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Length based data-limited methods: Application on the Atlantic bonito, *Sarda sarda* (Bloch, 1793) in Morocco

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ABSTRACT

In Morocco, the Atlantic bonito is one of the most landed species on the South Atlantic, with an average catch of about 4,000t per year. To assess the stock of this species, a study was conducted addressing three models of *Sarda sarda* (Bloch,1793), based on size frequencies. Data were determined with respect to the series of size data collected during the period from 2014-2019. The species under study, specifically the spawning individuals were exposed to a continuous pressure over time. The LBSPR (Length bases spawning potential ratio) model displayed an exploitation rate of 69%, whereas the catch curve showed an exploitation rate of 68%. Interestingly, the most optimistic model length cohort analysis/yield per recruitment (LCA/YPR) recorded a 54% exploitation rate, which is still worrying.

INTRODUCTION

Morocco occupies a special geographical location with a double seafront; the Atlantic Ocean and the Mediterranean Sea. The presence of the upwelling phenomenon offers the country a real potential for the production of fishery resources including minor tunas (*Sarda sarda*, *Katsuwonus pelamis*, *Orcynopsis unicolor*...). In Morocco, fishing for minor tunas is performed using multiple gears with a very marked seasonality. The longline fleet, for example, moves constantly among various ports of the region. This movement is conditioned by the search for target species associated to different abiotic conditions and motivated by prices granted by fish merchants.

In Morocco, Atlantic bonito is the minor tuna species most captured using coastal longliners with an average catch rate of about 4000 tonnes per year. For this purpose, these coastal longliners can use different fishing gears. Gillnets are the utmost gear used to target bonito, catching over 95% of the total catches of the species. Despite the availability of some information on the investigated species in literature, catch statistics and knowledge of the biology of minor tunas remain highly fragmented and incomplete considering several areas, among which the Moroccan coast is considered. In addition, the state of knowledge is highly dependent on the species in question. Therefore, this situation has made it difficult for ICCAT to assess the exploitation status of minor or small tuna populations **(ICCAT, 2017)**.

The main objective of this study was to determine the current stock status of Atlantic bonito in the southern Atlantic coast of Morocco. To accomplish this, the length composition data were determined in accordance to the catch of the Moroccan fleet and the life history information available for the region.

MATERIALS AND METHODS

Length composition data can either be found in complex integrated stock assessment methods **(Methot & Wetzel, 2013)** or in simple methods with few assumptions to estimate stock exploitation status **(Hordyk *et al.*, 2015)**. **Cotter *et al.* (2004**) recommended the use of simple methods due to their visual appeal, simple statistical basis, minimal assumptions and the ease with which estimates can be derived from different data sets. Nevertheless, the simple length-based methods do not estimate absolute abundance, and the accuracy of the fishing mortality rates is doubtful since the true natural mortality (*M*) is unknown.

1. Study area

Samples addressed were collected at the pot of Dakhla during the period that extended from 2014 to 2019. The geographical coordinates of the study site are 23°39’33’’ N and 15°56’47’’ W (Fig. 1). This region of the Kingdom of Morocco is the one of the most important fishing areas in the world due to the phenomenon of upwelling, which is almost permanent **(Makaoui *et al*, 2000)**. To the North of Cap Boujdour, the water surface temperature fluctuates between 18.4 and 20°C. In the South of Cap Boujdour, the temperature varies between 18.4 and 21.6°C. The distribution of surface salinity corresponds to the temperature distribution, with 36.2-36.4 ppm in upwelling zone and 36.5-36.8 ppm in deeper waters (Fig. 2). The Atlantic bonito can adapt itself to temperatures ranging from 12 to 27°C and at salinities from 14 to 39 ppm **(Bianchi *et al.*, 1999)**.

2. Data

The length frequency data for Atlantic bonito during the period from 2014-2019 depended on the biological sampling conducted on a monthly basis at the ports of Dakhla, located south of Morocco where the landing of small tunas was recorded. Fish fork length (FL) was taken to the nearest centimetre using a graduated woody broad. The catch at size was estimated by raising the size frequency data to the total catch of the vessel and then to the total catch by port.

3. Methods

The methods used to assess the Atlantic bonito stock are based on size frequencies. In this study, three methods were used; namely,

- The Powell-Wetherall curve to estimate total mortality Z and the catch curve analysis and age splitting to assess vulnerability at age (selection model).

- Length Based Spawning Potential Ratio (LBSPR); the LBSPR package version 0.1.2 **(Hordyk, 2017)**.
- LCA, Length cohort analysis

Length-based methods can be either complex integrated stock assessment methods or simple methods with few assumptions. In a review of **Cotter *et al*. (2004)**, the authors recommended the use of simple methods because of their visual appeal, simple statistical basis, minimal assumptions and the ease with which estimates can be obtained from different data sets.

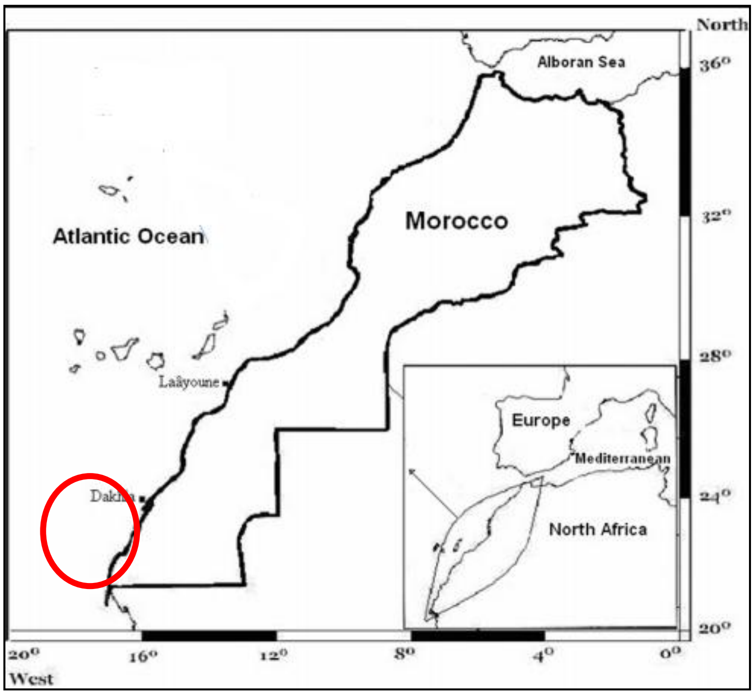

Fig. 1. Location of the study area

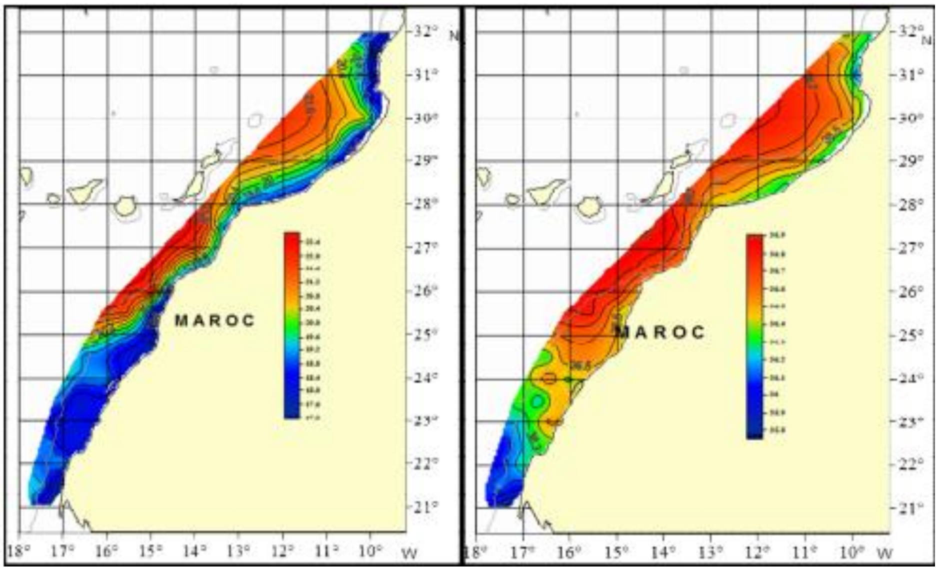

Fig. 2. Distribution of the surface temperature in °C (left) and salinity in Ppm (right) (Source: **(Atlantida, 2012)**

3.1. Powell-Wetheral method

Beverton and Holt (1956) developed a method for estimating total mortality (Z) from length data as follows:

$$Z = K\frac{L_\infty - \overline{L}}{\overline{L} - L'} \quad (1)$$

Z=Total mortality, K=Growth rate, L∞=Asymptotic length, L'= length for which all fish of that length and longer are under full exploitation, Lbar=Maximum length.

