P. notialis stock assessment in Senegal - Mauritanie by length frequencies analysis - Rectified pseudo-cohort analysis & LBB -

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Introduction

In these two decades, partially due to the extreme overexploitation of many demersal fish stocks (Gascuel et al., 2004), shrimp has become one of the major marine resources for many coastal countries of West Africa. Exploitation is mainly focusing on the white shrimp, *Penaeus notialis* (Peres-Farfante, 1967) which lives on muddy bottoms, from the coast to 65 m depth, is exploited by specialized trawlers and small-scale fisheries.

Shrimps' stocks present rapid and instable dynamics (Thiaw et al., 2009). Their potential of production varies greatly from year to year. Modelling and understanding shrimps' exploitation is a challenge for several reasons: shrimp distribution and abundance are influenced by environmental variation (Caverivière and Rabarison, 1997; Lhomme, 2001; Caverivière and Razafindrakoto, 2007), rapid growth and short life cycle. Life cycle of shrimps is very short and recruitment is usually considered highly dependent of the upwelling intensity. Thus, fisheries management should be based on the diagnosis establihed from stock assessment taking account of environmental variability.

According to recent FAO report (2019), only about 11% of fisheries in the world are assessed by advanced models or have been well managed. In fact, in data-limited fisheries the scarcity of long series of age structure data and stock abundance indices makes it incredibly tough to assess the stock status using conventional models (Magnusson and Hilborn, 2007). In recent years, various data-moderate methods have been developed in order to meet the increasing demand for scientific management for these fisheries, (Winker et al., 2018; Froese et al., 2018). In the present report we will used two of these data-poor adapted methods, which are first introduced, before application to the P. notialis stock of Mauritania-Senegal.

This work aims to establish the state of exploitation of the main stocks of coastal shrimp (*Penaeus notialis*) exploited in West Africa, from Mauritania to Guinea. This species is exploited both by artisanal fishing in the mouth areas and the various estuaries (Saint-Louis, Sine Saloum, Gambia, Casamance, Bijagos Islands) and industrial fishing at sea. Along the western continental shelf In Africa, three areas of importance for coastal shrimp fishing are distinguished, namely the Nouadhibou area (North Mauritania), the Saint-Louis area (South Mauritania and North Senegal) and Senegal southern area (Senegal, Gambia and Guinea Bissau).

1. Material and methods

1.1. Length-based Bayesian Biomass approch (LBB)

Length-based Bayesian Biomass (LBB) is a new Bayesian size-based approach (Froese et al., 2018) for estimating stock status in data-constrained situations. LBB only requires size frequency data and length at maturity (Lmat), and one year sampling is enough to conduct an analysis. In addition, it offers the possibility to specify a priori distributions for the parameter's asymptotic length (L_∞), length at first capture (L_c) and relative natural mortality (M/K). In addition, relative fishing mortality (F/K) is estimated. By combining these estimates with standard fishing equations, stock status parameters such as the currently exploited biomass relative to the unexploited biomass (B/B_0 depletion) and F/M can be estimated. Then, these parameters can be used to estimate length indicators. First, given the estimates of L_∞ and M/K, L_{opt}, i.e. the size at which the cohort biomass is at its maximum, can be obtained from eq (1):

$$L_{opt} = L_\infty \left(\frac{3}{3 + M/K}\right) + \frac{M}{K} \qquad (1)$$

Based on eq (2) and a given fishing pressure (F/M), the average length at first catch, which maximises catch and biomass (Lc_{opt}), can be obtained from:

$$Lc_{opt} = \frac{L_{\infty} \cdot \left(2 + 3 \cdot \frac{F}{M}\right)}{\left(1 + \frac{F}{M}\right) \cdot \left(3 + \frac{M}{K}\right)} \qquad (2)$$

Then, Lc_{opt} estimates are used to calculate proxy of the relative biomass capable of producing maximum balanced catches B_{MSY} (Froese et al., 2018). Note that LBB, unlike corrected pseudo-cohort analysis, relies rely on strong assumptions, as constant recruitment and effort.

1.2. Species biology,spatial distribution and stocks definition

The coastal shrimp *P. notialis* (Figure 1) is encountered in the Eastern Atlantic and its tributaries, particularly on the West African coast, from Mauritania to Angola (Lhomme, 1981; Pérez-Farfante and Kinsley, 1997). It belongs to the Penaeidae family which is only constituted of amphihalines species. Adults, eggs and early larval stages are found at sea while juveniles develop in brackish or over-salted environments, estuaries or lagoons (Lhomme, 1981; Lhomme and Garcia, 1984; Lhomme, 2001; Laë et al., 2004; Brown, 2005). In hydrologically suitable areas, the presence of significant concentrations of harvestable shrimp is dependent on the presence of estuaries or lagoons (Lhomme and Garcia, 1984).

Figure 1 - *Penaeus notialis* collected during DEMERSTEM project in Dakar (Senegal)

The coastal shrimp is gonochoric. In addition, there is sexual dimorphism of certain external characters and of the genital apparatus (FAO, 2002; Gillet, 2008; Paramo et al., 2014). At the end of the juvenile phase, secondary sexual characteristics begin to develop, marking the beginning of the pre-adult phase (Gillet, 2008). The coastal shrimp reproduction is continuous, but spawning peaks are observed at certain times of the year (Caverivière et al., 2008). On average, a weak seasonal cycle is noted with a relatively more intense spawning period from August to January

(Table 1). In Mauritania, shrimps' males develop very early and are mature throughout the year (Garcia-Isarch et al., 2020). Mature females were found during all months sampled throughout all annual cycles analysed, although in higher proportions in certain months, suggesting the existence of at least one spawning peak per year. One main spawning peak was identified between August and October, which was variable among the years analyzed.

