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REVIEW

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Stock assessment of the blue jack mackerel, *Trachurus picturatus*, in the North-eastern Atlantic

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Abstract

A total of 49,151 blue jack mackerel, *Trachurus picturatus*, (Bowdich) was collected in Madeira Island (North-eastern Atlantic) between 2002 and 2016 to evaluate possible influence of fishing on landings and reproductive parameters. A decreasing trend in the length composition was observed over the study period and length at first maturity decreased by 2.78 cm TL. Maximum yield per recruit decreased from 2002 to 2016 but the corresponding fishing mortality was constant (F_{max} = 0.4/year). Considering the fishing mortality level in 2016, it is evident that the stock may be exploited beyond its sustainability limit. Amendments of the purse-seine fishing regulations and implementation of measures to reduce fishing effort are suggested.

KEYWORDS
fishing mortality, size and age at first maturity, yield per recruit model

1 | INTRODUCTION

The impact of fisheries on marine organisms is manifest worldwide and is seen through reduction in the individual size of the target populations (Kaiser & De Groot, 2000), changes in terms of number and weight (biomass), in length and age composition and change in geographical distribution (Haddon, 2001).

Blue jack mackerel, *Trachurus picturatus* (Bowdich) (Osteichthyes, Carangidae), is an oceanic pelagic species that occurs in the Eastern Atlantic (Cárdenas et al., 2005) from the Bay of Biscay (France) southward to Morocco, Madeira, Azores, Canary Islands and eastward into the Mediterranean Sea (Froese & Pauly, 2017; Karaiskou, Apostolidis, Triantafyllidis, Kouvatsi & Triantafyllidis, 2003). This species is found between 100 and 575 m depth (Menezes, Sigler, Silva & Pinho, 2006), and although being a commercially exploited species, no information exists on the population structure (ICES, 2016) and exploitation levels in European waters, or specifically in the Madeira Archipelago.

In Madeira, artisanal purse seine fishing is the most economically important fishery within the small pelagic fisheries sector (Jesus,

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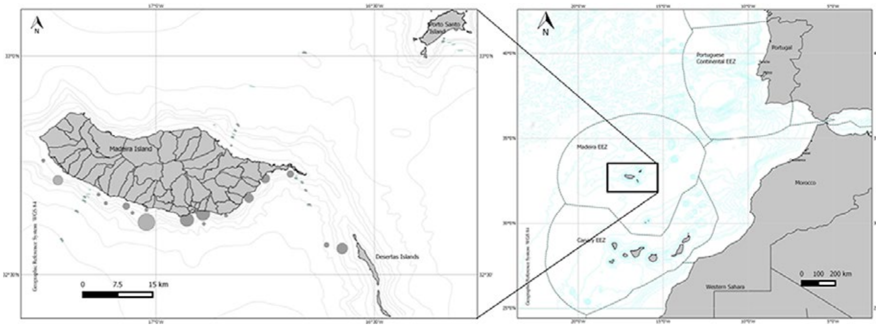

FIGURE 1 Map of the southern part of the north-eastern Atlantic showing the sampling locations (grey spots) of blue jack mackerel in the Madeira archipelago (Source: DRP). [Colour figure can be viewed at wileyonlinelibrary.com]

1992; Vasconcelos, Alves, Faria & Gouveia, 2006). It is the only type of fishery targeting *T. picturatus* in Madeira, capturing large schools of small fish near the surface in the south of Madeira Island (Figure 1), along with other small pelagic species, such as Atlantic chub mackerel, *Scomber colias* Gmelin, sardine, *Sardina pilchardus* (Walbaum) and the bogue, *Boops boops* L. They are caught during the night, being attracted and concentrated by chumming (locally called engodo) and by intense spotlights (candeio), a very efficient method to catch pelagic species (Jesus, 1992). The nets have an average length of 500 m and a height up to 120 m (Jesus, 1992). The legal mesh size is 16 mm.

