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Seasonal variation of gonado-somatic index and length-weight relationship in the horse mackerel, *Trachurus trachurus* (Osteichthyes: Carangidae) from the eastern Adriatic Sea

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Abstract: Seasonal changes in length-weight relationships (LWRs), gonado-somatic index (GSI) and condition factor in the horse mackerel *Trachurus trachurus* (Linnaeus, 1758) were studied. A total of 1136 specimens (580 males and 556 females) ranging from 15.7 to 37.0 cm in total length (TL) were collected in the eastern Adriatic Sea. Samples were taken at monthly intervals (January-December 2004) using bottom-trawls. The GSI reached maximum values in March and minimum in September. Including specimens collected in all seasons, the *b* values of length-weight relationships ($W = aL^b$) showed that growth of both males and females was isometric. However, values of *b* varied during the year: positive allometric growth was noted in winter, while in late spring (May) and summer (June and July) negative allometric growth was observed. The condition factor was the lowest immediately after spawning (July) and the highest at the recovery phase (September). Seasonal variations of LWRs and condition factor of the horse mackerel were probably connected with the gonadal changes.

Résumé : *Variations saisonnières de l'indice gonado-somatique et de la relation taille-poids du chinchard* Trachurus trachurus *(Osteichthyes : Carangidae) de la Mer Adriatique orientale.* Les variations saisonnières des relations taille-poids (LWRs), de l'indice gonado-somatique (GSI) et du facteur de condition du chinchard (*Trachurus trachurus* L.) ont été étudiées. 1136 spécimens (580 mâles et 556 femelles) de longueur totale (TL) de 15,7 à 37,0 cm ont été récoltés en Mer Adriatique orientale. Les échantillons ont été récoltés mensuellement (de janvier à décembre 2004) à l'aide de chaluts de fond. Les valeurs de b des relations taille-poids ($W = aL^b$) ont varié au cours de l'année selon la saison et la condition. La valeur de b, toutes saisons confondues, montre que la croissance des mâles et des femelles est globalement isométrique. Le GSI a atteint des valeurs maximales en mars et minimum en septembre. Le facteur de condition était minimum juste après la ponte (juillet) et maximum à la fin de la phase de rétablissement (septembre). Les variations saisonnières des LWRs et du facteur de condition des chinchards sont probablement liées au développement gonadique.

Keywords: Length-weight • Gonads • *Trachurus trachurus* • Adriatic Sea

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Introduction

The horse mackerel, *Trachurus trachurus* (Linnaeus, 1758), is distributed throughout the eastern Atlantic, the Mediterranean and Black Sea (Smith-Vaniz, 1986). The horse mackerel is very common in the Adriatic Sea, especially off shore near the continental shelf and in the Jabuka Pit (central Adriatic) above muddy and sandy bottoms down to depths of 80-200 m (Jardas, 1996). It spawns in winter-spring seasons (Jardas, 1996). There are no reliable statistical on *T. trachurus* landings in the eastern Adriatic, but rough estimates of annual catch are around 400 tones (FAO, 2005). In the Mediterranean, this species is of major importance in the pelagic and demersal fisheries where annual landings fluctuated between 5155 to 14960 tones from 1999 to 2005 (FAO, 2005).

Despite its abundance, very little is known about biology of this species in the Adriatic Sea. Only a few studies have provided some biological information of the horse mackerel in the Adriatic Sea (Alegria-Hernandez, 1984 & 1994; Jardas et al., 2004). Alegria-Hernandez (1984 & 1994) analysed reproductive aspects and documented length-weight relationships (LWRs) for a limited area in the central Adriatic. Jardas et al. (2004) described variation of feeding intensity of the horse mackerel in relation to GSI. However, detailed seasonal changes in gonado-somatic index (GSI), and relationships with parameters of LWRs and condition factor have not been analysed for this species in the eastern Adriatic. In the other hand, many aspects of the biology and the ecology of the horse mackerel were investigated in eastern Atlantic (Arruda, 1984; Kerstan, 1985; Borges & Gordo, 1991; Olaso et al., 1999) and Mediterranean Sea (Turki, 1987; Ben-Salem, 1988a,b; Karlou-Riga & Economidis, 1997; Karlou-Riga & Sinis, 1997).

