Aquat. Living Resour. 2019, 32, 14
© EDP Sciences 2019
https://doi.org/10.1051/alr/2019011

Aquatic Living Resources
Available online at:
www.alr-journal.org

RESEARCH ARTICLE

Reproductive cycle of the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), off the Portuguese continental coast

Ana Maria Costa*

Instituto Português do Mar e da Atmosfera (IPMA), Av. Doutor Alfredo Magalhães Ramalho, n° 6, 1495-165 Lisbon, Portugal

Received 26 September 2018 / Accepted 29 April 2019

Handling Editor: Flávia Lucena Frédou

Abstract – This work provides for the first time a description of the reproductive biology of *Trachurus picturatus* in Portuguese continental waters (between 41° 49′ and 36° 57′ latitude North). From January 2010 to December 2016 a total of 7409 individuals were sampled from bottom trawlers operating on the northwestern coast of Portugal. The observed sex ratio was 0.56 in favor of the females. Monthly variations in gonadosomatic index, proportion of actively spawning individuals, hepatosomatic index and Fulton′s condition factor were analyzed. More than 60% of spawning individuals were recorded in the first quarter, corresponding to the highest values of GSI, and Fulton's K and hepatosomatic index increased after the start of spawning. The morphometric relationships between total length and gutted weight showed significant correlations (high determination coefficient, $r^2 > 0.9$) and isometric growth ($b = 3$) for both sexes. Results indicate that the spawning season of *T. picturatus* starts in December and extends until April–May, with a peak in March, which agrees with what has been indicated by other authors for the northeast Atlantic. This work provides important biological information on a species that although not subject to stock assessment is currently the 5th species landed by weight in Portuguese continental waters.

Keywords: *Trachurus picturatus* / spawning season / Portuguese coast / blue jack mackerel

1 Introduction

Studies on population dynamics, life history characteristics (growth and reproductive traits) provide basic data for stock assessment (Cadima, 2003) and allow to estimate the exploitation status of stocks and the effects of environmental factors for the management of fisheries (Cook and Heath, 2005).

The main objective of a reproductive strategy is to maximize reproductively active offspring in relation to available energy and parental life expectancy (Wootton, 1984; Roff, 1992; Pianka, 2000). Most marine fish species of commercial importance are iteroparous, that is they spawn more than once during their lives, and gonochoristic, that is their sexes are separate, possess no external sexual dimorphism and exhibit external fertilization without parental care (Murua and Saborido-Rey, 2003). In fisheries biology, analysis of life history traits related to reproduction has mainly focused on females, in part because offspring production is limited to a greater degree by egg production than sperm production (Helfman et al., 1997).

The blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), is a small, shoal forming, benthopelagic carangid, with a broad geographic distribution in the Atlantic, Mediterranean and Black Seas. It can be found from the southern Bay of Biscay to southern Morocco, including the Macaronesian archipelagos, Tristan de Cunha and Gough Islands (Smith-Vaniz, 1986). It is known to migrate between the coast of the Sahara and the Cape Verde Islands (https://www.fishbase.de/summary/*Trachurus-picturatus*). This species occurs not only on the continental shelf and upper slope, but also around offshore islands and over seamounts, from about 100 m to 550 m (Fischer et al., 1981; Menezes et al., 2006). Around the islands of Madeira and the Azores it is one of the most common fish, used fresh for human consumption and as live bait for fishing of tuna and black scabbard fish (Jesus, 1992). As a coastal pelagic species it holds a key position in food webs especially around sea mounts. Diverse species depend on *T. picturatus* as prey organism, such as demersal and coastal pelagic fishes (Morato et al., 1999; Barreiros et al., 2003), cephalopods (Martins, 1982), marine sea birds (Xavier et al., 2011) and marine mammals (Quérouil et al., 2008).

Since the end of the 1960's official landings statistics exist for *Trachurus picturatus* for mainland Portugal, Azores and

*Corresponding author: amcosta@ipma.pt

Madeira Islands (https://www.dgrm.mm.gov.pt/esta). Off the Portuguese continental coast this species is caught with trawls, purse seines and polyvalent gears often mixed with two other *Trachurus* species: *T. trachurus* and *T. mediterraneus* (Gonçalves et al., 2013) and several other small pelagic species, including sardine (*Sardina pilchardus*), Atlantic chub mackerel (*Scomber colias*), mackerel (*Scomber scombrus*) and European anchovy (*Engraulis encrasicolus*). The most important purse seine fishing ports are Matosinhos in the North, Sesimbra in the center and Olhão in the South (Feijó et al., 2012). The landing ports of the species caught by trawling depend on the decision of the master of the fishing vessel, and is determined by the time of year (existence of individuals of small sizes) and by the sale value at fishing auctions (Fernandes et al., 2008).

In particular for the Portuguese mainland studies on *Trachurus picturatus* are rare, limited to the information obtained by the research surveys carried out by IPMA (Portuguese Institute for Sea and Atmosphere) on abundance and distribution.

Although an annual TAC (Total Allowable Catch) is set for *Trachurus* spp. in ICES Division 9.a (thus applied to the combined catches of the three *Trachurus* species around the Iberian Peninsula) as well as to *Trachurus picturatus* in area 10 (Azores), *Trachurus picturatu*s catches have undergone large fluctuations around the Portuguese mainland (ICES, 2017). Therefore it is very important to know the biology of this species, in particular its spawning season.

In the literature studies on the reproduction of this species are scarce and only refer to Madeira (Jesus, 1992; Gouveia, 1993; Vasconcelos et al., 2006, 2017, 2018; Faria and Vasconcelos, 2008; Vasconcelos, 2016), the Azores (Westhaus-Ekau and Ekau, 1982; Isidro, 1990; Garcia et al., 2015) and the Canary Islands (Jurado-Ruzafa and Santamaría, 2013).

There are, however, some other publications on this subject by Russian authors written in Russian.

In this study, the proportion of reproductively active and inactive fish as well monthly variations of the gonadosomatic index were studied which helped to identify the spawning season, and provides information to improve future fisheries management. Being the first work on the biology of blue jack mackerel around the Iberian Peninsula, particularly with regard to its reproduction, this study aims to serve as a basis for the development of other works that allow a better knowledge of a species whose landings have been increasing in continental Portuguese waters (Vasconcelos et al., 2018).

2 Materials and methods

From January 2010 to December 2016 a total of 7409 *Trachurus picturatus* were obtained from landings of trawlers at the Matosinhos fishing harbor (41° 10′ lat. N; 08° 41′ long. W), northwest coast of Portugal, ICES Division 9.a (Fig. 1).

Total length (TL, ±0.1 cm), total weight (TW, ±0.01 g) and gutted weight (GW, ±0.01 g) were registered for all sampled individuals. Sex and maturity stages were determined through macroscopic examination of the gonads observed with the naked eye, according to the Brown-Peterson et al. (2011) scale: (1) immature (never spawned); (2) developing (gonads beginning to develop, but not ready to spawn); (3) spawning capable (fish are developmentally and physiologically able to spawn in this cycle); (4) regressing (cessation of spawning); (5) regenerating (sexually mature, reproductively inactive). The gonads (GonW, 0.01 g) and the liver (LW, 0.01 g) were removed and weighted. The sex ratio (M:F, males:females) was calculated by year and per month for the 6437 specimens for which the sex could be determined.