These species are locally called ruama, and are caught throughout the year, although in less quantity during the winter months due to adverse weather conditions (Jesus, 1992). Until 1980, the annual catch of blue jack mackerel landed in Madeira did not exceeded 1,000 t and was captured with conical shaped nets. In the first half of the 1980s landings increased rapidly and reach 2,006 t in 1986. This initial increase was not only due to the introduction of purse seine nets in 1977 but also due to the shortage of tunas during the years 1978–1988. During those years, there was some contribution of tuna vessels in the harvesting of this species (Jesus, 1992). The fishery has high importance in the total fish landings in the Madeira Archipelago representing about 15% and 9% of the total landings by weight and value, respectively, in the last decade. Nevertheless, annual landings of blue jack mackerel have decreased from 2,006 t in 1986 to 617 t in 2016.

Monitoring the life history parameters and the spawning biomass is crucial for effective long-term management and conservation of a given resource (Jørgensen et al., 2007; Trippel, 1995). Increased mortality can select towards maturation at an earlier age (Chuwen, Potter, Hall, Hoeksema & Laurenson, 2011; Nash, Pilling, Kell, Schön & Kjesbu, 2010) and smaller size (Cardoso & Haimovici, 2014; Heino & Godø, 2002), since a delayed maturation results on a decreased probability of surviving long enough to reproduce (Morgan & Colbourne, 1999). Length and age at first maturity can be used as indicators of stock size, that is, a decrease in these parameters may indicate an important stock response to reduction in population size. Thus, measuring these parameters annually allows indirect assessment of trends in population size (Trippel, 1995). Worldwide, changes have occurred in age at maturity in numerous populations exploited over decades (Trippel, 1995). Heino, Dieckmann and Godø (2002). Jørgensen et al. (2007), however, pointed out that the time from the ceasing of the fishery to the fish return to maturation schedules similar to those before exploitation is much longer than the reduction phase.

Information on the biology of this species around Madeira is scarce and limited to only one study on age and growth (Vasconcelos et al., 2006) and another on fecundity regulation strategy (Vasconcelos, Faria, Freitas & Gordo, 2017a). A few biological studies have been carried out on the blue jack mackerel from the Azores (Garcia, Pereira, Canha, Reis & Diogo, 2015; Isidro, 1990) and Canary Islands (Jurado-Ruzafa & Santamaría, 2013). However, no studies have focused on assessing the impact of fisheries on the reproduction and biomass of this species in the study area.

This study aims to analyse the population structure of the blue jack mackerel in Madeira archipelago, North-eastern Atlantic, over a 15-year period (2002–2016) and consider three aspects: (a) the length composition of the annual landings; (b) the length at first maturity; and (c) a yield per recruit model. Finally, management options are considered.

2 | METHODS

2.1 | Data collection

Specimens were obtained from two sampling methodologies, randomly selected each week from the commercial purse-seine fleet landings in Port of Funchal, Madeira Island: (a) large samples, sampled in situ for monthly length-frequency estimation (unsexed fish) of landings; and (b) small samples, which were taken to the laboratory for further biological sampling.

To study the structure of landings of blue jack mackerel from Madeira, about 100 unsexed fish per sample were selected from one of the three vessels exclusively dedicated to purse seine fishing (sampling always a different vessel) and individual total length (TL, cm) and total sample weight were registered. The annual landing data for this period was obtained from DRP (Regional Fisheries Department).

For the biological samples, individual total length (TL, cm), individual total (TW, g) and eviscerated (EW, g) weight and gonad (GW, g) and liver weights (LW, g) were recorded. Both sagittal otoliths were removed (ventral extraction), cleaned and stored dry in labelled vials for later age determination. The age of each fish was assigned by a single reader through interpreting and counting growth rings, assumed as annual growth zones, on sagittal otoliths.

Sex and maturity stages were assigned by macroscopic examination of the gonads using a five-stage maturity scale: (I) immature, (II) developing, (III) spawning capable, (IV) regressing (V) regenerating (reproductively inactive), as suggested by Brown-Peterson, Wyanski, Saborido-Rey, Macewicz and Lowerre-Barbieri (2011). Histological analyses were performed on a subsample of reproductive tissue to confirm the maturity stage assignment.