Size at first matutity of *P. notialis* in Mauritania was studied by IEO thought the analysis of the biological information collected by observers on board Spanish shrimper trawlers (Garcia-Isarch et al., 2020). The first maturity length estimated for 2010-2018 varies between 28.4 and 35.6 mm CL. This difference from one year to the next could be due to the possibility that two stocks are analyzed together.

The shrimp *P. notialis* is a short-lived species, about 20 months, with a high growth rate (Garcia, 1989; Caveriviere, 2002). However, its growth depends on water temperature, quantity and quality of food, sex and salinity (Dall et al., 1990). At equal age, females are often larger. In *P. notialis*, the sexes are separated from birth, and a strong sexual size dimorphism is observed in favor of females (Pacheco et al., 2021). This difference is instead explained by faster growth of females (Guitart et al., 1988; Gillett, 2008; Lacoursière-Roussel and Sainte-Marie, 2009; Paramo and Saint-Paul, 2010; FAO 2019).

Table 1 - Spawning periods of the coastal shrimp *P. notialis* taken from the literature.

Area	Authors	Spawning period	Maximum	Season
Mauritania	Garcia-Isarch et al., 2021	All months	August-September	
Saint-Louis	Lhomme, 1981	July-November	September	Hot season
Roxo Bijagos		All months	July-January	
Saint-Louis	Lhomme et Garcia, 1984	August-December	September-November	Beginning and end of the hot season
Roxo Bijagos		All months	August, November, January	Hot season, transition period, full cold hydrological season

Stocks definition

On the West African coast, 14 stocks of *P. notialis* have been identified (Garcia and Lhomme, 1979; Lhomme, 1981). In Senegal, two shared coastal shrimp stocks have been identified, one in the south of Senegal between Casamance, Gambia, and Guinea-Bissau (Roxo-Bijagos stock) and the other in the north between the Cayar pit and Saint-Louis. The essential difference between the two stocks lies in the much lower importance of freshwater inputs (Caverivière and Rabarison 1997; Thiaw et al., 2009; Thiaw, 2010; Faye et al., 2015; FAO, 2020).

For this report we consider three shrimps' stocks (Figure 2) in North-West Africa:

(i) in the North of Mauritania of Mauritania (Nouadhibou) named the Northen stock of Mauritania,

(ii) the shared stock between Senegal and Mauritania, named the Senegal- and Mauritanian stock and

(iii) the Senegal Southern Stock, which is also a shared shrimp stock between Senegal, Gambia and Guinea-Bissau.

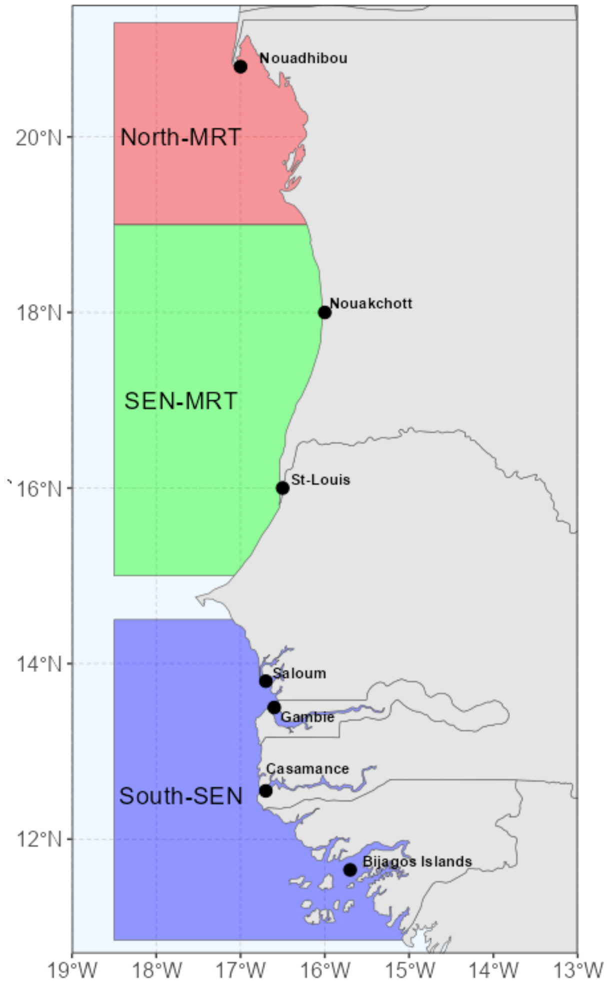


Figure 2 - Cartes des stocks de *Penaeus notialis* etudiés

1.3. Data exploration

1.3.1. Lenght frequencies data

Length frequencies data are available from several sources:

- **During Demerstem project**, sampling was carried out in Mauritania, Senegal and Gambia between 2019 and 2021. In Senegal and Gambia, the shrimp sampled come from catches made mainly by fishermen using drag nets or “kili”, which is an artisanal fisheries. Monthly sampling was carried out by CRODT as part of the DEMERSTEM project between September 2019 and January 2021 in Djifère and St-Louis (Senegal) and between July 2020 and February 2021 in Wharfnjago (Banjul). In Mauritania, shrimp size frequency data are available over the same period. These data were collected according to the biological shrimp sampling protocol defined during the implementation of the Demerstem project.