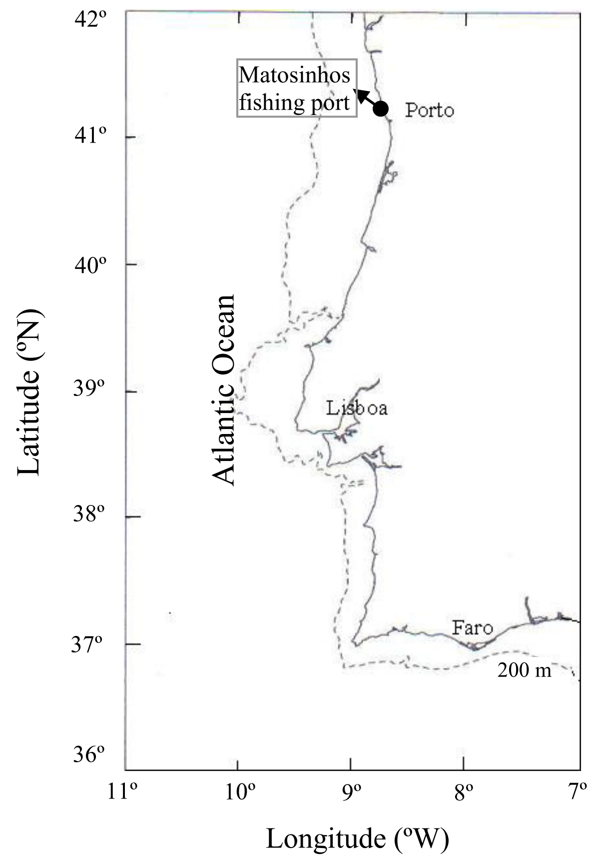

Fig. 1. Geographic location of Matosinhos, the fishing port where samples of *Trachurus picturatus* were taken.

The reproductive period was identified from the monthly proportion of fish in the mature stage and the temporal variation of the gonadosomatic index (GSI) (King, 1995):

$$GSI = \frac{GonW}{GW} \times 100,$$

as well as the monthly evolution of the hepatosomatic index (HSI) (Muñoz et al., 2005):

$$HSI = \frac{LW}{GW} \times 100,$$

and the Fulton index (K) (Fulton, 1911):

$$K = \frac{GW}{TL^b} \times 100,$$

where b is the exponent from the pooled (both sexes) length–weight relationship. The proportions of reproductively active and inactive individuals were analyzed according to the

Table 1. Annual summary of *Trachurus picturatus* sampled monthly from trawler landings at Matosinhos, Portugal. Minimum, maximum, modal lengths and standard deviation are also indicated for each year.

Sample	Male	Female	Immature or unsexed	Males size range (cm)	Mean male TL (cm)	Females size range (cm)	Mean female TL (cm)	Immature or unsexed size range (cm)	Mean immature or unsexed TL (cm)	Mode all ind. (cm)	St. dev. all ind.
2010	542	572	61	22.3–38.2	28.0	20.4–39.4	28.2	21.4–33.4	26.8	27.9	2.6
2011	487	546	40	23.8–34.1	28.8	24.4–40.0	29.2	24.8–32.7	28.8	30.2	1.8
2012	257	293	36	24.9–36.5	30.8	24.5–37.8	31.2	27.1–35.4	30.3	29.8	2.2
2013	468	529	225	21.8–43.1	30.8	24.0–38.3	30.9	17.8–36.2	26.2	29.9	3.3
2014	404	581	171	21.1–44.3	31.2	19.5–39.5	30.9	20.3–36.7	25.8	30.7	3.9
2015	329	552	276	22.2–36.7	29.3	20.9–40.1	28.1	19.9–35.1	26.4	27.2	3.2
2016	345	532	163	23.3–38.8	28.6	23.0–41.3	27.9	21.6–37.5	26.8	26.5	2.3
Total	2832	3605	972	21.1–44.3	29.5	19.5–41.3	29.4	17.8–37.5	26.6	30.2	3.1

Table 2. Parameters of the morphometric relationships GW = a TL^b established between total length (TL) and gutted weight (GW) for *T. picturatus* from the north-east Atlantic waters (ICES area 9.a). SE, standard error.

Sex	N	TL range (cm)	a	b	SE b	r^2
Males	2832	21.1–44.3	0.0076	3.012	0.055	0.931
Females	3605	19.5–41.3	0.008	2.983	0.029	0.936
Combined	6437	19.5–44.3	0.008	2.995	0.022	0.934

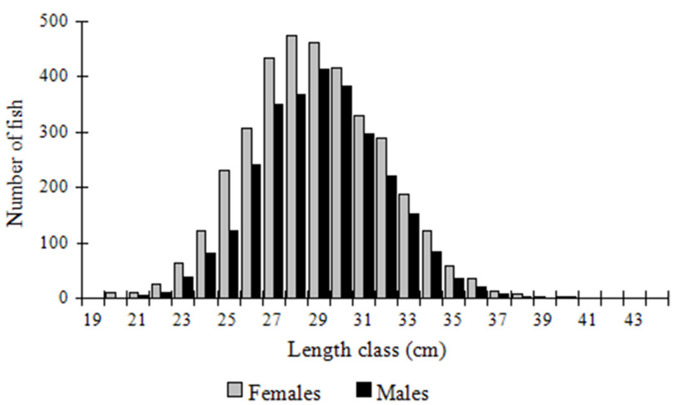

Fig. 2. Number of male and female *Trachurus picturatus* by length class.

percentages they represent among all mature individuals. Length–weight relationships were estimated by fitting the following model (Ricker, 1975):

$$W = a \times L^b,$$

where a is the initial condition factor; parameter were estimated using the least-squares method. Model fit was evaluated using the coefficient of determination (r^2).

3 Results

For this study a total of 7409 individuals were sampled, with average length 29.1 cm (range 17.8–44.3 cm) and standard deviation 3.1 cm (Tab. 1).

The morphometric relationships established between TL and GW for *Trachurus picturatus* off the Portuguese coast indicated significant correlations ($r^2 > 0.9$) and an isometric growth ($b \cong 3$) for both sexes (Tab. 2).

Considering all specimens, analyzed females outnumbered males (M:F of 1:1.27), corresponding to a sex ratio of 0.56. In the length classes up to 20 cm only females were identified, while individuals larger than 43 cm were all males (Fig. 2). Considering the whole study period, the number of females was higher than the number of males (44% males versus 56% females), corresponding to a sex ratio significantly different from 1:1, in all years except 2010 (Chi-square test, $p \leq 0.05$; 2011: $\chi^2 = 3.26$; 2012: $\chi^2 = 2.36$; 2013: $\chi^2 = 3.61$; 2014: $\chi^2 = 31.45$; 2015: $\chi^2 = 55.94$; 2016: $\chi^2 = 39.45$) (Fig. 3a). In relation to the monthly evolution during 2010 and 2016 (Fig. 3b), a sex ratio of 1:1 can only be assumed for February and March based on the significant chi-square test results for all other months (Chi-square test, $p \leq 0.05$; January: $\chi^2 = 8.42$; April: $\chi^2 = 3.12$; May: $\chi^2 = 3.70$; June: $\chi^2 = 43.15$; July: $\chi^2 = 27.20$; August: $\chi^2 = 7.26$; September: $\chi^2 = 3.41$; October: $\chi^2 = 4.80$; November: $\chi^2 = 5.52$; December: $\chi^2 = 14.191$).

Table 3 shows that most of the *T. picturatus* sampled were in maturity stages 2 (developing) and 4 (regressing). The analysis of the monthly proportion of reproductively active (fish being capable of spawning within the current reproductive cycle – maturity stages 2 and 3) and inactive (sexually mature but reproductively inactive – maturity stages 4 and 5) *T. picturatus* revealed that the period from January to May may be considered active spawning, while in the second half of the year most of the fish were in their inactive phase (Fig. 4).

