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RESEARCH ARTICLE

# Blue whiting (*Micromesistius poutassou*) sex ratio, size distribution and condition patterns off Portugal

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**Abstract** – The sex ratio is an important trait of natural populations and a key parameter for assessing the reproductive potential and stock status of exploited fish populations. In fisheries research, knowledge on spatial and temporal sex ratio variation can inform on the capacity of a population to support exploitation and environmental changes. Blue whiting (*Micromesistius poutassou*) shows sexual growth dimorphism after maturation, with females achieving greater lengths than males. The main goal of this work was to investigate seasonal patterns in the blue whiting sex distribution, size structure and condition in three areas along the Portuguese coast (north, southwest and south), based on bottom trawl surveys performed in autumn and winter between 1998 and 2015. Smaller blue whiting (12–24 cm) were found in shallow areas down to 250–300 m while larger individuals (>24 cm) were spread deeper down to 400–500 m. Condition factor Fulton $K$ differed significantly between seasons in all the areas ($F=11.72$; $p$-value $<0.001$) and between sexes ($F=6.14$; $p$-value $<0.05$). The proportion of females changed between autumn and winter ($\chi^2(1)=4.38$, $p=0.03$) and across depths ($\chi^2(1)=4.73$, $p=0.03$). Thus, this study revealed seasonal and depth variations in the blue whiting sex ratio along the Portuguese coast.

**Keywords:** Blue whiting / *Micromesistius poutassou* / Spawning / Sex ratio / Portuguese coast

## 1 Introduction

The sex ratio is an important trait of natural populations (Charnov, 1982) and is a key parameter for assessing reproductive potential and stock status of exploited fish populations (Vazzoler, 1996). In theory, it is expected that natural selection should maintain a 1:1 sex ratio by continuously favouring the less represented sex, thereby always returning skewed sex ratios to equality (Fisher, 1930). However in nature sex ratios can vary, though neither causes nor implications of this variation are fully understood for most species (Székely et al., 2014).

The sex ratio of exploited populations can be modified by non-random harvest as a consequence of sex specific behaviour, size, or morphology (Schultz, 1996; Marealle et al., 2010). Sex ratios can also be environmentally driven, namely by changes in temperature regime that may trigger changes in food availability (Vicentini and Araújo, 2003) leading to sex specific growth and mortality (Conover and Kynard, 1981; Kappus, 2012). The perception that sex ratios vary, and that males and females often differ in key ecological traits, suggests that sex ratio variation may modify the effect of species on communities and ecosystems (Fryxell et al., 2015).

In fishes, some populations can exhibit strong deviation from the expected 1:1 sex ratio (Trippel, 2003), which can vary over space and time (Pawson and Pickett, 1996; Trippel, 2003). Knowledge on spatial and temporal sex ratio variation can inform on the capacity of populations to sustain exploitation and environmental variation (Palsbøll et al., 2007; Schwartz et al., 2007). Many fish species present sexual growth dimorphism; the sex with slower growth rate is more likely to be exposed to extended predation on early life stages, leading to premature depletion before entering into next development phases (Nikolsky, 1963). However, in the majority of fishes the dimorphism on growth occurs after fish initiate maturation. Sexual dimorphism has the potential to influence species spatial distributions because predator–prey relationships are size-dependent (Brose et al., 2006), with body size conditioning overall feeding rate (Rall et al., 2012). Males and females can also be dimorphic in behavioural or

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morphological traits (Shine, 1989). Sexual dimorphisms as well sexual differences in size have been reported for many types of mesopelagic fishes (Clarke, 1983).

Blue whiting (*Micromesistius poutassou*) is a mesopelagic widely distributed species, living generally deeper than 200 m (Monstad, 2004; Dolgov et al., 2010). Growth in blue whiting is sexually differentiated, with females achieving greater lengths than males (Monstad, 1990; Trenkel et al., 2015); this differentiation was only visible at sizes above the length of first maturity (20 cm). Blue whiting, which are also a commercially important species (Pálsson, 2005), with the major fishing areas located at the spawning grounds west off Ireland and Scotland, the Norwegian Sea and the Bay of Biscay (ICES, 2016a). Although, the most important spawning area is the region to the west of the British Isles (Bailey, 1982), local spawning occurs in many areas, e.g. along the coasts of Iceland, in the Norwegian Sea, in some fjords along the Norwegian coast (Zilanov, 1968; Coombs et al., 1981; Monstad, 1990; Giæver and Mork, 1995) and on the shelf of Spain and Portugal (Silva et al., 1996; Ibaibarriaga et al., 2007).

