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Inshore *versus* offshore length distribution of round sardinella (*Sardinella aurita)* in the middle eastern Adriatic Sea

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Round sardinella, Sardinella aurita *specimens (N= 2,033) were caught in inshore (Virsko more) and offshore waters (Dugi otok) of the eastern middle Adriatic Sea by commercial purse seine, monthly from November 2007 to January 2009. Out of all specimens, 983 were male (48.4%), 1,021 were female (50.2%) and 29 (1.4%) were undetermined specimens, giving an overall sex ratio of m/f=0.96. Round sardinella specimens from inshore waters (N=526) and offshore waters (N=1,507) showed total length (LT) range 13.0-32.5 cm and 10.0-30.0 cm, respectively. In total, they showed positive allometry (b=3.2266). Fulton's mean condition factor for round sardinella from inshore waters was* $\overline{K}$ *=0.76 ± 0.23, and for samples from offshore waters, it was* $\overline{K}$ *=0.73 ± 0.05. Females indicated better condition (*$\overline{K}$ *=0.75 ± 0.05) in both analyzed areas than males (*$\overline{K}$ *=0.74 ± 0.05).*

Key words: round sardinella, Adriatic, length distribution, length-weight relationship, condition

INTRODUCTION

Round sardinella *Sardinella aurita* Valenciennes, 1847, is a subtropical, thermophilic pelagic species wildly distributed between 47° N - 40° S and 98° W - 43° E. The greatest catches are made in the western Atlantic Ocean off the Venezuelan and southern Brazilian coast with 200 000 t of fish per year (LONGHURST & PAULY, 1987; LOWE-MCCONNELL, 1987; FAO, 1992) and off West Africa in Senegalo-Mauritanian, Ivoro-Ghanaian and Congo-Angolese waters where annual catches are up to 650 000 t (FRÉON, 1988; DO CHI, 1994; MARCHAL, 1991). In the eastern and south western, warmer parts of the Mediterranean, round sardinella is also very frequent (BEN –TUVIA, 1960). Since 1980s this species has widened its living area in the northern Mediterranean (FRANCOUR *et al*., 1994; SABATÉS *et al*., 2006; TSIKLIRAS, 2008) and the Adriatic Sea (SINOVČIĆ *et al.,* 2004).

It is interesting that the first written data on the fishing and distribution of small pelagic fish date back to 10th century (BASIOLI, 1974) and that the areas included were the same as in this study - the southern part of Dugi otok and bays of Molat Island. This oldest written data on Croatian fishing are related to the island area of Zadar County, which was and still is, one of the top fishing areas regarding small pelagic fish, especially sardines.

In Croatia, this species is mostly used for feeding tunas in cages and rarely as a food product of the fish canning industries (MUSTAĆ, 2010). In the Adriatic Sea, round sardinella is

usually caught by purse seine together with sardine *Sardina pilchardus*, anchovy *Engraulis encrasicolus* and other pelagic fishes. Even though its caches have increased since 1980s, it is still present in smaller numbers in comparison to other pelagic fish species, as sardines, anchovies and chub mackerels (GAMULIN & HURE, 1983; DULČIĆ & GRBEC, 2000; SINOVČIĆ *et al*., 2004; MUSTAĆ, 2010).

Since this species was uncommonly caught and noted in the Adriatic three decades ago, data on biological parameters of round sardinella in that area are fragmentary and rare. Thus KAČIĆ (1975) analyzed some biological parameters of round sardinella (*N*=126). Planktonic phase of this species was described by REGNER (1977), growth parameters of its larvae phase were observed by DULČIĆ (1998), while SINOVČIĆ *et al*. (2004) described juvenile round sardinella specimens in the eastern middle Adriatic Sea. Some recent studies presented its growth parameters, reproduction and biochemistry, referring to the changes in the Adriatic Sea due to global climate change (MUSTAĆ & SINOVČIĆ, 2011, 2012a, 2012b).

This subtropical thermophilic species has adapted to lower temperatures in the Adriatic Sea, especially during winter months, although the lowest sea temperatures had occasionally caused round sardinellas mass mortality (GUIDETTI *et al.,* 2002). Since its adaptation to specific conditions of the Adriatic Sea is mostly unknown, the goal of this study was to define its population characteristics and to compare them with the same species from other seas. Therefore, this study presents length distribution, length-weight relationship and condition of round sardinella in inshore (Virsko more) and offshore (Dugi otok) waters of the eastern middle Adriatic Sea.