Seasonal variations in the percentage of individuals capable of spawning (maturity stage 3) (Fig. 5) and the gonadosomatic index (Fig. 6) showed the same pattern for

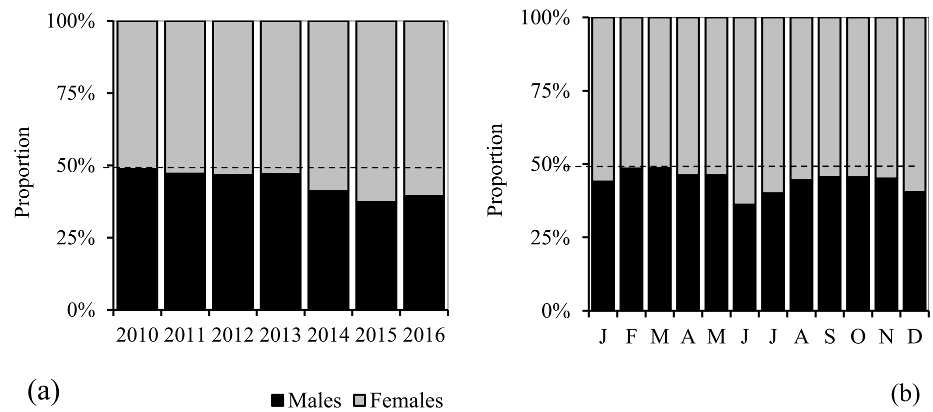

Fig. 3. Proportion of males and females of *T. picturatus* sampled off the Portuguese coast by year (a) and by month (b).

Table 3. Number of fish from the Portuguese coast sampled per maturity stage.

Maturity stage 1 Immature		Maturity stage 2 Developing		Maturity stage 3 Spawning capable		Maturity stage 4 Regressing		Maturity stage 5 Inactive	
Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
59	105	967	1768	373	270	1059	726	324	676

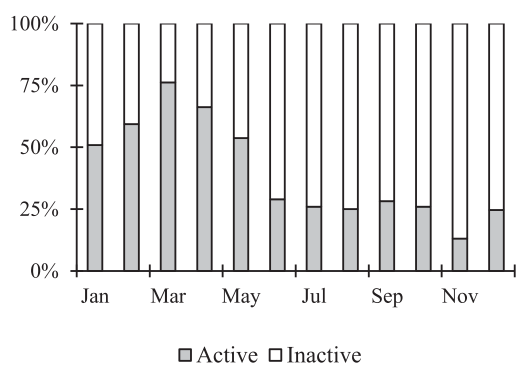

Fig. 4. Monthly proportions of reproductively active (fish being capable of spawning within the current reproductive cycle) and inactive *T. picturatus* (sexually mature but reproductively inactive) from the Portuguese coast. Males and females were combined.

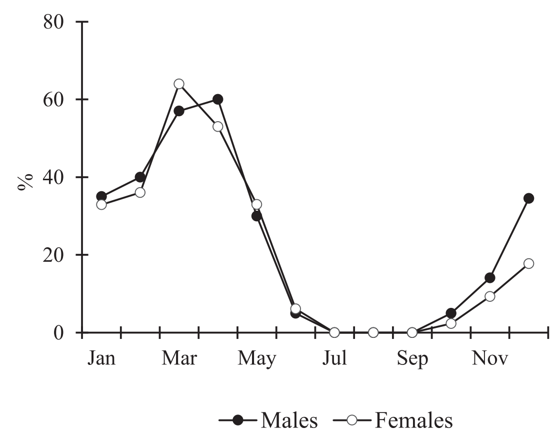

Fig. 5. Mean monthly frequency of spawning stage (stage 3) for male and female *T. picturatus* from north-east Atlantic waters (Portuguese coast).

males and females. The proportions of individuals in the spawning stage were higher in the first quarter and decreased during the second half of the year, with a new increase in November–December. GSI values, which were in general higher for females, except in January and February, ranged from 0.42 for males (November) and 0.74 for females (February) to 1.77 for males and 2.05 for females, both in March. The GSI obtained for both sexes showed small significant differences over the studied period ($F = 4.69$, $p = 0.030$).

The monthly variations of HSI and K were similar not only between them but also for males and females, reaching a maximum in June–August (Figs. 7 and 8). The hepatosomatic index varied between 0.77 in November and 1.56 in July, both for males, corresponding to a variation from 0.78 in February to 1.38 in June for females. The Fulton index, very similar for both sexes, showed little variation, ranging from 0.80 in February to 0.90 in August and November. The highest values of the HSI registered in summer, immediately after the decrease of the gonadosomatic index (Fig. 9) suggests that the liver losses weight during reproduction which may indicate the mobilization of hepatic reserves for gonads maturation.

4 Discussion

Larger stocks, often referred to as “commercially important”, are the main objective of fisheries research and

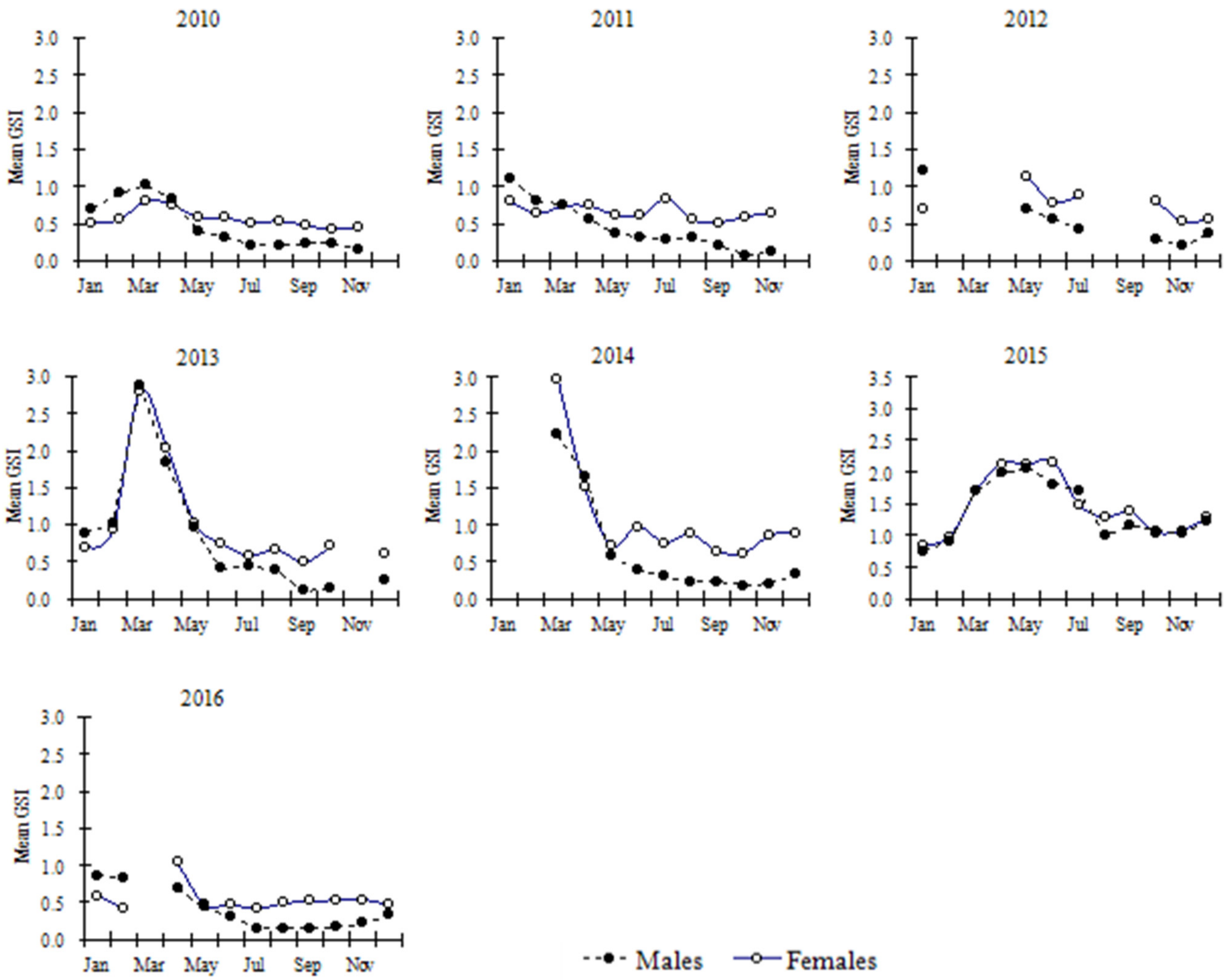

Fig. 6. Mean monthly gonadosomatic indices (GSI) (males and females) for *T. picturatus* from north-east Atlantic waters (Portuguese coast).