2.2 | Landings length composition

Length compositions were determined for four periods (2002–2005, 2006–2009, 2010–2013 and 2014–2016), using the annual length composition of the purse seine fishery landings. The length-frequency distributions were amplified from the sample to each vessel, day and month. The annual length compositions (2002–2016) were obtained by summing the monthly length compositions previously estimated.

2.3 | Length at first maturity

Length maturity ogives by sex were fitted to observe data collected during the spawning season (Vasconcelos et al., 2017a) for the same above-mentioned periods (2002–2005, 2006–2009, 2010–2013 and 2014–2016), and assuming that fish classified in maturity stages II to V were mature.

The length at first maturity (L_{50}) was obtained according to Jennings, Kaiser and Reynolds (2001):

$$P = \frac{100}{1 + e^{-b(L - L_{50})}}$$

where P is the proportion of mature individuals in the size class L, b is a constant, L the size class in TL and L_{50} is the size at which 50% of individuals are mature (in TL).

2.4 | Yield per recruit model

Estimates of Beverton and Holt's (1957) yield per recruit model were obtained for each period, sexes combined, according to:

$$\frac{Y}{R} = Fe^{(-M(T_c - T_r))} W_\infty \left[\frac{1}{Z} - \frac{3S}{Z+K} + \frac{3S^2}{Z+2K} - \frac{S^3}{Z+3K} \right]$$

where Y/R is the yield per recruit, $S = e^{(-k(t_c - t_0))}$, W_∞, K and t_0 are the von Bertalanffy growth parameters (estimated by Vasconcelos et al., 2006), T_c is the age at first capture (considered as the age of the lowest length class landed), T_r is the age at recruitment (assumed as 0), F is the fishing mortality, M the natural mortality (the mean value of the two methods' estimate) and Z the total mortality.

The instantaneous rate of natural mortality (M) was estimated using Pauly's (1980) method:

$$\text{Log}\,M = 0.0066 - 0.279\,\text{Log}\,L_\infty + 0.6543\,\text{Log}\,K + 0.4634\,\text{Log}\,T$$

where L_∞ is the asymptotic length expressed in cm (TL) and K the Brody growth coefficient from the von Bertalanffy growth function (VBGF) and T the mean annual environmental (seawater) temperature (in °C). T was set at 18°C for the study area and M and K were expressed on an annual basis.

Total instantaneous mortality rate (Z) was estimated based on the age distribution of the annual commercial landings using the age catch curve analysis (Beverton & Holt, 1957). Only fully recruited ages were used to estimate Z, as the age group at the top of the catch curve may not be fully vulnerable to the fishing gear (Ricker, 1975). Total mortality value was calculated as the negative slope of the regression between natural logarithm of the number of individuals caught at each age (Simpfendorfer, Bonfil & Latour, 2005).

Fishing mortality (F) was estimated according to Beverton and Holt (1957) as: $F = Z–M$.

3 | RESULTS

A total of 49,151 specimens of blue jack mackerel were sampled from monthly landings for length-frequency estimation (large samples) between 2002 and 2016 (see Table 1 for a summary of the descriptive statistics).

A total of 10,713 individuals (14.00–36.60 cm TL) were sampled annually between 2002 and 2016 to obtain biological parameters as input data for the stock assessment (Table 2).

Length composition (in number) of landings showed a decreasing trend on the length composition over time (Figure 2), with the lowest mean length (18.17 cm TL) and lowest modal length (17 cm TL) in the later period.

The length at first maturity for all individuals decreased from 19.44 cm TL in 2002–2005 to 16.66 cm TL in 2014–2016 (Figure 3). The smallest mature fish sampled was 14.60 cm TL (from 2006–2009; maturity stage III).

Natural mortality was estimated at 0.33/year. Total mortality varied between 0.75/year in 2014 and 1.76/year in 2003. In 2016, the estimated total mortality was 1.64/year.

A decreasing trend in the maximum Y/R was found over time (Figure 4). The maximum values decreased from 14.17 g in 2002–2005 to 12.94 g in 2014–2016, but they all were obtained at the same F (F_{max} = 0.4/year) (Figure 4).