Based on this equation, **Powell (1979)** developed a method that was lately modified by **Wetherall *et al*. (1987)** for estimating growth and mortality parameters. This assumes that the length frequency distribution is determined by the asymptotic length (L∞); the ratio between Z and the growth rate K. The **Beverton and Holt** methods assume good estimates for K and L∞, whereas the **Powell -Wetherall** methods require only an estimate of K, since L∞ is estimated by the method as well as Z / K. The estimates of L∞ can be used as a form of validation; they match the literature values.

It is assumed that growth follows the von Bertalanffy growth function. Thus, growth rates remain constant across cohorts, and a single growth curve can be used to describe both sexes with equal catchability. Moreover, it is suggested that the population is in a steady state with constant exponential mortality. Hence, natural mortality rates are constant at older ages, and the fishery selection pattern does not change, in addition selection is asymptotic, and recruitment is constant.

In the **Powell-Wetherall** method, L 'can take any value between the smallest and largest sizes. Then, equation 1 provides a series of estimates of Z. Plot equation 2 provides an estimate of L and Z / K. If K is known, it also provides an estimate of Z; Where,

$$\overline{L} - L' = a + bL' \quad (2)$$

$$b = \frac{-K}{Z + K} \quad (3)$$

$$a = -bL_\infty \quad (4)$$

$$L_\infty = -a/b \quad (5)$$

$$Z/K = \frac{-1 - b}{b} \quad (6)$$

Z=Total mortality, K=Growth rate, L∞=Asymptotic length, L'= length for which all fish of that length and longer are under full exploitation, L bar=Maximum length, a& b=length-weight relationship parameters.

The catch curve can be fitted to a real or "synthetic" cohort that uses catch data from a single year or few years. If the proportion of fish aged (pa) denotes the fraction of the total catch corresponding to age a, a linear regression of pa can be fitted to an age range [α, β]. As is also the case for the year-class curve analysis, the slope of the regression can be used to estimate total mortality (Z). However, the method in the current study was used to estimate selectivity because of the known bias in the estimates of F obtained by age range.

Selectivity can thus be estimated from the ratio of observed to expected catch proportions, then rescaled so that the maximum is equal to 1. In other words, selectivity is maximum (equal to 1) when there is no difference between the observed and expected curves and it becomes smaller as the difference between the two curves increases.

3.2. LBSPR (length based spawning potential ratio)

To determine the status of the Atlantic bonito in the southern Atlantic coast of Morocco a length-based approach was used following the description of **Hordyk *et al.* (2015)** who named it Length-based Spawning potential ratio (LBSPR). The Spawning Potential Ratio (SPR) in an exploited population is a function of the ratio of fishing mortality to natural mortality (F/M), selectivity and the two life history ratios M/k and Lm/L∞; k is the von Bertalanffy growth coefficient, Lm is the size of maturity, and L∞ is the asymptotic size **(Hordyk *et al*., 2015)**. The inputs to the LBSPR are: M/ k, L∞, the variability of length-at-age (CVL1), which was set as 0.1 and the size of maturity specified in terms of L50 and L95, the size at which 50 and 95% of a population are determined as matures (Table 1). Given the assumed values of the M/k and L∞ parameters and length composition data from an exploited stock, the LBSPR model uses maximum likelihood methods to estimate the selectivity ogive, which is assumed to be a logistic curve defined by the selectivity-at-length parameters S50 and S95 and the relative fishing mortality (F/M), which are then used to calculate SPR **(Hordyk *et al*., 2015)**. LBSPR estimates a selectivity curve for each length sample. Estimates of SPR are primarily determined by the length of the fish in a sample, relative to the maturity and L∞. For example, if a reasonable proportion of fish in a sample attain lengths approaching L∞, estimates of F/M would be relatively low leading to a high estimate of SPR. However, the proportion of length samples near L∞ would vary with the life history parameters such as fecundity-at-age/length and selectivity. LBSPR is an equilibrium-based method with some underlying assumptions, including (i) asymptotic selectivity, (ii) growth adequately described by the von Bertalanffy equation, (iii) a single growth curve can be used to describe both sexes with equal catchability, (iv) length-at-age which is normally distributed, (v) rates of natural mortality constant across adult age classes, (vi) growth rates remain constant across the cohorts within a stock and (vii) constant recruitment **(Hordyk *et al*, 2015)**. In this study, the LBSPR package version 0.1.2 was used **(Hordyk, 2017)** for R.

A harvest strategy that targets a fishing mortality rate that is expected to result in 40% of the unfished spawning output (SPR40%) is considered a reasonable proxy of BMSY (biomass that enables a fish stock to deliver the maximum sustainable yield). SPR40% is sometimes considered a threshold beyond when the stock experiences overfishing **(Clark, 2002)**.

Table 1. Input parameters for LBSPR model

Parameter	Value	References
Asymptotic length L∞ (cm)	73	**Baibbat *et al*., 2020**
Growth rate, K (years^{-1})	0.31	**Baibbat *et al*, 2020**
Theorical age when size is zero, t_0 (years)	-2.45	**Baibbat *et al*, 2020**
Maximum age, Tmax (years)	5	**Baibbat *et al*, 2020**
Size of fist maturity, L50 (cm)	42.6	**Baibbat *et al*, 2020**
Natural mortality, M (years^{-1})	0.46	**Jensen 1996 method**

3.3. LCA (length cohort analysis) and YPR (Yield per recruitment)

A major element in the assessment of the status of fish stocks is the estimation of the abundance and structure of the stock (distribution of the individuals or biomass among different classes of age or size), as well as that of the level and pattern of fishing mortality. When data (estimates) on the distribution of the numbers of individuals captured per age-group are available (which presupposes being able to age the fish captured) a technique is often used, determining that 0 Virtual Population Analysis (VPA) or Cohort Analysis (CA). Sometimes these techniques are also called Sequential Population Analysis (SPA). When the age distribution of the catch is not available, it is possible to use the length distribution, making use of length as a proxy for age, converting from one to the other using growth equations. The method of Length Cohort Analysis (LCA) was first proposed by **Jones (1965)** for this situation.

The followings are the input data:

- Information on the length class groupings used (Lower limit of the smallest length class, Class interval and largest class with catch data)
- Growth parameters (of the Bertalanffy growth equation) adopted for the stock being analysed (tzero, L∞ and K)
- Parameters of the length-weight relation (a and b)
- Mortality parameters: (Natural mortality, M and Exploitation rate in last length class)

Thomson and Bell's LCA and yield per recruit (YPR) cohort analysis models were applied. The size data used is the average of size values determined in the years starting from 2014 - 2019 period. These two models used are described in **Sparre and Venema (1996)**. This choice is largely justified by the availability of a regular series of size frequencies collected during the sampling of this species in the port of Dakhla. The LCA model fit was performed using a natural mortality of the order of 0.46/year obtained by the Jensen method, based on a species longevity of the order of 5 years **(Baibbat *et al,* 2020)**. The Von Bertalanffy growth parameters used were: K=0.31/yr, Linf =73cm and Tzero=-2.45.