However, they come from both industrial and artisanal fisheries and the information on fishing gear isn't available.

- **From national survey** : in Mauritania, samples from industrial fisheries between 2010-2019 from spanish on board observers are also available. However, as the area is not known, they could not be associated with a specific stock (North-MRT or SEN-MRT). In Senegal, some sampling was carried out on indutrial vessels in Dakar, nevertheless, the same issue arose and the fishing zone is unknown. In addition, as in Mauritania, samples were collected by spanish on board observers in Guinea-Bissau, but the size of the collection was not sufficient for more in-depth analysis.

Data collected by stock during demerstem project are summarized in Figure 3

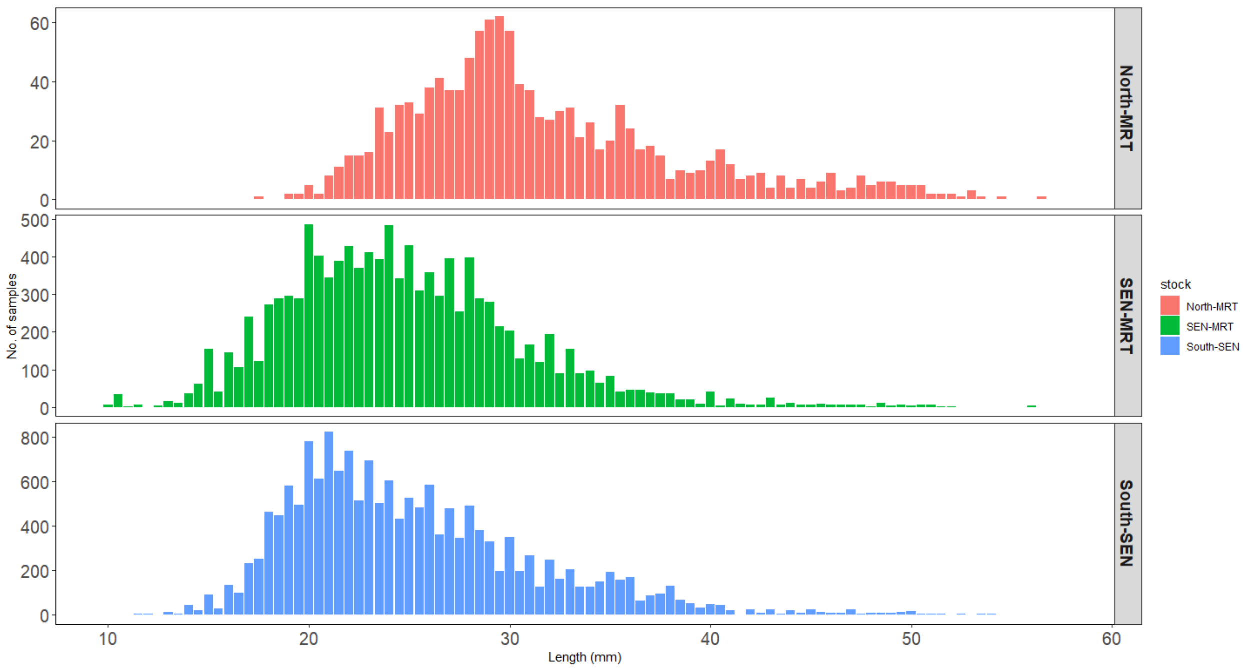


Figure 3 - Shrimps agregated samples over 2019-2021 period by stock

Three different fishing units of *P. notialis* have been identified in the Coastal Western Africa area. A spawning and nursery area is situated in the Banc d'Arguin (Mauritania), another at the mouth of the Senegal River, and the last one in the area near the Saloum, Gambia, and Casamance estuaries and the Bijagos Islands. However, considering data limits on North-MRT and SEN-MRT stocks (Mauritanian length frequencies on industrial fisheries do not give the location while artisanal fisheries catches are insignificant compared to the indutrial one), this study will focus on a South-SEN shrimps stock asssessment using the Demerstem length frequencies. The unit associated with the southern Senegal estuaries is composed of four sub-units related to the Saloum, Gambia, Casamance, and Bijagos Islands. Thess data are presented in Figure 4.