In the Portuguese part of the stock, blue whiting is mainly caught as a by-catch species by the bottom-trawl fishery. In 2015, the Portuguese blue whiting catches represented 0.2% of total catches in the Northeast Atlantic (ICES, 2016a). The catch-at-age data used in stock assessment is based on sampling landings by countries involved in blue whiting fisheries. The Portuguese blue whiting sampling data collection for length and age distributions is stratified by sex. For estimating catch-at-age based on these data, a sex ratio of 1:1 is subsequently assumed. However, if the sex composition of catches was not as expected 1:1, this should be taken into account when producing the data to be used on assessment, in order to better reflect the stock dynamics in this area.

The aim of this study was to better understand the stock dynamics of blue whiting on the Portuguese shelf in view of improving the design of the commercial sample data collection. For this we studied seasonal patterns in blue whiting sex distribution, size and condition in three areas along the Portuguese coast (north, southwest and south), based on catch data from bottom trawl surveys, autumn and winter/spring, performed between 1998 and 2015.

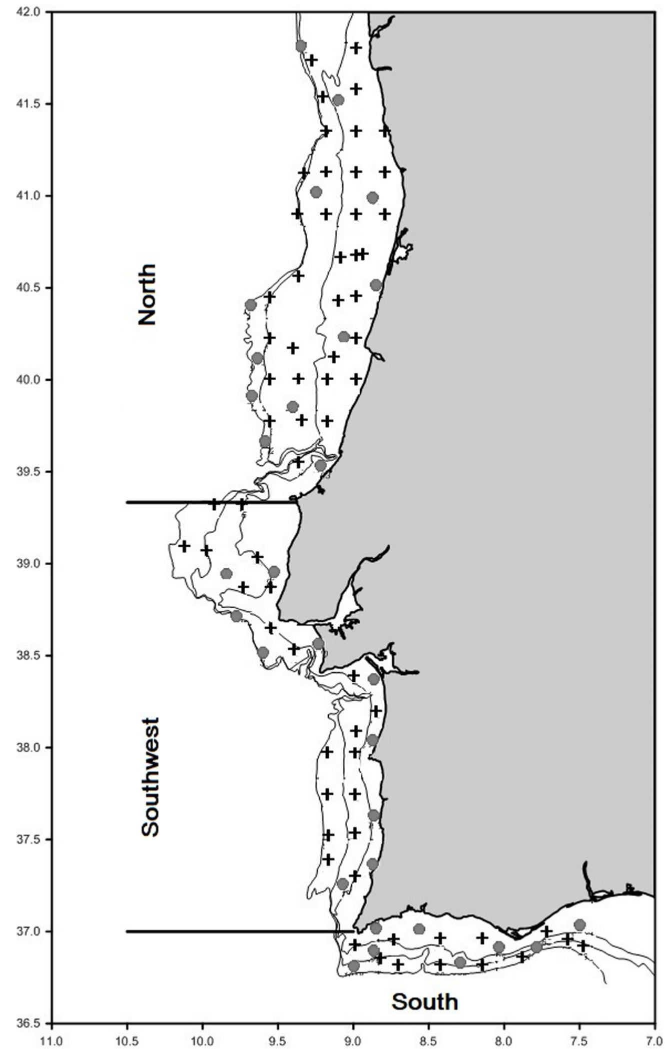


**Fig. 1.** Portuguese continental margin showing the sampling stations for bottom trawl surveys conducted between 1990 and 2011, where blue whiting was sampled, and 100 m, 200 m and 500 m isobaths. + Fixed stations; ● random stations.