MATERIAL AND METHODS

A total of 2,033 round sardinella specimens were collected from November 2007 to January 2009 by monthly random sampling of commercial purse seine catches (mesh size: 8 mm) in inshore (Virsko more) and offshore (Dugi otok) waters (Fig. 1) of the eastern middle Adriatic Sea (43°30 N; 15°30 E; and 44°30 N; 15°00 E).

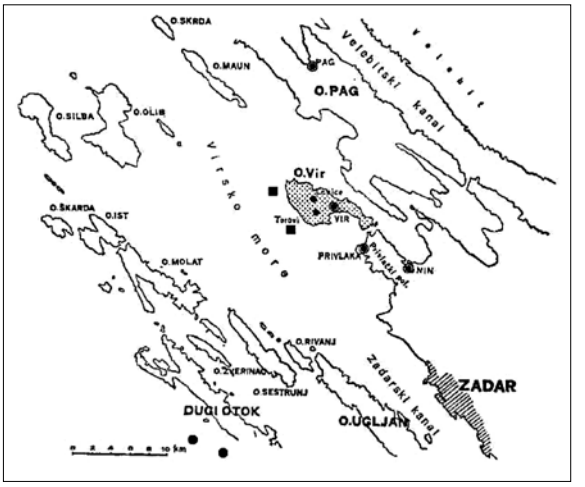

Fig.1. A map showing the sampling area of Sardinella aurita*, in inshore waters (Virsko more; ■) and offshore waters (Dugi otok; ●) during November 2007-January 2009*

Inshore waters are located between Kvarnerić in the northwest and the channel of Zadar in the southeast. Virsko more surrounds the island of Vir and the Novopoljanski Channel in the northwest, the island of Maun in the northern part and the islands of Olib and Silba in the west, Ist, Molat and Sestrunj in the southeast and Privlački Zaton in the south. The greatest measured depth was in the Maun Channel (80-90 m), while the average depth in Virsko more is 45 m. The sea bottom is mostly sandy (MAGAŠ, 1997). Monthly average sea surface temperature (*SST*) varied from 12.2°C (January) to 26.5°C (August) (MUSTAĆ, 2010).

Offshore waters are located in the outer part of the islands off the eastern coast of the Adriatic Sea and, with their specific, great length, they present important natural protection of northern Dalmatian archipelago and land (MAGAŠ, 1997). The northeast coast is well-indented, with many bays and coves, whereas the southwest coast is turned to the offing, winds and waves of offshore waters, where sampling of this study was done. Monthly average sea surface temperature (*SST*) varied from 12.4°C (March) to 23.6°C (June) (MUSTAĆ, 2010).

A total of 983 males, 1,021 females and 29 specimens whose sex could not be deter-

mined were examined; 526 specimens were from inshore waters, and 1,507 round sardinella specimens were from offshore water samples. Each fish was weighted to the nearest milligram and measured to the nearest millimeter. The length growth of both sexes from two sampled areas was analysed according to round sardinella mean total lengths and standard errors, which was estimated using STATISTICA (statistics software package - Statsoft 2007). Sex was determined macroscopically on the basis of the shape, appearance and structure of gonads.

The length-weight parameters were determined on the basis of the logarithmically transformed equation (LE CREN, 1951): $TW=a+ TL^b$ where *TW* is the total weight of the fish in g, *TL* is the total length in cm; *a*-proportionality constant and *b*-regression coefficient. In addition, recommendations for length-weight relationships of fishes were also considered (FROESE *et al.,* 2011).

To compare distributions from two sampled areas, t-test and two-sample Kolmogorov – Smirnov test were used.

To avoid length/size bias in the condition analysis, only fish between 15.0 and 27.0 cm *TL* were used for comparison between the two sexes and two analyzed areas. The cubic condition factor (*K*) was analyzed according to Fulton's coefficient (LE CREN, 1951): $K = 100\ WL^{-3}$, where *K* is the cubic condition factor, *W* - body weight and *L*- total length of round sardinella.

The χ^2 test (SOKAL & ROHLF, 1981) was used to compare the observed sex ratio to the theoretical 1:1 ratio.