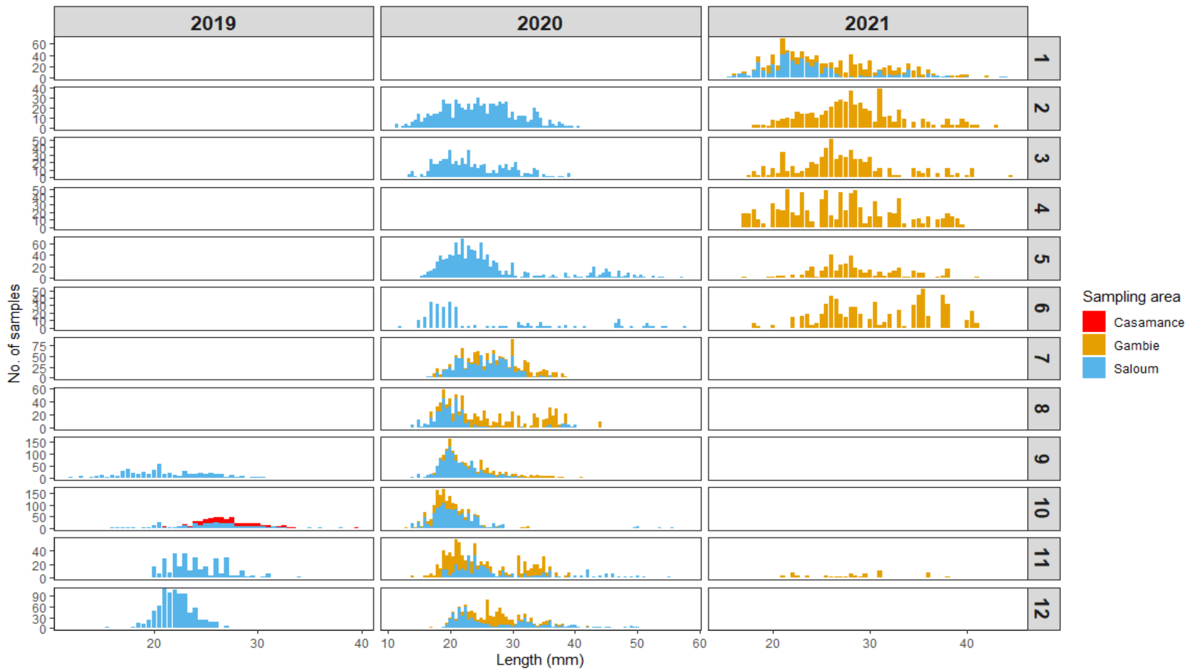


Figure 4 - Shrimps samples in South-SEN stock (2019-2021).

To study length frequencies, extrapolation must be done. In addition, in order to get a study over several years, we will subsitute length frequencies to fill gaps, using monthly data of the adjacent year, multiplied by corresponding catches. Considering data in Casamance are not sufficient, they are removed.

1.3.2. Extrapolation and substitution

The size-weight relationships is estimated by aggregating all the data sampled during demerstem project. Outliers are filtered and a and b parameters are estimated using NLS package (non least square). This estimate will allow extrapolation to the total catch.

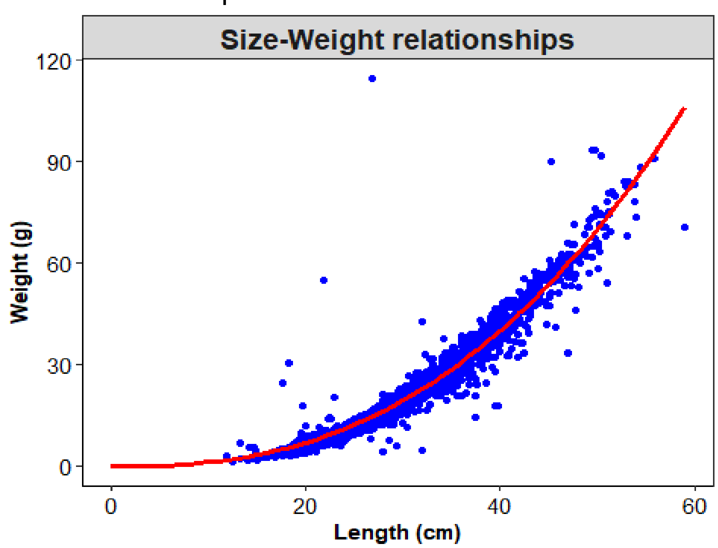


Figure 5 - Weight-size relationship fitted to data collected during demerstem project for P. notialis in South-SEN stock

Estimated growth parameters useful for LBB approach are summarised in the Table 2. Length at maturity was estimated by Lhomme (1981) and Linf = Lmax * 95%.

Table 2 - Growth parameters from the literature or estimated for *P. notialis* South-Sen stock

Growth parameters				
	a	b	Lm (cm)	L+∞ (cm)
Estimation	0.0038	2.51	27	52.8

Extrapolated and substituted length frequencies in Saloum and Gambia region between 2019-20121 are presented in Figure 6.