Gonado-somatic index has been largely used as indicator of changes during the gonadal development. In other hand, length-weight relationships have several applications, namely on fish biology, physiology, ecology, and fisheries assessment. In biological studies, LWRs enable seasonal variations in fish growth to be followed and calculation of condition indexes (Richter et al., 2000). However, LWRs are fundamental for the estimation of weight-at-age (Petrarkis & Stergiou, 1995), production and biomass of fish population (Anderson & Gutreuter, 1983). Finally, LWRs are useful for comparisons of fish population from different regions (Gonçalves et al., 1997).

This study presents the length-weight relationships as related to the gonado-somatic index and condition of the horse mackerel. These data contribute to a better knowledge of biology of this species in the eastern Adriatic Sea.

Material and methods

Samples of the horse mackerel were collected in the eastern Adriatic Sea along the continental shelf mostly at depths from 60 to 175 m (Fig. 1). Fishes were sampled with commercial bottom-trawls (stretched cod-end mesh size of 22-24 mm).

Monthly samples were collected from January to December 2004 and a total of 1136 specimens (580 males and 556 females) were measured. Total length (TL) of all specimens was measured to the nearest 0.1 cm, and body weight to the nearest 0.1 g. Sex was assigned macroscopically. Gonads of all specimens were dissected and weighed to the nearest 0.001 g to calculate the gonado-somatic index (GSI = [weight of gonads/weight of fish] x 100). The relationship between weight and total length, $W = aL^b$, was converted into its logarithmic expression: $\log W = \log a + b \log L$. Parameter b is the exponent of the arithmetic form of LWRs and the slope of regression line in the logarithmic form (Froese, 2006). When $b = 3$, TL and W are growing at the same rate (isometry); when $b > 3$, W is increasing faster than TL (positive allometry); when $b < 3$, W is increasing slower than TL (negative allometry) (Froese, 2006). The parameters a and b were calculated by least-squares regression, as was the coefficient of determination (R^2). Statistical methods used for data processed include the usual calculations of means and standard deviations. Significant difference of b values from 3, which represent isometric growth, was tested with the t-test (Pauly, 1983). To test for possible significant differences between sexes we used analysis of covariance (ANCOVA). A t-test was used to compare the b values between this study and some previously reported in the Adriatic and Mediterranean Sea.

Changes in condition were measured by indices on weight-length data. Condition factor (K) was estimated according to the Fulton equation: $K = (W/L^3) \times 100$.

The correlation between values of b with GSI, and values of b with K were tested by Pearson's correlation ($p < 0.05$).

Results

Total lengths of males ranged from 15.7 to 37.0 cm, and weight from 36.1 to 430.2 g. (Fig. 2a). Total lengths of females ranged from 14.5 to 36.8 cm, and weight from 21.3 to 484.0 g. (Fig. 2b). Number of specimens and length range caught in each month were: January (n = 100, 21.7-34.4 cm TL), February (n = 100, 20.0-33.9 cm TL), March (n = 103, 16.1-34.3 cm TL), April (n = 109, 18.4-32.5 cm TL), May (n = 102, 18.3-37.0 cm TL), June (n = 92, 17.3-32.1 cm TL), July (n = 94, 16-36.8 cm TL), August (n = 92, 18.3-36.6 cm TL), September (n = 93, 15.7-32.9 cm TL),