RESULTS

Sex ratio

Out of 2,033 analysed round sardinella, 983 were males (48.4%), 1,021 were females (50.2%) and 29 (1.4%) were undetermined specimens, giving an overall sex ratio of m/f=0.96 which did not deviate from the hypothetical distribution of 1:1 (χ^2 =0.72; d.f. =1; P<0.005).

Sex ratio of round sardinella was analysed according to the fishing grounds - 526 specimens were from inshore waters and 1,507 were from offshore waters. The samples from inshore waters were collected during two periods: November – December 2007 and August - October 2008. Out of 526 round sardinella specimens, there were 255 males (48.5%) and 271 female (51.5%), with a sex ratio of *m/f*=0.94. From the total number of analysed specimens from offshore waters (1,507) which were collected from February to October 2008 and January 2009, 728 were males (48.3%) and 750

Table 1. Monthly sex ratio of Sardinella aurita *caught in the eastern middle Adriatic Sea, November 2007- January 2009*

Month	N	Male %	Female %	Ratio m/f
November 2007	102	53.92	46.09	1.17
December 2007	129	56.59	43.41	1.30
February 2008	91	60.44	39.56	1.53
March 2008	70	58.57	41.43	1.41
April 2008	79	60.76	39.24	1.55
May 2008	164	53.05	46.95	1.13
June 2008	301	45.18	54.82	0.82
July 2008	268	39.55	60.45	0.65
August 2008	211	34.59	65.40	0.53
September 2008	285	47.71	52.28	0.91
October 2008	275	57.09	42.91	1.33
January 2009	29	55.17	44.83	1.23
Total	2004	49.05	50.95	0.96

females (59.8%) and 29 undetermined (1.9%), juvenile specimens. Sex ratio was *m/f*=0.97.

The most uniform relationship between male and female was noticed in September (*m/f*=0.91), whereas during August (*m/f*=0.53) and April (*m/f*=1.55) the greatest aberration in sex ratio was found (Table 1). In both fishing grounds, females slightly predominated over males.

Length distribution

The total length of all analysed round sardinella (*N*=2,033) ranged from 10.0 to 32.5 cm. Specimens from inshore waters (*N*=526) showed total length distribution from 13.0 to 32.5 cm (Fig. 2). Modal length class was 23.0 cm. As presented in Figure 3a, male (*N*=255) total length ranged from 15.0 to 27.0 cm (mean=21.8 ± 2.57 cm); in females (*N*=271) it varied from 13.0 to 32.5 cm (mean=21.7 ± 3.25 cm). Kolmogorov-Smirnov test indicated that maximum difference between length of males and females was *D*=0.09; *p*<0.15.

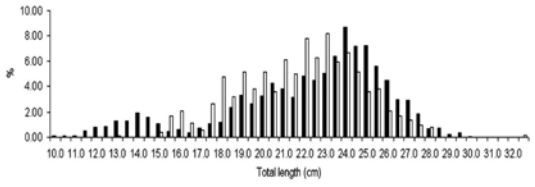

Fig. 2. Length-frequency distribution of Sardinella aurita *caught in inshore (Virsko more; □) and offshore (Dugi otok; ■) waters, eastern middle Adriatic Sea, November 2007-January 2009*

Round sardinella specimens from offshore waters (*N*=1,507) indicated that their total length (*TL*) varied from 10.0 to 30.0 cm. Modal value was 24.0 cm. Female (*N*=750) length range (from 11.0 to 30.0 cm; mean=22.8±3.76 cm) was greater than that of males (*N*=728) (from 11.5 to 28.0 cm; mean=21.8±3.42 cm) (Fig. 3b). Kolmogorov-Smirnov test showed that maximum sex differences in length of round sardinella were greater in offshore than in inshore waters (*D*=0.2; *p*<0.001). Undetermined species (*N*=29) were the smallest specimens with the mean total length of 12.6±1.27 cm.