## 2 Material and methods

Data were obtained from samples collected during 26 scientific bottom trawl surveys performed between 1998 and 2015 (1998–2015 in autumn ($n = 22$); and 2005–2008 also in winter/spring ($n = 4$)) along the Portuguese coast, between latitudes 41°49.5 N and 36°41.0 N and between the 20 m and 500 m isobaths (Fig. 1), carried out by IPMA (Instituto Português do Mar e da Atmosfera). Three different areas were considered along the Portuguese coast: northern coast (north); southwestern coast (southwest); and southern coast (south) (Fig. 1). Most of the surveys were performed on board RV "Noruega" using a Norwegian Campelen bottom-trawl with a 20 mm cod end mesh size with a vertical opening of 4.6 m and a ground rope with bobbins. The 1999, 2003 and 2004 surveys were conducted aboard RV "Capricórnio" using a bottom-trawl without bobbins in the ground rope. The surveys between 1998 and 2002 followed a fixed grid of 97 one hour tow sampling stations, performed during daytime at a target speed of 3.5 knots (Cardador et al., 1997). Between 2002 and 2004 the same grid was covered with 30 min daytime tows at 3.5 knots (WKPGFS, 2004). In 2005, the autumn surveys followed a fixed grid of 66 stations plus 30 random, and in the winter surveys 50 fixed stations plus 25 random. The surveys first aim was to study the demersal fish communities along the Portuguese coast, the primary species were hake, horse mackerel, blue whiting, mackerel, and Spanish mackerel (ICES, 2016b).

During the surveys the bottom depth (m) of each bottom trawl station was recorded. Total length (cm), total weight (g), sex and the macroscopic maturity stage of all blue whiting sampled were recorded. A five stages maturity key was used, with stages classified as: 1 – immature or resting; 2 – development; 3 and 4 – spawning; 5 – post-spawning. The maturity classification of gonads was based on their main macroscopic characteristics and has been validated through histology (Amorim, 2000). A good agreement was obtained between the maturity classifications made visually at sea and using histology, after the surveys. Immature gonads are smaller

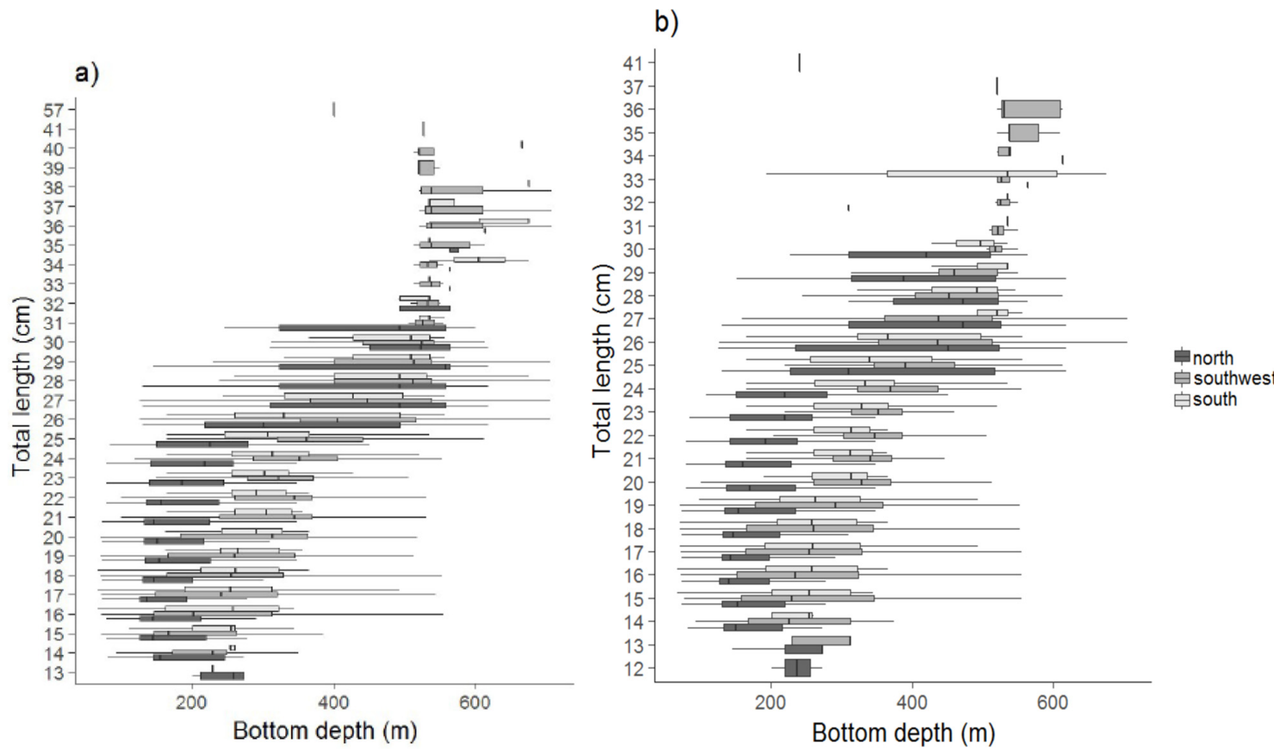


**Fig. 2.** Length (cm) distribution of blue whiting individuals by depth. (a) Females and (b) males. Sampling stations covered the depth range 20–750 m (see Fig. 1). The centre line of each box represents the median; the box limit indicates the 25th and 75th percentiles and the whiskers delimit the non-outliers range.

