ASSESSING THE NORTH-WEST AFRICAN STOCK OF BLACK HAKES (*MERLUCCIUS POLLI* AND *MERLUCCIUS SENEGALENSIS*) USING CATCH-MSY AND LENGTH-BASED SPAWNING POTENTIAL RATIO MODELS

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ABSTRACT

Shared by three countries (Morocco, Mauritania and Senegal), the black hakes (*Merluccius polli* and *M. senegalensis*) stocks are some of the most important resource exploited in northwest African waters. Since they resemble each other and are caught together in high proportions, the fisheries statistics record them as one species. The catches were high in the 1970s before sharply declining since 1980 as a result of an intense exploitation by the domestic and foreign vessels using bottom-trawls and longlines. Each of these countries has its own records about catch, efforts, CPUE and catch composition which generally led to pooled stock assessments during CECAF Working Groups. This study attempts to perform stock assessments using regional data (catches in metrics and in length composition) from FAO reports and data-limited methods such as Catch-MSY and Length-Based Spawning Potential Ratio (LBSPR) model as a preliminary work in order to compare reference points with existing literature and consolidate them for the fisheries management purpose. The objectives of this study were to (1) obtain information about life history parameters of both species from literature review, (2) estimate natural mortality rate M and M/k using data-limited methods, (3) provide recommendations based on assessments of black hakes using Catch-MSY and LBSPR models. Sensitivity analyses were also performed to test the reliability of the results according to some changes in the input parameters. The results from Catch-MSY assessments showed that the MSY ranged between 19,400 and 29,150 tonnes, according to the scenarios. The B_{MSY} values were very high (137,000- 352,000 tonnes), resulting in a high carrying capacity K. However, the intrinsic growth rates were very low (0.12 to 0.30). For the LBSPR assessments, the spawning potential ratio appeared too low (SPR < 0.2) for most cases suggesting recruitment overfishing. Finally, this study recommends to update life history parameters (L_{50}, L_{95}, k, L_∞, t_0 and M) regarding both species for stock assessment purpose and separate the two species in the fisheries departments statistics (catches, effort, CPUE and length frequencies) which could help scientists to assess them individually and give management advices based on accurate data.

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1   INTRODUCTION

The north-west African region is one of the four major eastern boundary upwelling systems (EBUS), characterized by high biological productivity owing to its upwelled nutrients, which help to sustain large fish populations (Thiaw et al., 2017). Studies have shown how climate drives the recruitment dynamics of black hake species (Meiners et al., 2010), whose success guarantees the overall abundance of the stock and supports the high catch in this region. Since the 1960s, black hakes (*Merluccius polli* and *M. senegalensis*) have been exploited by the Spanish and other foreign fleets using bottom-trawls and longlines in northwest African waters. The historical landings data series show large fluctuations with a peak of around 100,000 tons in the 1970s (Meiners et al., 2010).

Merluccius spp. are predominantly a demersal species in the subtropical northwest African waters (Lloris et al., 2003). Ecologically, they are a key group in the demersal community inhabiting the continental shelf and especially on the upper slope (Ramos and Fernández-Peralta, 1995). Black hakes feed on a wide spectrum of prey, have extended spawning seasons, and high vertical and horizontal migration ability (Alheit and Pitcher, 1995).

Due to their morphological resemblance, their overlapping occurrence at certain depths and large catches, which hinder the correct and reliable sorting onboard, both species are mixed in landings and commonly marketed as *Merluccius* spp. (Cervantes and Goñi 1985; Ramos-Martos and Fernández-Peralta, 1995). Therefore, stock assessment is carried out as a single stock (FAO, 2012; Rey et al., 2012; FAO, 2018). The data available (catch, effort, catch-per-unit-effort, length-frequencies, age, mortality) per fishing country are either sparse and discontinuous over time. Relatively few studies can be found on black hakes compared to European hake.

The existing literature on black hakes has dealt with reproduction (Fernández-Peralta et al., 2011), growth (Doutre, 1960; FAO, 1979; Bourdine, 1986; Wysokinski, 1986; Rey et al., 2012) and distribution (Ramos and Fernández-Peralta, 1995; FAO, 2012; Fernández-Peralta et al., 2017), and has shown some differences between the two species. However, the stock identity in stock assessment has not been resolved yet because of the overlapping depth and latitude and mixed catches, which have historically led scientists to perform stock assessment without separating the two species in the catches, even though the two species have different biological parameters.

This presents a situation where stock assessments and reference points based on them could be biased by the unknown species admixture. The most recent assessment of black hakes stock was performed during CECAF[1] working group in 2017 using dynamic production models (simple Schaefer model and Bayesian Fox model), Catch-MSY (Martell and Froese, 2013; Froese et al., 2016), Length Cohort Analysis LCA (Jones, 1984) and yield-per-recruit model (Thompson and Bell, 1934), in which the biological reference points calculated were the ratios B_{cur}/B_{MSY} and F_{MSY} as limit reference points (LRP), and $B_{0.1}$ and $F_{0.1}$ as the target reference points (TRP), compared to F_{cur} and B_{cur}

1.1   Objectives

The overall objective of this work is to assess the black hake stocks using data-limited methods with regional data to reflect the whole stock, in order to compare reference points with existing

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[1] Committee for the Eastern Central Atlantic Fisheries

ones and consolidate them for the fisheries management purpose of enhancing sustainability. To achieve this goal, the study will specifically focus on (1) obtaining information about life history parameters of both species from literature review, (2) estimating natural mortality rate M using biological parameters and several different methods, (3) using a variety of data-limited methods to analyse stock status of black hakes in the context of mixed species and shared stock between northwest African countries (Morocco, Mauritania and Senegal), and (4) provide recommendations on the monitoring and assessment of black hakes.

2   LITERATURE REVIEW

2.1   Taxonomy

Hakes belong to the class of *Actinopterygii*, the order of Gadiformes, the family of *Merlucciidae* and the genus of *Merluccius*. To date, sixteen valid species of the genus *Merluccius* have been described (Froese and Pauly 2016).
- *Merluccius albidus* (Mitchill, 1818)
- *Merluccius angustimanus* (Garman, 1899)
- *Merluccius australis* (Hutton, 1872)
- *Merluccius bilinearis* (Mitchill, 1814)
- *Merluccius capensis* (Castelnau, 1861)
- *Merluccius gayi gayi* (Guichenot, 1848)
- *Merluccius gayi peruanus* (Ginsburg, 1954)
- *Merluccius hernandezi* (Mathews, 1985)
- *Merluccius hubbsi* (Marini, 1933)
- *Merluccius merluccius* (Linnaeus, 1758)
- *Merluccius paradoxus* (Franca, 1960)
- *Merluccius patagonicus* (Lloris and Matallanas, 2003)
- ***Merluccius polli*** (Cadenat, 1950)
- *Merluccius productus* (Ayres, 1855)
- ***Merluccius senegalensis*** (Cadenat, 1950)
- *Merluccius tasmanicus* (Lloris and Matallanas, 2006).

Three species of *Merluccius* populate the waters of eastern central Atlantic (FAO, 1979; Thiam et al., 2009): the European hake (*Merluccius merluccius*), the Senegalese hake (*Merluccius senegalensis*) and the Benguela hake (*Merluccius polli*). These latter two (in bold above) are also known as black hakes due to their morphological similarities.

2.2   Morphological features

The two black hake species *Merluccius senegalensis* and *Merluccius polli* (Fig. 1) have the following morphological characteristics in common (1) fusiform body, wider in front; (2) large and elongated head; (3) mouth widely split with strong teeth; (4) fins: without spines, separate dorsal fins (the first is short and high, the second wide, indented and similar to the anal fin), pelvic fin in jugular position and a truncated caudal fin. Table 1 summarizes their distinctive morphological characteristics, which are also illustrated in Figure 1.

Figure 1: Photos of *Merluccius senegalensis* (left) and *M. polli* (right) (Thiam et al., 2014)

Table 1: Morphological characteristics of *Merluccius senegalensis* and *M. polli* (Cohen et al., 1990)

Distinctive morphological characters	M. senegalensis	M. polli
Color on the belly	silvery white	steel gray to blackish
Color on the back	steel gray to blackish	blackish
Number of scales on the lateral line	124 to 155	102 to 127
Number of rays on the 1st dorsal fin	9 to 10	8 to 11
Number of rays on the 2nd dorsal fin	38 to 41	37 to 41
Number of rays on the anal fin	37 to 40	36 to 42
Total number of dorsal soft rays	47 to 51	45 to 52
Total number of gill rakers on 1st arch	13 to 16 (18 max)	8 to 12
Total number of vertebrae	51 to 56	53 to 57
Head length vs. standard length	24.9 to 27.7%	24.8 to 28.9%
Upper jaw vs. head length	47.1 to 50.6%	45.3 to 51.3%
Snout vs. head length	30.2 to 34.1%	30.2 to 35.9%
Interorbital width vs. head length	27.0 to 31.0%	24.1 to 28.0%

2.3   Geographical and bathymetric distributions

Black hakes (*M. polli* and *M. senegalensis*) are two demersal sympatric species living the north-west African waters and sharing a common latitudinal and bathymetric area as they partially overlap. *Merluccius polli*, also known as Benguela hake, inhabits the continental shelves and the slopes of East Atlantic Ocean bottom from southern Morocco (28ºN) to northern Namibia (18.5ºS), although captures are rarely reported in the Guinean Gulf (Inada, 1981; Cohen et al., 1990; Lloris et al., 2003; Fernandez-Peralta et al., 2011, 2017; Manchih et al., 2018). It is the only *Merluccius* species living in both hemispheres.

While *Merluccius senegalensis*, also called Senegalese hake, is only found in the northern hemisphere between 12ºN and 33ºN off Northwest African coast. Its range largely overlaps the distribution area with *M. polli* between 12ºN and 28ºN, mainly in the Mauritanian EEZ (Ramos and Fernández-Peralta, 1995; Fernández-Peralta et al., 2011, 2017; Manchih et al., 2018). However, *M. polli* is considered as the deep-water species because living in waters down to 1100m depth, while *M. senegalensis* prefers shallower inshore waters < 600 m and disappearing beyond 700 m (Rey et al., 2016; Fernández-Peralta et al., 2017).