4 | DISCUSSION

To manage the fishery of a target species effectively, it is important to know the stock structure and how mortality and fishing effort are distributed, because each stock may have to be managed

TABLE 1 Number of individuals (*n*), mean length (TL cm) and mean sample weight (TW Kg) (±standard deviation) of *Trachurus picturatus* sampled for monthly landings length frequency-estimation (unsexed fish) in Madeira archipelago between 2002 and 2016 (large samples). Total length and sample weight ranges are given in brackets

Year	*n*	TL (cm)	Sample TW (kg)
2002–2005	9,947	19.10 ± 3.35 (10.00–35.00)	7.57 ± 3.15 (0.43–18.20)
2006–2009	7,383	19.19 ± 3.06 (11.00–36.00)	7.21 ± 2.95 (2.08–17.56)
2010–2013	21,341	21.06 ± 3.22 (11.00–44.00)	9.46 ± 5.20 (2.26–29.50)
2014–2016	10,480	20.39 ± 3.65 (11.00–38.00)	9.33 ± 5.57 (0.98–20.80)

TABLE 2 Number of individuals (*n*) for each sampling period (2002–2005, 2006–2009, 2010–2013 and 2014–2016) and mean length and weight (±standard deviation) of *Trachurus picturatus* sampled in Madeira archipelago. Total length (TL, cm) and weight (TW, g) ranges are given in brackets

Sampling periods	*N* Total	TL (cm)	TW (g)
2002–2005	2,902	22.64 ± 2.85 (14.20–33.80)	105.28 ± 43.64 (25.50–360.55)
2006–2009	4,388	22.01 ± 3.57 (14.00–36.60)	96.23 ± 57.78 (22.53–490.45)
2010–2013	2,650	21.11 ± 2.27 (14.00–31.00)	81.33 ± 27.97 (21.17–221.00)
2014–2016	773	20.51 ± 2.44 (15.30–28.30)	72.69 ± 27.18 (28.19–196.23)

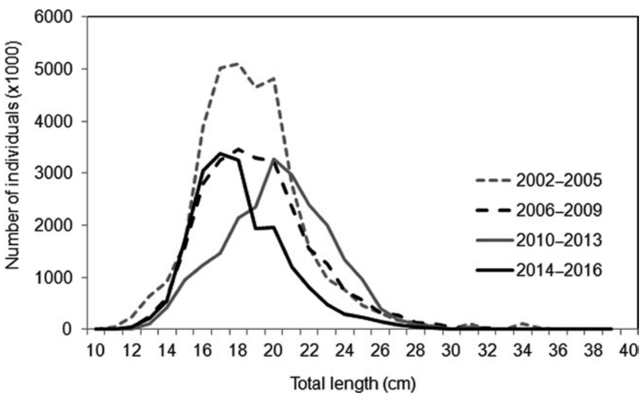

FIGURE 2 Length composition (by number) of *Trachurus picturatus* landings sampled in the four study periods (2002–2005, 2006–2009, 2010–2013 and 2014–2016) off Madeira archipelago

separately to optimise their yield (Begg, Friedland & Pearce, 1999). Lack of knowledge of the stock structure of an exploited species can lead to overfishing and consequently depletion of less productive stocks (Begg et al., 1999). Blue jack mackerel is one of the most important species captured in the archipelago of Madeira. This species has high commercial importance and represented 10.7% of total landings in 2016. Due to the importance of this fishery, it is vital to carry out a sustainable exploitation of the stock to preserve it.

Fishing activity results in the selective removal of lengths and age groups implying changes in population density and consequently in the fish's reproductive parameters (Jobling, 1996). It implies also a decrease in the number of older females capable of producing juveniles, thus reducing egg production time in the population (Botsford, 2005), and causing several negative implications in terms of recruitment (Berkeley, Hixon, Larson & Love, 2004).

According to Bellido, Pierce, Romeno and Millán (2000), applying length for age keys to length compositions of annual landings provides indications of the total length and age groups that support the fishing activity. In 2014–2016, about 93% of the blue jack mackerel caught in the Madeira fishery were smaller than 22 cm. This reduction in larger size classes will have implications for the future management of this species population.