RESULTS

In order to establish a status of exploitation and stock of Atlantic bonito, which is subject to continuous fishing pressure over the years, several methods based on the available data, in particular size frequencies (Length based methods), have been addressed to develop exploitation indicators for this species.

1. Powell-Watheral method

The analysis estimated the total mortality (Z) considering a fishing mortality (F) of 0.46/year **(Baibbat *et al,* 2020)** and from the annual frequency series of Atlantic bonito obtained through the sampling of this species in Dakhla port collected between 2014 and 2019. The growth parameters used were estimated in the study of **Baibbat *et al,* (2020)** for the same stock as follows: K=0.31/year, $L\infty$=73.5cm and t0= -2.4469.

The size frequency distribution during the period 2014-2019 shows a dominance of individuals with a size between 45 and 55 cm exceeding 60% of the total catches. This proportion corresponds to spawning individuals that are under continuous fishing pressure (Fig. 3). The difference between the sizes and average sizes of the individuals caught is shown in Fig (4). The catch curve showed that when size increases, the individuals become more accessible to the fishery. This may explain the dominance of spawners and the absence of juveniles in the catches of Atlantic bonito (Fig 5). In addition, the catches at age are shown in Fig (6).

Table 2. Estimated Z/K values and corresponding F/Z rates

Year	Z/K	*L∞* (Asymptotic length)	Z (Total mortality)	M (Natural mortality)	F (Fishing mortality)	F/Z
2014	0.57	57.756	1.85	0.46	1.39	0.75
2015	0.27	56.835	0.86	0.46	0.40	0.47
2016	0.52	60.4361	1.69	0.46	1.23	0.73
2017	0.35	56.65454	1.13	0.46	0.67	0.59
2018	0.40	59.98873	1.29	0.46	0.83	0.64
2019	0.46	60.66847	1.47	0.46	1.01	0.69

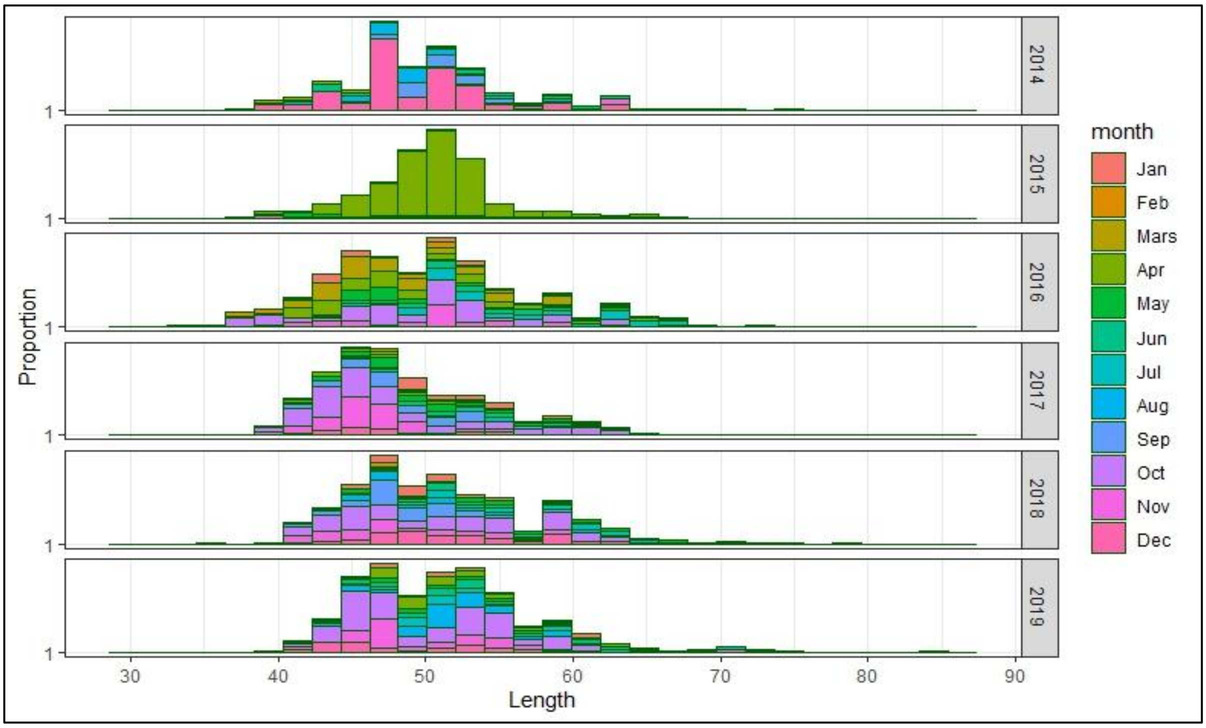

Fig. 3. Atlantic bonito size frequency distribution sampled during the study period (2014-2019)

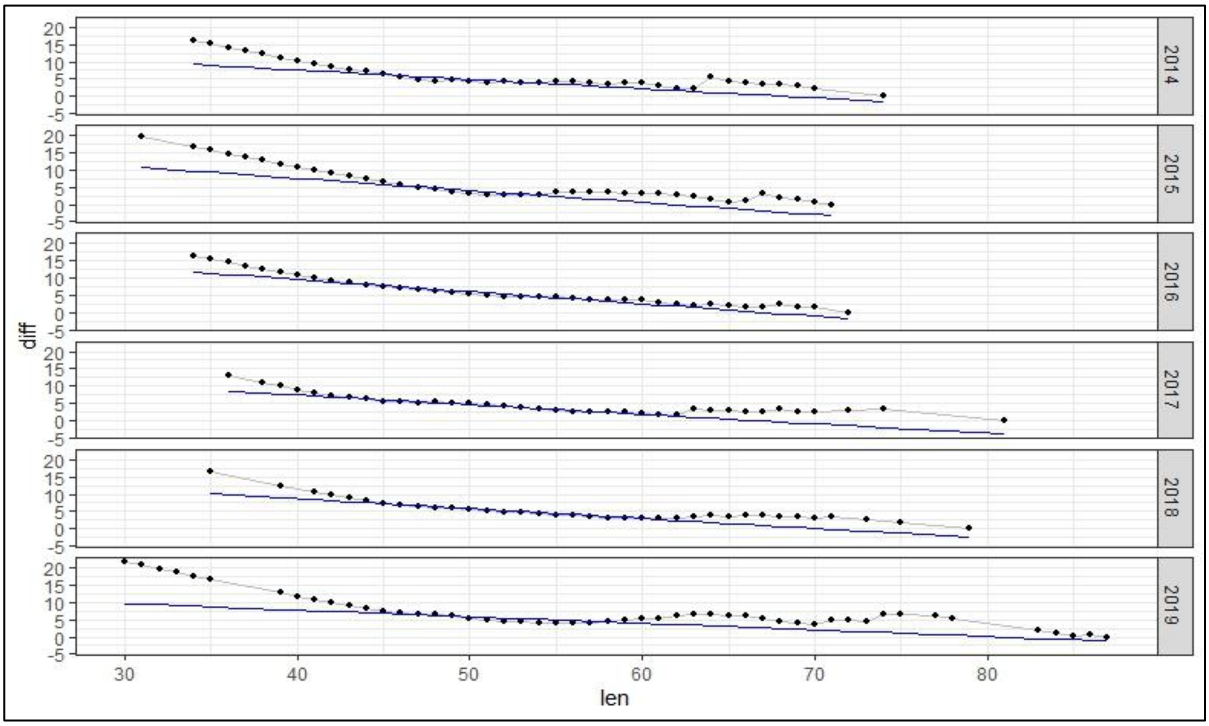

Fig. 4. A histogram sowing difference between sizes and average sizes during the study period (2014-2019)