Data presented in Fig. 2 clearly show that the specimens from offshore waters were more

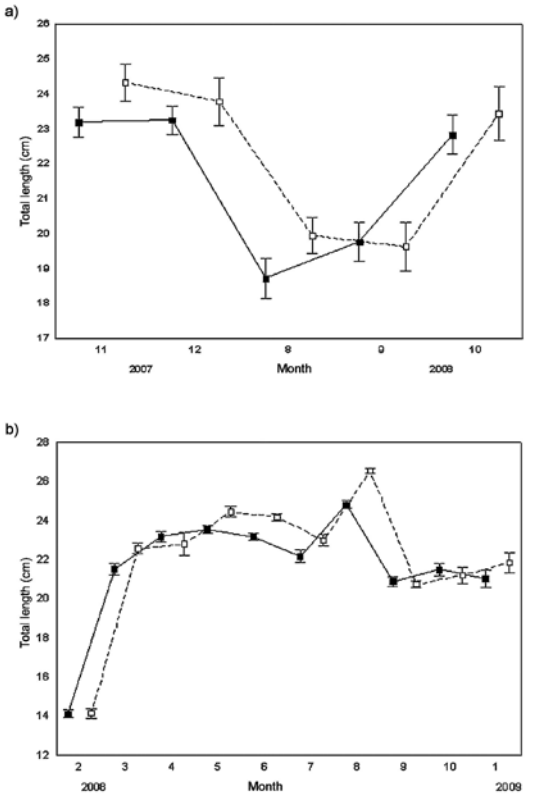

Fig. 3. Mean total length (TL ± SE) variations of Sardinella aurita *males (■) and females (□) caught in a) inshore waters (Virsko more) during periods: November-December 2007 and August-October 2008 and b) offshore waters (Dugi otok), February – October 2008 and January 2009, eastern middle Adriatic Sea*

frequent in longer length classes and the specimens from inshore waters were more frequent in the smaller ones. Nonetheless, the longest round sardinella (female; 32.5 cm) was found in inshore waters. The smallest specimen (undetermined) was found in offshore waters.

Samples from both fishery grounds showed relatively uniform variations of mean lengths in both sexes, except in inshore waters in August 2008 and in offshore waters in February (lowest amount) and August 2008 (highest amount) (Fig. 3b).

There was no significant difference between lengths of species from the stated fishing grounds (*t*=1.96, *p*<0.05).

Length-weight relationship

Length-weight relationship for all round sardinella (*N*=2,033) was $W=0.0036\ L^{3.2266}$; *r*= 0.9843.

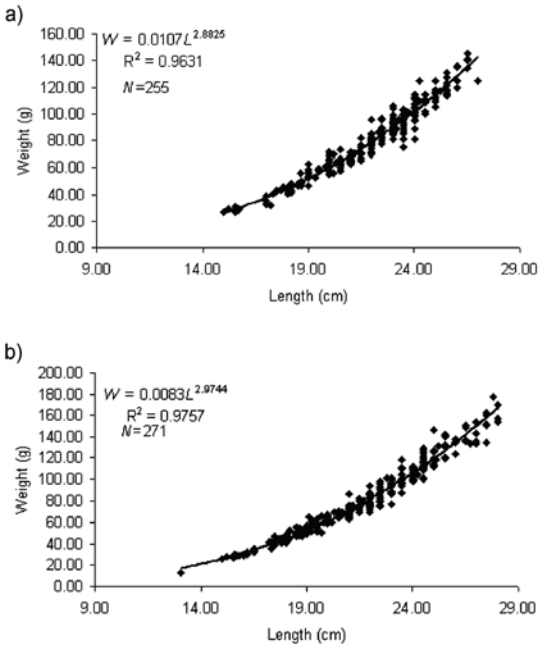

Fig. 4. Length-weight relationship of Sardinella aurita *male a) and female b), inshore waters (Virsko more), November-December 2007 and August-October 2008, eastern middle Adriatic Sea*