and composed of a homogeneous mass, in females without visible oocytes and in males the gonad appearance is like a thin ribbon or a small band. On mature gonads (stage 2 and 5), ovaries present visible opaque oocytes and testes appearance is opaque white with a large band as shape. Females at spawning stage (stage 3 and 4) are classified based on the presence of hydrated oocytes in the ovary which could easily flow/run under some pressure at the abdomen. Males at spawning stage (stage 3 and 4) present bigger gonads in which the sperm could flow under pressure on the abdomen. Fish classified as stages 2 and 5 were considered as mature and fish at stages 3 and 4 as spawners for this study. The proportion of immature, spawning and mature fish in the samples by season (autumn and winter) and sampling area (north, southwest and south) was determined. Similarly, sex ratio dynamics were studied using the proportion of females ($SR = F/(F + M)$) by length class, season and sampling area.

Blue whiting abundance, number caught per hour, was determined annually (1998–2015) based on sample stratified mean and variance (Cochran, 1960).

Fulton's condition factor ($K$) assesses the condition of mature fish as (Fulton, 1902):

$$K = \frac{W100}{L^3}$$

where $W$ is total fish weight (g) including gonads and $L$ is total fish length (cm). $K$ was calculated by sex (F and M), season and area. Analysis of variance (ANOVA) was used to examine variation of the Fulton's condition between sexes, areas and seasons.

A generalised linear mixed model was applied to analyse variations in the proportion of females. Year, season, depth and area were considered as fixed effects (main effects only). A random effect was used for station ID. Season, area and station ID were treated as factors. Residual plots were inspected visually for deviations from normality. Likelihood ratio tests were applied to test the effect of each variable in turn by comparing the full model including all variables against the model without the given variable.

Data analyses, including figures and models, were performed in R 3.3.1 (R Core Team, 2016) and using packages "ggplot2" (Wickham, 2009), "ggthemes" (Arnold, 2017) and "lme4" (Bates et al., 2015).

## 3 Results

Depth changes of blue whiting length composition and sex ratio differed between the studied areas along the Portuguese coast. Small blue whiting (12–24 cm) were found over shallow bottoms down to 250–300 m while larger individuals were spread deeper down to 400–500 m (Fig. 2). The depth occupied by males and females of the different length classes was similar. In the northern area, the majority of small fish (<25 cm) were observed between 100 m and 250 m while larger individuals (>25 cm) were found between 300 m and 600 m. In the southwestern area, the majority of small fish (14–20 cm) concentrated around the 200 m depth contour while larger fish (>24 cm) were mainly found between 300 m and 500 m. In the south, small fish (<24 cm) were spread over a

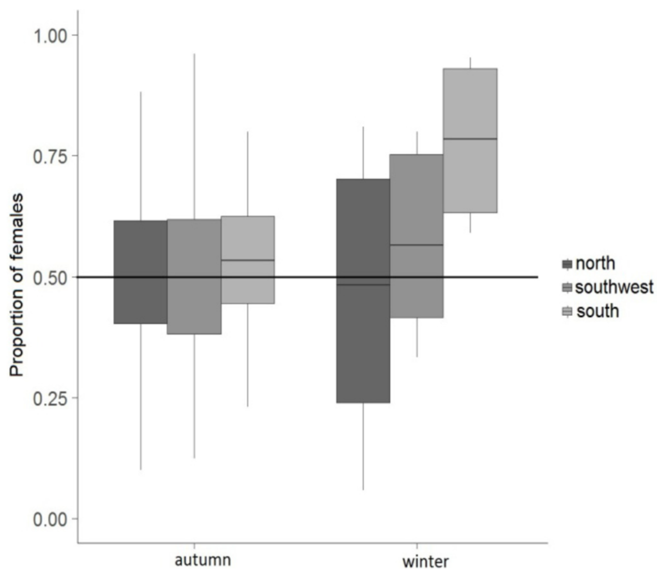


**Fig. 3.** Blue whiting proportion of females by season (autumn and winter) and area. The centre line of each box represents the median, the box limit indicates the 25th and 75th percentiles and the whisker delimits the non-outliers range. The horizontal line indicates the sex ratio 1:1.