Nevertheless, Manchih et al. (2018) reported that *M. senegalensis* was caught off Morocco down to 1055 m deep, a figure never recorded before. The two species share common depth ranges between 80 and 600 m, demonstrating a partial overlapping bathymetric (or vertical) distribution (Fernandez-Peralta et al., 2017). While the depth and the temperature are key elements in the occurrence and abundance of both hakes, the geographical positions (latitude and longitude) only affect *M. polli* with high presence around 17ºN. This latter is largely found in the Mauritanian waters compared to *M. senegalensis* with a wider bathymetric (80-

1100 m vs. 80-700 m) (Fernandez-Peralta et al., 2017). As shown in Fig. 2 below, black hakes consist in *Merluccius senegalensis* and *Merluccius polli* which overlap in the Northern-East coast of the African continent.
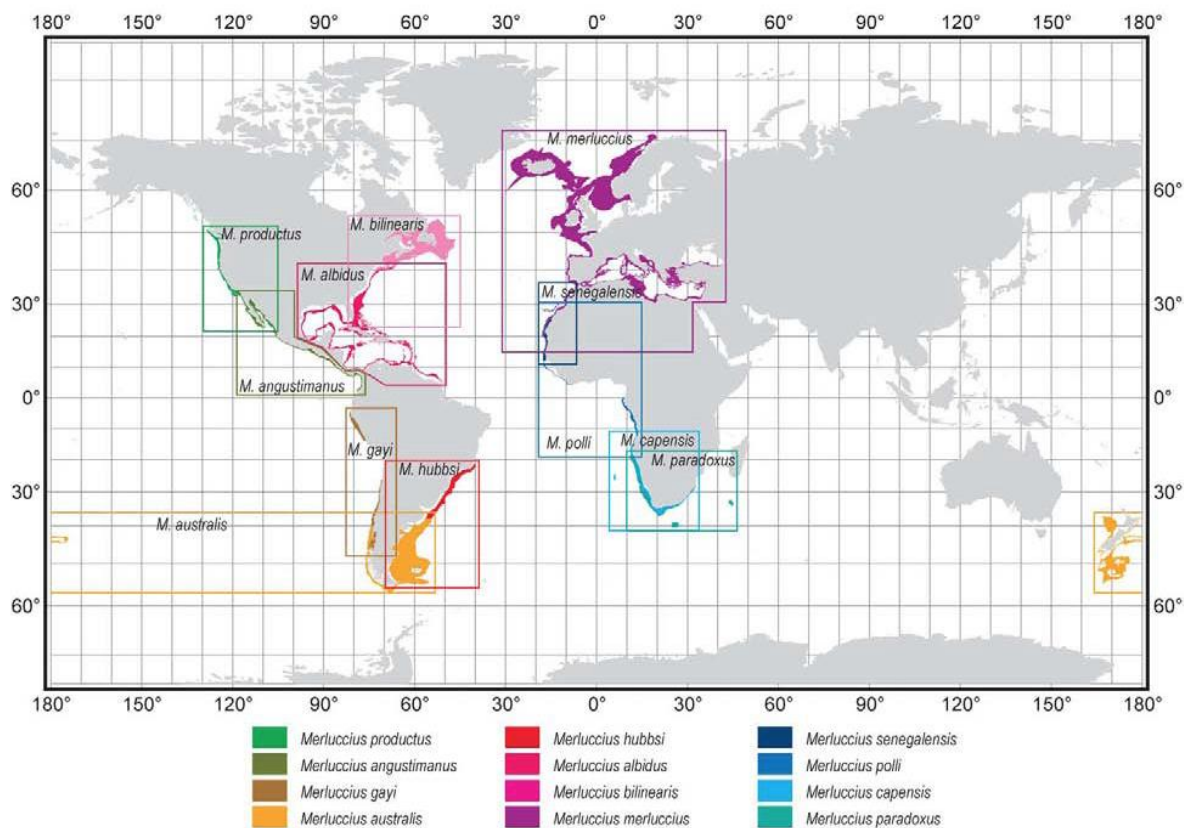
Figure 2: Geographical distribution of world hakes (Lloris et al., 2005)

2.4   Seasonal migrations and reproduction

A seasonal migration along the northwest African coast would be the main cause regarding the variation in the northern limit of black hake species distribution (Garcia, 1982; FAO, 1990, 2018; Lloris et al., 2005; Fernández Peralta et al., 2008, 2011, 2017; Carpenter and De Angelis, 2016). In fact, black hake species perform seasonal latitudinal migrations: during the warm season (June to October) corresponding to the summer, both migrate northwards of Senegal to avoid hot waters before moving to the opposite direction during autumn and winter when the northern cold starts to descend (Bourdine, 1986; Caveriviere et al., 1986; FAO, 1990; Wysokinski, 1986).

Moreover, the migration pattern is highly and negatively correlated with the regional climate index (North Atlantic Oscillation) which impacts the dynamics of black hake species along with the upwelling (Meiners et al., 2010). These migration processes are not only linked to the search for good environmental and trophic conditions, but also to reproduction need. The southward displacement of black hakes during the transition cold-warm season has been linked to the need of spawning in the Senegalese waters (Sobrino et al., 1990; Fernández-Peralta et al., 2011).

2.5   Fisheries and stock assessments

The black hakes resource was intensely exploited during the 1970s by the Russian, Spanish and Portuguese fleets operating off northwest African coast, landing up to 100,000 t per year before sharply declining in the 1980s (FAO, 1979; Ramos and Fernández, 1992; Ramos et al., 1998). The Mauritanian catches represented 70 to 83% of the total production in the northwest African coasts during the period 2000–2016 (FAO, 2018). Earlier studies regarding black hake species used to establish *M. senegalensis* as the predominant species, even attributing a large proportion of total catches in the area to it in comparison to *M. polli* (Boukatine, 1986; Bourdine, 1986; Overko and Milnikov, 1986; Overko et al., 1986; Wysokinski, 1986; Sobrino et al., 1990). The finding of Fernandez-Peralta et al. (2017) contradicts those previous studies by showing a high presence *M. polli* off Mauritanian waters as already shown to be off Senegal (Caverivière et al., 1986; López-Abellán and Ariz-Tellería, 1993). Nevertheless, until now, the total catches in the region continue to be mixed and recorded as *Merluccius* spp. which complicates the stock assessment using production models (FAO, 1990; Ramos-Martos and Fernández-Peralta, 1995; FAO, 2018).

3   MATERIAL AND METHODS

3.1   Area of study

This study is mainly focused on northwest African waters from southern Morocco to south of Senegal (orange area on the map) where the two species overlap in distribution along the continental shelves and the upper slope (Fig. 3). This region is known as one of the most productive worldwide ecosystems due the upwelling occurring along the coast. This upwelling is due to the strong wind regime from the Azores blowing for a long time period, and the Canary Current and the Ekman transport pushing the surface water offshore. The surface waters are then replaced by deep and nutrient-rich water rising to the surface. The nutrients are then used by phytoplankton, increasing productivity of the local ecosystem.
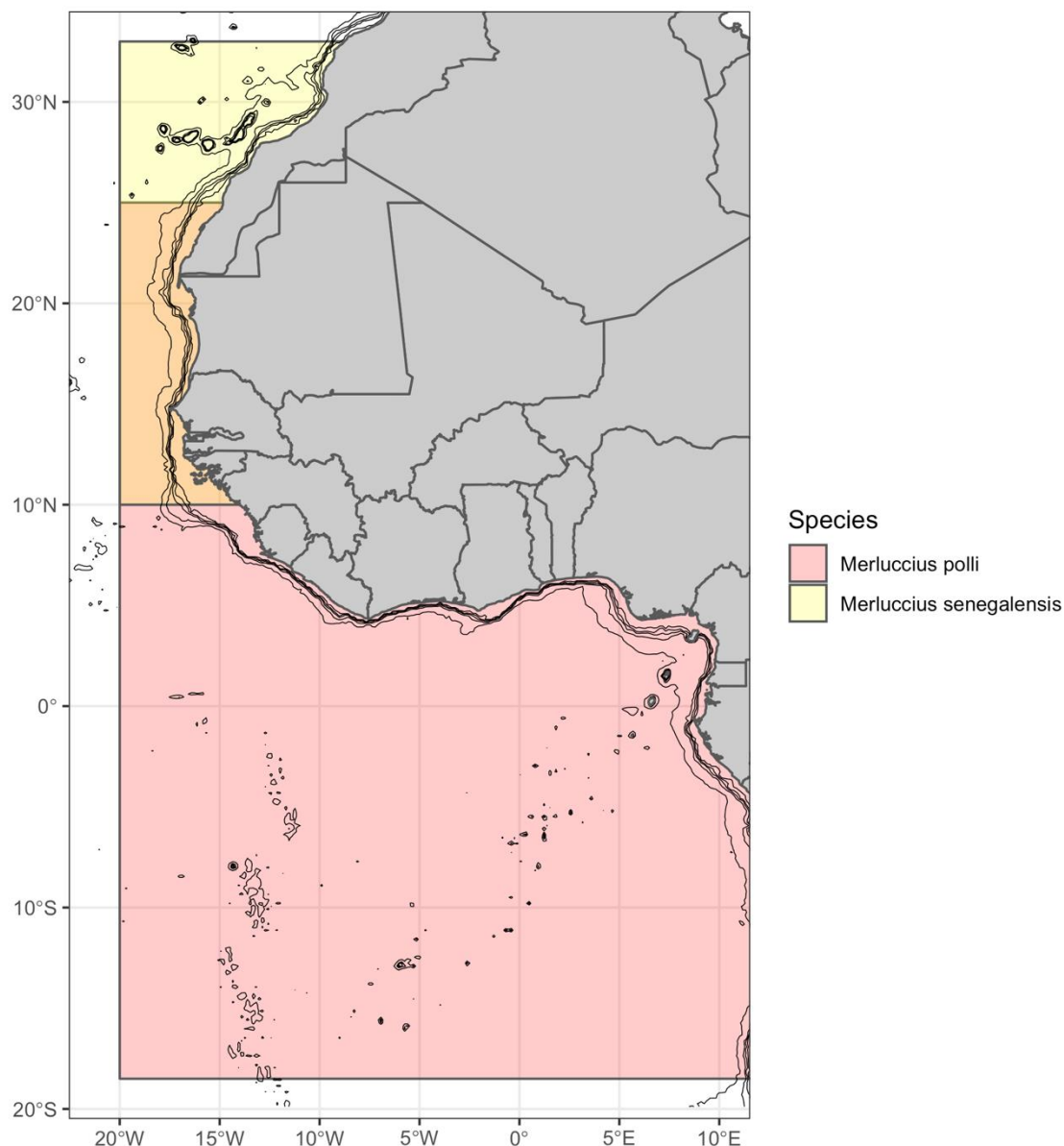
Figure 3: Geographical distribution of black hakes adapted from Ramos Martos and Fernández-Peralta (1995) and Fernandez-Peralta et al. (2017)

3.2   Sources of data

Two types of data have been used in this study: catch-only (landings) data and length frequency distributions of combined black hakes sourced from FAO (1990 and 2018) reports. Catch data consist of total landings of black hakes from Morocco, Mauritania and Senegal from 1962 to 2016, while the length compositions are structured as total number of individuals (extrapolated to total landing) per size classes (1 cm intervals) from 15 to 86 cm and from 1991 to 2016. These length distributions came mainly from Morocco (from 1991 to 2016), but also from Mauritania and Senegal for 2015-2016.