management and have at their disposal the funds and knowledge necessary to obtain understanding of their biology, ecology and fisheries (Scandol, 2005; Vasconcellos and Cochrane, 2005). However, there are many stocks around the world with limited or nonexistent management, due to the lack of data on their biology and ecology (Mahon, 1997; Vasconcellos and Cochrane, 2005; Costello et al., 2012). They are called "data poor fisheries" (Mahon, 1997; Scandol, 2005). Although these small stocks have some socio-economic importance for the countries where they are distributed, the methods for assessing and managing the large stocks, although applicable, are rarely feasible for them (Mahon, 1997; Fernandes et al., 2014, 2017; ICES, 2017, 2018). This study provides for the first time information on the reproductive cycle of *Trachurus picturatus* off the Portuguese coast.

The length range of the specimens observed (17–44 cm) is within the range reported for *T. picturatus* in other studies: 11–31 cm for the Algarve (southern Portugal) (Borges et al., 2003; 19–29 cm for the Portuguese west coast (Mendes et al., 2004), 25–36 cm for the northern area of Portugal (Hermida et al., 2016), 10–46 cm around the Madeira Islands (Jesus, 1992; Costa et al., 2000; Ferreira, 2004; Vasconcelos et al., 2006; Vasconcelos, 2016), 9–54 cm in the Azores region (Isidro, 1990; Rosa et al., 2006; Garcia et al., 2015), 10–31 cm around the Canary Islands (Jurado-Ruzafa and Santamaría, 2013), 11–32 cm in the Gulf of Cadiz (Torres et al., 2012) and 4–30 cm for the Mediterranean Sea (Merella et al., 1997). However, while our samples were caught by trawlers, the samples studied by these authors came mostly from purse-seiners and bottom long lines, which may influence the length range of the individuals captured.

Studies estimating trawl discards for *T. picturatus* along the Portuguese continental waters indicated that one important motive for discarding is the low commercial value (Fernandes et al., 2014, 2017) but discards due to fish catches below minimum legal size (15 cm) should be also considered. This study was based on fish market samples, hence if small fish were caught by the trawlers it is likely that they were discarded and hence not available for sampling at the Matosinhos fishing harbour. In this cases for length-weight relationships Petrakis and Stergiou (1995) suggested that the use of the achieved relationships should be limited to the size ranges used for the

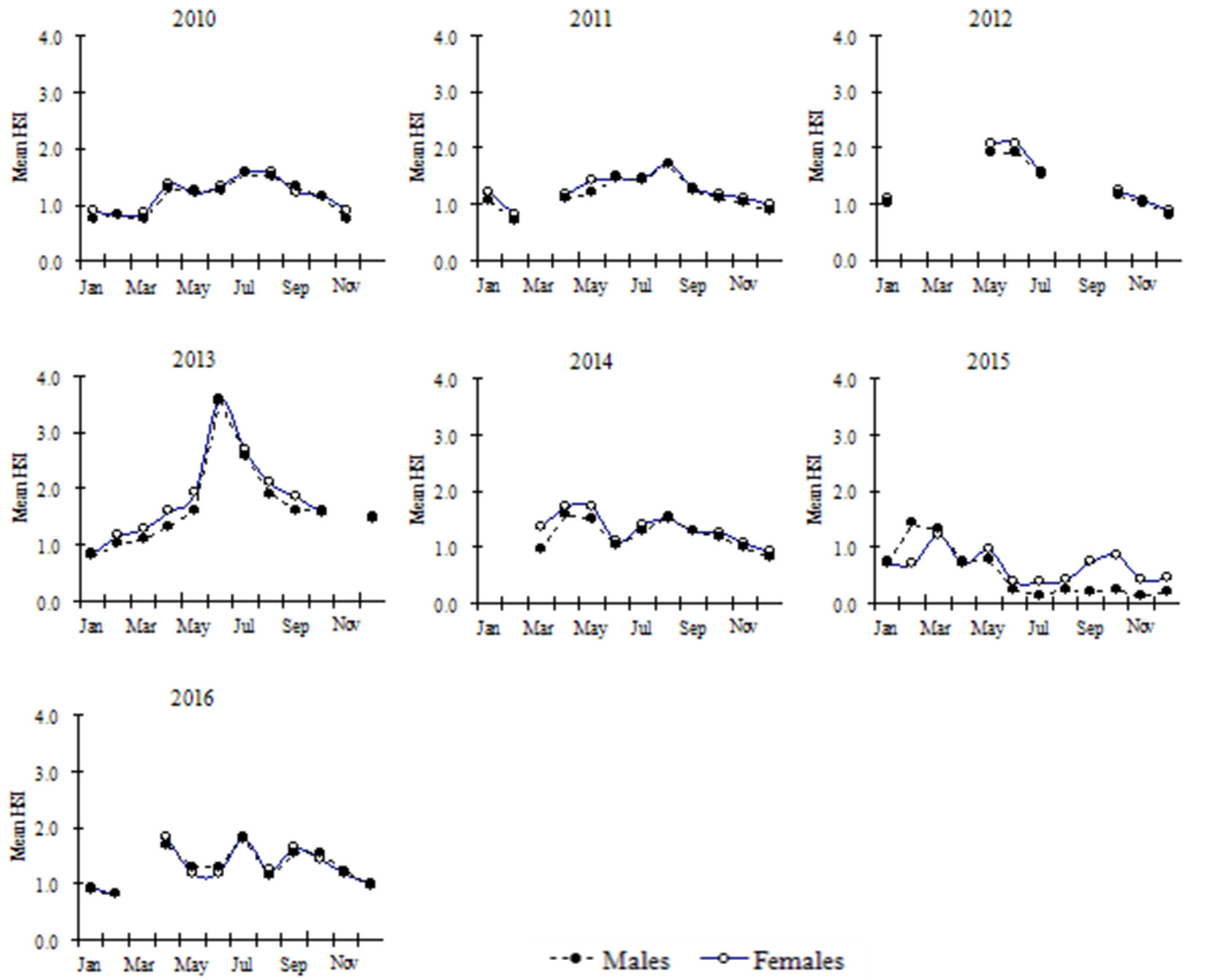

Fig. 7. Mean monthly hepatosomatic indices (HSI) (males and females) for *T. picturatus* from north-east Atlantic waters (Portuguese coast).

estimation and Bagenal and Tesh (1978) and Pepin (1995) stressed that it is particularly dangerous to extrapolate the relationship to unsampled sizes.

