form and after downloading the form on the digital media. A pre-test of the form is made followed by its updating and its final deployment. In the field, data collection was carried out by investigators already trained in the use of the Kobocollect collection software with smartphones. After having finished with a respondent, the interviewer proceeds to the actual control of the data before sending them to the server. The CAPI expert checks the data and collects the opinions of the day of data collection. He carries out the data export, the clearance of collected data, the creation of a database, the analysis and processing of data and the design of tables that can be used to produce histograms of frequencies and graphs.

Census of artisanal fishermen and fishing boat composition took place during

the main Sardinella fishing season (July to August 2021) where individual interviews and small focus groups with various artisanal fishermen were carried out. In order to carry out the work related to the survey and achieve the targeted objective, we surveyed a total of thirty-eight (38) artisanal fishermen, *i.e.* 80% of all the artisanal fishermen who target the species and who mainly use the Sardinella net as fishing gear but also other gear such as the large bottom gillnet, the small bottom gillnet, the purse seine and the Exocet net.

2.2. Mortalities and Exploitation Status of *S. maderensis*

The mortalities and current stock status of *S. maderensis* were determined from a population of 1240 specimens of the species sampled randomly from commercial catches of selected fishermen twice a week for 12 months (January to December 2021. On each specimen, data such as the total length and weight were collected. The methodology is based on examining the frequency distributions of the different size classes in the catches. The aim was to calculate the instantaneous coefficient of total apparent mortality Z which obeys the usual relationship: $\mathrm{Nt}+1=\mathrm{Nte}^{-z}$ using FiSAT. This method is a transposition of the catch-at-age curve method (Ricker, 1975 [9]). The instantaneous rate of natural mortality M, is calculated by the empirical equation of [10] using the mean surface temperature (T = 29.8˚C) as follows:

$$\mathrm{Log10M}=-0.0066-0.279\mathrm{Log10L}\infty+0.6543\mathrm{Log10K}+0.463\mathrm{Log10T}$$

The instantaneous rate of fishing mortality, *F*, is estimated from the relation: $F=Z-M$ (Pauly, 1980 [10]). The assessment of current stock status of *S. maderensis* is made by calculating the exploitation rate (*E*) from the formula: $E=\frac{F}{Z}$. This gives a rough estimate of whether or not the stock is overfished (Pauly, 1983 [11]). The reported optimal value of *E* is approximately equal to 0.5 assuming that efficiency is optimized when *F* is approximately equal to M (Gulland, 1971 [12]).

3. Results and Discussion

3.1. Census of Artisanal Fishermen and Boat Composition

3.1.1. Number, Age and Seniority in Sardinella Fishermen

Figure 2 and **Figure 3** illustrate the frequency respectively according to the age and seniority groups of fishermen in the field of the flat Sardinella fishermen. **Figure 2** shows a dominance of individuals of age group 35 - 45. The least represented age group is that of 25 - 35 years, while individuals whose seniority is between 30 and 50 years predominate within the sample.

3.1.2. Composition of a Fishing Boat

Flat Sardinella fishermen use three types of boats, namely 1) the large model boat that can hold a crew of 11 people with a length of 9.30 m (overall) and a width of 1.30 m and a depth of 0.56 m, 2) the medium model 8 m long (overall)

and 1.15 m wide, capable to containig a crew of 9 people and 3) the small model intended for monitoring the nets laid with dimensions 5 m by 1 m with a depth of 0.40 m for a crew of 2 or 4 people.

- ***Number of fishermen per boat***

Figure 4 shows that commonly, three or four fishermen board per boat during a sea trip.

- ***Number of fishing gear on board per trip***

During a sea trip to catch the flat Sardinella, the majority of fishermen carry a

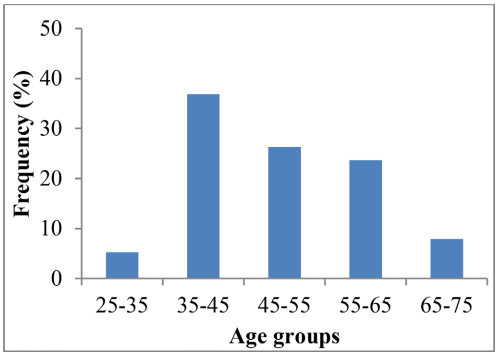


Figure 2. Frequency histogram of Fishermen according to age groups.