3.3   Data limited methods

3.3.1   Catch MSY
The Catch-MSY model is a Schaefer surplus production model developed by Martell and Froese (2013) for data-poor stocks that only needs as inputs a time series of catch, the resilience of the species categorized as "very low" (between 0.015 and 0.1), "low" (from 0.05 to 0.5) or

"high" (0.6 - 1.5), and if available, a time series of abundance indices to determine stock status and parameters. Fisheries reference points can also be inputted for management strategy evaluation. In this study, a time series of abundance indices was not available; and M. senegalensis is considered as "low resilience" species (https://www.fishbase.se/summary/Merluccius-senegalensis.html), while M. polli is a "medium resilience" species (https://www.fishbase.se/summary/Merluccius-polli.html, last visited on Feb/07/2020).

The other input parameters within the model that can be set, depending on the scientist's knowledge of the fishery, are the prior ranges of (1) the carrying capacity K, (2) the intrinsic growth rate r of the stock, (3) the initial and final biomass as proportions of K (depletion levels) and the process errors (no process error means the model is deterministic, i.e. assuming only an observation error occurs in the model) (Martell and Froese, 2013; Jørgensen, and Chrysafi, 2014). The estimations of r were based on the priors of the resilience which was set "low" firstly, then "medium" to take into account both species resiliencies.

The model also sets the boundaries of K by assuming it falls within the range of the maximum catch of the time series to x times the catch (x = 10, 20, 30, 40, and 50 successively the model), and the biomass depletion levels based on the knowledge and development of the fishery (Martell and Froese, 2013). The model updates the Schaefer model parameters using a likelihood function (Bernoulli distribution) and tries to find the best r and K combinations that can avoid the stock collapsing or exceeding the carrying capacity. It also generates the relative biomass estimates, along with the fisheries reference points (the Maximum Sustainable Yield MSY, the corresponding fishing mortality at MSY F_{MSY}, and the corresponding biomass when fishing MSY B_{MSY} in the long term).

3.4   Biological parameters needed for analysis using LBSPR

A series of certain life history parameters are needed for input to analyze stock status using Length-Based Spawning Potential Ratio (LBSPR, Hordyk et al., 2015). The life history parameters were drawn from several studies related to the black hakes (Table 2) except for the natural mortality rates M, which were estimated using "FSA" R-package (Ogle, 2016). This package uses several methods to estimate natural mortality rates (Alverson and Carney, 1975; Richter and Efanov, 1976; Pauly, 1980; Jensen, 1996, 2001; Hewitt and Hoenig, 2005; Zhang and Megrey, 2006; Gilason et al., 2010; Charnov et al., 2013; Kenchington, 2014; Then et al., 2015) from diverse types of data, including growth parameters (asymptotic length L_∞ , growth rate k and theoretical birth time t_0 corresponding to zero length from the von Bertalanffy (1938) equation), maximum age, age at 50% maturity and water temperature. The three growth parameters in this study (Table 2) came from literature synthesis, except for three cases (with the symbol "*") where t_0 was estimated using the Pauly's empirical equation (Pauly, 1980), resulting in 6 growth scenarios (Table 2):

$$\log_{10}(-t_0) \approx -0.3922 - 0.2752 \times \log_{10} L_\infty - 1.038 \times \log_{10} k$$

Table 2: von Bertalanffy growth parameters drawn from literature review

Species	scenario	k (year^{-1})	L_∞ (cm)	t_0	Authors
Merluccius polli	1	0.394	64.4	-0.34*	Doutre (1960)
	2	0.0838	76.5	-1.88	Wysokinski (1986)
Merluccius senegalensis	3	0.17	85.2	-0.61	Doutre (1960)
	4	0.24	61.4	-0.574*	Bourdine (1986)
	5	0.14	90	-0.904*	FAO (1979)
	6	0.0679	116	-1.287	Wysokinski (1986)

For each growth scenario (1 to 6), 24 natural mortality rates M were estimated from the "FSA" R package methods. Then, a sensitivity analysis was conducted by only using the minimum, the median and the maximum of all M values for each growth scenario because the natural mortality estimation is rather uncertain and can vary widely among methods. Since the ratio of M/k is a driving input for LBSPR analysis, the minimum, median and maximum M of the 6 growth scenarios were then divided by the corresponding k, which led to 18 M/k input values (6 min, 6 medians and 6 max). The scenarios were arbitrarily ordered from 1 to 6 according to the species and growth rate k: scenarios 1 and 2 for *M. polli* and 3 to 6 for *M. senegalensis,* each considering a min, median and max M value. Two cases were excluded because of unrealistically high M/k (scenario 4_{max}) and a combination of a low M/k and a very high L_∞ (scenario 6_{med}).

Finally, the lengths at which 50% and 95% of a population matures (L_{50} and L_{95}) for *M. polli* and *M. senegalensis* were drawn from the paper of Fernandez-Peralta et al. (2011) and used in the model. L_{50} and L_{95} was set at 44.2 cm and 53.3 cm respectively for *M. polli* while for *M. senegalensis* maturity parameters, $L_{50} = 39.7$ cm and $L_{95} = 45$ cm.

3.5   Length-Based Spawning Potential Ratio (LBSPR)

The Length-Based Spawning Potential Ratio (LBSPR) model has been recently developed, described and tested with simulation by Hordyk et al. (2014a, b) before being applied to real data by Prince et al. (2015). As opposed to using information about catch levels and assumptions about depletion and resilience of the stock to infer stock status, as is done in the Catch MSY method, information regarding stock status is taken from the frequency distribution of lengths from catches while assuming various life history processes. The LBSPR model requires annual length composition of the catch, life history parameters (M/k and L_∞) and estimates of lengths at maturity (L_{50} and L_{95}).

The equilibrium-based LBSPR model assumes that the size composition of the catch is representative of the exploited population at steady state. It applies maximum likelihood methods to find estimates of the 50% and 95% selectivity-at-length (SL_{50} and SL_{95}) and the relative fishing mortality (F/M) that reduce the difference between the observed and predicted length composition of the catch. The corresponding spawning potential ratio SPR is then calculated and can be used as an indicator of stock status (Hordyk et al*.,* 2014a, b; Prince et al*.,* 2015).

Defined as the proportion of the remaining reproductive potential of a stock under any level of fishing pressure (Goodyear, 1993; Mace and Sissenwine, 1993; Walters and Martell, 2004), the spawning potential ratio (SPR) is commonly used to set target and limit reference points for fisheries (Hordyk et al., 2014b). The SPR is equal to 1 in an unfished stock, and zero when all mature fish have been removed, or all female fish have been caught (i.e., without spawning). General guidelines for SPR reference points to use as proxy for MSY (Prince et al., 2015) indicate that at 40% ($SPR_{40\%}$ or SPR = 0.4), whereas closer to 20% ($SPR_{20\%}$ or SPR = 0.2) indicates a threshold for which recruitment rates are likely to be threatened (Walters and Martell, 2004; Prince et al*.,* 2015).

4   RESULTS

4.1   Assessment using catch data and resilience: Catch MSY method

The catches of black hakes were very low in the beginning of the 1960s with around 4,000 tonnes (Fig. 4a). They started to increase until reaching 18,000 tonnes during mid-1960s before dropping in 1970 to ~ 10,500 tonnes. Since then, a sharp increase in catches was noted, peaking around 100,000 tonnes during the 1973-1976 period with a fall in catches (38,000 tonnes) in 1975. 1976 onwards marked a period of decrease in catches compared to the previous period with year-to-year variability and an annual average of 20,000 tonnes in catches. However, we can note a declining trend in catches to around 5,000 tonnes from the beginning of the 2000s to 2013 with a peak of 13,500 tonnes in 2009. The last three years see the catches increase a bit to around 11,000 tonnes.

The sensitivity analyses performed during the assessments allowed display of the median estimates of the parameters as well as the biological reference points in Table 3. The overall results showed that the intrinsic growth rate r of the stock varied between 0.12 and 0.30, while the carrying capacity K were in the range 274247 – 704155 tonnes and the MSY ranged between 19,420 and 29,148 tonnes. The ranges of the biomass and the fishing mortality at MSY were estimated at B_{MSY} = {137123 – 352078 tonnes} and F_{MSY} = {0.06 – 0.15}, and the ratios of the current catch (11,561 tonnes in 2016) over the MSY were between 0.40 and 0.60.
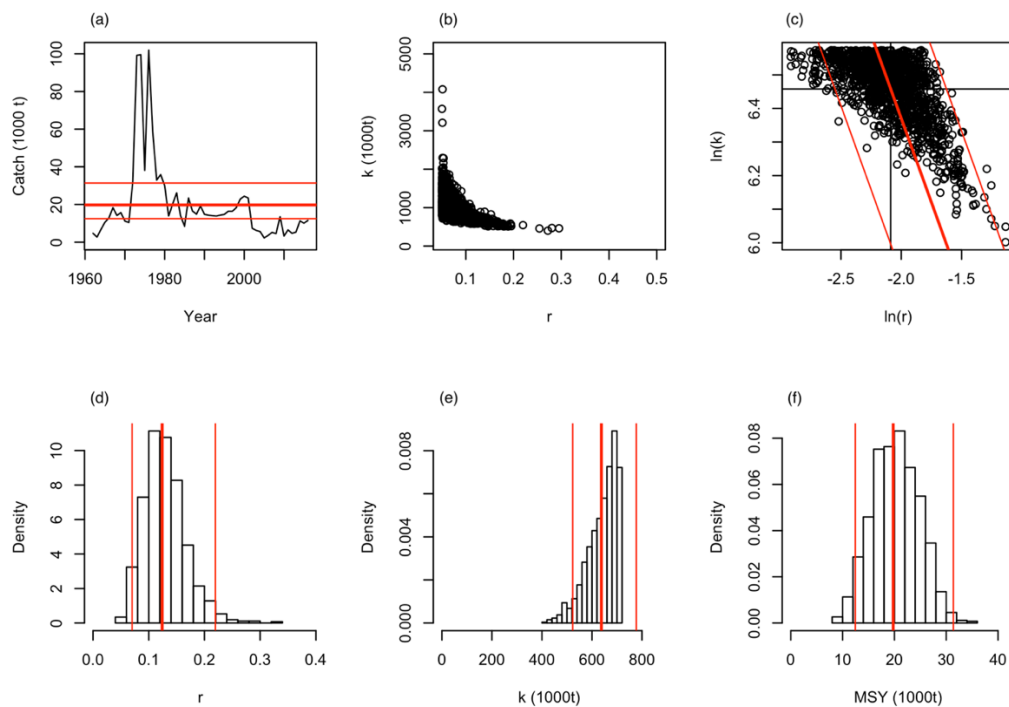