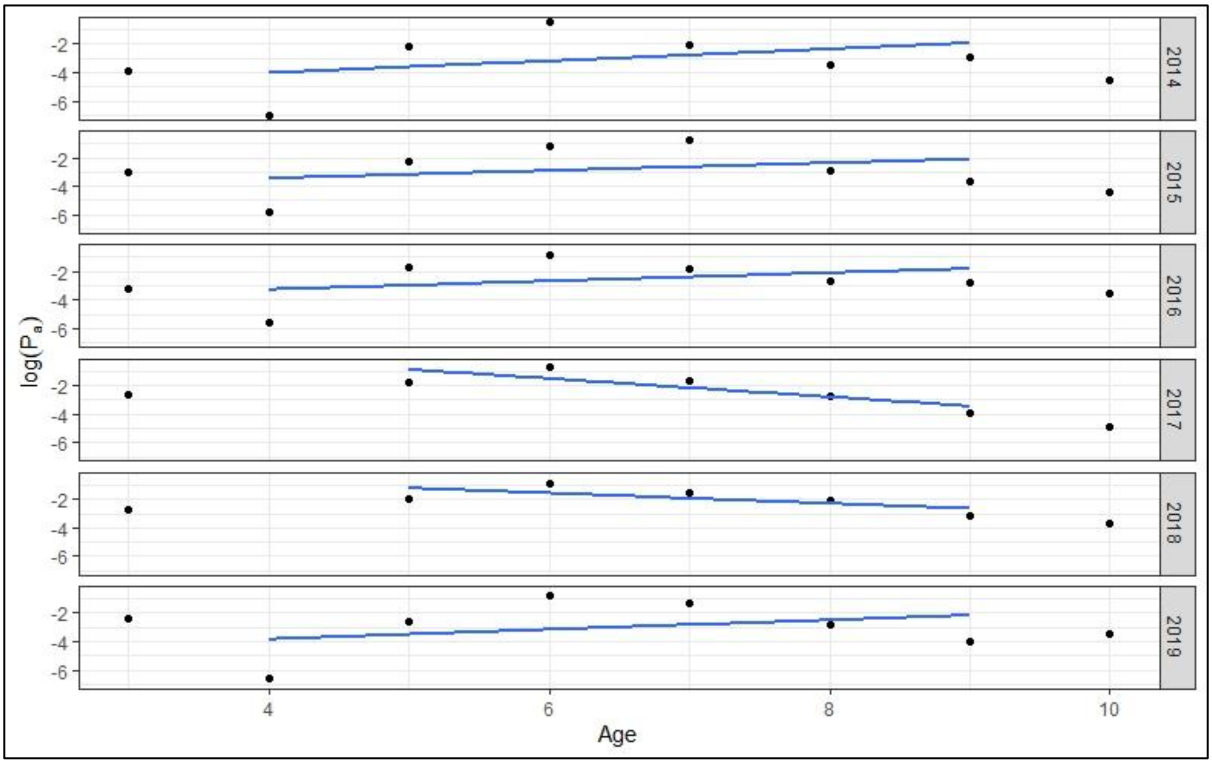

Fig. 5. A histogram showing annual catch curve of Atlantic bonito sampled between 2014-2019

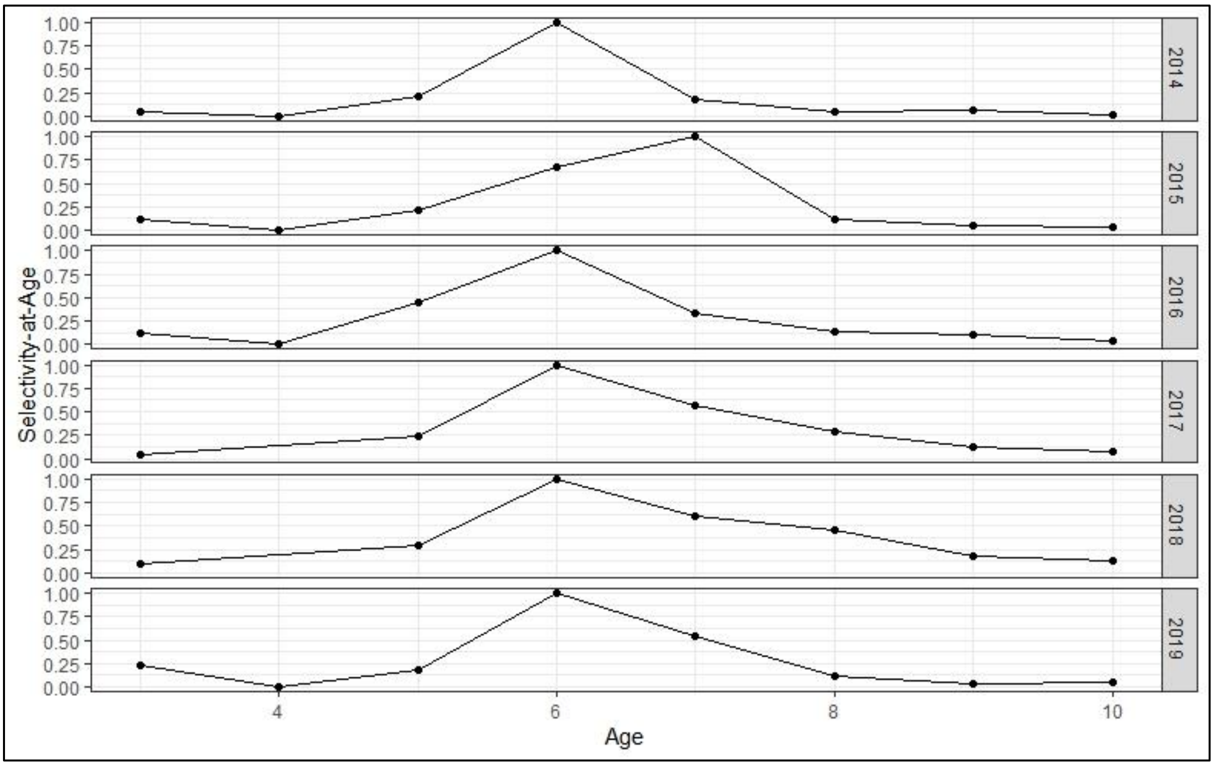

Fig. 6. A histogram showing catch-at-age estimated of Atlantic bonito sampled during 2014-2019

In terms of fishing mortality in the stock, there was a decrease in 2015 which gradually reduced the exploitation rate (F/Z). Thereafter, the intensity resumed its increasing trend until 2019, which reflects an increasing fishing pressure on the stock (Fig. 7).

It should be noted that the current exploitation rate is 68%, which indicates an overexploitation of the stock (Fig. 7). Notably, these results are confirmed by the increase in fishing mortality observed. This situation is also elucidated by the fishing selection curve, especially the catches at age, which reflects an enormous pressure on the spawning individuals (Fig 6). Furthermore, the analysis of this curve indicates that Atlantic bonito are accessible to fishing from age 5, which corresponds to the age of first sexual maturity **(Baibbat *et al.*, 2020)**.