wider depth range (100–300 m) and, similar to the other areas, larger sized individuals were found between 250 m and 550 m. In general, larger fish were distributed over a smaller depth range compared to smaller fish. Thus, larger fishes were confined to deeper areas (≥500 m) in which the sampling intensity was much smaller with 21 stations out of 97.

In winter, the proportion of females (SR) increased from south to north while in autumn it was constant around 0.5 (1:1 sex ratio) in all regions (Fig. 3; Tab. 1). Thus, females were more abundant in winter in the north, with a median SR of around 0.75. In the autumn months, in all areas, the SR of individuals with length size above 25 cm was 1:1 (Tab. 1). During winter, blue whiting individuals in the surveys were <30 cm. The largest differences in SR between areas were observed in winter (Tab. 1). The GLMM results confirmed that season but also year and depth significantly explained variations in SR (Tab. 2; Fig. 4). Blue whiting abundance varied over time years, with the greatest abundances observed in 2001, 2009 and 2015 (Fig. 4b).

The percentage of immature fish, observed in the samples, was higher in autumn compared to winter and somewhat higher in the north compared to the other two areas (Fig. 5). Conversely, the percentage of mature fish was higher in winter except for the southwest was it remained constant between autumn and winter at around 50%. The percentage of spawners was higher during winter in all the areas. On the south and southwest coasts, fishes at spawning stage were sampled in both seasons while in the north spawners were mostly observed during winter.

Mature blue whiting had a condition factor (Fulton *K*) between 0.45 and 0.8 (Fig. 6). During winter, mature males and females were in slightly lower condition compared to autumn, the difference being more pronounced in the north (Fig. 6a), than in the other two areas (Fig. 6b, c). Differences in condition factor *K* were statistically significant for season combining all individuals ($F(4) = 9.76$; $p$-value $<0.001$) and for sex ($F(1) = 6.42$; $p$-value $<0.05$).

## 4 Discussion

In this study, the sex ratio of blue whiting was analysed using bottom trawl survey data from the Portuguese coast. Blue whiting is a mesopelagic species that occupies deeper waters than other pelagic species (Heino and Godø, 2002), but can also be found close to the seafloor (Bailey, 1982). In the Barents Sea, a relatively shallow area with an average depth of 230 m, the species has been described to live close to the sea floor, allowing for the possibility of strong ecological interactions with the demersal fish community (Heino and Godø, 2002). The same seems to occur on the Portuguese coast, where in the bottom trawl surveys planned to study demersal communities, blue whiting often composed more than 90% of the biomass in the catches of the shallow (100–200 m) and deeper assemblages (>200 m) (Gomes et al., 2001; Sousa et al., 2005). Further, the diel vertical migration of this species occurs at night (Johnsen and Godø, 2007). Thus, although by using the data from bottom trawl sampling an unknown part of the Portuguese blue whiting stock component remained unsampled, the results obtained should still be representative for sex ratio and condition variations. The lack of pelagic sampling during the Portuguese trawl surveys precluded studying SR patterns in the water column. In contrast, data from the annual international acoustic blue whiting survey performed during the spawning period covering the main spawning area and also the annual Spanish acoustic pelagic survey among others, could provide understanding and a description of vertical SR patterns.

Differences in blue whiting abundances were observed among years and also found for the proportion of females. These inter-annual differences reflect intrinsic species distribution dynamics off Portugal, rather than methodological challenges or biases linked to the natural behaviour or distribution of blue whiting along the coast. As the survey sampling selectivity was standardised, the results are representative of the true blue whiting distribution in this area, taking into account the species' close association to the sea bottom observed in this study and in previous studies (Gomes et al., 2001; Sousa et al., 2005).