The allometric coefficient is expressed by the slope b of the linearized relationship. Isometric growth occurs when $b = 3$ (Mayrat 1970; Ricker 1975). If $b < 3$ negative allometric growth occurs and $b > 3$ is a positive allometric growth (Sokal and Rohlf, 1987). According to Bagenal and Tesh (1978), the parameter b is characteristic of the species and generally does not vary significantly throughout the year, while the parameter a may vary seasonally, daily and/or between different habitats. The value of the parameter a estimated in the present study is similar to that recorded by most of the authors who studied this species both off Madeira and around the Azores (Isidro, 1990; Ferreira, 2004; Garcia et al., 2015). However, Jesus (1992) and Vasconcelos (2016) for Madeira, Westhaus-Ekau and Ekau (1982) for the Azores Islands, Torres et al. (2012) for the Gulf of Cadiz, Merella et al. (1997) for the Mediterranean Sea and Borges et al. (2003) for the Portuguese mainland of Algarve estimated lower values, while on the contrary, Rosa et al. (2006) recorded a much higher value for the Azores Islands. Like in the present work, isometric growth for *Trachurus picturatus*, obtained with gutted weight was reported by Garcia et al. (2015) and Ferreira (2004) for total weight. However, Vasconcelos (2016), Borges et al. (2003), Torres et al. (2012), Isidro (1990) and Jesus (1992), these last two using the fork length, indicated a positive allometric growth for this species. Further, Merella et al. (1997), Westhaus-Ekau and Ekau (1982) and Rosa et al. (2006), the last two using fork length, indicated negative allometric growth. However, it should be noted that all these authors used the total weight of the individuals, with the exception of the aforementioned study by Garcia et al. (2015). In this work the gutted weight was applied to avoid the influence of the weight of the stomach and / or the weight of the gonads, which depends on the maturity stage of the fish.

The observed sex ratio (M:F = 1:1.27) showed a dominance of samples by females. A similar pattern was observed by Isidro (1990) (1:1.47) for the Azores islands and by Jesus (1992) (1:1.20), Gouveia (1993) (1:1.25) and Vasconcelos (2016) (1:1.21) for Madeira. In contrast, the results presented by González et al. (2012) (1:0.73) and Jurado-Ruzafa and Santamaría (2013) for the Canarias and Garcia et al. (2015) for

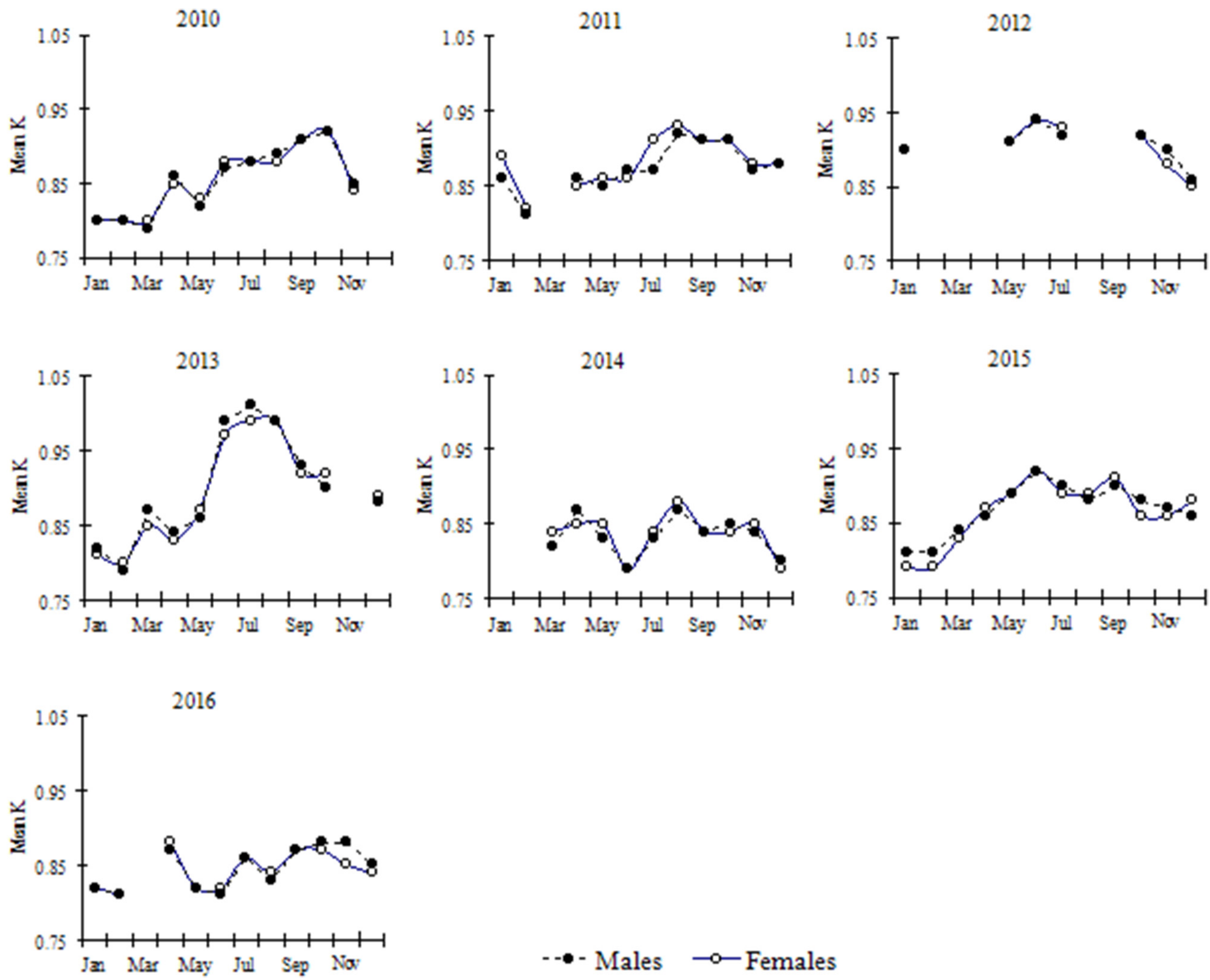

Fig. 8. Mean monthly condition factors (*K*) (males and females) for *T. picturatus* from north-east Atlantic waters (Portuguese coast).

the Azores indicated that males were more abundant than females, respectively, 1.36:1 and 1.11:1. Cousseau (1967) studying *Trachurus picturatus australis* from Mar del Plata also indicated a slight predominance of females (1:1.17). All these authors reported similar to our results that the highest numbers of females were found during the spawning season. Several factors can explain this finding, such as growth variations that affect the vulnerability of juveniles to predation, the ecological behavior of the species (Arkhipov et al., 2002; Menezes et al., 2006; Pakhorukov, 2008), temperature that influences sex determination (Conover and Kynard, 1981). Recruitment or migration patterns may also cause changes in the 1:1 sex ratio and lead to a greater capture of a given sex (Vicentini and Araújo, 2003; Amenzoui et al., 2006; Silva, 2007). The predominance of females at the peak of spawning may be due to the fact that in winter they form dense shoals in the deeper waters, while in spring they become far more dispersed, as has been observed in related species (Abaunza et al., 2003).

The seasonal variation of maturity stages represented in the population is a good indicator of the spawning period of a species. Similarly, the gonadosomatic index (GSI) is directly related to the development of the gonads. In the present study the GSI values for females were in general higher than those for males which is in accordance with the results reported for other species of Carangidae, such as *Trachurus trachurus* (Macer, 1974; Lucio and Martin, 1989), *Trachurus picturatus* from Madeira (Jesus, 1992; Gouveia, 1993; Vasconcelos, 2016) and the Azores Islands (Isidro, 1990) and *Trachurus mediterraneus* (Viette et al., 1997). The seasonal pattern of the gonadosomatic index was the same for both sexes, with maximum values in March–April, coinciding with those reported by other authors (e.g. Gouveia, 1993; Garcia et al., 2015).