Stocks under commercial exploitation usually do not include larger individuals and/or older individuals (Conover & Munch, 2002), not only because fishers seek to capture the largest individuals but also due to the regulatory measures of the fishing gear that impose a minimum landing/legal size. However, the decrease in larger fish in landings since 2002 to present may have different origins. Apparently, there is no commercial interest in catching the smaller specimens since they have little value in the market; but also there was no apparent shift in the fishers' behaviour to operate at lower depths where smaller specimens are found. So, the absence of larger fish in the landings may result from a move to fishing in shallower waters or far from seamounts (e.g., Unicorn, Seine) where larger specimens are commonly caught. In 2017, larger specimens were caught during a prospective stock survey in the former seamounts (R. Sousa pers. comm). Finally, this absence may also be due to a real depletion of larger fish due to fishing. These hypotheses must be explored in the future to understand fully the species population structure.

Changes in maturation, such as a decrease in size at first maturity, may be associated with a decline in stock size in response to fishing pressure (Trippel, 1995). At low population size, the lower competition provides an increase in food intake per individual and thus an increase in maturation at a younger age (Trippel, 1995). Lower mean size results in less weight landed, associated with a lower commercial value. Length at first maturity fluctuated over the years, shifting towards smaller sizes. Between 2002–2005 and

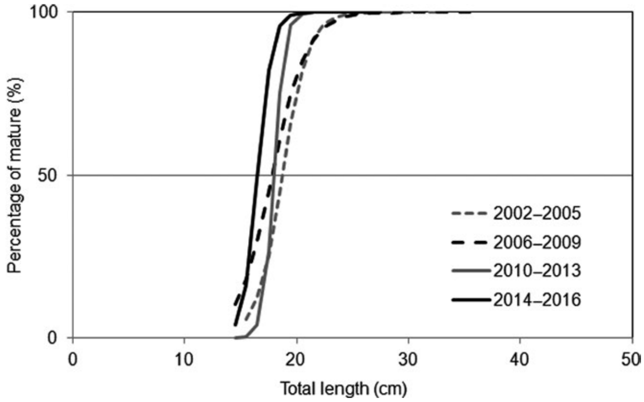

FIGURE 3 Length maturity ogives for *Trachurus picturatus* caught off Madeira archipelago between 2002 and 2016: P 2002–2005 = 100/1 + $e^{-(-19.38)(L-19.44)}$; P 2006–2009 = 100/1 + $e^{-(-12.33)(L-17.75)}$; P 2010–2013 = 100/1 + $e^{-(-25.81)(L-17.44)}$; P 2014–2016 = 100/1 + $e^{-(-10.50)(L-16.66)}$

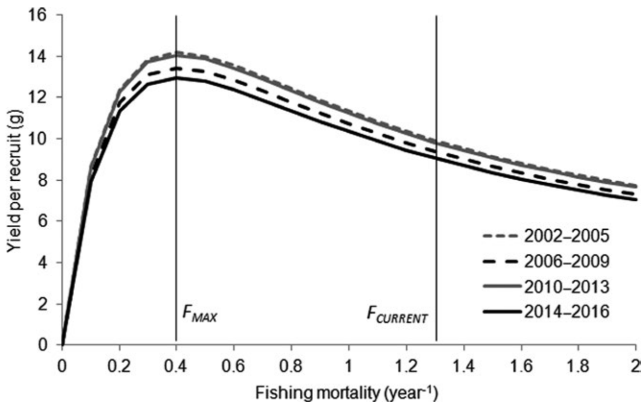

FIGURE 4 Two-dimensional curve of production (capture) and biomass per recruit for *Trachurus picturatus* off Madeira archipelago. The parameters used are W_∞ 2002–2005 = 703.22 g; W_∞ 2006–2009 = 665.56 g; W_∞ 2010-2013 = 696.74 g; W_∞ 2014–2016 = 642.12 g; K = 0.163/year; T_c = 0.8 year; T_0 = −2.56 years; M = 0.33/year. The downward curve shows the decline of biomass per recruit (B/R) with increasing fishing mortality (F)

2014–2016, L_{50} decreased by 2.78 cm TL. This shift is most likely an adjustment to attain the maximal reproductive output and enables the reduced stock to recruit earlier (Trippel, 1995). Hunter, Speirs and Heath (2015) also reported regional differences in the rates of L_{50} consistent with the hypothesis that fishing had influenced maturation. They suggested it occurred directly though fisheries-induced evolution (selection for smaller sizes) or indirectly through other fishing consequences (e.g., relaxed social pressures due to disproportionate removal of large mature fish).