Differences in the distribution of males and females have been noted for many species, resulting in spatial trends in their sex ratio (Trippel, 2003). Some of these trends were associated with migration behaviour during the spawning season (Stoner et al., 1999). For blue whiting, the observed seasonal pattern could also be related to spawning. The majority of blue whiting individuals were at mature stage (>20 cm) and at depths between 250 m and 500 m. At those depths, blue whiting find large concentrations of the main items of their diet composed of zooplanktonic crustaceans, mainly copepods and euphausids (Cabral and Murta, 2002). The spawning period described for this species along the Portuguese coast spans January to March, with a peak in February (Amorim, 2000). Thus, the higher number of spawners during winter in the northern and southwestern areas confirms this peak season at least for these two areas.

**Table 1.** Mean proportion of blue whiting females (standard deviation in brackets) by length class (cm) by survey season and study area on the Portuguese shelf. NA – not available.

| Area | Length class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | <20 cm | | 21–25 cm | | 26–30 cm | | >31 cm | |
| | Autumn | Winter | Autumn | Winter | Autumn | Winter | Autumn | Winter |
| North | 0.49 (0.16) | 0.48 (0.27) | 0.53 (0.29) | 0.35 (0.39) | 0.79 (0.20) | 0.48 (0.01) | NA | NA |
| Southwest | 0.49 (0.16) | 0.64 (0.01) | 0.45 (0.16) | 0.50 (0.25) | 0.67 (0.24) | 0.37 (0.21) | 0.93 (0.10) | NA |
| South | 0.51 (0.19) | NA | 0.54 (0.19) | 0.81 (0.14) | 0.68 (0.07) | NA | NA | NA |

**Table 2.** Summary of the generalised mixed model results for blue whiting proportion of females on the Portuguese shelf. df – degrees of freedom; std. error – standard error.

| Variable | df | Estimate | Std. error | *z*-value | Probability | Probability (>\|*z*\|) |
|---|---|---|---|---|---|---|
| Intercept | | 9.449 | 1.727 | 5.472 | 4.44e−08 | ** |
| Year | 1 | −0.005 | 0.001 | −5.356 | 8.53e−08 | ** |
| Season | 1 | −0.641 | 0.303 | −2.113 | 0.0346 | * |
| Depth | 1 | 0.002 | 0.001 | 2.239 | 0.0252 | * |
| Area | 2 | −0.163 | 0.224 | −0.728 | 0.4668 | |

* <0.01.
** <0.001.

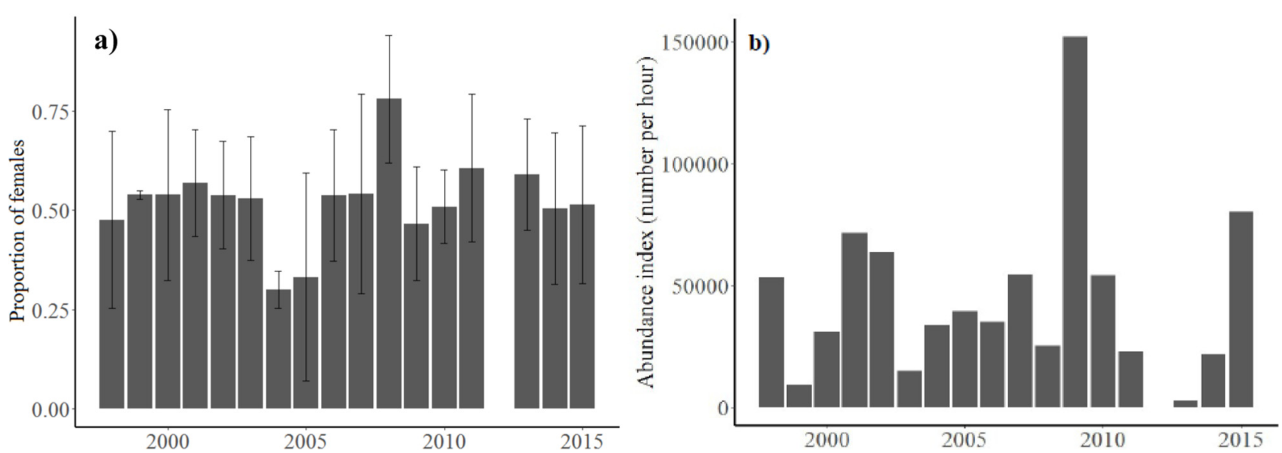


**Fig. 4.** The average of (a) proportion of females (mean ± SD) and (b) abundance index (mean number of individuals caught per hour) by year for blue whiting on the Portuguese shelf.