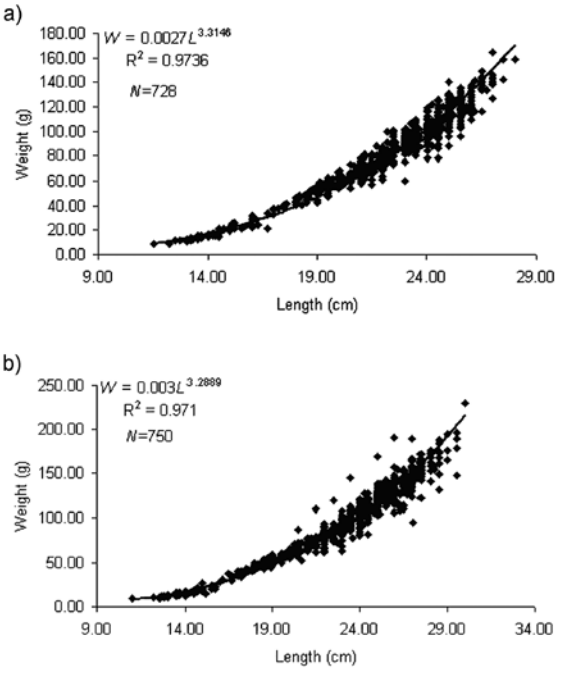

Fig. 5. Length-weight relationship of Sardinella aurita *male a) and female b), offshore waters (Dugi otok), February – October 2008 and January 2009, eastern middle Adriatic Sea*

Round sardinella from inshore waters showed negative allometry (b=2.9238; t=-0.867, p<0.05). The regression coefficient (b) of males was lower (b=2.885; r^2 = 0.963) than that of females (b= 2.9744; r^2= 0.9757). Determination coefficients were very high and significant (Fig. 4).

The samples from offshore water specimens showed positive allometry (b=3.2803). When compared to inshore waters, male length weight coefficient was slightly higher (b=3.3146; r^2=0.9736) than that of females (b= 3.2889; r^2= 0.971). Determination coefficients were very high and significant (Fig. 5).

Cubic condition factor

For comparison purpose, the cubic condition factor of specimens with total length range found in both sexes and both analysed areas (from 15.0 to 27.0 cm) was analysed.

The mean condition factor of round sardinella from inshore waters was $\overline{K}$ =0.76 ± 0.23. Male cubic condition factor ranged from K=0.63 to K= 0.82 (Fig. 6a). For females, the cubic condition factor varied from K=0.62 to K=0.81 (Fig. 6b). The mean cubic condition value for males was $\overline{K}$ =0.75 ± 0.04; it was slightly higher for

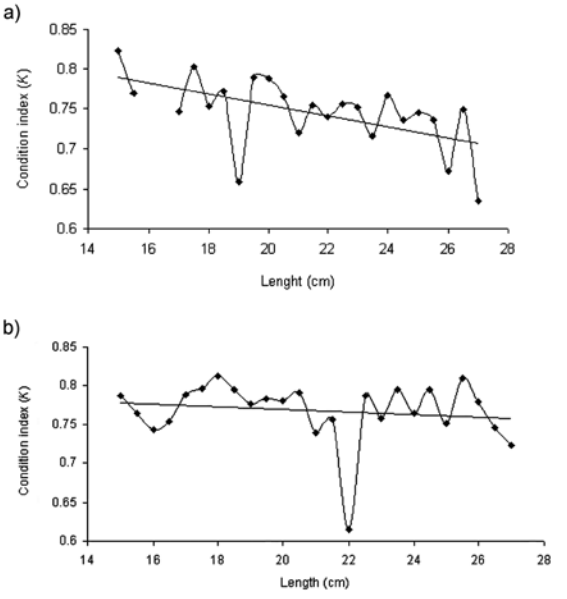

Fig. 6. Condition index (K) of Sardinella aurita *male a) and female b), inshore waters (Virsko more), November-December 2007 and August-October 2008, eastern middle Adriatic Sea*

female $\overline{K}$ =0.77 ± 0.04. Male cubic condition values were fluctuating, showing a decreasing trend as the fish length increased (Fig. 6a). Female cubic condition factor values fluctuated around their mean with an exception in length class of 22.0 cm in which the condition value was the lowest.

The mean condition factor for specimens from offshore waters was $\overline{K}$ =0.73 ± 0.05. Male condition ranged from *K*= 0.63 to *K*=0.78, with the mean $\overline{K}$ =0.72 ± 0.05 (Fig. 7a). Female condition had wider length range than male - from *K*=0.59 to *K*=0.77, with the mean $\overline{K}$ =0.74 ± 0.04 (Fig. 7b). In offshore waters, the cubic condition factor of both sexes slightly increased with the increase of fish length (Fig. 7).