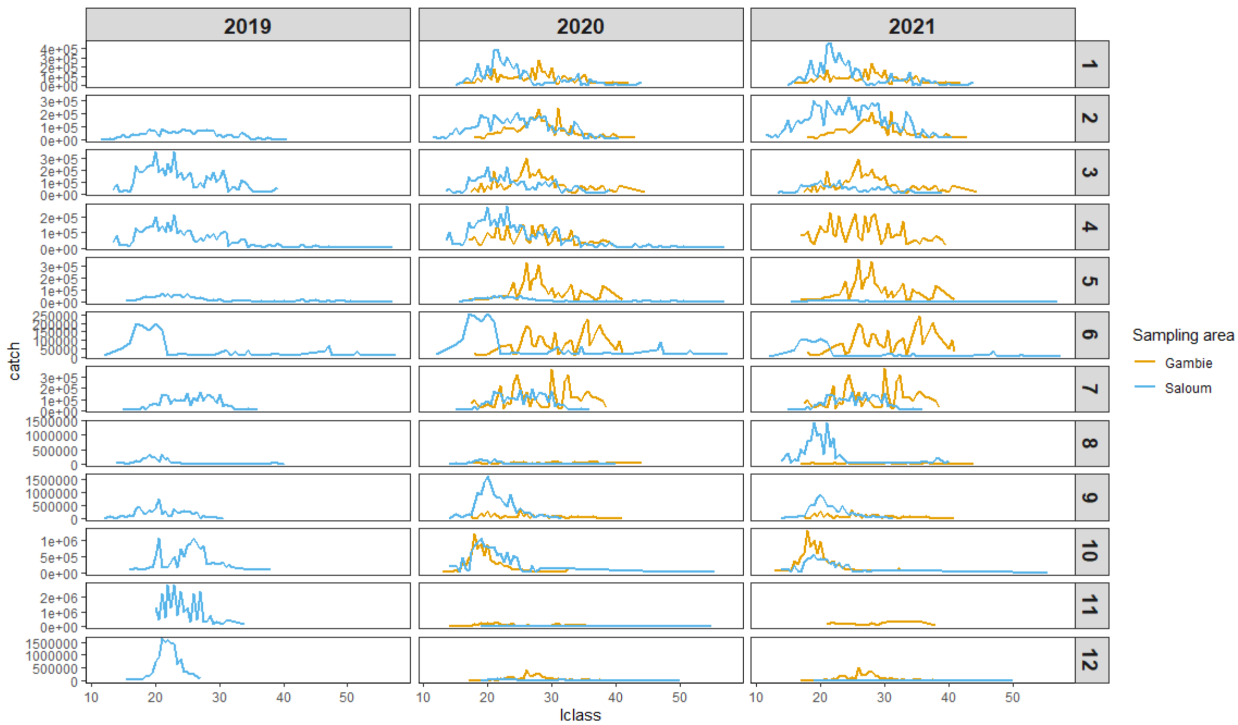


Figure 6 - Monthly length frequencies after extrapolation and subsitution (2019-2021)

2. Length-based Bayesian Biomass (LBB) estimator method

In LBB, we'll conduct several analyses by distinguishing the stock **South-SEN** and its main estuaries: Saloum and Gambia. Hence, the year 2019 is removed from the study, as there are no observations in Gambia for this year. First approach is to filter the aberrant years. For this we study the shape of the selectivity curve and all LF data exhibited good patterns to reflect resource status and met the requirements of LBB (Figure 7). This figure presents results when using all the data available. Graphics for each region are presented in Annex.

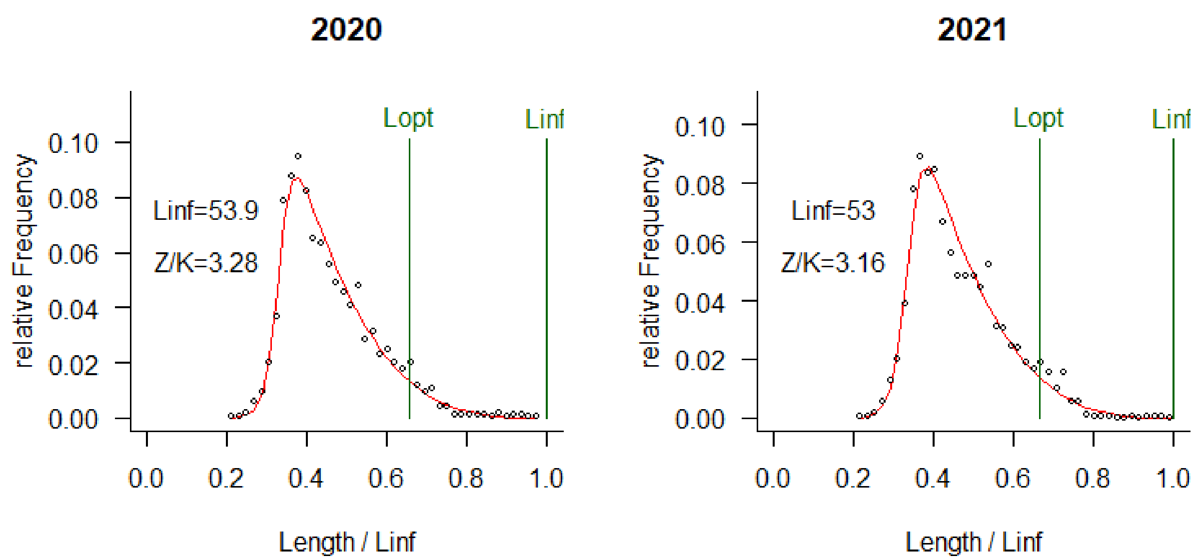


Figure 7 - Results from LBB analysis. The red curves shows the LBB fit, which provides estimates of Z/K, M/K, F/K, Lc, and Linf. From Linf and M/K is calculated Lopt and shown as a reference. (Gambia and Saloum case).

The L_{opt} dash lines indicate relatively good stock status or good length structures if they are at the middle or left of the peak of the curves. It in this study is not the case regardless of the year. The red curve shows the fit of the LBB for each stock, providing estimates for fishery reference points, i.e., M/K, F/M, B/B_{MSY}, B/B_0, L_{mean}/L_{opt}, and Lc/Lc_{opt}. Figure 8 shows the accumulated LF data over all assessment years used to estimate priors.