Figure 4: Graphic output (corresponding to the case 1) for analysis of the mixed black hakes stock (Merluccius spp.) using the Catch MSY method

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Table 3: Results of sensitivity analyses performed on the priors K and r : the lower bounds of K were set at the maximum catch of the series (i.e 101,934 tonnes) in the cases 1-5 and 11-15, and in the cases 6-10 and 16-20 the highest catches (~ 100,000 tonnes) of the series were excluded and the series started in 1977. The upper bounds of K were set at 'x times' the maximum catch of the series, x varying from 10 to 50 and the step =10. The priors of r were also tested by varying the resilience of the species between 'low' and 'medium' since the two species have different resiliencies, and the outputs presented are median estimates.

case	Prior K_{low} C_{max}	Prior K_{up} x	Prior r Resilience	Outputs r	K	MSY	Y_{cur}/MSY	B_{MSY}	F_{MSY}	B_{cur}/B_{MSY} (%)	F_{cur}/F_{MSY} (%)
1		10		0.12	704155	21542	0.54	352078	0.06	110	53
2		20		0.13	687366	21774	0.53	343683	0.06	114	47
3	101934	30	Low	0.13	697219	21703	0.53	348609	0.06	117	42
4		40		0.13	690019	21832	0.53	345009	0.06	117	42
5		50		0.14	655093	22136	0.52	327546	0.07	118	40
6		10		0.28	284889	19420	0.60	142445	0.14	124	45
7		20		0.30	274247	20098	0.58	137123	0.15	124	44
8	58589	30	Low	0.26	301066	19454	0.59	150533	0.13	123	44
9		40		0.29	275422	20016	0.58	137711	0.15	121	45
10		50		0.29	278963	19776	0.58	139481	0.15	124	44
11		10		0.26	442729	28841	0.40	221365	0.13	123	34
12		20		0.27	439792	29148	0.40	219896	0.13	129	32
13	101934	30	Medium	0.26	440687	28790	0.40	220343	0.13	122	33
14		40		0.26	442187	28580	0.40	221094	0.13	120	36
15		50		0.26	443282	28746	0.40	221641	0.13	120	36
16		10		0.28	285582	19627	0.59	142791	0.14	128	44
17		20		0.28	281255	19524	0.59	140627	0.14	123	45
18	58589	30	Medium	0.29	283465	19890	0.58	141733	0.14	123	45
19		40		0.28	287587	19530	0.59	143794	0.14	124	44
20		50		0.27	298734	19666	0.59	149367	0.13	124	43

4.1 Data-limited assessment using length data

4.1.1 Natural mortality M and M/k estimates

The estimation of natural mortality rates for each of the 6 growth scenarios using different types of methods available on 'FSA' R package gave minimum values of M varying between 0.07 and 0.40, while the median M ranges between 0.12 and 0.61 and the maximum M (0.33 – 0.80). The ratio of these values (min, median and max) over the estimates of von Bertalanffy growth k allow to have 18 M/k input values varying from 0.29 to 3.72 (Table 4).

Table 4: Estimation of natural mortality rates M and M/k ratio according to different methods. Green rows indicate the minimum, median and maximum values of M, while blue rows indicate their corresponding M/k ratios used in LBSPR model.

| | *M. polli* | | *M. senegalensis* | | | |
| | case 1 | case 2 | case 3 | case 4 | case 5 | case 6 |
Method	k = 0.394	k = 0.0838	k = 0.17	k = 0.24	k = 0.14	k = 0.0679
Then (2015)	0.80	0.19	0.36	0.16	0.51	0.31
Hoenig (1983)	0.60	0.13	0.26	0.11	0.37	0.22
Hoenig (1983)	0.58	0.12	0.25	0.10	0.35	0.20
Hoenig (1983)	0.66	0.18	0.32	0.15	0.43	0.28
Hoenig (1983)	0.45	0.12	0.22	0.10	0.29	0.18
Kenchington (2014)	0.65	0.12	0.26	0.10	0.38	0.21
Kenchington (2014)	0.62	0.09	0.22	0.07	0.34	0.18
Kenchington (2014)	0.70	0.16	0.31	0.13	0.44	0.26
Kenchington (2014)	0.66	0.13	0.27	0.10	0.39	0.22
Then *et al.* 2015	0.75	0.16	0.32	0.13	0.46	0.26
Hewitt and Hoenig (2005)	0.58	0.12	0.25	0.10	0.35	0.21
Then *et al.* 2015	0.70	0.15	0.30	0.12	0.43	0.25
Then *et al.* 2015	0.53	0.16	0.26	0.12	0.37	0.22
Pauly (1980)	0.57	0.20	0.30	0.15	0.42	0.26
Then *et al.* 2015	0.67	0.14	0.29	0.11	0.41	0.24
Then *et al.* 2015	0.71	0.23	0.36	0.20	0.47	0.32
Jensen (1996)	0.59	0.13	0.26	0.10	0.36	0.21
Jensen (2001)	0.79	0.33	0.46	0.31	0.56	0.42
Alverson and Carney (1975)	0.60	0.13	0.25	0.10	0.37	0.21
Rikhter and Efanov (1976)	0.61	0.17	0.52	0.33	0.43	0.50
Pauly (1980)	0.61	0.20	0.32	0.16	0.43	0.27
Zhang and Megrey (2006)	0.70	0.14	0.32	0.13	0.42	0.25
Rikhter and Efanov (1976)	0.55	0.18	0.60	0.39	0.40	0.54
Zhang and Megrey (2006)	0.40	0.08	0.18	0.07	0.24	0.14
M_{min}	0.40	0.08	0.18	0.07	0.24	0.14
M_{median}	0.61	0.15	0.29	0.12	0.40	0.24
M_{max}	0.80	0.33	0.60	0.39	0.56	0.54
M_{min}/k	**1.01**	**0.97**	**1.04**	**0.29**	**1.71**	**2.08**
M_{med}/k	**0.77**	**0.76**	**0.81**	**0.76**	**0.80**	**0.79**
M_{max}/k	**1.32**	**2.51**	**2.30**	**3.72**	**1.52**	**2.48**

4.2 Length-Based Spawning Potential Ratio (LBSPR)

With the life history parameters and the length composition data drawn from literature review, the LBSPR model estimated the selectivity sizes at 50 and 95% (SL_{50} and SL_{95}), the relative fishing mortality rates (F/M) and Spawning Potential Ratio (SPR). The histograms of length frequencies by year (from 1991 to 2016) mostly exhibited two modes except those of 2005, 2006, and from 2009 to 2015 (Fig. 5). The size structure predicted by the model fitted to the histograms allowed to match the length composition of the catch.

For most bimodal distributions of length frequencies, the first and highest peak occurs around 30 cm (± 1 cm) while the second lower is found around 40-46 cm with more centered at 42 cm. For unimodal distributions, the peaks were mostly found between 38 and 43 cm with two exceptions in 2014 and 2016 when the modal lengths were at 48 and 46 cm, respectively. The histograms also showed that fish sizes smaller than the sizes at maturity for *M. polli* ($L_{50} = 44.2$ cm and $L_{95} = 53.3$ cm) and *M. senegalensis* ($L_{50} = 39.7$ cm and $L_{95} = 45$ cm) were found in a high proportion of the catches, except the last three years.
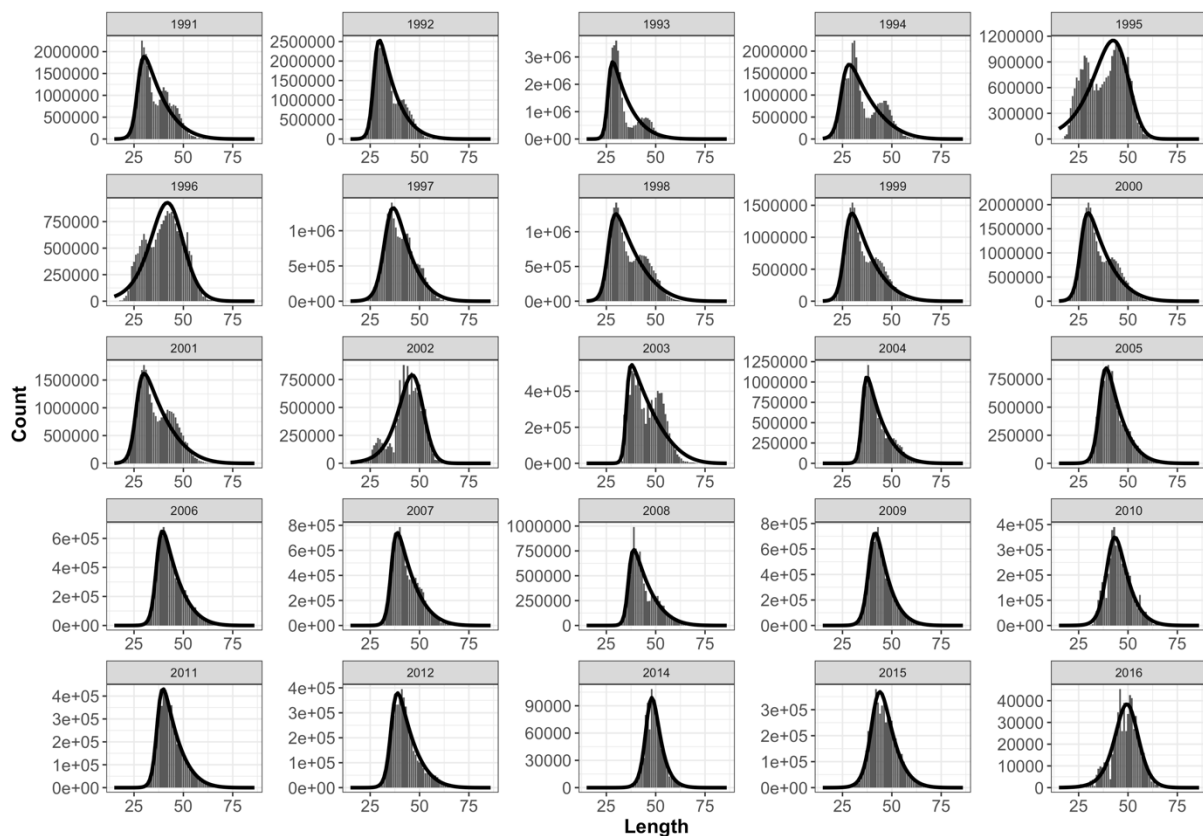

Figure 5 : Length-frequency histograms with fitted size composition curves by the LBSPR model

Figure 6 shows the variation of observed and fitted values of sizes selectivity (SL_{50} and SL_{95}) with a slightly increasing trend over years for all the cases (from ~30 cm to ~44 cm for SL_{50} and from ~37 cm to ~51 cm for SL_{95}), except the 4_{max} and 6_{med} scenarios that did not work.