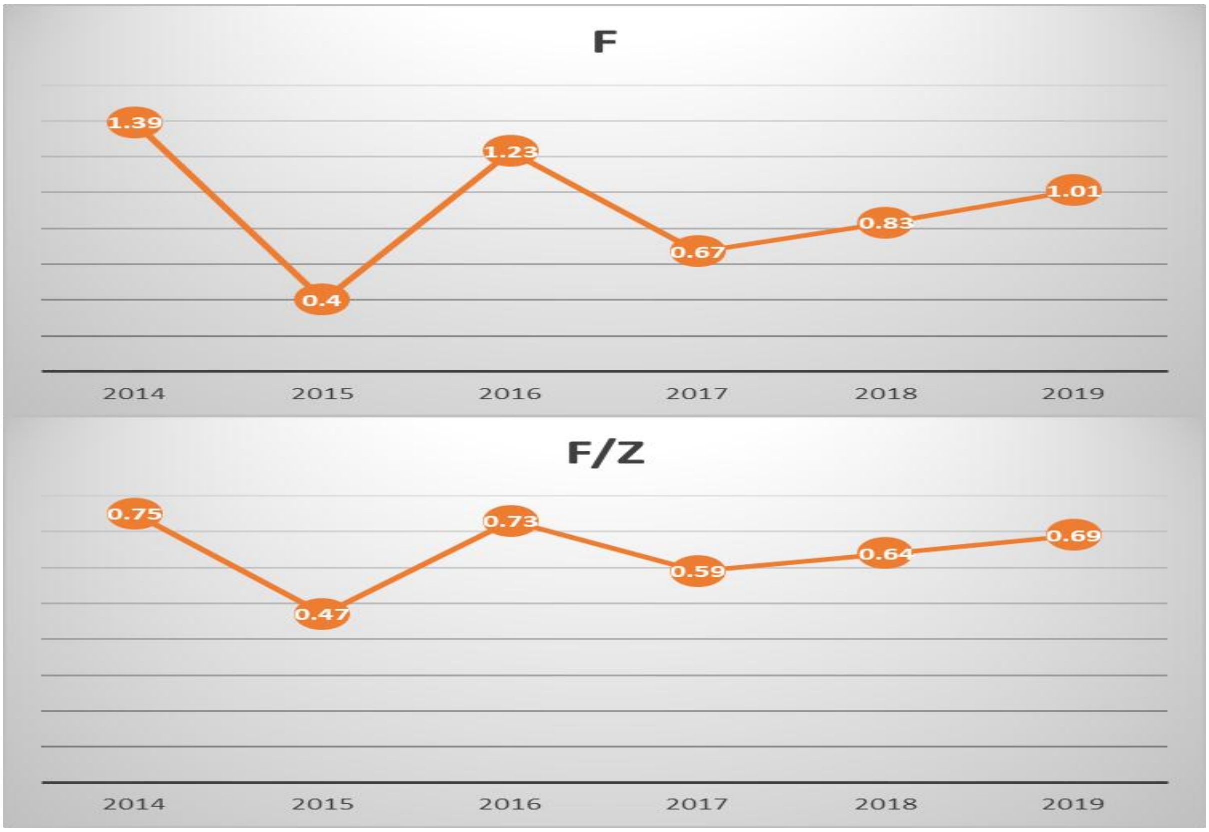

Fig. 7. A histogram showing fishing mortality curves (top); exploitation rate (bottom)

2. Length based spawning ratio (LBSPR)

To assess the status of Atlantic bonito on the southern Atlantic coast of Morocco, a length-based approach was used following the description of **Hordyk *et al.* (2015)** who named it: Length-Based Spawning Potential Ratio (LBSPR). The results of the model are presented in Table (3).

Fig (8) shows the length frequency distributions by year with their corresponding LBSPR model fits. The average size in 2014 was 52.9 cm and in 2017 it dropped to 49.2 cm. However, all the fish caught are adults, the estimated selectivity curves are higher than the maturity curve (Fig. 9& Table 3). The estimated specific parameters (SL50, SL95), the F/M ratio and SPR by year are presented in Table (3) and shown in Fig (10). Most of the SPR values estimated were less than 0.34; values were below SPR40%, which corresponds to BMSY. Thus, this stock could be overfished, F/M values greater than 1 also support this conclusion.

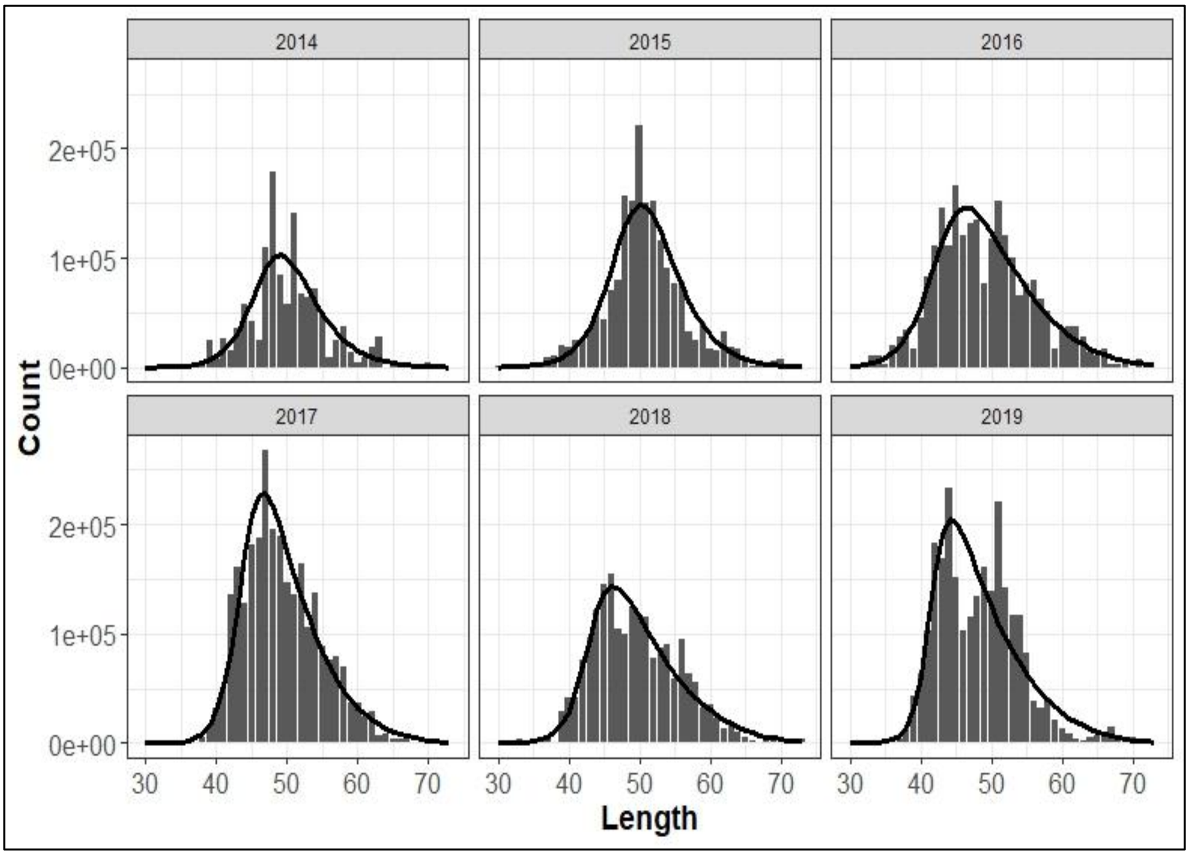

Fig. 8. A histogram showing length frequency distributions by year with their corresponding LBSPR model fits

Table 3. Selectivity values estimated by the model

Year	SL50 (50% selectivity)	SL95 (95% selectivity)	F/M (fishing and natural mortality ratio)	SPR (spawning potential ratio)
[2014]	44.99	51.00	1.94	0.34
[2015]	44.85	50.83	1.89	0.34
[2016]	44.38	50.18	1.79	0.35
[2017]	44.09	49.61	1.74	0.34
[2018]	43.82	49.14	1.69	0.34
[2019]	43.61	48.79	1.68	0.34