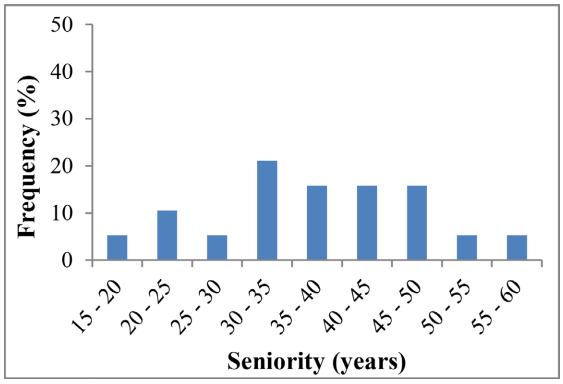


Figure 3. Frequency histogram of Fishermen according to their seniority.

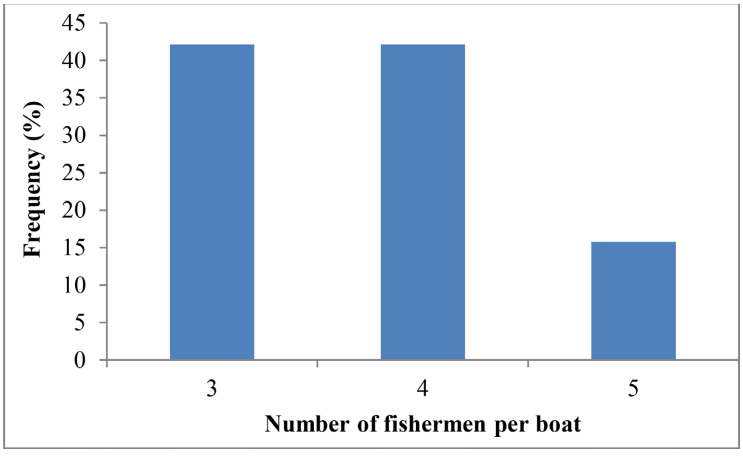


Figure 4. Frequency of people on board per trip.

single Sardinella net. Sometimes they carry two or three gear depending on the number of persons on board the motorized boat. Figure 5 illustrates the frequency of fishing units on board per sea trip. Most of fishermen (73.68%) embarked with one gear.

3.2. Typology of Fishing Gear Used in Sardinella Fishing

Several fishing gear are used by the artisanal fishermen to fish the flat Sardinella. But Sardinella net was the most used gear by fishermen. Some of them used the large bottom gillnet, the small bottom gillnet the turning and sliding seine and Exocet drift gillnet. Figure 6 shows the frequency distribution of the fishing gear used in the Sardinella fishery. The Sardinella net was the main gear in Sardinella fishing. Other fishing gear incidentally captures the species.

3.3. Structure of Fishing Gear and Its Mode of Capture (Table 1)

- ***The drifting or encircling Sardinella net*** commonly called Sardinella net or "Mahundô" in local language is designed for catching fish in open water. The target species are Sardinella (flat and round). It is at least 200 m long and 20 to 35 m depth with a mesh size of 46 to 50 mm. It is used either drifting (at night) or by encircling Sardinella shoals (during the day). A beating of the water is then