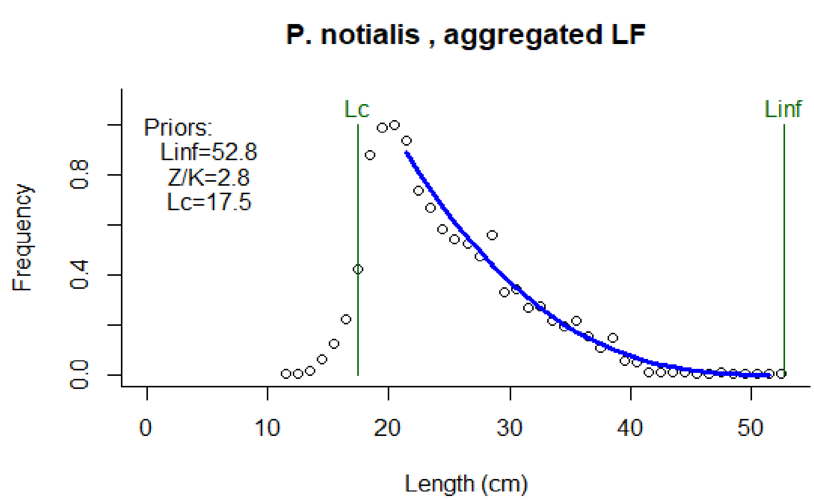
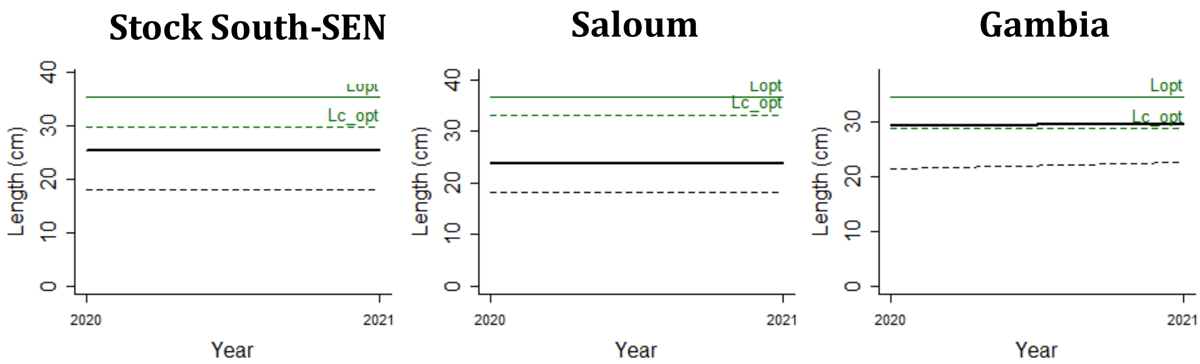


Figure 8 - Fitness to the fully selected part of the catch in the numbers curve used to obtain Linf (cm), Lc (cm), and Z/K priors for the studied fish stock. Black dots indicate the observed LF data.

Finally, Figure 9 show length indicators for each analysis. On these plots, we can see L_{mean} (bold black curve) relative to L_{opt}, and L_c (dashed black curve) relative to Lc_{opt}. The L_{mean}/L_{opt} and L_c/Lc_{opt}) ratios are inferior to 1, suggesting fishing of too small individuals and a stock suffering from overfishing (Zhang et al., 2021b).



Estimates of fishery management indicators (LBB)

Indication of the FMSY proxy level ($F = M$), relative biomass B/B_0 and a proxy for B_{MSY} and B_{pa} or 0.5 B_{MSY} are also available and summarised in Table 3. In particular, F/F_{MSY} and B/B_{MSY} informations are presented in a Kobe plot with a dot representing each case study (Figure 10).

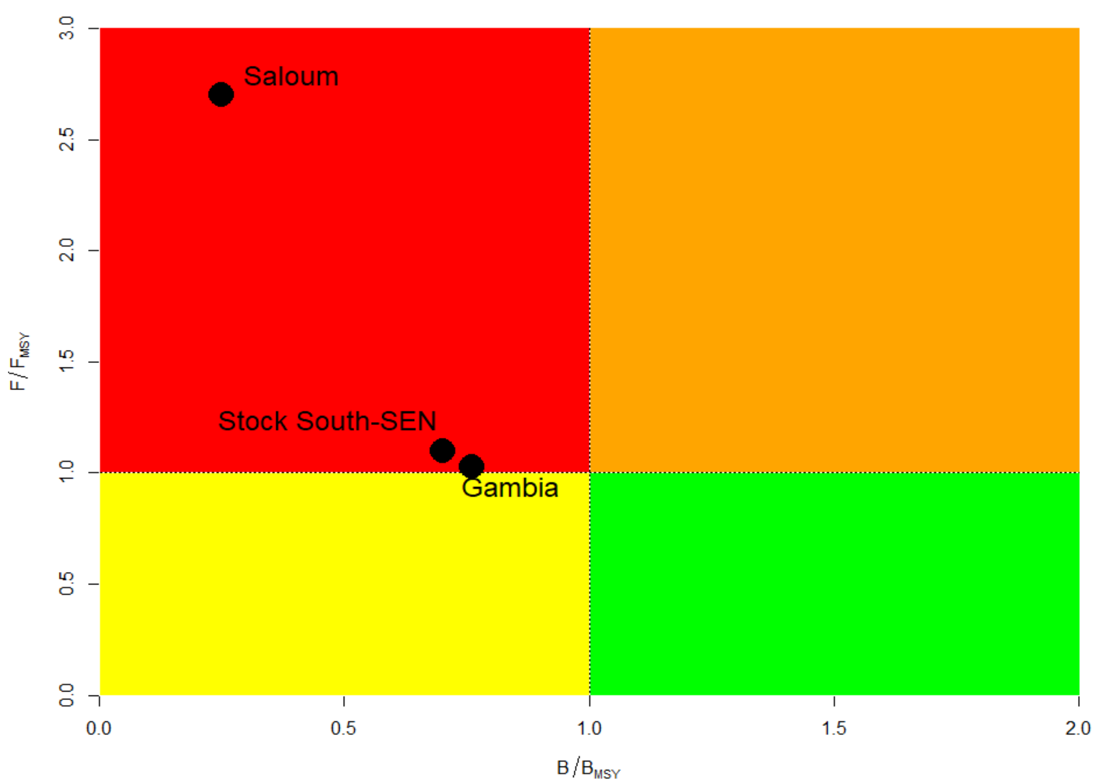


Figure 10 - Kobe phase plot with current stock status (2020) described by each model