Variations in the hepatosomatic index reflect energy storage for reproduction (Hoar, 1969). The observed seasonal changes in the hepatosomatic index with a maximum in June–July, higher for males than for females, seems to indicate a relationship between the accumulation of fat and sexual maturity. Similar results have been presented by Jesus (1992), Faria and Vasconcelos (2008) and Vasconcelos (2016) for the Madeira *Trachurus picturatus*, although these authors found, in contrast to the present study, higher HSI values for the females than for males.

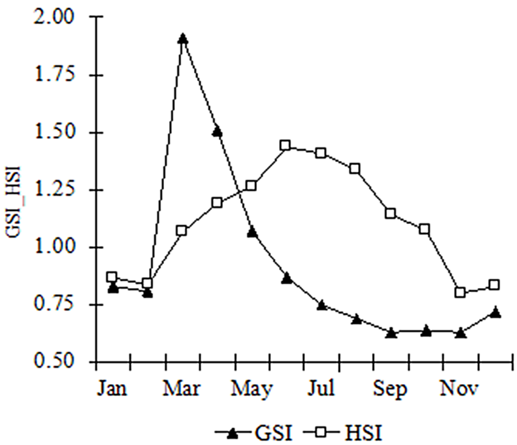

Fig. 9. Mean monthly gonadosomatic (GSI) and hepatosomatic (HSI) indices averaged across 2010–2016 (sexes combined) for *T. picturatus* from north-east Atlantic waters (Portuguese coast).

The condition factor (*K*) is a quantitative measure of the well-being of a fish and reflects feeding conditions. This factor varies due to the influences of physiologic factors, fluctuating according to different stages of the development. Differences in the condition factor have been interpreted as a measure of histological events such as fat reservation, adaptation to the environment and gonadal development (Le Cren, 1951). The minimum values of HSI and *K* obtained in the present study for both sexes during the spawning season can be interpreted as the result of mobilization of somatic energy reserves needed for reproductive development, influenced by reduced feeding during this period (Maddock and Burton, 1999). The only available information on this parameter for this species was reported by Vasconcelos (2016) who indicated, similar to this study, minimum values in January–February, corresponding to the spawning season, and maximum values in June–July, after spawning.

The importance of spawning timing has long been recognized as a critical factor in the recruitment process of marine fish stocks due to its effect on the initial synchrony between larvae and favorable environmental conditions (Hjort, 1914; Cushing, 1975; Cury and Roy, 1989; Mertz and Myers, 1994). However, the spawning season of many fish species is not a short event but extends over several weeks to months (Scott et al., 2006), which seems to be what happens for *Trachurus picturatus* off the Portuguese coast. The reproductive period extends from December to May, with a peak in March for females and in April for males. However, due to the fact that the spawning time is extended, mature gonads were observed almost all year round.

These results are in line with the long spawning season of the Central Eastern Atlantic *Trachurus picturatus*, which extends over a long period, from December to June, as reported by several authors for the waters of Madeira (Jesus, 1992; Gouveia, 1993; Faria and Vasconcelos, 2008; Vasconcelos, 2016), Azores (Isidro, 1990; Arkhipov et al., 2002; Garcia et al., 2015) and the Canary Islands (Cousseau, 1967; Shaboneyev and Ryazantseva, 1977; Rivero, 2006; Jurado-Ruzafa and Santamaría, 2013). On the contrary, in Mar del Plata, Cousseau (1967) indicates the spawning period in December–January as well as in the Mediterranean, where the spawning season is significantly shorter, between June and August (Lloris and Moreno, 1995). Previous studies carried out in the same area indicated two spawning periods: the beginning of winter off the North Saharan shore and the end of spring off the Moroccan coast (Gail, 1955; Garcia, 1982).

The differences found between our results and those presented by some of the other works consulted may be due to an adaptation of the populations off mainland Portugal to high-latitude environments, and therefore to a faster growth rate than that of the Macaronesian archipelagos populations. Considering that the northeast Atlantic system, the Canary Islands and the region of the Iberian Peninsula form two quite distinct subsystems (Dias, 2015), their separation is not only geographic but also a result of the unique oceanographic features of the northeast Atlantic region; the discontinuity of currents imposed by the flow of the Mediterranean Sea through the Strait of Gibraltar to the Gulf of Cadiz (Dias, 2015).

Although *Trachurus picturatus* is economically more important in the Macaronesian islands of Madeira and Azores, the landings of this species on the Portuguese mainland have suffered strong fluctuations. Landings have tripled, from 2005 to 2007, 2007 being the year with the highest recorded landings. The hypothesis that the fluctuations in landings could be due to changes in availability or abundance, and not just changes in fishing effort, is supported for the Portuguese mainland by the observation of fluctuations in the abundance indices obtained from research surveys (ICES, 2017). The minimum catch size for this species is 15 cm (European Community legislation – Commission Delegated Regulation 2016/2377 of 14 October 2016) and, although the EU allows a small catch of individuals below this length class, its low commercial value leads to a species with high discards (Fernandes et al., 2014). Thus the introduction of a minimum landing size could also have affected landings.

Despite not being subject to stock assessment, *Trachurus picturatus* is currently the 5th species landed by weight from Portuguese continental waters (https://www.dgrm.mm.gov.pt/esta) and the present results may contribute to better understand its biological characteristics and contribute to improve management decisions. However, to corroborate the information on the spawning season of this species the macroscopic scale of sexual maturity should be validated by a histological study of the maturation development of the gonads. Further studies should also be carried out to determine the length at first maturity in Portuguese coastal waters. The lack of studies on *Trachurus picturatus* in this region does not allow a correct evaluation of its socio-economic value. However, the increase in catches of this species in recent years, as previously mentioned, seems to indicate an increasing importance in the fishing communities where it is preferentially captured, such as Peniche (center of Portugal), Olhão (Algarve) and Sesimbra (region of Lisbon) (https://www.dgrm.mm.gov.pt/esta).

Acknowledgements. This work was supported by the PNAB/EU DCF – Data collection Framework. The author is grateful to Georgina Correia and Diana Feijó that performed the biological sampling that made this work possible.

References

Abaunza P, Gordo L, Karlou-Riga C, Murta A, Eltink ATGW, García Santamaría MT, Zimmermann C, Hammer C, Lucio P, Iversen SA, Molloy J, Gallo E. 2003. Growth and reproduction of horse mackerel, *Trachurus trachurus* (carangidae). *Rev Fish Biol Fisher* 13: 27–61.

Amenzoui K, Ferhan-Tachinante F, Yahyaoui A, Kifani S, Mesfioui AH. 2006. Analysis of the cycle of reproduction of *Sardina pilchardus* (Walbaum, 1792) off the Moroccan Atlantic coast. *C R Biol* 329: 892–901.

Arkhipov AG, Kozlov DA, Shnar VN, Sirota AA. 2002. Structure of waters and distribution of fish at different ontogenetic stages around seamounts of Central-Eastern Atlantic Ocean. ICES C.M 2000/M: 03.

Bagenal TB, Tesh FW. 1978. Age and growth, in: T. Bagenal (Ed.), Methods for Assessment of Fish Production in Freshwaters. Blackwell Scientific Publications – XV (IBP Handbook n° 3), Oxford, pp. 101–136.

Barreiros JP, Morato T, Santos RS, Borba AE. 2003. Interannual changes in the diet of the Almaco jack, *Seriola rivoliana* (Perciformes: Carangidae) from the Azores. *Cybium* 27: 37–40.

Borges TC, Olim S, Erzini K. 2003. Weight-length relationships for fish species discarded in commercial fisheries of the Algarve (southern Portugal). *J Appl Ichthyol* 19: 394–396.