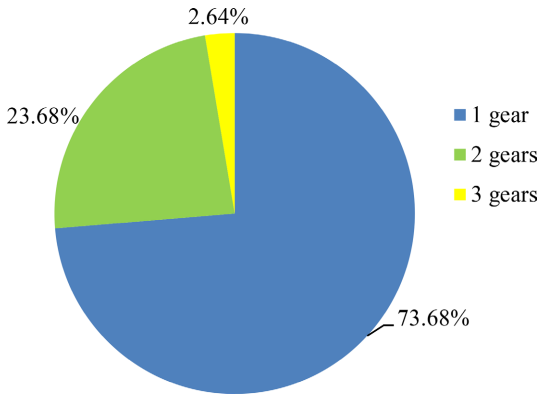
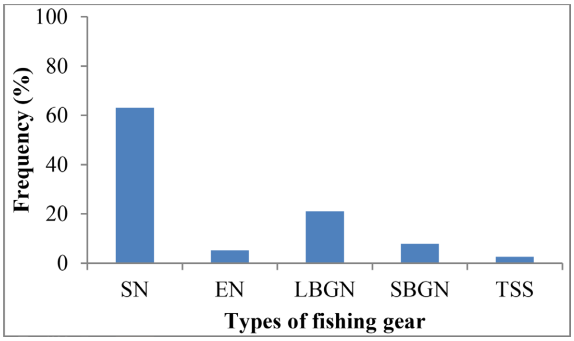


Figure 5. Diagram of the number of fishing gear on board per trip.



SN: Sardinella net; EN: Exocet net; LBGN: Large bottom gillnet; SBGN: Small bottom gillnet; TSS: Turning and sliding seine.

Figure 6. Frequency of fishing gear used in Sardinella fishing

Table 1. Structure of fishing gear and mode of capture of *Sardinella maderensis.*

Type of gear	Local names	Total length (m)	Height (depth, m)	Conventional Stretched mesh size (mm)	Current stretched mesh size (mm)	Mode of capture
Sardinella net	Mahoundô	200	20 - 35	46 - 50	20 - 30	Active
		200 - 250	20 - 24	35 - 45	18 - 25	Active
Small bottom gillnet	Sovi	100	1	40	25	Passive
		100 - 150	2	20 - 30	18 - 25	Passive
Large bottom gillnet	Tohounga	100	1	62 - 70	30 - 40	Passive
		100 - 200	2	50 - 60	25 - 35	Passive
Turning and sliding seine	Watcha	500 - 700	50 - 55	30 - 40	20 - 25	Active
		400	50 - 55	10 - 40	10 - 20	active
Exocet drift gillnet	Aviondô	100	1.75	50	30	Active
		120	1.5	50	30	Active

practiced in order to promote the meshing of the fish. This net is reinforced in its upper and lower parts with mesh sheets of 60 mm stretched mesh. Motorized Ghanaian dugout canoes of 9 to 14 m are used (Kébé *et al.*, 1997 [13]).

- ***The small bottom gillnet*** commonly called "Soovi" or "Sovi" in local language is generally 100 m long and approximately 1 m depth. The mesh varies from 30 to 40 mm stretched mesh. It is intended for catching small demersal species such as *Galeoides decadactylus*. It is actually more of a subsistence fishery than a commercial fishery. In some camps, the machine is lifted approximately every two hours. In other landing stages, it is placed in the evening and raised in the morning. The net may remain in the water for several days if it is not damaged; the fisherman raising it only when the catches seem acceptable to him. Its low drop limits its performance. Kébé *et al.* (1997) [13] recommend increasing its height by 40 to 60 meshes (depending on the financial capacities of the users).

- ***The large bottom gillnet*** commonly called "Tohounga" in local language: The dimensions of this bottom net vary depending on the financial capacity of the fisherman. The characteristics, strategy and fishing technique are similar to those of the "soovi", except the mesh size 62 to 70 mm of stretched mesh. Few craft using this gear are motorized, paddles and sailing being the usual modes of propulsion (Kébé *et al.*, 1997 [13]).

- ***The Turning and sliding seine*** commonly called "Watcha" in local language. The fishing technique and the gear are of Ghanaian origin. This net is intended for catching Sardinella, mackerel, trevally, barracuda, tunny and associated species. It measures between 500 and 700 m long and 50 to 55 m depth. A crew of 12 to 14 people is needed to operate this net from a 12 to 15 m motorized semi-deck canoe. The pocket is closed by the base by means of a rope (slide), passing through rings thus making it possible to block any exit of the

surrounded fish (Kébé *et al.*, 1997 [13]).