Analyses conducted over the stock or its main estuaries indicates contrasted status between Saloum and Gambia. Overall, estimated values of $B_{20-21} < B_{MSY}$ and $F_{20-21} > F_{MSY}$ (median across 2020 and 2021) suggest an overfishing status whatever the case study (Table 3 and Figure 10).

Table 3 - Stock status indicators estimate (median across 2020 and 2021) over the stock or its main estuaries

LBB model	**Stock status indicator**					
	Lmean/Lopt	Lc/Lc_opt	F/FMSY	B/BMSY	B/Bpa	B/B0
South-SEN	0.72	0.6	1.1	0.7	1.4	0.26
Saloum	0.64	0.55	2.7	0.25	0.5	0.01
Gambia	0.86	0.78	1.03	0.76	1.52	0.29

3. Conclusion

This work was focusing on producing a stock assessment for 3 stocks of *P. notialis* in West Africa. However, working with length frequencies data raise several issues. In fact, the reliability of a diagnostic established with LBB relies on data representativeness of the studied fisheries. As stated by Froese et al. (2018), combining different length frequencies might be challenging and working with the predominant fishing gear is essential. Then, we did identify that data are lacking to produce any analysis for the North-MRT and SEN-MRT stocks. Here, information on length frequencies of industrial fishery catches wasn't available, while it was recognized to be responsible for the bulk of catches.

In the case of South-SEN stock, when using data from artisanal fishery we did identify that the two stocks from the Sine Saloum and Gambia estuaries are overexploited. In both cases $F_{current} > F_{MSY}$ and $B_{current} < B_{MSY}$ and length indicators suggest fishing of too small individuals. However, these results should be mitigated for several reasons. First, the asymptotic length (L_∞) value is a key parameter of initial life-history, and sensitivity analysis showed that biases on L_∞ has a strong influence on the reference points of conservation of mature individuals, spawning potential ratio, fishing mortality and the biomass relative to the maximum sustainable yield (Froese et al., 2018, Hordyck et al., 2019, Medeiros-Lea et al., 2022). Hence, misleading estimates of this parameter in the case of a lack of large individuals is due to a stock being overfished and would greatly impact the diagnostic. In addition, as previously explained, this study could not be based on the whole catches because lacking data on industrial fisheries. Thus, the diagnostic must be held knowing limits of this case study which strengthen the need for more length frequency data.

To conclude, the length-based Bayesian Biomass estimation approach (LBB) is a powerful method providing diagnosis on fishing intensity and length indicators estimates and it does shows management should take account gear selectivity as it impacts population demographic structure. Our results indicate an overfishing status of the South-SEN stock, still these results are preliminary and require more investigation.