At the beginning of the sampling (1991), the estimated selectivity length-at-50% was very low compared to the length-at-first-maturity (represented by the lower horizontal bound of the beige area in Figure 6). Then, SL_{50} started to increase a little bit throughout years until being above L_{50}, especially for the cases 3_{min} to 6_{max}. Considering the *M. polli* growth scenarios (1_{min} to

2_{max}), SL_{50} was always below L_{50} for the entire time-series (the red line always being below the beige area), while for the *M. senegalensis* growth cases 3 (min to max) and 5 (min to max), SL_{50} was above L_{50} for the last five years. The similar observation was done for the scenarios 4 and 6 in which $SL_{50} > L_{50}$ for the last three and six years, respectively.

SL_{95} (blue dash line) also followed the same pattern as SL_{50} except that it became greater than L_{50} from the early period (1994) to the end for the case 3, 5 and 6 (from min to max, each). SL_{95} was also above L_{50} for the 2012-2016 period for the scenario 1 (min to max). The cases 2 (min to max) showed a selectivity size at 95% smaller than L_{50} from 1991 to 2009 before the situation reversing from 2010 onwards. Similarly, the 4th scenarios (min and median) exhibited SL_{95} values higher than L_{50} for only the last decade.
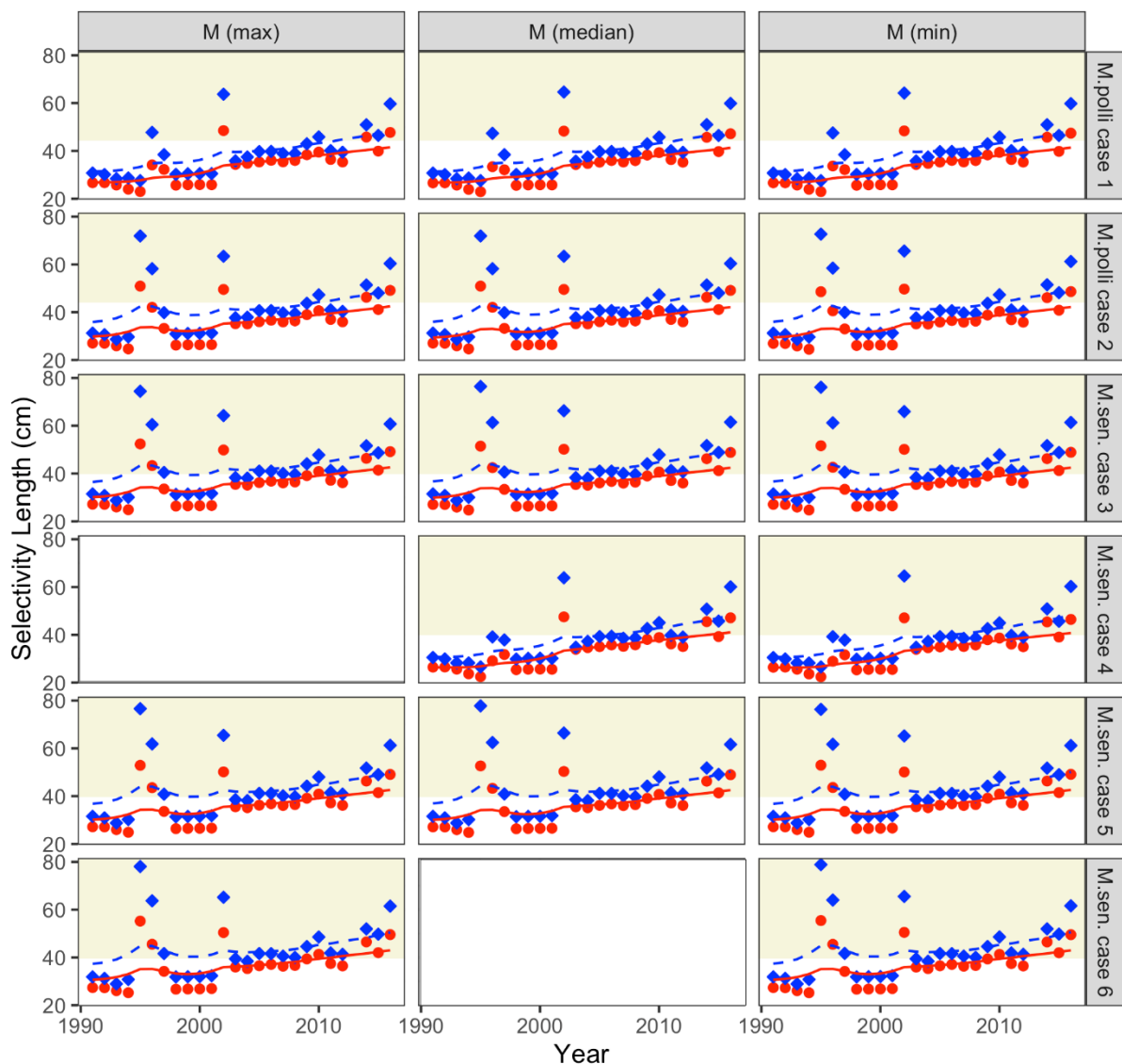
Figure 6. Interannual variation of selectivity lengths according to each growth scenario: blue diamond and red dots represent the observed SL_{50} and SL_{95}, respectively; whereas the blue and red lines are their fitted values. The beige area represents the mature individual sizes (above L_{50}) while the white are immature sizes. The life history ratios for *M. polli* and *M. senegalensis* are used in the cases (1 – 2) and (3 – 6), respectively.

Whatever the scenario considered, interannual variabilities of relative fishing mortality rates (F/M) were observed with at least one or two highly "unrealistic" values of F/M in 1995 and 2002 (Fig. 7). The fitted F/M curves were trendless for all the cases and the entire series and one can notice a slight increase of relative fishing mortality for the first period (1991-1995) followed by a decreasing trend from 1995 to 2002 and before finishing with a little increase.

Considering the maximum scenarios, the F/M ratios were low for the 1st, 2nd and 3rd cases compared to 5th and 6th where F/M curves were higher and attained the mark 5 in 1995, 2002 and 2016. For the median values, F/M < 5 for the 1st and 4th cases, otherwise it exceeded the value of 5 for the other cases, especially for the 5th one (nearing the value 10). The same pattern was observed for the minimum cases for which the ratio F/M were below 5 for only 2 scenarios (1st and 5th), in the other cases, F/M > 5.
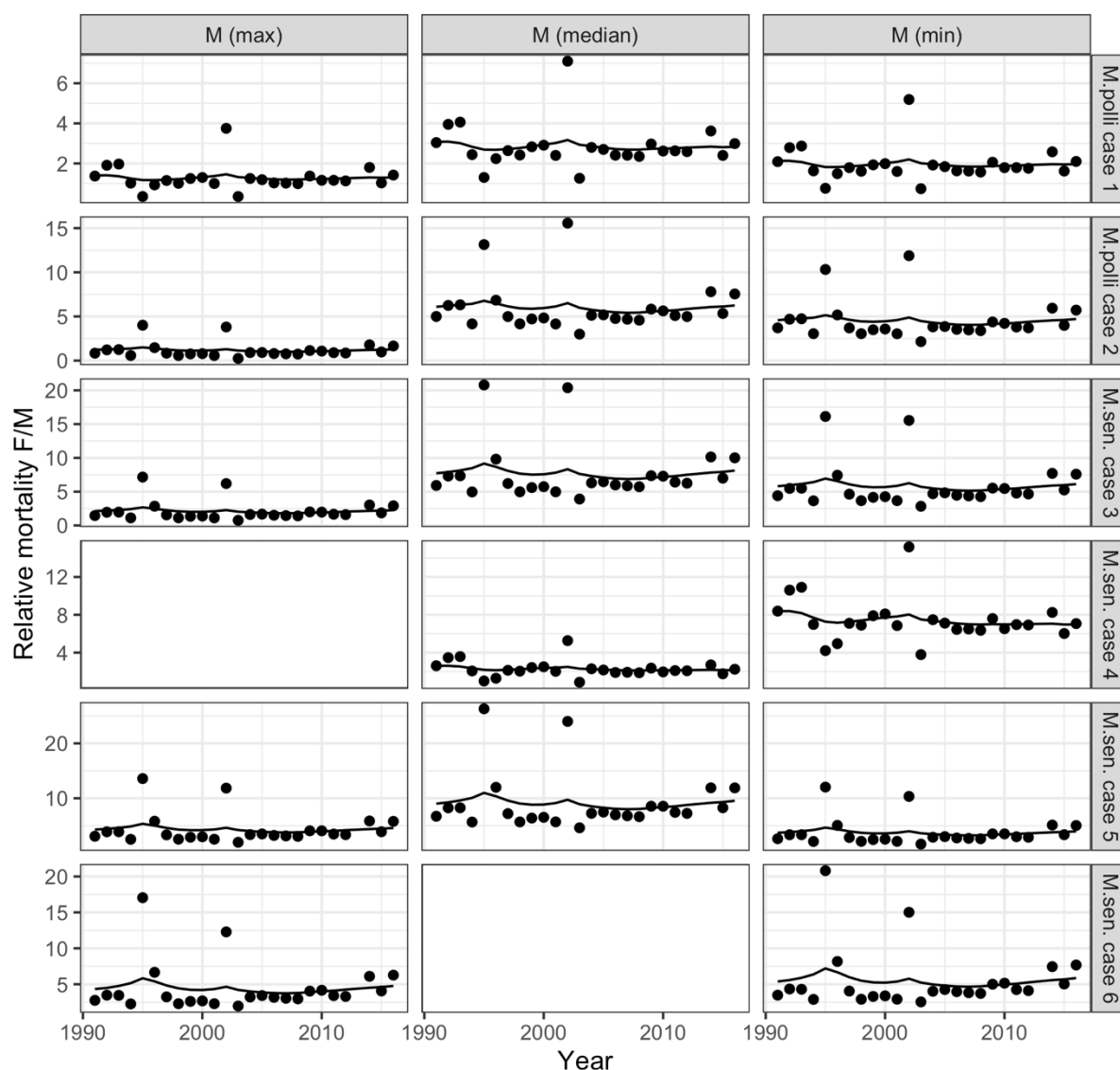

Figure 7. Variation of relative fishing mortality (F/M) throughout years for the 18 scenarios.