- ***The Exocet drifting gillnet*** commonly named "Aviondo" in local language: The dimensions of this surface net vary according to the financial possibilities of the fisherman. The average length of a mounted machine is 100 m for 1.75 m in depth approximately. Fishing is seasonal, generally between October and April. Ghanaian dugout motorized canoes of 6 to 10 m long are used for this fishing, which is practiced at night, contrary to what is observed in Southeast Asian countries (Kébé *et al.*, 1997 [13]).

Table 20 shows a comparative study between the results reported by Kébé *et al.* (1997) [13] and the information collected during our survey.

The mesh size of gillnets used to catch *S. maderensis* was 1-3 inches, with most nets being doubled to reduce mesh size. This indicates that both types of gear likely use smaller mesh sizes than the legal minimum mesh size of 50 mm (Dunba, 2015 [14]). It therefore appears, in view of these results and in relation to the regulatory texts governing sea fishing in Senegal that Sardinella individuals sampled are subject to size restrictions. The lack of adequate implementation of fisheries policies and regulations in Sierra Leone, combined with the inadequate material and financial capacity of the Ministry have certainly accelerated juvenile fishing throughout the coastal zone which is home to millions of fishermen. These factors have increased landings of juveniles, which are mainly due to targeted artisanal fishing and competition between coastal communities. From an economic point of view, consumer demand for juveniles also encourages this method of fishing (Boyce, 1996 [15]).

3.4. Rate of Non-Conventional Gear Used in the Flat Sardinella Fishing

Figure 7 shows 86.85% of fishing prohibited gear in terms of mesh size.

3.5. Assessment of Fishing Effort

3.5.1. Average Duration of a Fishing Trip

The average duration of a fishing trip depends on the type of fishing gear on board for the sea trip. If it is a Sardinella net, the duration of a fishing trip varies between eight o'clock and twelve o'clock. But the bottom-set gillnets (Sovi and Tohounga) can take one to two days for a trip to the sea because it depends on

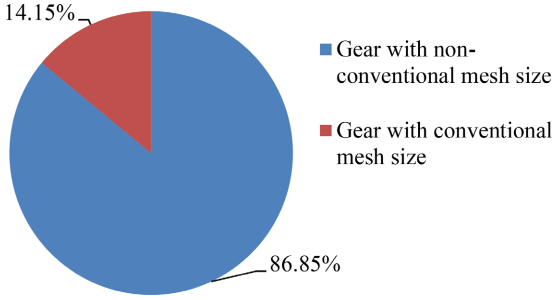


Figure 7. Rate of non-conventional gear in the flat Sardinella fishing.

the level of filling of the net set by the fishermen. The Exocet driftnet is only used at night to catch fish.

3.5.2. Average Number of Fishing Days per Trip

For Sardinella fishing, the most used fishing gear on the Beninese coast is the Sardinella net. The frequency of outings to sea is daily as shown in **Figure 8**, which illustrates the number of respondents according to the number of fishing days per trip, it can be seen that more than 75% of artisanal fishermen catch Sardinella within one day. Fishermen who work two days or more use other types of gear, namely set gillnets and purse seines.

3.5.3. Average Quantity of Catch Landed per Trip

According to collected information from artisanal fishermen in the survey, the quantity of *Sardinella maderensis* specimens landed during a sea trip varies considerably depending on the fishing season. During periods of rarity of the species, fishermen sometimes find a quantity of *S. maderensis* less than 10 kg. Contrariwise, during a good season, they find a quantity greater than 30 kg or the average quantity of catch landed per trip varies between 25 and 30 kg.

3.5.4. Average Number of Outings per Week

According to our respondents, for Sardinella fishing and mainly those who use the Sardinella net, they go to fishing almost every day of the week except one day, the "Zogbodo" which is a sacred day for them. For other fishing gear, fishermen go to fish twice to thrice a week.