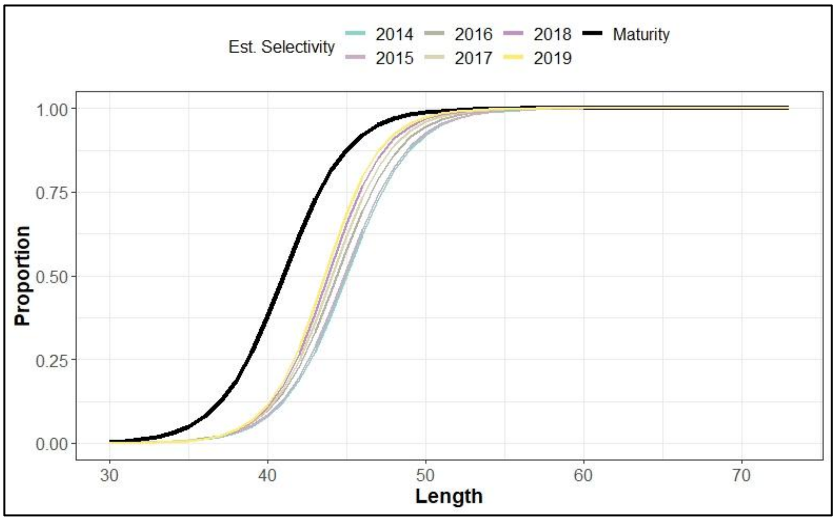

Fig. 9. A histogram showing selectivity and maturity curves for Atlantic bonito

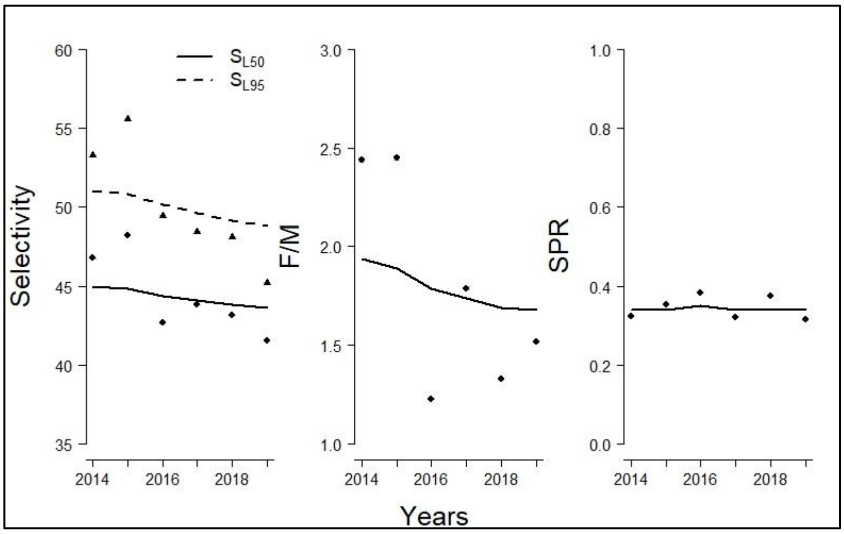

Fig. 10. A histogram showing F/M ratio and SPR by year

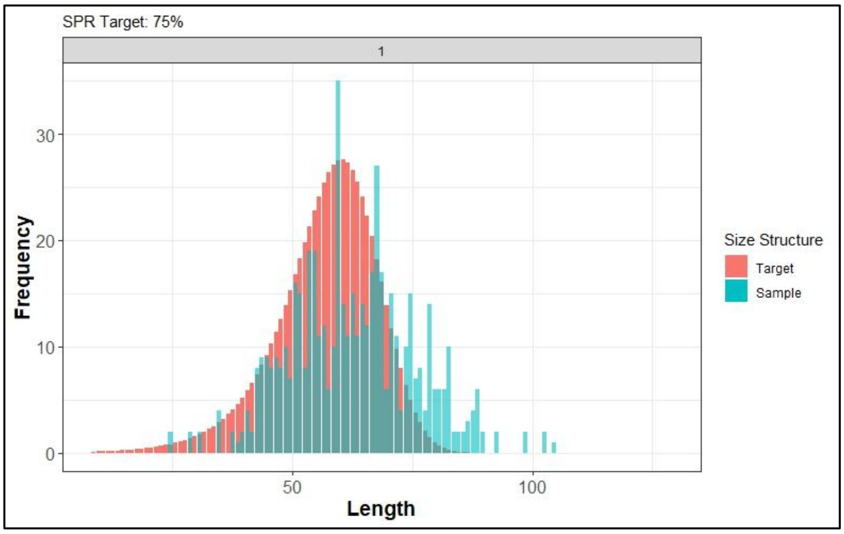

Fig. 11. A histogram showing sampled and target size frequency distribution

Fig. (12) shows that most of the fish are caught at an early age and before they reach their maximum growth rate, which affects the productivity of the stock (Fig. 12c). The current catches are below the maximum sustainable yield MSY (Fig. 12d). Based on these results, fishing mortality and catches of this stock should be reduced. One option to achieve this is to set a size limit above the average size observed in this fishery. This measure should be subject to a management strategy evaluation **(Carruthers & Hordyk, 2018)** to objectively study its effect and assess its impact on the stock.

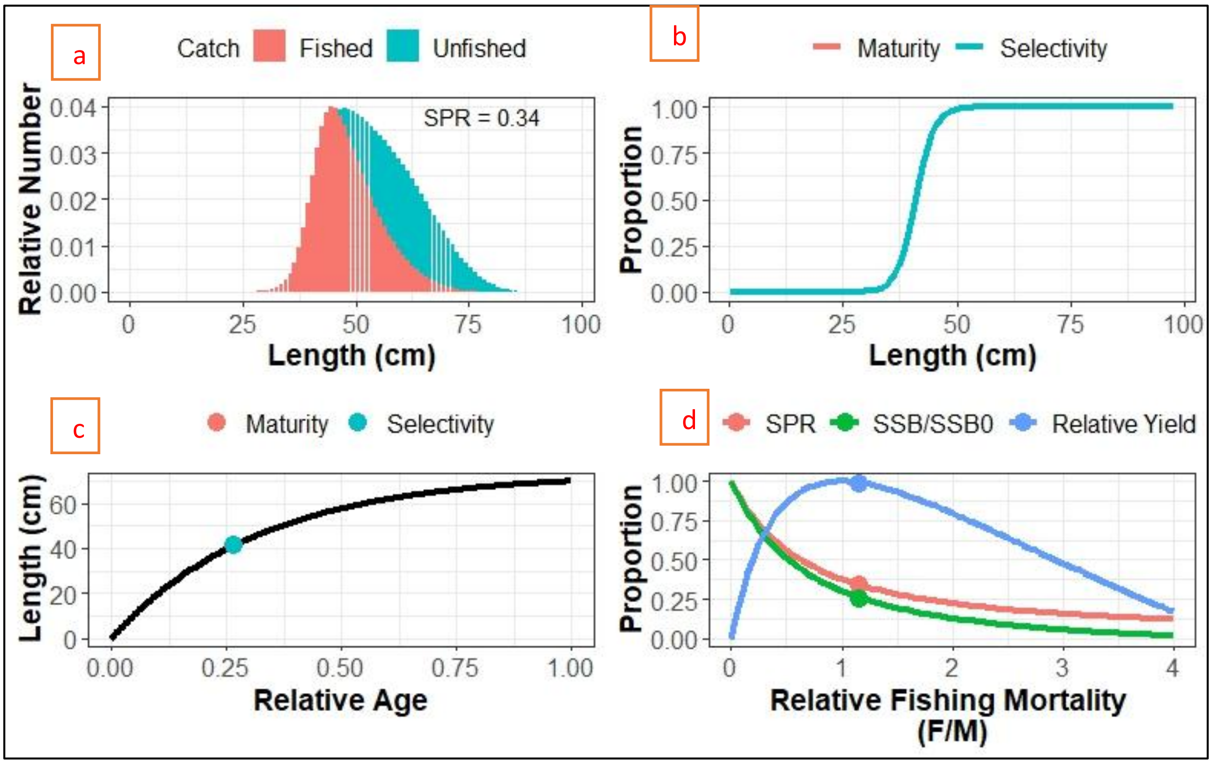

Fig. 12. Histograms showing **(a)** Expected (equilibrium) size structure of catch and the expected unfished size structure of vulnerable population; **(b)** Maturity and length selectivity curves; **(c)** Von Bertalanffy growth curve, and **(d)** Relative fishing mortality

3. Length Cohort Analysis (LCA)/Yield Per Recruit (YPR)

The LCA model indicates that fishing mortality is exerted mainly on a size range from 44 to 60 cm, with a relatively high fishing pressure on sizes between 51 and 55 cm (Fig. 13). It is worthy to mention that the fraction exploited mainly by the longliners has a unimodal pattern of 51 cm, which corresponds to adults. The minimum size sampled is 34 cm.