Brown-Peterson NJ, Wyanski DM, Saborido-Rey F, Macewicz BJ, Lowerre-Barbieri SK. 2011. A standardized terminology for describing reproductive development in fishes. *Mar Coast Fish* 3: 52–70.

Cadima EL. 2003. Fish stock assessment manual. FAO Fisheries Technical Paper. No. 393. FAO, Rome, pp. 1–161.

Conover DO, Kynard BE. 1981. Environmental sex determination: interaction of temperature and genotype in a fish. *Science* 213: 577–579.

Cook RM, Heath MR. 2005. The implications of warming climate for the management of North Sea demersal fisheries. *ICES J Mar Sci* 62: 1322–1326.

Costa G, Chubb JC, Veltkamp CJ. 2000. Cystacanths of *Bolbosoma vasculosum* in the black scabbard fish *Aphanopus carbo*, oceanic horse mackerel *Trachurus picturatus* and common dolphin *Delphinus delphis* from Madeira, *Portugal. J Helminthol* 74: 113–120.

Costello C, Ovando D, Hilborn R, Gaines SD, Deschenes O, Lester SE. 2012. Status and solutions for the world's unassessed fisheries. *Science* 338: 517–520.

Cousseau MB. 1967. Contribucion al conocimiento de la Biologia del surel (*Trachurus picturatus* australis) del area de Mar del Plata (Pisces, Fam. Carangidae). *Bol Inst Biol Mar, Mar del Plata* 15: 5–37.

Cury PM, Roy C. 1989. Optimal environmental window and pelagic fish recruitment success in upwelling areas. *Can J Fish Aquat Sci* 46: 670–680.

Cushing DH. 1975. Marine ecology and fisheries. Academic Press, London.

Dias EC. 2015. A circulação oceânica costeira de Portugal. Dissertação para obtenção do grau de Mestre em Ciências Militares Navais, na especialidade de Marinha. Alfeite. 49 pp.

Faria G, Vasconcelos J. 2008. Reproduction biology of the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825) off Madeira Archipelago. Funchal, Madeira: XV Simpósio Ibérico de Estudos de Biologia Marinha.

Feijó D, Marçalo A, Wise L, Silva A. 2012. Protocolo de amostragem a bordo na pesca de cerco. Relat. Cient. Téc. IPIMAR, Série digital, n° 57, 11 pp + X anexos.

Fernandes AC, Prista N, Azevedo M. 2017. Discards from the Portuguese bottom otter trawl operating in ICES Division 27.9.0 (2004–2015). Relat. Cient. tec do IPMA (http://ipma.pt), n° 18. 18p+Anexos.

Fernandes AC, Barbosa S, Silva D, Pestana G. 2008. Composição dos desembarques e das rejeições por espécie da frota portuguesa de arrasto de fundo. Relat. Cient. Téc. IPIMAR, Série digital, n° 46, 38 pp + anexos.

Fernandes AC, Pérez N, Prista N, Santos J, Azevedo M. 2014. Discards composition from Iberian Trawl fleets. *Mar Policy* 53: 33–44.

Ferreira SFM. 2004. Contribuição para o estudo da idade e do crescimento do chicharro, *Trachurus picturatus* (Bowdish, 1825), da Ilha da Madeira, Undergraduate thesis, Faculdade de Ciências do Mar e do Ambiente, Universidade do Algarve.

Fischer W, Bianchi G, Scott WB (Eds.). 1981. FAO species identification sheets for fishery purposes. Eastern Central Atlantic; fishing areas 34, 47 (in part). Department of Fisheries and Oceans Canada, by arrangement with the Food and Agriculture Organization of the United Nations, Canada, Ottawa.

Fulton T. 1911. The sovereignty of the sea: an historical account of the claims of England to the dominion of the British seas and of the evolution of the territorial waters, with special reference to the rights of fishing and the naval salute. William Blackwood and Sons, Edinburgh.

Gail R. 1955. Nouvelles observations sur *Trachurus picturatus* Bowdish. *Rapp. P.-V. Réun. CIEM* 137: 57–58.

Garcia A, Pereira JG, Canha A, Reis D, Diogo H. 2015. Life history parameters of blue jack mackerel *Trachurus picturatus* (Teleostei: Carangidae) from north-east Atlantic. *J Mar Biol Ass UK* 95: 401–410.

Garcia S. 1982. Distribution, migration and spawning of the main fish resources in the Northern CECAF Area. FAO. CECAF/ECAF Series 82/25, 1–9.

Gonçalves P, Henriques E, Angélico MM. 2013, Co-occurrence of *Trachurus trachurus* and *Trachurus picturatus* spawners in Atlantic Iberian waters and the ability to distinguish their eggs in plankton samples. *Fish Res* 138: 139–145.

González JA, Pajuelo JG, Lorenzo JM, Santana JI, Tuset VM, Jiménez S, Perales-Raya C, González-Lorenzo G, Martin-Sosa P, Lozano IJ. 2012, Talla mínima de captura de pesces, crustáceos y moluscos de interés pesquero en Canarias. Una propuesta científica para su conservación. Viceconsejería de Pesca del Gobierno de Canarias, Las Palmas de Gran Canaria.

Gouveia ME. 1993. Aspectos da biologia do chicharro *Trachurus picturatus* (Bowdich, 1825) da Madeira. Undergraduate thesis. Faculdade de Ciências da Universidade de Lisboa.

Helfman GS, Collette BB, Facey DE. 1997. The diversity of fishes. Blackwell Science, London, England, 529 pp.

Hermida M, Pereira A, Correia AT, Cruz C, Saraiva A. 2016. Metazoan parasites of blue jack mackerel *Trachurus picturatus* (perciformes: Caramgidae) from Portuguese mainland waters. *J Helminthol* 90: 410–416.

Hjort J. 1914. Fluctuations in the Great Fisheries of Northern Europe Viewed in the Light of Biological Research. Rapp. P.-V. Réun. CIEM 20, 228 pp.

Hoar WS. 1969. Reproduction, in: W.S. Hoar, D.J. Randall (Eds.), Fish Physiology – Vol. III – Reproduction and Growth; Bioluminescence, Pigments and Poisons. Academic Press, New York and London, pp. 1–72.

ICES. 2017. Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA). ICES CM 2017/ACOM:17.

ICES. 2017. Report of the Benchmark Workshop on Pelagic Stocks, 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35.

ICES. 2018. Report of the Eighth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks. ICES CM 2018/ACOM:40.

Isidro HA. 1990. Age and growth of *Trachurus picturatus* (Bowdich, 1825) from the Azores. *Arquipelago-Life Mar Sci* 8: 45–54.

Jesus GT. 1992. Study of the growth and reproduction of *Trachurus picturatus* (Bowdich, 1825) in Madeira. Doc. No XIV/C/1-1991/03 (DG XIV/CE), 1–66.

Jurado-Ruzafa A, Santamaría GMT. 2013. Reproductive biology of the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), off the Canary Islands. *J Appl Ichthyol* 29: 526–531.

King M. 1995. Fisheries biology, assessment and management. Blackwell Science, Oxford.

Le Cren DE. 1951. The length–weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). *J Anim Ecol* 20: 201–219.

Lloris D, Moreno T. 1995. Distribution model and association in three pelagic congeneric species (*Trachurus* spp.) present in the Iberic Mediterranean Sea. *Sci Mar* 59: 399–403.

Lucio P, Martin I. 1989. Biological aspects of horse mackerel (*Trachurus trachurus* L. 1758) in the Bay of Biscay in 1987 and 1988. ICES CM 1989/H:28.

Macer CT. 1974. The reproductive biology of the horse mackerel *Trachurus trachurus* (L.) in the North Sea and English Channel. *J Fish Biol* 6: 415–438.