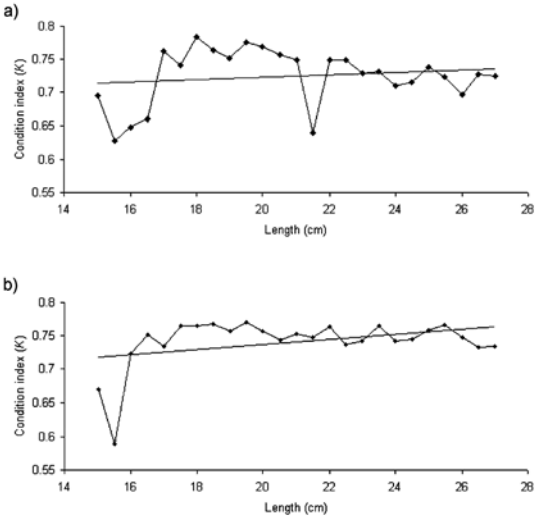

Fig. 7. Condition index (K) of Sardinella aurita *male a) and female b), offshore waters (Dugi otok), February – October 2008 and January 2009, eastern middle Adriatic Sea*

The average cubic condition value for all 2,033 round sardinella was $\overline{K}$ =0.71 ± 0.08.

DISCUSSION

Sex ratio of round sardinella females slightly predominated over males when analysing specimens from both - offshore and inshore - waters. The greatest aberration of sex ratio was found in August (*m/f*=0.53) when this species intensively spawns (MUSTAĆ, 2010). Sex ratio in general did not deviate from the hypothetical distribution of 1:1. Same findings were reported for round sardinella in Venezuela and the Aegean Sea (FRÉON *et al*., 1997; TSIKLIRAS & ANTONOPOULOU, 2006). A slight domination of females over males which has been noted during this study in the Adriatic Sea was also noted in the West Atlantic and South Mediterranean (BOELY & CHAMPAGNAT, 1970; GAAMOUR *et al*., 2001).

The length distribution of round sardinella generally indicates that samples from offshore waters were slightly longer than those from inshore waters. Specimens from inshore waters were more frequent at smaller length classes, while those from offshore waters predominated at larger ones, although the largest specimen noted during this study was found in the inshore waters (32.5 cm) and the smallest specimens were found in open waters (10.0 cm). Besides, females from both areas were more present in longer length classes, especially in total length classes over than 25 cm (*TL*>25 cm); males were more frequent in the smaller ones. Such differences could be explained by lower mortality and higher growth in females than in males (MUSTAĆ, 2010). Besides, large size of female individuals is of greater benefit: bigger females had higher fecundity than the smaller ones (SALVANES & KRISTOFERSEN, 2001). It was also found that round sardinella females are significantly longer than males from the South and East Mediterranean (BENSAHLA-TALET *et al*., 1988; GAAMOUR *et al*., 2001; TSIKLIRAS & ANTONOUPOULOU, 2006).

Round sardinella revealed different allometric growth in the Adriatic Sea, depending on the catch location and sex. The samples from inshore waters indicated negative allometric growth, whereas the samples from offshore waters showed positive allometry. When comparing regression coefficients of round sardinella with respect to sex and fishing ground, the lowest value of the regression coefficient was found in male specimens from inshore waters. The greatest *b* was found in males from offshore waters. However, in total, offshore samples were greater in number (*N*=1507) than those from inshore waters (*N*=526), which could influence presented length-weight results (FROESE *et al*.,

2011). The regression coefficient of all analyzed specimens showed positive allometric growth which was also found for the same species from other seas (TSIKLIRAS *et al*., 2005a; DO CHI, 1994).

SINOVČIĆ *et al.* (2004) also found positive allometry in juvenile round sardinella in the Adriatic Sea (b=3.1162; a=0.0043). This species also showed positive (b=3.16; a=0.0040) allometric growth (CLARO & GARCÍA-ARTEAGA, 1994) in Cuba. STERGIOU & MOUTOPOULOS (2001) noted negative allometric growth (b=2.804; a=0.0157) in round sardinella from Greek waters (Cyclades), KARTAS (1981) noted almost isometric growth of this species in the South Mediterranean (b=3.0090; a=0.0053). ANYANGWA (1991) and DO CHI (1994) reported positive allometric growth of this species from the Ivory Coast (b=3.260; a=0.0029) and Senegal (b=3.29; a=0.0061), respectively. TSIKLIRAS *et al*. (2005a) found a slightly greater slope b in round sardinella females (b=3.084) than in males (b=3.064) in the northeastern Mediterranean (Aegean Sea).