The results of LBSPR assessments based on the scenarios of variating the species life history parameters and the corresponding M/k ratios (min, median and max) indicated that the SPR model fit well to the data, except those of 4_{max} and 6_{med} (Fig. 8). These two cases failed to fit the model because of a high M/k (3.72) for the first and a combination of low M/k (0.76) and high L_∞ (116) for the second

Regarding the general trend of the SPR curves, they were very low at the beginning of the sampling period, then increased over time with a year-to-year variability, depending on the exploitation rate, with exception of the 2_{max} (Figs. 7 and 8). In other words, the lower the relative mortality rates (F/M), the higher the SPR outputs become (see cases 1_{max}, 2_{max}, 3_{max} and 4_{med}).

The minimum value of M/k ratios resulted in SPR being lower than the limit reference point (0.2 or the red area) for the whole series and for 5 cases (from 2 to 6). Only in the 1st case SPR > 0.2 but for just the last three-four years. The median M/k values were also similar (SPR < 0.2 for the entire series) except for the 4th case in which the SPR curve remained in the yellow area (0.2 < SPR < 0.4) since 2008. The maximum M/k values were the more optimistic cases compared to the previous ones; only two scenarios (5th and 6th) exhibited very low SPR estimates related to F/M ≥ 5. In the other maximum cases, the SPR curves were in the yellow area, at least from the second half period.
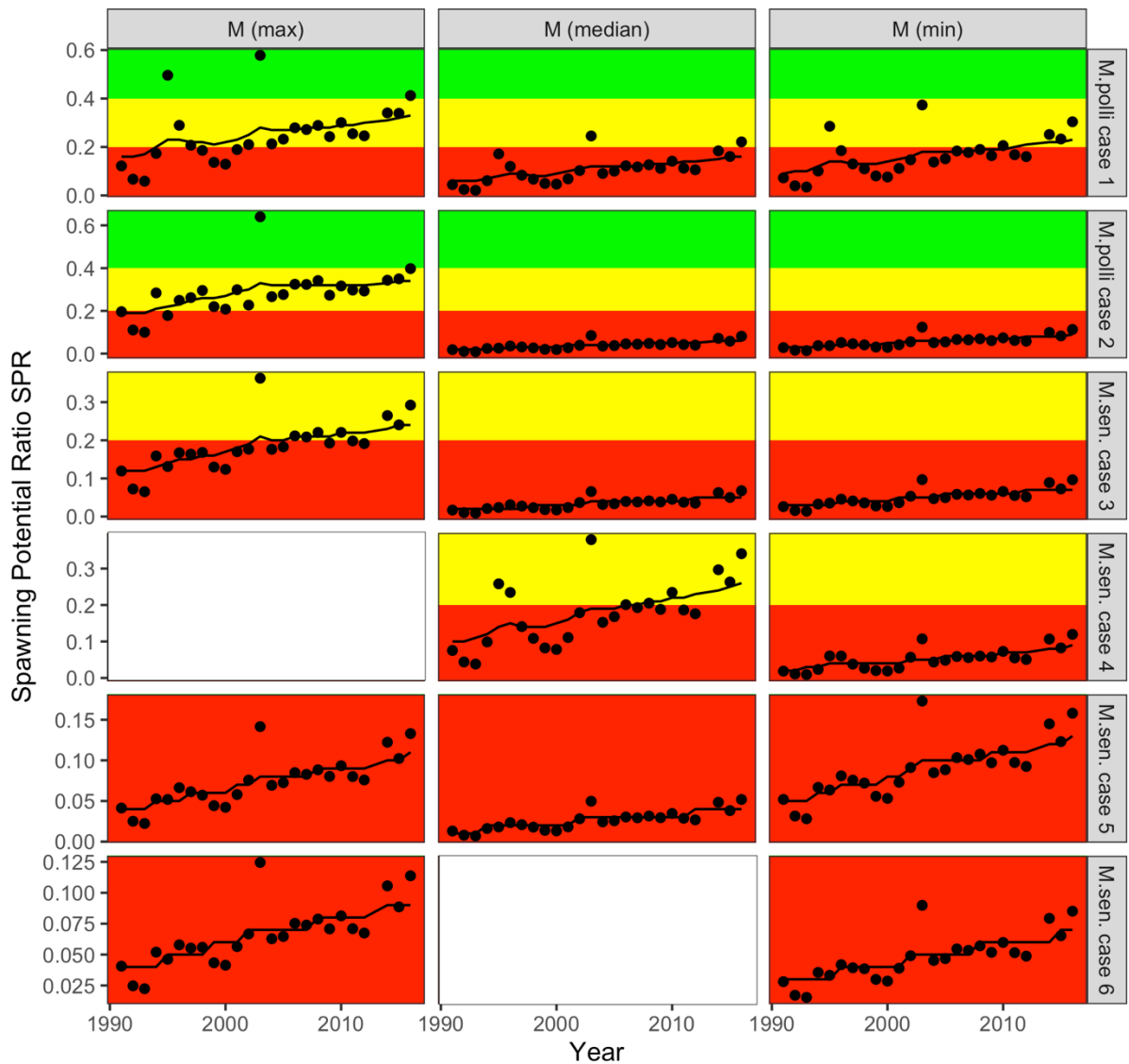
Figure 8: Year-to-year variability of Spawning Potential Ratio SPR depending on the scenarios (1 to 18) : the "red stripe" or "dangerous zone" refers to SPR value being below the Limit Reference Point (LRP = 0.2) ; while in the "yellow stripe", the SPR value is between the LRP and the Target Reference Point (TRP = 0.4) and in the "green stripe" or "safe zone" the SPR value is above the TRP.

Table 5 summarizes the results of the last year (2016) of LBSPR model scenarios. SL_{50} and SL_{95} estimates were respectively smaller than L_{50} and L_{95} values for *Merluccius polli* (scenarios 1 and 2, from min to max); but the opposite was noted for the *Merluccius senegalensis* cases ($SL_{50} > L_{50}$ and $SL_{95} > L_{95}$). In fact, the selectivity estimates SL_{50} range from 41.3 to 42.5 cm and SL_{95} from 48.5 to 49.7 cm with regard to the *M. polli* 50 and 95% lengths at maturity set at 44.2 and 53.3 cm, respectively. While for *M. senegalensis*, the selectivity sizes at 50% varied from 40.8 to 43 cm and SL_{95} from 48.3 to 50.6 cm when the lengths at 50 and 95% were equal to 39.7 and 45 cm, respectively.

Depending on each case, the ratio F/M varied from low value 1.27 to very high 8.12, which led to fishing mortality rates F being between 0.27 and 1.12. Within the species, F/M ranged from 1.27 to 6.25 for *M. polli* and from 2.15 to 8.12 for *M. senegalensis*. While considering both species, F/M values were smaller than 5 for all maximum cases (F/M varying from 1.27 to 4.76) and two minimums (1_{min} and 5_{min}) and two medians scenarios (2_{med} and 4_{med}).

The spawning potential ratio results varied across and within species life history parameters. For *M. polli*, SPR were below the limit reference point LRP (0.2) when M/k < 1, L_∞ low (64.4 and 76.5 cm) and F/M > 2 (see Table 4, scenarios 1_{med}, 2_{min} and 2_{med}). In contrast, when M/k were between 1 and 2.5, same L_∞ but F/M < 2 (1_{min}, 1_{max} and 2_{max}), the SPR appeared to be between the limit and the target reference points TRP (0.2 < SPR < 0.4).

The results were different regarding *M. senegalensis* cases (3 to 6): the ranges of L_∞ are wider (from 61.4 to 116), more or less the same range of M/k ratios as *M. polli* but much more bigger values for F/M (from 2.15 to 8.12). SPR were between LRP and TRP for only two cases (3_{max} and 4_{med}); otherwise, the spawning potential ratio was very low (SPR < 0.13) and suggesting a severe recruitment overfishing.

Table 5: LBSPR model outputs for the last year (2016) according to different scenarios of input values of M/K (minimum, median and maximum), maturity (L_{50} and L_{95}) and growth parameters (L_∞ and k). MP stands for *Merluccius polli* and MS, *Merluccius senegalensis*.

Species	Scenario			M/k	k	L_∞	L_{50}	SL_{50}	L_{95}	SL_{95}	F/M	F	SPR
MP	1	min		1.01	0.394	64.4	44.2	41.4	53.3	48.5	1.96	0.78	0.23
		median		0.77	0.394	64.4	44.2	41.3	53.3	48.5	2.83	0.86	0.16
		max		1.32	0.394	64.4	44.2	41.5	53.3	48.5	1.30	0.68	0.33
	2	min		0.97	0.0838	76.5	44.2	42.2	53.3	49.7	4.71	0.38	0.09
		median		0.76	0.0838	76.5	44.2	42.1	53.3	49.7	6.25	0.40	0.06
		max		2.51	0.0838	76.5	44.2	42.5	53.3	49.4	1.27	0.27	0.34
MS	3	min		1.04	0.171	85.2	39.7	42.5	45	50.0	6.12	1.09	0.07
		median		0.81	0.171	85.2	39.7	42.4	45	50.1	8.12	1.12	0.05
		max		2.30	0.171	85.2	39.7	42.6	45	49.8	2.26	0.89	0.24
	4	min		0.29	0.24	61.4	39.7	40.8	45	48.3	6.98	0.49	0.09
		median		0.76	0.24	61.4	39.7	41.1	45	48.3	2.15	0.39	0.26
		max		**3.72**	0.24	61.4	39.7		45				
	5	min		1.71	0.14	90	39.7	42.6	45	50.1	3.97	0.95	0.13
		median		0.80	0.14	90	39.7	42.3	45	49.9	6.83	1.07	0.07
		max		1.52	0.14	90	39.7	42.6	45	50.1	4.58	0.97	0.11
	6	min		2.08	0.068	116	39.7	43.0	45	50.6	5.86	0.83	0.07
		median		**0.79**	0.068	**116**	39.7		45				
		max		2.48	0.068	116	39.7	43.0	45	50.5	4.76	0.80	0.09

5 DISCUSSION

5.1 Stock status

The stock assessments using the Catch-MSY model showed that the black hakes stock have a high carrying capacity (K > 250,000 tonnes) and a B_{MSY} around 140,000 tonnes for the least scenario. However, the intrinsic growth rates were very low (0.11 to 0.29), as well as the maximum sustainable yields which were around 3 to 7% of the carrying capacity. The current catch represents about 39 to 61% of MSY, depending on the scenarios, which highlights a decrease in catches compared to the early period of exploitation (Fig. 4a). The ratio of B_{cur}/B_{MSY} ranged between 110 and 129%, while F_{cur}/F_{MSY} varied between 32 and 53%. These results were similar to those of FAO (2018) using Biodyn model (B_{cur}/B_{MSY} = 126% and F_{cur}/F_{MSY} = 124%) except that our current fishing mortality was below the fishing mortality at MSY. During the FAO (2018) working group, several stock assessment models have been used and resulted in B_{cur}/B_{MSY} being between 95 and 163% whereas F_{cur}/F_{MSY} ranged between 113 and 313%.