Maddock DM, Burton MPNM. 1999. Gross and histological observations of ovarian development and related condition changes in American plaice. *J Fish Biol* 53: 928–944.

Mahon R. 1997. Does fisheries science serve the needs of managers of small stocks in developing countries? *Can J Fish Aquat Sci* 54: 2207–2213.

Martins HR. 1982. Biological studies of the exploited stock of *Loligo forbesi* (Mollusca: Cephalopoda) in the Azores. *J Mar Biol Assoc UK* 62: 799–808.

Mayrat A. 1970. Allometrie et taxonomie. *Rév Stat Appl* 18: 47–58.

Mendes B, Fonseca P, Campos A. 2004. Weight/length relationship for 46 species of the Portuguese west coast. *J Appl Ichthyol* 20: 355–361.

Menezes GM, Sigler MF, Silva HM, Pinho MR. 2006, Structure and zonation of demersal fish assemblages off the Azores Archipelago (mid-Atlantic). *Mar Ecol Prog Ser* 324: 241–260.

Merella P, Quetglas A, Alemany F, Carbonell A. 1997. Length-weight relationship of fish and cephalopods from the Balearic Islands (Western Mediterranean). *Naga ICLARM Q* 20: 66–68.

Mertz G, Myers RA. 1994, Match/mismatch predictions of spawning duration versus recruitment variability. *Fish Oceanogr* 3: 236–245.

Morato T, Solà E, Grós MP, Menezes G. 1999. Diet of forkbeard (*Physis physis*) and conger eel (*Conger conger*) off the Azores during spring of 1996 and 1997. *Arquipélago – Life Mar Sci* 17A: 51–64.

Muñoz M, Sàbat M, Vila S, Casadevall M. 2005. Annual reproductive cycle and fecundity of *Scorpaena notata* (Teleostei: Scorpaenidae). *Sci Mar* 69: 555–562.

Murua H, Saborido-Rey F. 2003. Female reproductive strategies of marine fish species of the North Atlantic. *J Northwest Atl Fish Sci* 33: 23–31.

Pakhorukov N. 2008. Visual observations of fish from seamounts of the Southern Azores region (the Atlantic Ocean). *J Ichthyol* 48: 114–123.

Pepin P. 1995. An analysis of the length-weight relationship of larval fish: limitations of the general allometric model. *Fish Bull* 93: 419–426.

Petrakis G, Stergiou KI. 1995. Weight-length relationships for 33 fish species in Greek waters. *Fish Res* 21: 465–469.

Pianka ER. 2000. Evolutionary ecology. Benjamin-Cummings, Addison-Wesley-Longman, San Francisco, 6th edn., 528 pp.

Quérouil S, Silva MA, Cascão I, Magalhães S, Seabra MI, Machete MA, Santos R. 2008. Why do dolphins form mixed-species associations in the Azores? *Ethology* 114: 1183–1194.

Ricker WE. 1975. Computation and interpretation of biological statistics of fish populations. *Bull Fish Res Bd Can* 191: 203–233.

Rivero IH. 2006. Biometrics of pelagic fish in Gran Canaria Island waters (Canary Islands). Final Project. Universidad de Las Palmas de Gran Canaria, 17 p.

Roff DA. 1992. The evolution of life-history variation in fishes, with particular reference to flatfishes. *Neth J Sea Res* 27: 197–207.

Rosa A, Menezes G, Melo O, Pinho MR. 2006. Weight-length relationships of 33 demersal fish species from Azores archipelago. *Fish Res* 80: 329–332.

Shaboneyev IY, Ryazantseva YI. 1977. Population structure of the oceanic horse mackerel (*Trachurus picturatus picturatus*). *J Ichthyol* 17: 954–958.

Scandol 2005. Use of quality control methods to monitor the status of fish stocks, in: G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R. M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, D. Woodby (Eds.), Fisheries assessment and management in data-limited situations. Alaska Sea Grant College Program, Univ. Alaska, Fairbanks, AK, pp. 213–233.

Scott BE, Marteinsdottir G, Begg GA, Wright PJ, Kjesbu OS. 2006. Effects of population size/age structure, condition and temporal dynamics of spawning on reproductive output in Atlantic cod (*Gadus morhua*). *Ecol Model* 191: 383–415.

Silva A. 2007. Geographic variation in sardine population traits: implications for stock assessment. Doctoral Thesis. Universidade do Algarve, Faro, 235 pp.

Smith-Vaniz WF. 1986. Carangidae, in P.J.P. Whitehead, M.L. Bauchot, J. C. Hureau, J. Nielson, E.R. Tortonese (Eds.), Fishes of the North-Eastern Atlantic and Mecditerranean, Volume II. UNESCO, Paris.

Sokal RR, Rohlf FJ. 1987. Introduction to Biostatistics, 2nd edn. Freeman, New York.

Torres MA, Ramos F, Sobrino I. 2012. Length–weight relationships of 76 fish species from the Gulf of Cadiz (SW Spain). *Fish Res* 127–128: 171–175.

Vasconcelos J. 2016. Estrutura Populacional do Chicharro, Trachurus picturatus do Atlântico Nordeste. Tese de Doutoramento em Ciências Biológicas. Universidade da Madeira, 277 pp.

Vasconcelos J, Alves A, Gouveia E, Faria G. 2006. Age and growth of the blue jack mackerel, *Trachurus picturatus* Bowdich, 1825 (Pisces: Teleostei) off Madeira archipelago. *Arquipelago-Life Mar Sci* 23A: 47–57.

Vasconcelos J, Faria G, Freitas R, Gordo LS. 2017. Fecundity regulation strategy of the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), off Madeira Island (NE Atlantic). *Fish Res* 190: 150–156.

Vasconcelos J, Vieira AR, Sequeira V, González JA, Kaufmann F, Gordo LS. 2018. Identifying populations of the blue jack mackerel (*Trachurus picturatus*) in the Northeast Atlantic by using geometric morphometrics and otolith shape analysis. *Fish Bull* 116: 81–92.

Vasconcellos M, Cochrane K. 2005. Overview of world status of data-limited fisheries: inferences from landings statistics, in G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, D. Woodby (Eds.), Fisheries Assessment and Management in Data-Limited Situations, pp. 1–21.

Vicentini RN, Araújo FG. 2003. Sex ratio and size structure of *Micropogonias furnieri* (Desmarest, 1823) (Perciformes, Sciani-dae) in Sepetiba Bay, Rio de Janeiro, Brazil. *Braz J Biol* 63: 559–566.

Viette M, Giulianini PG, Ferrero EA. 1997. Reproductive biology of scad, *Trachurus mediterraneus* (Teleostei, Carangidae), from the Gulf of Trieste. *ICES J Mar Sci* 54: 267–272.

Westhaus-Ekau P, Ekau W. 1982. Preliminary report of the investigations on "Cavala" (*Scomber japonicus*) and "Chicharro" (*Trachurus picturatus*) at the Department of Oceanography and Fisheries, Horta, 54 pp.

Wootton RJ. 1984. Introduction: tactics and strategies in fish reproduction, in: G.W. Potts, R.J. Wootton (Eds.), Fish reproduction: strategies and tactics. Academic Press, New York, 1–12.

Xavier JC, Magalhães MC, Mendonça AS, Antunes M, Carvalho N, Machete M, Santos R, Paiva V, Hamer KC. 2011. Changes in diet of Cory's Shearwaters *Calonectris diomedea* breeding in the Azores. *Mar Ornithol* 39: 129–134.

Cite this article as: Costa AM. 2019. Reproductive cycle of the blue jack mackerel, *Trachurus picturatus* (Bowdich, 1825), off the Portuguese continental coast. *Aquat. Living Resour.* 32: 14