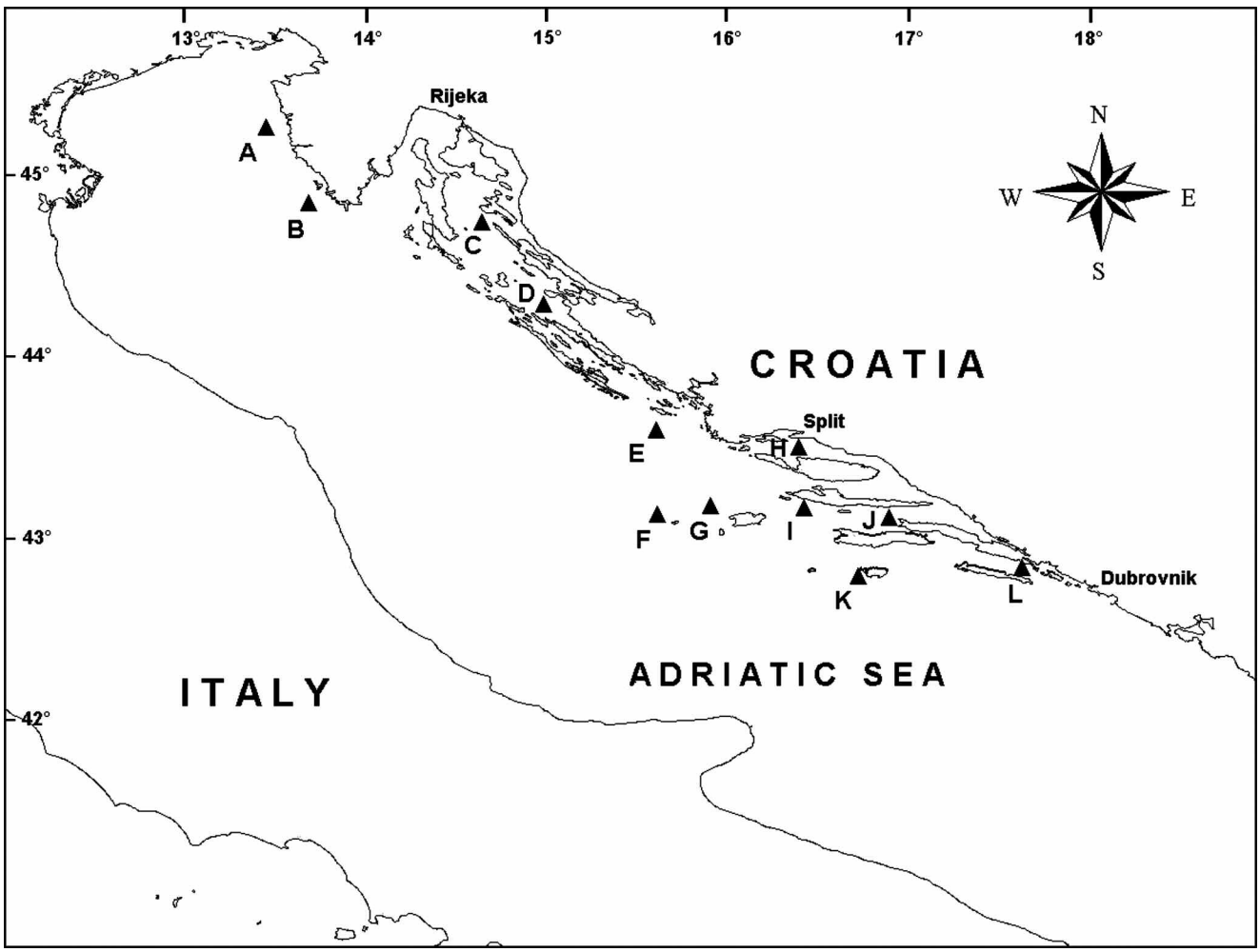

Figure 1. *Trachurus trachurus*. Study area and all sampling stations in the eastern Adriatic Sea: A - South of Novigrad, B - South of Rovinj, C - Kvarnerić, D - Near island of Pag, E - Blitvenica fishing area, F - Islands of Jabuka, G - Near islands of Vis and Svetac, H - Split Channel, I - South of Maslenica, J - Korčula Channel, K - Area of island Lastovo, L - Area of island Mljet.

Figure 1. *Trachurus trachurus*. Zone d'étude et localisation des stations de prélèvement en Mer Adriatique orientale : A - Sud de Novigrad, B - Sud de Rovinj, C - Kvarnerić, D - Près de l'île du Pag, E - Parage de pêche de Blitvenica, F - Îles de Jabuka, G - Près des îles Vis et Svetac, H - Canal de Split, I - Sud de Maslenica, J – Canal de Korčula, K - Région de l'île Lastovo, L - Région de l'île Mljet.

October (n = 84, 14.5-32.5 cm TL), November (n = 84, 16.8-32.4 cm TL), December (n = 83, 18.0-34.5 cm TL).

Number of specimens, parameters *a* and *b* of the LWRs, standard error of *b*, coefficient of determination R^2 and t-values for each month are presented in Table 1. The sample size ranged from 109 individuals in April to 83 in December. The R^2 values ranged from 0.890 for females in May to 0.983 for males in July and all regressions were highly significant ($p < 0.001$).

The *b* values of horse mackerel ranged from 2.416 (S.E. = 0.093) for males in May to 3.523 (S.E. = 0.088) for males in March. The *b* values of males and females significantly increased in winter (January, February and March), while in spring (May and June) and early summer (July) the values significantly decreased (t-test). Estimates of *b* did not significantly differ from 3 in other months. Significant differences of *b* values between sexes were observed in March (ANCOVA: $F = 7.84$, $F_{0.01} = 6.85$, $P < 0.01$) and May (ANCOVA: $F = 10.12$, $F_{0.01} = 6.85$, $P < 0.01$) but, overall, there is no significant difference of *b* between sexes (ANCOVA-test). Including all males (N = 580) and females (N = 556) collected during the year, values of *b* for males ($b = 2.972$, $t = 1.09$, $t_{0.01} = 2.58$), females ($b = 3.035$, $t = 1.36$, $t_{0.01} = 2.58$) and sexes combined ($b = 3.003$, $t = 0.19$, $t_{0.01} = 2.58$) did not significantly differ from 3.