The sensitivity analyses showed that the estimations of MSY were closely related to the priors of r (low or medium resilience) and the lower bounds of K when the resilience is medium (MSY ≈ 19,800 tonnes). The estimations of the carrying capacity seem to be mainly influenced by the priors of the lower bounds of K (maximum catch of the series) then by the resilience, contrarily to the intrinsic growth rate estimates which are likely to be the opposite (resilience first, then the lower bounds of the priors of K). Since the choice of setting the upper bound for K depends on the knowledge of the stock and expertise (Chrysafi and Jørgensen, 2014), several scenarios were tried but the results seemed not affected by the variation of the upper bound of prior K.

These findings suggest a decline in fishing mortality through time resulting in lower fishing effort in the recent period. In fact, the black hakes stock in the northern-west African coasts (Morocco, Mauritania and Senegal) has been exploited by domestic and foreign trawlers and longliners under fishing agreements (especially the Spanish fleet). This latter has changed its fishing strategy by reducing the number of operating vessels and fishing trips in the area and by fishing deeper (up to 1 000 m) as a result of strict conditions imposed by the Fisheries Partnership Agreement (FPA) in 1998 (Fernández-Peralta et al., 2011; FAO, 2012; 2018). The prohibition of landing small individuals (< 30 cm TL) in the FPA and the relatively low market price of black hake compared to the European hake has strongly impacted the black hakes fishery, thus changing the historic trends of the catch series (FAO, 2018).

For the LBSPR assessments, overfishing recruitment (SPR < 0.2) occurred in 11 scenarios where the spawning potential ratio appeared too low as a consequence of high relative fishing mortality ratios F/M and low or very high M/k ratio. SPR were above the limit reference point LRP of 0.2 in only 5 cases, but did not reach the target reference point TRP (SPR_{TRP} = 0.4) considered as a proxy of MSY. The model failed to fit the data in two cases: in the first one the M/k ratio was very high (3.72) and in the second M/k ratio was low but L_∞ very high.

The results also suggest that the closer the individual sizes to L_∞, the greater SPR estimates are. The maximum individual class size (86 cm) was greater than four L_∞ values provided by literature review. In contrast, very high estimates of L_∞ and/or low M/k ratios resulted in low SPR (< 20%) at which recruitment impairment is likely and F/M exceeding the upper bound of 5 set by Prince et al. (2015). Considering only F/M ≤ 5 as suggested by these latter, the SPR estimates range between 0.09 and 0.34.

5.2   Catch-MSY vs LBSPR

The two models used in this study are both data-limited models but differ greatly in the data required for its use. Based on the Schaefer function, the Catch-MSY method is a surplus production model which only requires as inputs a catch time series, a measure of the resilience of the species (categorized in four: "very low", "low", "medium" and "high"), and priors on the carrying capacity and the biomass depletion at the beginning ang the end of the series. With these inputs, the Catch-MSY model estimates the biological reference points such as the maximum sustainable yield MSY and its corresponding biomass B_{MSY} and fishing mortality F_{MSY}.

However, the model does not take into account the age structure of the stock, the variabilities in recruitment process and individual growth of fish and its vulnerability to fishing gears (Hilborn and Walters, 1992; Haddon, 2011). The model also assumed the carrying capacity and intrinsic growth rate of the stock to be constant over time regardless the environmental variations. Since the thermal ranges of black hakes is wide (between 5.9 and 17.7°C) and they can dive up to 1000 m (Fernandez-Peralta et al., 2017; Manchih *et al.* 2018), the environmental conditions may influence the carrying capacity and the intrinsic growth rate. Even these authors suggested that the climatic variability could affect the interannual variation in abundance.

Although simple to use, the Catch-MSY model also assumed the stock to be close to immigration and emigration. The distribution of the black hakes is known to be extensive from southern Moroccan coast to southern Senegal for *M. senegalensis* and to Namibia for *M. polli* (Inada, 1981; Cohen et al., 1990; Lloris et al., 2003; Ramos and Fernández-Peralta, 1995; Fernandez-Peralta et al., 2011, 2017; Manchih et al., 2018), which may suggest a possibility of sub-stocks or several scattered small units of stock since very few individuals are caught in the Gulf of Guinea (the central part of *M. polli* distribution).

For the LBSPR model, instead of catch data, length composition of catches is needed along with different life history parameters such as L_∞, the ratio M/k, L_{50} and L_{95} to estimate the spawning potential ratio (SPR), the relative fishing mortality (F/M) and the selectivity-at-length parameters (SL_{50} and SL_{95}). However, it relies on several assumptions among which: (1) the growth and natural mortality rates are supposed to be constant throughout generations, (2) the growth curve is modeled by the von Bertalanffy equation without sex discrimination, (3) the female length-at-maturity parameters are used and (4) the length composition is assumed to have a normal distribution while the selectivity ogive is described using a logistic curve.

In our work, we ran this model several times according to the data, the different life history parameters published for the black hakes through scientific literature and the scenarios implemented to see if the model outputs will remain constant or not and what factor mostly influences the results.

The sensitivity analyses suggest that the LBSPR model was very sensitive to high M/k, low M/k combined to very high L_∞ and high variabilities in recruitment. According to Prince et al. (2015), L_∞ is the main source of uncertainties and the most important determinant of LBSPR assessment, followed moderately by the misspecification of M/k, whereas the sizes at maturity have little effects on the estimations. These authors also stated that the SPR value was strongly influenced by the largest fish size in the sample and a high estimate of SPR will be obtained if the sizes of fish in the sample are big enough to approach L_∞; conversely when a small portion of fish exceed the lengths at maturity, a very low estimate of SPR will be predicted.

Furthermore, the fact that high proportion of fish sizes smaller than the sizes at maturity for both species were found in catches, except for the last three years may result in a shift of sizes at selectivity (SL_{50} and SL_{95}) of fishing gears. In fact, at the beginning of the sampling, the fishing gears were less selective compared to now (an increasing trend of size selectivity can be noticed). The trawl mesh size has been increased to 70 mm and a minimum landing size set at 30 cm by the Fisheries Partnership Agreement between EU and the coastal countries to adapt to the evolution of the fishery and prevent an overexploitation of the stock of black hakes (FAO, 2018).

6   CONCLUSION AND RECOMMENDATIONS

In this work, two data-limited models have been used to assess the stock status and the biological reference points of the black hake stock in the northwest African coasts. These models are simple to use but require catch data, information about species' life history parameters, several hypotheses and scientific knowledge about the fishery. When the Catch-MSY model only needs catch data (in metric tonnes), species resilience and priors about carrying capacity and biomass depletion, the Length-Based Spawning Potential Ratio (LBSPR) is more demanding in inputs. Besides the length composition of catch, this technique requires further knowledge regarding the life history parameters (L_∞, k and M) and the lengths at maturity (L_{50} and L_{95}).

The Catch-MSY model estimated biological reference points (MSY, B_{MSY} and F_{MSY}) to be around 22 500 tonnes in average, 212,000 tonnes and 0.12, respectively, considering all scenarios. The mean ratios of B_{cur}/B_{MSY} and F_{cur}/F_{MSY} were 121% and 42%, respectively, which suggest that the stock was not fully exploited as already mentioned in FAO (2018). The final estimations of r, MSY and F_{MSY} seems to be low and show less variabilities compared to the final and high estimates of K and B_{MSY} whatever the scenarios run. We would except difficulties for the stock to maintain its level considering the low to medium resilience of the species, but the high carrying capacity may allow the stock to stabilize or increase the catches as seen in mid-2000s period onwards.

In the LBSPR model, the results suggest that 12 of the 18 cases, SPR value for the last year is less than 20%, the limit of recruitment overfishing. The LBSPR model has been described to be very sensitive to the estimate of L_∞ but still robustly predicts SPR estimates, whereas F/M and selectivity parameters (SL_{50} and SL_{95}) are poorly estimated (Hordyk et al., 2014b). These latter can lead to confusion when fitting the data because very high selectivity sizes and relative fishing mortality ratios have the same results than the realistic values (Prince et al., 2015). Furthermore, poor quality data and input parameters can add uncertainties to the estimation of LBSPR parameters (Hordyk et al., 2014b; Prince et al., 2015).

Since the life history parameters of a species which is being assessed come generally from the synthesis of the scientific literature, Prince et al. (2015) drew attention to the fact that some growth parameters estimates of can be doubtful and advised their re-estimation or the use of a professional judgment to decide whether they are reliable or not before using them as inputs. The authors also suggested the use of the life history ratios (M/k and L_{50}/L_∞), if available, because of their stability across species' range instead of the individual life history parameters which may vary with environment changes and population densities (Beverton and Holt,1959; Prince et al., 2014 & 2015). These parameters must be used cautiously either in LBSPR or

Catch-MSY model because of the several assumptions required. Nevertheless, LBSPR model remains a powerful and easy tool to estimate SPR, especially for data-poor fisheries.

All the biological parameters which is used in this study was drawn from literature review and dated back more than 30 years ago; and on this basis, the stock status of black hakes (*Merluccius spp.*) was given. The information regarding the life history parameters (L_{50}, L_{95}, k, L_∞, and t_0) and natural mortality rate M should be updated for each species, especially for L_∞ (more influential parameter in LBSPR model), based on a good sampling protocol covering the whole stock in order to better estimate the spawning potential ratio SPR and other outputs.

As a precautionary approach, it would be good to reduce both the catch and the fishing effort regarding the black hakes exploitation insofar as there is a recent development of a national fleet targeting these species combined to the EU fleet operating in northwest African EEZs under agreement. This study also recommends fisheries departments of each country to clearly identify and separate the two species when collecting data (catches, effort, CPUE and length frequencies) which could help scientists to assess them individually and give management advices based on accurate data for the sustainability of the stocks.

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REFERENCES

Alheit J, Pitcher TJ (eds) .1995. Hakes: biology, fisheries and markets. Fish fisheries series 15. Chapman and Hall, London.

Alverson, D.L. and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. Journal du Conseil International pour l'Exploration de la Mer. 36:133-143.