3.6. Fishing Seasons (Periods of Abundance and Scarcity of the Flat Sardinella)

According to the artisanal fishermen, the periods of abundance of *Sardinella maderensis* on the Beninese coasts occur from December to January and from June to October which corresponds respectively to the small and the large hydrological cold season on the Beninese coasts. However, the periods of rarity of the species resource are November and February to May which correspond respectively to the small and the large hydrological warm season on the Beninese coasts. **Figure 9** shows the different periods of abundance and scarcity of the flat Sardinella.

3.7. Evolution of the Flat Sardinella Production over the Last Ten Years on the Beninese Coast

Figure 10 illustrates the variation in the production of the flat Sardinella off the Beninese coasts depending on the year. Overall, production has experienced a remarkable strong downward trend from year 2014 (1878.82 tonnes) to year 2017 (101.16 tonnes). From 2010 to 2011, the production decreased significantly before rising to 867.38 tons in 2012. Production increased to 918.00 tons in 2018 before dropping 724.30 tonnes in 2019. Indeed, data on production for the year

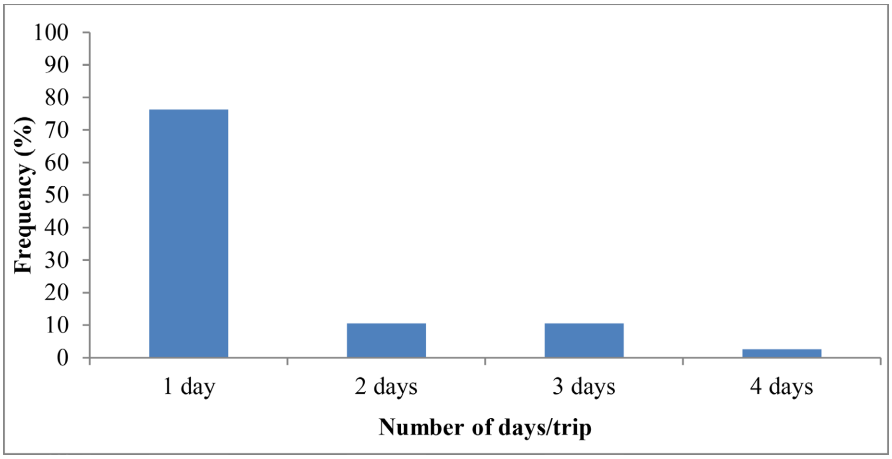


Figure 8. Frequency of number of fishing days per sea trip.

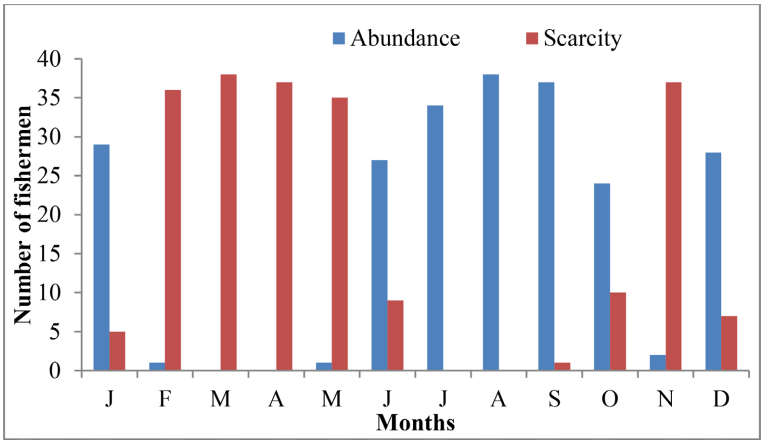


Figure 9. Periods of abundance and scarcity of *S. maderensis* from the Beninese coasts.

2013 was not available. The data used to construct the graph in **Figure 9** was obtained from the Directorate of Fisheries production (DPH) in Benin.