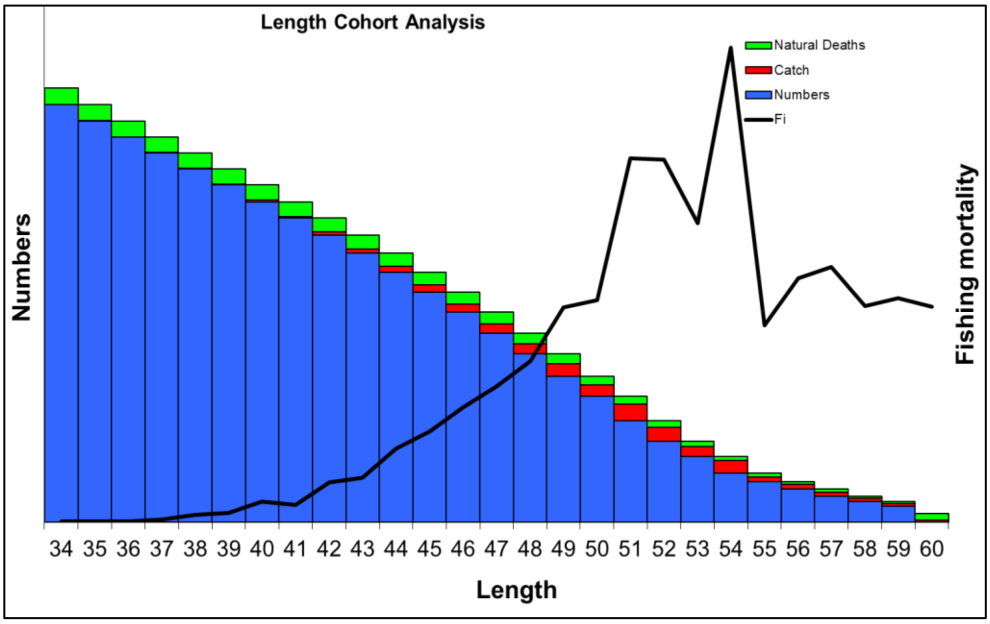

Fig. 13. A histogram showing LCA model results with sizes recorded under fishing pressure

The diagnosis attained from the YPR model, considering a natural mortality of 0.46/year, indicates that the level of current fishing mortality (Fcur) is almost at the same level as the fishing mortality corresponding to F0.1, with a ratio of Fcur/F0.1 of about 95 percent (Fig. 14). This result indicates that this stock is overexploited. However, the exploitation rate, which represents the proportion of fishing mortality in relation to the total mortality suffered by the stock is 54%, which indicates a slight over-exploitation of the bonito stock.

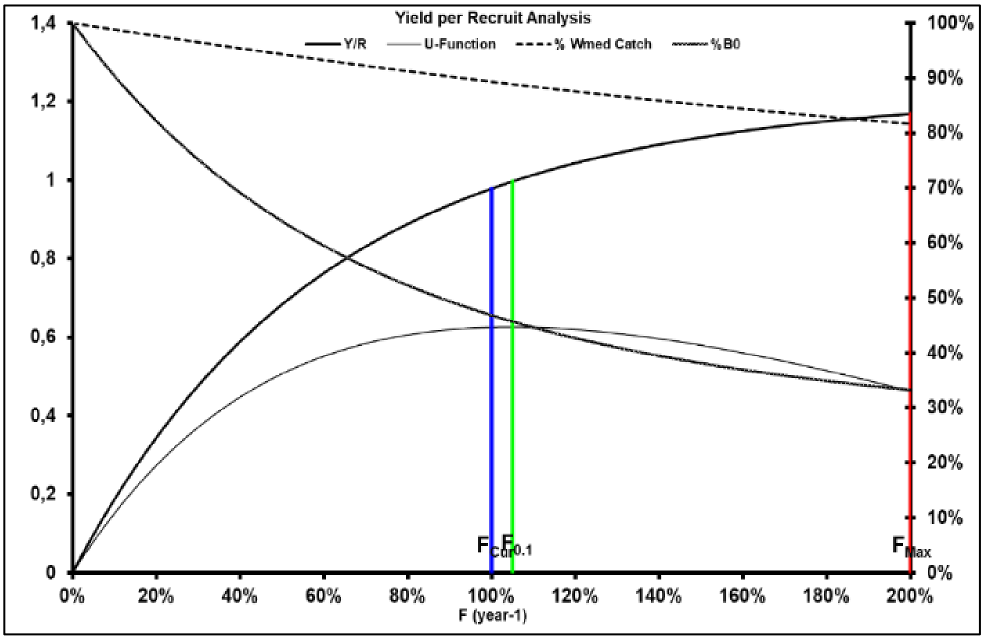

Fig. 14. A histogram showing YPR model results and the level of different fishing mortalities

Considering the results based on the two referential points mentioned above and as a precautionary approach, the bonito stock is considered slightly exploited.

Table (4). The reference points obtained for this stock

Reference points	%
$F_{cur}/F_{0.1}$	95%
F_{cur}/F_{max}	86%
$F_{cur}/(F_{cur}+M)$	54%

F_{cur}: Current fishing mortality, $F_{0.1}$: Fishing mortality corresponding to F_{cur}, F_{max}: maximum fishing mortality, M: natural mortality.

The evolution of the average sizes and weights of Atlantic bonito sampled at the Dakhla ports indicates a decreasing trend in size between 2013 and 2017. After 2017, an improvement was detected in the average size sampled until 2019. This last upward trend could indicate a possible improvement of this stock during the last two years compared to the period before 2017.

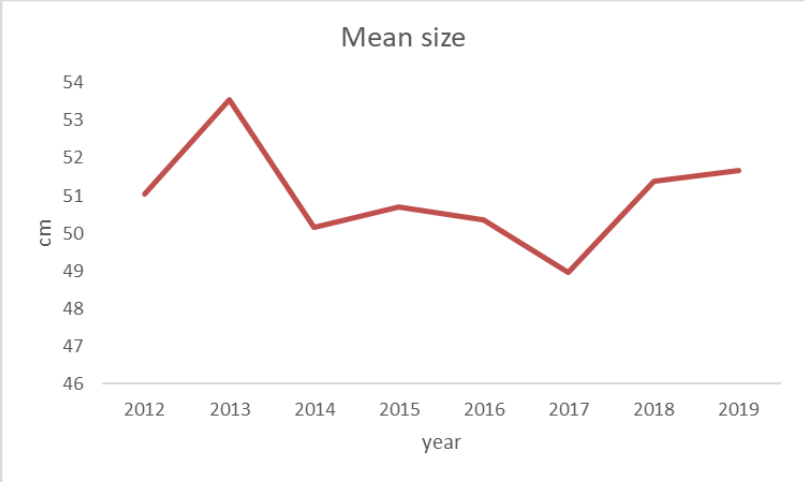

Fig. 15. A histogram showing annual evolution of the average size of Atlantic bonito sampled in the South Atlantic between 2012 and 2019

DISCUSSION

Like the case in the other countries of the North African Atlantic, Atlantic bonito is mainly exploited by coastal and artisanal units. In Morocco, more than 90% of the catches are gathered in the southern area by coastal longliners using the gillnet as the main gear. At the global level, this species represents about 34% of the catches of small tunas **(ICCAT, 2017)**.