When comparing the cubic condition factor of round sardinella of the same length range but from various fishing grounds, the specimens from inshore waters showed greater condition value (K=0.7565) than those from offshore waters (K=0.7330). This could be explained by the fact that inshore waters of the Adriatic Sea are more productive with a greater human and landscape impact than offshore waters, which are more influenced by the winds and sea currents from the Mediterranean (BULJAN & ZORÈ-ARMANDA, 1976).

Females showed better condition and greater condition variability in both analysed areas than males. In total, the average cubic condition factor value was $\overline{K}$ = 0.71 ± 0.08, which is in agreement with some earlier studies. Namely, TSIKLIRAS (2004) also found better condition of females (from K=0.68 to K=0.82) than of males (from K=0.66 to K=0.81) in Greek waters. MUSTAĆ (2010) and TER HOSTEDE *et al.* (2007) noticed that greater condition values of fish coincided with higher sea surface temperature (*SST*). The same authors reported that it could also be related to the spawning period - after spawning, sudden decrease in round sardinella condition was noted in the Adriatic Sea and in north west Africa. Growth of condition during spring months, when intensive primary and secondary production takes place (VUČETIĆ, 1975), was noted in round sardinella which intensively feeds on zooplankton (TSIKLIRAS *et al.,* 2005b; MOROTE *et al*., 2008; LOMIRI *et al.*, 2008) to gain better condition for upcoming spawning. Furthermore, round sardinella migrates seasonally from inshore to offshore waters to find better biotic and abiotic conditions, with respect to food, reproduction cycle and sea temperature (QUAATEY & MARAVELIAS, 1999; TER HOSTEDE *et al.,* 2007). Those conditions varied throughout the year (VILHJÁLMSSON, 1994; CARSCADDEN *et al.,* 1997).

Even though round sardinella is a termophilic species, it has adapted to a lower sea temperature in the Adriatic Sea where it occupies the same ecological niche with other small pelagic fishes, such as sardine *Sardina pilchardus* and anchovy *Engraulis encrasicolus*. Since these related species compete for space and food at all stages of their life (PALOMERA & SABATÉS, 1990) and the abundance of round sardinella becomes higher in the Adriatic, further study on biological and ecological parameters of this species in the Adriatic Sea is needed. Moreover, distributional and population density changes may have an ecological effects to the marine ecosystem and local fisheries economics by altering the composition and amounts of the catches (TSIKLIRAS, 2008).

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Usporedba dužinske raspodjele srdele goleme (*Sardinella aurita*) iz obalnog i otvorenog mora istočnog dijela srednjeg Jadrana

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SAŽETAK

U radu se uspoređuje dužinski sastav, dužinsko maseni odnos i kondicija srdele goleme *Sardinella aurita* iz obalnog (Virsko more) i otvorenog (Dugi otok) mora istočnog dijela srednjeg Jadrana. U svrhu navedenih istraživanja su korišteni mjesečni uzorci iz lovina plivarice ostvarenih tijekom razdoblja studeni 2007.- siječanj 2009. god. Ukupno je analizirano 2 033 jedinki, od čega 983 mužjaka, 1021 ženka i 29 jedinki kojima nije bilo moguće odrediti spol. Odnos spolova je iznosio *m/ž*=0,96. Totalne dužine (*LT*) jedinki iz uzoraka lovina obalnog mora (*N*=526) su kolebale od 13,0 do 32,5 cm, te od 10,0 do 30,0 cm kod jedinki iz otvorenog mora (*N*=1507). Ukupno su jedinke pokazale pozitivan alometrijski rast (*b*=3,2266). Kubični faktor kondicije (*K*) je za jedinke iz obalnog mora iznosio $\overline{K}$ =0,76 ± 0,23 a za srdelu golemu s područja otvorenog mora je bio $\overline{K}$ =0,73 ± 0,05. Ženke su pokazale bolju kondiciju ($\overline{K}$ =0,75 ± 0,05) od mužjaka ($\overline{K}$ =0,74 ± 0,05) u oba analizirana područja.

Ključne riječi: srdela golema, Jadran, dužinska raspodjela, dužinsko maseni odnos, kondicija