The yield per recruit model gives an indication of the status of the fishery based on fishing mortality estimation corresponding to potential maximum sustainable yield (MSY). Considering the values of maximum yield per recruit estimated for the last period (Y/R 2014-2016 = 12.94 g) and the corresponding fishing mortality (F_{max} = 0.4), estimated by Beverton and Holt's yield per recruit model the stock may be being exploited beyond MSY. In the present study, the estimated fishing mortality for 2016 was higher than 2/3 M (0.23), which, according to Patterson (1992), is associated with declines in stock. The apparent decline in fish length and weight of the catches landed throughout the present study reinforces the suggestion of high levels of fishing mortality. These data indicate that the *T. picturatus* population of Madeira is currently being explored above sustainable levels. The depletion of the breeding population of this species will result in long periods of population recovery with an associated economic loss. However, these values must be taken with caution since landings reflect mainly the immature fraction of the population. Catching immature fish may constitute a problem in terms of fisheries sustainability but fisheries exploiting immature fish exist and may be sustainable (e.g., semelparous species).

Although some migration occurs, the blue jack mackerel population caught by the Madeira fleet can be considered an isolated population unit (Vasconcelos, Hermida, Saraiva, González & Gordo, 2017b; Vasconcelos et al., 2018); thus, based on the results obtained and aiming to reverse the present scenario and return to the sustainable exploitation of the resource in the short term, management actions should be adopted locally.

Before 2010, management measures for blue jack mackerel in Madeira archipelago included an annual landing limit (TAC), a minimum fish size landing restrictions for fish smaller than 15 cm TL, a minimum mesh size (18 mm), maximum size of the purse seine net, the number and power of lights for attraction and fishing with this gear is only allowed below a depth of 50 m. These measures have not, however, been enough, and in 2010, the local administration made an adjustment plan to reduce fishing effort of the Madeira purse seine fleet that resulted in fishing by two of the five purse seine vessels in the local fleet. This measure was also used in the past for the black scabbard (*Aphanopus cargo*, Lowe) fishery in Madeira in an attempt to reduce fishing pressure on the stock.

The present results show that fishing pressure is still very high and, besides the reduction in number of boats, reduction in the annual TAC (from 1,229 t in 2010 to 995 t in 2016), maintenance of the minimum landing size and enforcement of control mechanisms to assure that the present regulations are implemented, other management measures should be implemented. These include: (a) reduction in the number of fishing days; (b) increase in the minimum landing size; and (c) implementation of closed areas to fishing.

The reduction in number of fishing days is important to decrease fishing mortality (F), as it is proportional to the fishing effort. Fishery managers should reduce the maximum number of purse-seine fishing days allowed per year by approximately 20% per vessel, the capture of small pelagic with purse seines should be prohibited for 48 consecutive hours each week or, alternatively, reduce the number of vessels operating in this segment. These measurements combined will have direct impact on fishing effort and also help reduce discards and valorisation of the sale price on market. This measure was applied to the sardine fishery

(*Sardina pilchardus* (Walbaum)) in Portugal and Spain, through a management agreement between the two countries that includes limitations on annual catch and fishing effort (maximum 180 fishing days per vessel and fishing prohibition for 2 days a week at the weekend). An increase in the minimum landing size is a function of net selectivity (Sparre & Venema, 1998) and should be taken into account by amending the purse-seine fishery regulation to increase net dimensions and reduce the catch of immature fish. In this context, a reduction in the overall net size (height and length) and increase in net mesh size to 18 mm and increasing fishing distance to the coast (bathymetry from 50 to 60 m) could be some of the management actions that can be adopted by fishery managers.

Finally, establishment of a closed season for the purse seine fishery during the spawning period (first trimester of the year) should be implemented. This measure was also taken into account for the sardine with the establishment of closed period coinciding with the spawning period of the species (between December and April, depending on the area) and more recently limits to the capture of juveniles.

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