The lowest condition indices (Fulton's *K*) were found in winter while in autumn higher values were observed, except in the southern area where no differences were evident. Similar results have been reported for cod, for which condition values were lowest during the spawning season (winter), increased during post-spawning, to reach the maximum values in autumn (Mello and Rose, 2005). The low condition in winter could result from the high energy spent on spawning which is not sufficiently replaced by food intake; adult blue whiting may also cease feeding during spawning (Bailey, 1982). In the south during winter, few spawners were observed and the samples were mostly composed of mature females (SR ≈ 0.81) in better condition, in contrast to what was observed in the other areas. These females were between 21 cm and 25 cm total length. The absence of spawners may be explained by horizontal migration or by earlier spawning in warmer temperatures (Relvas et al., 2007). Spawning is induced in gonads at a late stage of development by a combination of changes in temperature and light periodicity. On the Portuguese coast waters become warmer from south to north (Relvas et al., 2007).

This study revealed the existence of a seasonal pattern in the sex ratio of blue whiting off the Portuguese coast. On the northern and southwestern coasts, the sex ratio during spawning was around 0.5 in all length classes, an unequal outside spawning. Sex differentiated seasonal migrations have been described for several species. In lingcod (*Ophiodon elongatus*), seasonal migrations differ by sex, with males aggregating in shallow waters and adult females in deep water

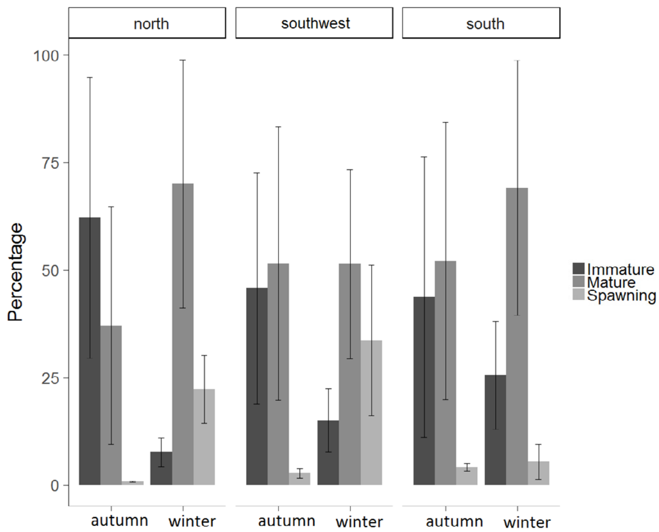


**Fig. 5.** The percentage immature, mature and spawning fishes, data combined from both sexes, in the samples by season (autumn and winter) and for each of the three areas (north, southwest and south).

during winter, while in summer both sexes are distributed equally over deep and shallow sea bottoms (Okamura et al., 2014). For megrims and other flatfish the opposite has been noticed, the proportion of males increases with increasing bottom depth (Poulard et al., 1999). Other studies have reported that in general females were more vulnerable to environmental conditions than males (Vicentini and Araújo, 2003). Nikolsky (1963) described that when food is abundant, females predominate, with the situation inverting in regions where food is limited. Thus, blue whiting females might remain near the bottom at mature stages where food is more abundant and during spawning might migrate to shallower depths, at least during daytime when the samples were collected. This seasonal migration could also be to and from the main spawning grounds to the west off the British Isles, although the presence of spawning individuals indicates the occurrence of spawning events in Portuguese waters. In the south, where the number of spawners was small and samples were composed of smaller fish, the horizontal migration to the main spawning ground seems less plausible. If occurring it should be to and from the southwest or to the neighbouring Mediterranean Sea.

Significantly different body sizes and sex composition have been reported for fish caught by different nets. For example, longlines were found to catch mostly females of black dogfish (*Centroscyllium fabricii*) (Wirtz and Morato, 2001). For blue whiting, the individuals dominating in bottom trawl catches were generally larger than those caught by midwater trawls in a number of areas (Bailey, 1982). During spawning the opposite was observed (Pawson, 1979). The same effect was observed in this study with the absence of larger fish in winter.

Blue whiting is commonly caught as by-catch by Portuguese bottom trawl fleets targeting finfish and crustaceans (ICES, 2016a). Although these fleets operate to deeper depths and thereby catch fish bigger than the ones caught by the surveys (unpublished data), the survey data are still representative of the Portuguese component of the population.