3.8. Current Status of the Sardinella Stock on the Beninese Coasts

3.8.1. Mortalities

Figure 11 gives an estimate of the mortality parameters of *Sardinella maderensis* as outputted from FiSAT. The annual fishing mortality rate (F = 2.88 yr^{-1}) is higher than the annual natural mortality rate (2.22 yr^{-1}). The value of total mortality Z is equal to 5.10.

The total mortality Z in current study was higher than those reported by Sossoukpe *et al.* (2016) [16] in Benin, Olopade *et al.* (2019) [17] in Nigeria, Amponsah *et al.*, (2019) [18] and Osei (2015) [19] on the Ghanaian coasts. The high estimate of Z in a study may indicate greater pressure on the species that may result from increasing one or both components (M and F) of Z (Olopade *et al.*, 2019) [17]). The value of M = 2.22 yr^{-1} in this study is extremely low compared to what was reported in Sierra Leone M = 4.22 yr^{-1} by Anyangwa (2007) [20]. Differences in natural mortality (M) are likely due to the fact that *S. maderensis*

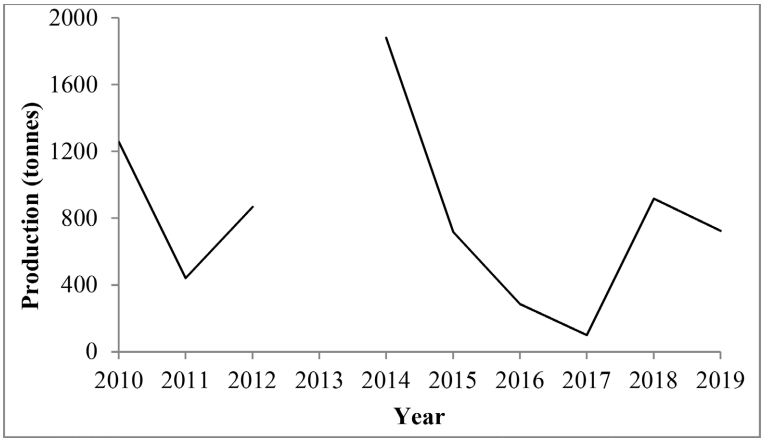


Figure 10. Trend of the production of *S. maderensis* over a period of 10 years (Source: DPH, 2022).

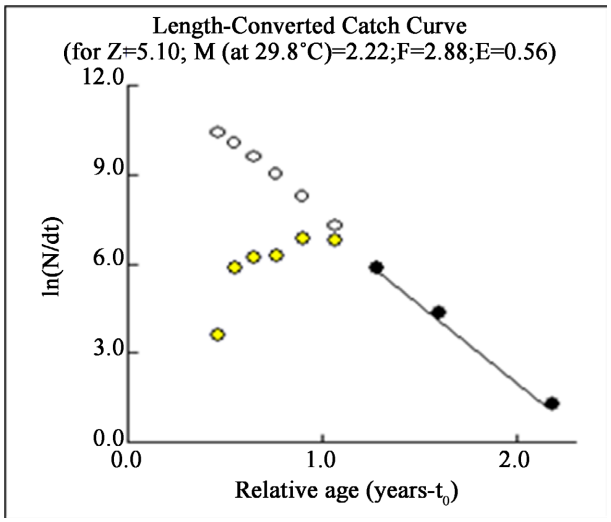


Figure 11. Mortality parameters of *Sardinella maderensis.*

in coastal waters of Benin is not readily available to predators or is not vulnerable to natural factors such as disease and life in an environment of high productivity (Sossoukpe *et al.*, 2016) [16]). The fishing mortality is higher than the natural mortality and the estimated exploitation rate (E = 0.56) shows that the exploitation level is already high compared to the optimal level which is 0.5 and suggested that the stock is subject to overfishing (King, 1995 [21]).