Given that fishing pressure is found throughout the year and that the exploited fraction is represented mainly by large individuals, among them spawners, the stock status of this species is increasingly worrying. The biological information available does not allow a quantitative assessment of the stock. Nevertheless, other methods have been used by different authors in different regions to assess the stock of Atlantic bonito.

These methods, called data poor methods, are based on lengths and nominal catches only. Nonetheless, the selection depends on the availability and quality of the data. In the case of size frequencies, it is necessary to ensure that the size distribution in the population of interest is representative.

The application of three methods based on the size frequencies of Atlantic bonito in Morocco has shown that this stock is subject to significant fishing pressure, mainly on the spawners. The results of the evaluation of the status of this stock by the different analytical methods based on size frequencies are illustrated in Table (5) as follows:

Table 5. Summary of the results of the Atlantic bonito assessments in Morocco (current study)

Method	Exploitation rate (F/Z)	Stock status
Length based Spawning Potential Ration (LBSPR)	69%	overexploited
Catch curve (Z/K)	68%	overexploited
Length Composition Analysis LCA/ Yield Per Recruit (YPR)	54%	overexploited

Most of the models used for the assessment of the Atlantic bonito stock suggest that this stock is/or may be subject to overfishing, especially for spawning adults (Table 6).

Table 6. Results of assessments conducted on the northern Atlantic stock of Atlantic bonito

Method	Type of data	Period	Area	Result	Stock status	Author
Length based Spawning Potential Ration (LBSPR)	Size frequency	2014-2047	North Atlantic	SPR=0.23	Overexploited	**Pons *et al* 2019**
				SPR=0.34	Overexploited	**Baibbat *et al* 2019**
The length-based integrated mixed effects LIME		2014-2017	North Atlantic	SPR=071	Fully exploited	**Pons *et al*, 2019**
Depletion-Based Stock Reduction Analysis DBSRA	Catch	2014-2017	North Atlantic	B/BMSY=1.63	Overexploited	**Pons *et al*, 2019**
Length based stock synthesis SSS		2014-2017	North Atlantic	B/BMSY=1.98	Overexploited	**Pons *et al*, 2019**

However, all results related to those methods should be taken with caution as there are many different sources of uncertainty in these types of models. Remarkably, most of these models suggest that selectivity is asymptotic by default **(Hordyk *et al*., 2015)** If large or small fish are absent, the model assumes that they do not exist in the population. The logistic selectivity assumption is generally violated in highly size-selective fisheries, such as the case of the gillnet, which is the main gear deployed by the Moroccan longline fleet operating in the Southern Kingdom.

Consequently, it is recommended to reduce the catches of this species and preserve spawners (e.g., establishing a market size). In addition, assessments are recommended to be conducted on samples from other fishing gears other than gillnets.

The assessment of the Atlantic bonito stock by various methods based on size frequencies; namely, LBSPR, LCA/YPR and Powel-Whetherall (Z/K) has shown that this species is under great pressure, especially regarding the spawners. The results show a worrying state of over-exploitation. The Powel-Wherherall model gave an exploitation rate equal to 68%, accompanied with a very high fishing mortality that has been continuously increasing since 2017. The results of the LBSPR model confirm the situation of over-exploitation of the bonito stock, since the value of the SPR estimated by the model is equal to 0.34. The other two models used in this work are the LCA and YPR, which showed an alarming situation of over-exploitation, with great pressure on the spawners, whose size is between 51 and 55 cm. The most optimistic model is the YPR (yield per recruit), with an estimated exploitation rate of 54% although this situation indicates a slight over-exploitation of the stock. Hence, it is recommended to preserve the spawners of this species in the longline fishery to reduce fishing mortality and establish a market size above the average size observed in the catches.

REFERENCES

Baibat, S.A.; Malouli, I.M.; Abid, N.; Bensbai, J. and Benazzouz, B. (2020). Growth and Biometry Analysis of the Atlantic Bonito (Sarda sarda (Bloch, 1973)), in the Southern Coast of Morocco. Acta Scientific Veterinary Sciences, 2.3: 01-10.

Baibbat, S.A.; Pons, M.; Ait-Chattou, E.M.; Abid, N.; Bensbai, J. and Houssa, R. (2019). A length-based assessment for Atlantic bonito (*Sarda sarda*) exploited in the Moroccan Atlantic coast, Collect. Vol. Sci. Pap. ICCAT, 76(7): 174-180 (2019)

Beverton, R. J. and Holt, S. J. (1993). On the dynamics of exploited fish populations. Springer Science & Business Media. V.11.

Bianchi, G.; Carpenter, K.E.; Roux, J.P.; Molloy, F.J.; Boyer, D. and Boyer, H.J. (1999). Field guide to the living marine resources of Namibia. FAO species identification guide for fishery purposes. Rome, FAO. 265 pp., 11 colour plates.

Carruthers, T. R. and Hordyk, A. R. (2018). The Data- Limited Methods Toolkit (DLMtool): An R package for informing management of data- limited populations. Methods in Ecology and Evolution, 9: 2388-2395.

Clark, W. G. (2002). F35% revisited ten years later. North American Journal of Fisheries Management, 22: 251–257.

Cotter, J.; burt, L.; Paxton, C.; Fernandez, C.; Buckland, St. and Pan, J-x. (2014). Are stock assessment methods too complicated? . Fish and fisheries, 2004, 5: 235–254.

Hordyk, A. R. (2017). LBSPR: Length-Based Spawning Potential Ratio. R Package Version 0.1.3. https://github.com/AdrianHordyk/ LBSPR (last accessed 10 July 2018).

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

ICCAT. (2017**).** Report of the small tuna's species group intersessional meeting, Miami, United States, 24–28 April 2017. Collective Volume of Scientific Papers of ICCAT, 74: 1–75.

Jones, R. (1956). Assessing the effect of changes in the exploitation pattern using length composition data (with a note on V P A and cohort analysis). FAO Fisheries Technical Papers No. 256. 118 pp.

Makaoui.A; Larissi, J.; Orbi, A.; Hilmi, K. and Zizah, S. (2000). Evolution des principales caractéristiques océanographiques de la côte Atlantique marocaine de 1994 à 1998. In Rapp. INRH.

Methot, R. D. and Wetzel, C. R.(2013). Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research, 142: 86–99.

Pons, M.; Kell, L.; Rudd, M. B.; Cope, J. M. and Lucena-Fre´dou, Fla´v. (2019). Performance of length-based data-limited methods in a multifleet context: application to small tunas, mackerels, and bonitos in the Atlantic Ocean. – ICES Journal of Marine Science, doi:10.1093/ icesjms/fsz004.

Powell, D. G. (1979). Estimation of mortality and growth parameters from the length frequency of a catch [model]. Rapports et Proces-Verbaux des Reunions (Denmark).

Sparre, P. and Venema, S. (1996). Introduction à l'évaluation des stocks de poissons tropicaux. Première partie : Manuel, FAO (Rome), Document technique sur les pêches, No 306/1, Rev. 1. 401pp.

Wetherall, J. A.; Polovina, J. J. and Ralston, S. (1987). Estimating growth and mortality in steady-state fish stocks from length-frequency data. In ICLARM Conf. Proc., 13: 53-74.