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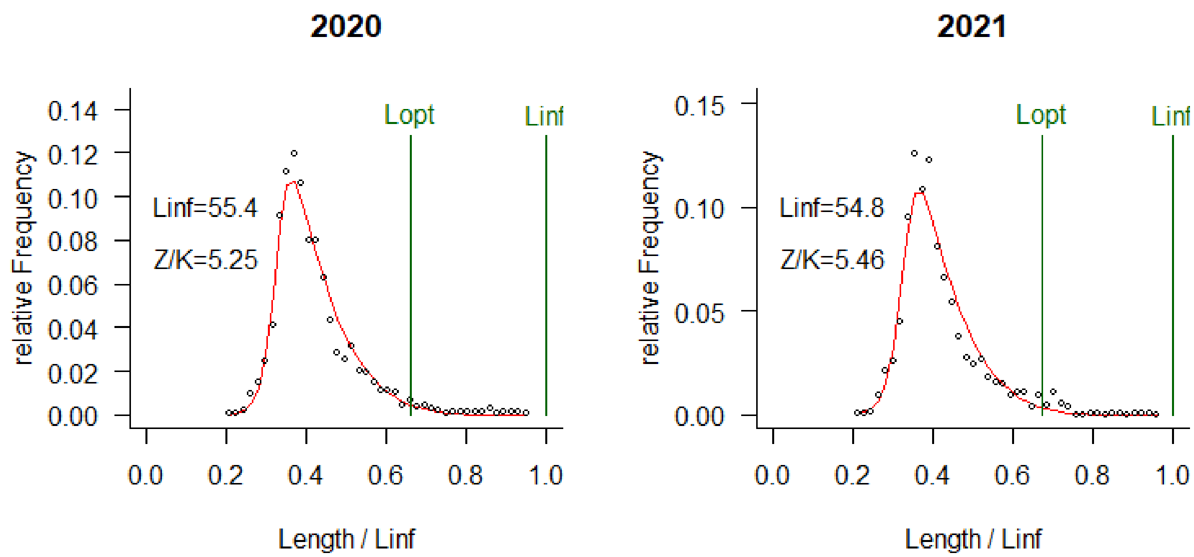
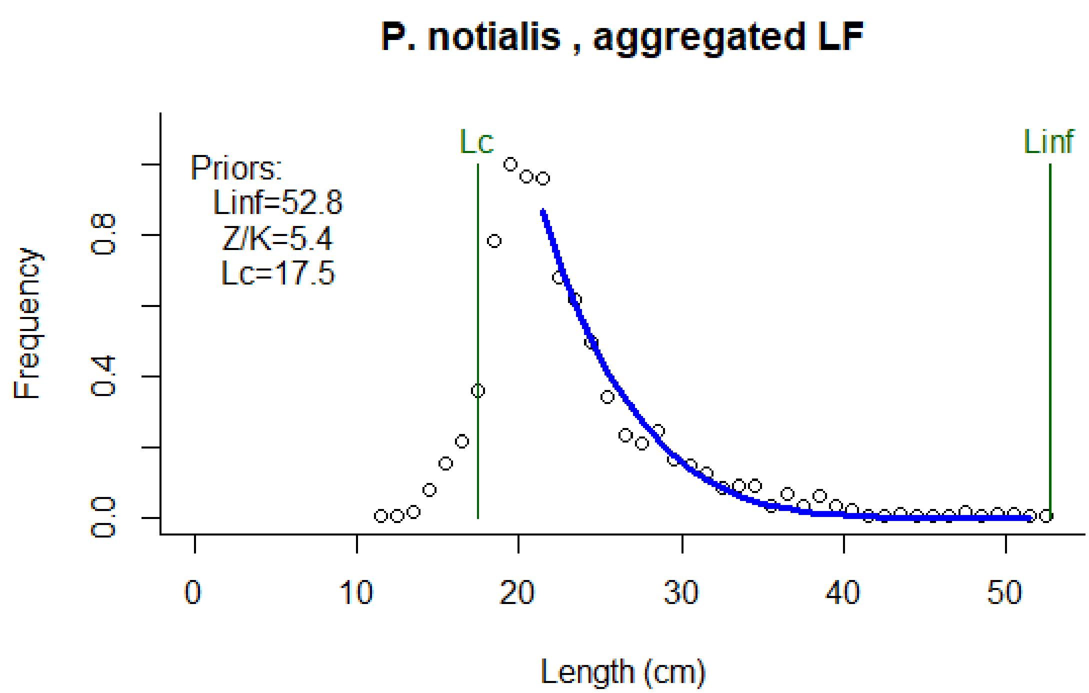
ANNEX

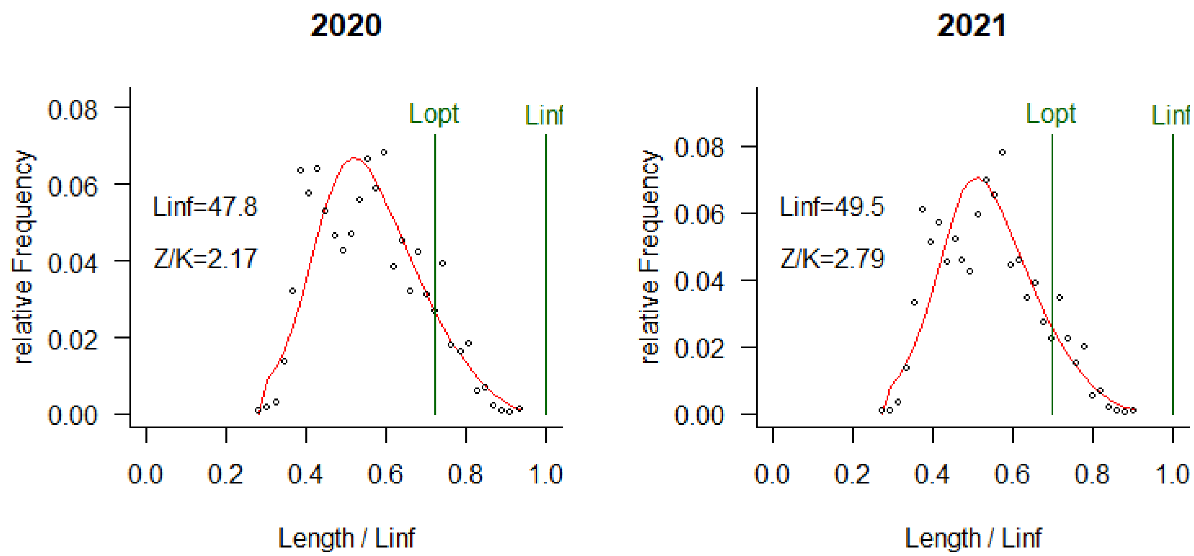
Annex 1: Results from LBB analysis. The red curves shows the LBB fit, which provides estimates of Z/K, M/K, F/K, Lc, and Linf. From Linf and M/K is calculated Lopt and shown as a reference. (Saloum case).



Annex 2 : Fitness to the fully selected part of the catch in the numbers curve used to obtain Linf (cm), Lc (cm), and Z/K priors for the studied fish stock. Black dots indicate the observed LF data - Saloum case



Annex 3 : Results from LBB analysis. The red curves shows the LBB fit, which provides estimates of Z/K, M/K, F/K, Lc, and Linf. From Linf and M/K is calculated Lopt and shown as a reference. (Gambia case).



Annex 4 : Fitness to the fully selected part of the catch in the numbers curve used to obtain Linf (cm), Lc (cm), and Z/K priors for the studied fish stock. Black dots indicate the observed LF data - Gambia case