3.8.2. Exploitation Rate

The exploitation rate of *S. maderensis* population as generated by FiSAT was: E = 0.56. This rate is slightly higher than the optimal rate (E = 0.5) As a result, the species is overfishing on the coasts of Benin. The current state of the stock of *S. maderensis* on the Beninese coasts indicates that this species is slightly overexploited (E = 0.56). The results of the survey allow us to say that this overexploitation is due to the use of non-regulatory mesh fishing gear that is not selective in fish size and to sustained fishing effort all year round, leaving no chance of

replenishment to stock. These results are consistent with those found by Yokie (2019) [22] on the Liberian coasts, Gueye *et al.* (2020) [23] on the Senegalese coasts and Sheriff *et al.* (2010) [24] on the Sierra Leonean coasts. These authors confirm that the population of *S. maderensis* could suffer overfishing recruitment. Recruitment overfishing occurs when too many fish individuals are harvested before they reach maturity, which limits the ability to rebuild (Florian, 2015 [25]).

3.8.3. Perception of Fishermen on the Causes of Current Stock Status of the Flat Sardinella

According to the artisanal fishermen, the causes linked to the reduction in the stock of *S. maderensis* on the Beninese coasts are numerous and various. Firstly, they mentioned the situation of climate change which affects physical and biological nature of the sea. They also declare the use of fishing gear with smaller mesh sizes as another cause. According to them, the destruction of fish nursery areas by commercial vessels could also be a cause of the stock collapse of the flat Sardinella stock.

3.9. Economic Value of the Activity

3.9.1. Estimated Cost of a Sea Trip

For a sea trip, respondents estimated between 38 and 46 US dollars for Sardinella fishing. This amount covers fuel costs, meals, purchase of ice and batteries to operate at night.

3.9.2. Estimated Cost of One kg of Sardinella at Landing

At landing, the cost price of one kilogram varies according to the fishing periods. Fish is often sold in plastic at a price varying from 6 to 8 US dollars depending on the period, this plastic contains at most five kilograms of fish. Thus the price of one kilogram of fish varies between 1.2 and 1.5 US dollars.

3.9.3. Economic Profitability of the Activity

According to the artisanal fishermen, the activity is no longer profitable. They practiced it for lack of finding better. According to them, the activity was very profitable 30 or 40 years ago, because fishing was productive and at one landing, they could count nearly 400 kg of fish. Even if they sold at a price of 0.8 or 0.9 US dollars per kilogram, the activity remained lucrative.

3.10. Difficulties Encountered by Artisanal Fishermen

3.10.1. For the Organization of an Outing

To organize a fishing campaign, fishermen often have financial problems and this is the only major problem. Some of them are self-financing, but the majority referred to fishmongers who fully finance their trips to sea.

3.10.2. During Outings

During the trips, the artisanal fishermen are confronted with several difficulties.

Among these difficulties, there are 1) engine breakdowns in the open sea, 2) threats at sea made by Toffins fishermen armed with guns, machetes and other dangerous objects, 3) destruction of nets by sharks or other fixed solid objects in the water, 4) destruction of the nets by commercial boats which tear the nets especially at night and 5) the pressure of the wind, of the tides which unbalance the boats.

3.10.3. When the Product Is Unloaded

When the catches are landed, fishmongers often agree among themselves and set the price at which they will buy the products landed, especially if the fishing is successful.

4. Conclusions

Knowing the state of the fish stock is essential for responsible, sustainable management and keeping the aquatic ecosystem in balance. The stock of the *Sardinella maderensis* species in the coastal waters of Benin is slightly overfished.

This work has identified some of the causes of this overexploitation. These are 1) the use of non-regulatory gear with little or no fish size selection, 2) an almost daily fishing frequency, 3) the destruction of nurseries. Several of these causes are due to non-compliance with the Framework Law on fishing, and the lack or absence of capacity building for small-scale fishermen on the current challenges of small-scale maritime fishing in Benin. In addition, control bodies such as the river police, the fisheries brigade, and the naval forces involved in the surveillance and repression of violations of fisheries regulations such as the use of illegal fishing gear and illegal fishing fail to fully play their roles, probably because they are not sufficiently equipped.

Acknowledgements

This work is part of a Ph.D. Thesis undertaken at Department of Zoology of Faculty of Sciences and Technology. We owe much gratitude to fishermen for their fruitful cooperation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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