Beverton RJH, Holt SJ. 1959. A review of the lifespans and mortality of fish in nature and the relation to growth and other physiological characteristics. Ciba Found. Colloquium Ageing 5, 142–177.

Boukatine P. 1986. Les ressources biologiques du talus continental mauritanien. FAO COPACE/PACE Série 86(37):147–170.

Bourdine, J., 1986. Quelques aspects biologiques des stocks de merlus dans la division statistique du Sahara littoral (34.1.3). p. 121-138. *In* Rapport du groupe de travail spécial sur les pêcheries de merlus et de crevettes profondes dans la zone nord du COPACE. COPACE/PACE Série 86/33.

Caverivière A, Thiam M, Thiam D, López Abellán L (1986) Rapport de synthèse des quatre campagnes conjointes hispano-sénégalaises de chalutages sur les stocks profonds du Sénégal (1982–1984). Archives Centre de Recherches Oceanographique, Dakar-Thiaroye 151.

Cervantes A, Goñi R .1985. Descripción de las pesquerías españolas de merluzas y crustáceos de África Occidental al norte de Cabo Blanco. In: Bas C, Margalef R, Rubies P (eds) International symposium on the most important upwelling areas off Western Africa, vol 2. Instituto de Investigaciones Pesqueras, Barcelona, pp 825–850.

Charnov EL, Gislason H, Pope JG. 2013. Evolutionary assembly rules for fish life histories. Fish and Fisheries. 14:213-224.

Cohen DM, Inada T, Iwamoto T, Scialabba N. 1990. FAO species catalogue. Vol. 10. Gadiform fishes of the world (Order Gadiformes). An annotated and illustrated catalogue of cods, hakes, grenadiers and other gadiform fishes known to date. FAO Fish. Synop. 125(10). Rome: FAO. 442 p.

Doutre, M., 1960. Les merlus du Sénégal. Mise en évidence d'une nouvelle espèce. Rev. Trav. Inst. Pêches Marit. 24(4):513-536.

FAO. 1979. Rapport du groupe de travail ad hoc sur les merlus (*Merluccius merluccius, M. senegalensis, M. cadenati*) dans la zone du COPACE. Comité des Pêches pour l'Atlantique Centre-est. COPACE/PACE Séries 90/51. 93 p.

FAO. 1990. Rapport du groupe de travail sur les merlus et les crevettes d'eaux profondes dans la zone Nord du COPACE dans la zone du COPACE. Comité des Pêches pour l'Atlantique Centre-est. COPACE/PACE Séries 78/9.

FAO. 2012. Report of the FAO/CECAF working group on the assessment of demersal resources-subgroup North. Agadir, Morocco, 8–17 Feb 2010. FAO CECAF/ECAF Series 11/72, Rome. 302 p.

FAO. 2018. Report of the FAO/CECAF Working Group on the Assessment of Demersal Resources – Subgroup North. Tenerife, Spain, from 6 to 15 June 2017. CECAF/ECAF Series. No. 18/78. Rome. 502 p.

Fernández-Peralta L, Salmerón F, Rey J, Puerto MA, García-Cancela R. 2011. Reproductive biology of black hakes (*Merluccius polli* and *M. senegalensis*) off Mauritania. Cienc Mar 37 (4B):527–546

Fernández Peralta L., Quintanilla L. F., Rey J. 2017. Overlapping distribution of two sympatric species: the case of black hakes, *Merluccius polli* Cadenat 1960 and *Merluccius senegalensis* Cadenat 1960, off Mauritania. *In*: Deep-sea ecosystems off Mauritania: researching marine biodiversity and habitats in West African deep. Ramos A., Sanz J. L., Ramil F. (eds), Springer, Dordrecht, Netherlands, pp. 241-275.

Gislason, H, Daan N, Rice JC, Pope JG. 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries 11:149-158.

Haddon M. 2011. Modeling and quantitative methods in fisheries. Chapman and Hall/CRC. 465p.

Hilborn R. and Walters CJ. 1992. Quantitative fisheries stock assessment: Choice, Dynamics and uncertainty. Springer; Har/Dskt edition. 570 p.

Hewitt, D.A. and J.M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin. 103:433-437.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin. 82:898-903.

Hordyk A, Ono K, Prince JD, Walters CJ. 2016. A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks. Can. J. Fish. Aquat. Sci. 13: 1– 13.

Hordyk, A.R., Loneragan, N.R., and Prince, J.D. 2015c. An evaluation of an iterative harvest strategy for data-poor fisheries using the length-based spawning potential ratio assessment methodology. Fish. Res. 171: 20– 32.

Hordyk, A.R., Ono, K., Sainsbury, K.J., Loneragan, N., and Prince, J.D. 2015a. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. ICES J. Mar. Sci. 72: 204 - 216.

Hordyk, A.R., Ono, K., Valencia, S.R., Loneragan, N.R., and Prince, J.D. 2015b. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES J. Mar. Sci. 72: 217 – 231.

Inada T. 1981. Studies on the Merluccid fishes. Bull. Far Seas Fish. Res. Lab. 18: 172 pp.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences. 53:820-822.

Jensen, A.L. 2001. Comparison of theoretical derivations, simple linear regressions, multiple linear regression and principal components for analysis of fish mortality, growth and environmental temperature data. Environometrics. 12:591-598.

Jørgensen, OA, Chrysafi, A. 2014. MSY from catch and resilience. Paper presented at 33rd Scientific Council Research Meeting NAFO, Nova Scotia, Canada. NAFO SCR Doc.14/021, Serial No. N6316, 29p.

Jones, R. 1984. Assessing the effects of changes in exploitation pattern using length composition data in fish stock assessments (with notes on VPA and cohort analysis). FAO Fisheries Technical Paper 256.

Kenchington TJ. 2014. Natural mortality estimators for information-limited fisheries. Fish and Fisheries. 14:533-562.

Lloris, D., Matallanas, J., Oliver P. 2003. Hakes of the world (Family Merlucciidae). An annotated and illustrated catalogue of hake species known to date. FAO Species Catalogue for Fishery Purposes. No. 2. Rome. 57p.

Mace P, Sissenwine M. 1993. How much spawning is enough? Risk evaluationand biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120, 101–118.

Manchih K, Fernández Peralta L, Bensbai J, Najd A, Bekkali M. 2018. Distribution of black hakes *Merluccius senegalensis* and *Merluccius polli* along the Moroccan Atlantic coast. AACL Bioflux 11 (1): 245-258.

Martel S, Froese R. 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries,14: 504-514.

Froese R, Demirel N, Coro G, Kleisner KM, Winker H. 2017. Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18, 506–526.

Meiners C, Fernández-Peralta L, Salmerón F, Ramos A. 2010. Climate variability and fisheries of black hakes (*Merluccius polli* and *Merluccius senegalensis*) in NW Africa: a first approach. J Mar Syst 80:243–247.

Ogle, D.H. 2016. Introductory Fisheries Analyses with R. Chapman & Hall/CRC, Boca Raton, FL.

Overko S, Boukatine P, Ly B .1986. Quelques données sur les merlus de la zone économique mauritanienne. FAO COPACE/PACE Séries 86(33):187–201.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal du Conseil International pour l'Exploration de la Mer. 39:175-192.

Prince JD, Victor S, Kloulchad V, Hordyk A. 2015. Length based SPR assessment of eleven Indo-Pacific coral reef fishpopulations in Palau. Fisheries Research 171: 42–58.

Prince JD, Hordyk A, Valencia SV, Loneragan N, Sainsbury K. 2015. Revisiting the concept of Beverton–Holt life-history invariants with the aim of informing data-poor fisheries assessment. ICES Journal of Marine Science, 72: 194 - 203.

Ramos-Martos A, Fernández L. 1995. Biology and fisheries of North-west African hakes (*M. merluccius*, *M. senegalensis* and *M. polli*). In: Alheit J, Pitcher TJ (eds) Hake: biology, fisheries and markets. Fish fisheries series 15. Chapman and Hall, London, pp 89–124

Rey J, Fernández-Peralta L, Esteban A, García-Cancela R, Salmerón F, Puerto MA, Piñeiro C. 2012. Does otolith macrostructure record environmental or biological events? The case of black hake (*Merluccius polli* and *Merluccius senegalensis*). Fisheries Research 113:159–172.

Rey J, Fernández-Peralta L, García A, Nava E, Clemente MC, Otero P, Villar EI, Piñeiro CG. 2016. Otolith microstructure analysis reveals differentiated growth histories in sympatric black hakes (*Merluccius polli* and *Merluccius senegalensis*). Fish Res 179:280–290.

Rikhter, V.A., and V.N. Efanov. 1976. On one of the approaches for estimating natural mortality in fish populations (in Russian). ICNAF Research Document 76/IV/8, 12pp.

Then, A.Y., J.M. Hoenig, N.G. Hall, and D.A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science. 72:82-92.

Thiam N, Fall M, Diadhiou HD, Diop M, Thiam D, Barry S. 2009. Bioécologie et évaluation des stocks de merlus (*Merluccius* spp) au Sénégal. Rapport commission technique "Eco-biologie et évaluation des stocks démersaux profonds. MEMTMP/DPM/UE/CRODT, 28 p.

Thiam N, Fall M, Sylla M. 2014. Essai de discrimination des merlus noirs *Merluccius senegalensis* et *Merluccius polli*. Fiche technique. Centre de Recherches Océanographiques de Dakar-Thiaroye (CRODT/ISRA). BP 2241, Dakar, Senegal. 5p.

Thiaw M, Auger P-A, Ngom F, Brochier T, Faye S, Diankha O, Brehmer P. 2017. Effect of environmental conditions on the seasonal and interannual variability of small pelagic fish abundance off NorthWest Africa: The case of both Senegalese sardinella. Fisheries Oceanography 26:583–601.

Thompson WF, Bell FH. 1934. Biological statistics of the Pacific halibut fishery. 2. Effect of changes in intensity upon total yield and yield per unit of gear. Reports of the International Fisheries (Pacific halibut) Commission, 8: 49 p.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology 10:181–243.

Walters C, Martell SJD. 2004. Fisheries Ecology and Management. Princeton Uni-versity Press, Princeton, NJ, 399 p.

Wysokinski, A., 1986. Evaluation des stocks de merlus dans les divisions statistiques 34.1.3 et 34.3.1 du COPACE, basée sur les données polonaises (1966-1975). p. 72-85. In Rapport du premier groupe de travail spécial sur les pêcheries du merlus et de crevettes profondes dans la zone nord du COPACE/PACE Séries 86/33.

Zhang CI, Megrey BA. 2006. A revised Alverson and Carney model for estimating the instantaneous rate of natural mortality. Transactions of the American Fisheries Society. 135-620-633.