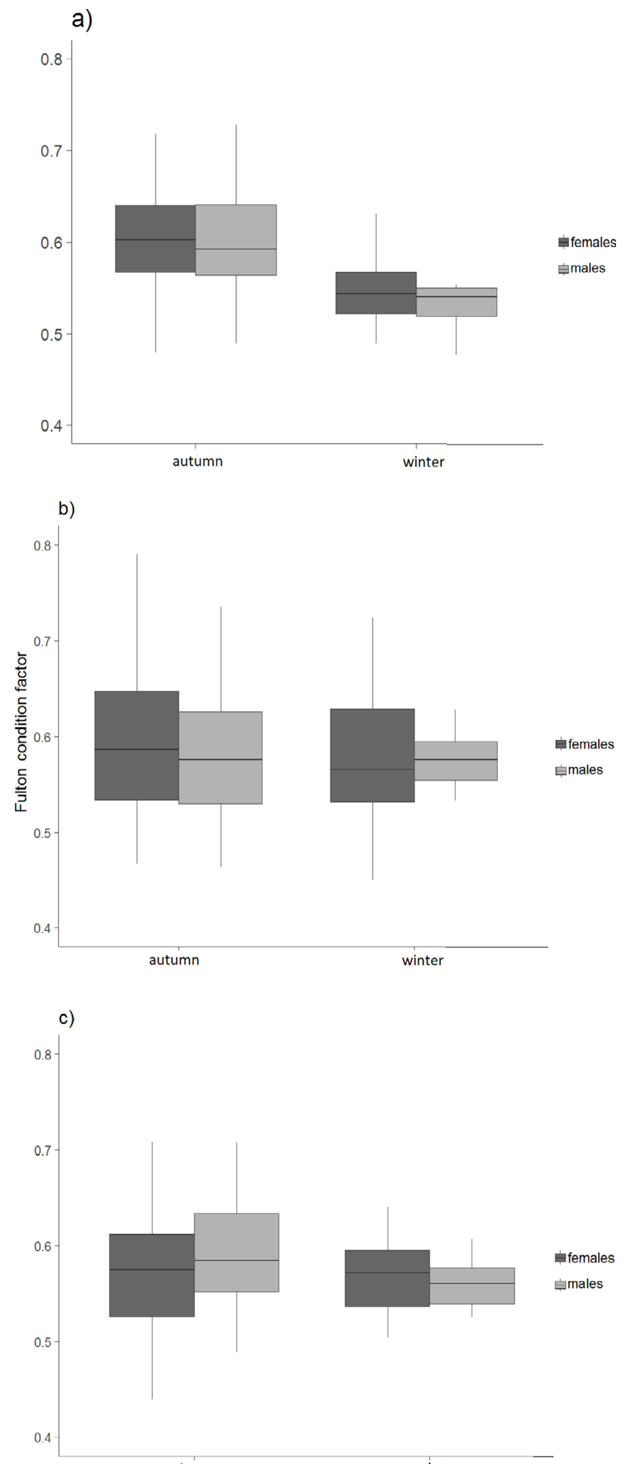


**Fig. 6.** The Fulton condition factor ($K$) for mature blue whiting, by sex (F – females; M – males) and by season (autumn and winter) along the areas of sampling: (a) north, (b) southwest and (c) south. The centre line of each box represents the median, the box limit indicates the 25th and 75th percentiles and the whisker delimits the non-outliers range.

Thus, the results from this study based on bottom trawl sampling revealed that attention must be paid to the area and season where the fleet is operating, because a shift in the 1:1 sex composition, for a species with dimorphism in growth, if not taken into account may bias the age-at-length key and subsequently the data produced for assessment. However, sampling during the surveys took place during daytime, while the fishing fleets operate day and night. Thus the sex composition of commercial catches could also change related to the time of capture (day versus night), due to diel vertical migrations (Johnsen and Godø, 2007). This suggests that the use of separate age-length keys by season and area reflecting the sex composition in commercial catches should be evaluated.

In conclusion, outside the spawning season blue whiting females occurred predominantly close to the sea bottom during the day. During spawning, males remained in great numbers close to the sea surface. However, the underlying processes remain unknown. Implementing acoustic echosounder recordings during the Portuguese bottom trawl surveys would be a first step to study blue whiting vertical migrations and contribute to improve community and ecosystem studies.

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