The monthly variations of GSI and values of *b* (including sex combined) are shown in figure 3a. The GSI

Table 1. *Trachurus trachurus*. Length-weight relationships ($W = aL^b$) in the eastern Adriatic Sea from January to December 2004. Number of specimens (N), parameters *a* and *b* of the relationships ($W = aL^b$), standard error of *b* (S.E.), coefficient of correlation R^2, and t-values (I, isometry; P, positive allometry; N, negative allometry). * Significant differences (ANCOVA, $p < 0.01$) of *b* values between males (M) and females (F).

Tableau 1. *Trachurus trachurus*. Relations taille-poids ($W = aL^b$) en Mer Adriatique orientale de janvier à décembre 2004. Nombre de spécimens (N), paramètres *a* et *b* des relations ($W = aL^b$), erreur type de *b* (S.E.), coefficient de corrélation R^2, et valeurs du test t (I, isometry ; P, allométrie positive ; N, allométrie négative). * Différences significatives (ANCOVA, $p < 0{,}01$) des valeurs de *b* entre les mâles (M) et les femelles (F).

Month	Sex	N	*a*	*b*		S.E. (*b*)	R^2	t
January	M	55	0.0074	3.274	P	0.138	0.977	4.92
	F	45	0.0041	3.228	P	0.119	0.980	3.10
	Total	100	0.0058	3.239	P	0.123	0.977	5.63
February	M	49	0.0045	3.311	P	0.096	0.972	4.10
	F	51	0.0023	3.447	P	0.032	0.970	5.11
	Total	100	0.0033	3.389	P	0.075	0.969	6.04
March	M	54	0.0016	3.523	P	0.088	0.980	6.81
	F	49	0.0030	3.297*	P	0.102	0.967	3.19
	Total	103	0.0020	3.438	P	0.117	0.975	7.21
April	M	48	0.0050	3.159	I	0.076	0.966	1.61
	F	61	0.0056	3.114	I	0.087	0.968	1.53
	Total	109	0.0039	3.128	I	0.071	0.968	2.23
May	M	51	0.0523	2.416	N	0.093	0.902	4.58
	F	51	0.0162	2.704*	N	0.121	0.890	3.90
	Total	102	0.0357	2.511	N	0.086	0.896	5.12
June	M	49	0.0529	2.427	N	0.065	0.939	4.83
	F	43	0.0462	2.466	N	0.085	0.961	5.93
	Total	92	0.0513	2.435	N	0.074	0.949	7.51
July	M	46	0.0097	2.691	N	0.133	0.983	4.25
	F	48	0.0330	2.737	N	0.143	0.968	3.23
	Total	94	0.0175	2.705	N	0.111	0.968	4.78
August	M	51	0.0103	2.934	I	0.071	0.978	0.82
	F	41	0.0078	3.014	I	0.092	0.965	0.11
	Total	92	0.0087	2.984	I	0.083	0.971	0.21
September	M	49	0.0070	3.044	I	0.135	0.957	0.48
	F	44	0.0101	2.929	I	0.119	0.943	0.56
	Total	93	0.0080	3.002	I	0.128	0.951	0.04
October	M	44	0.0066	3.090	I	0.165	0.961	0.95
	F	40	0.0039	3.114	I	0.122	0.923	1.63
	Total	84	0.0053	3.102	I	0.101	0.942	1.79
November	M	40	0.0047	3.164	I	0.087	0.980	2.28
	F	44	0.0064	3.078	I	0.034	0.979	1.16
	Total	84	0.0053	3.127	I	0.076	0.979	2.55
December	M	44	0.0049	3.154	I	0.149	0.976	2.02
	F	39	0.0051	3.149	I	0.129	0.969	1.62
	Total	83	0.0050	3.151	I	0.104	0.973	2.60
All months	M	580	0.0093	2.972	I	0.143	0.967	1.09
	F	556	0.0075	3.035	I	0.108	0.967	1.36
	Total	1136	0.0084	3.003	I	0.277	0.966	0.19

reached maximum values in March and minimum values in September. Pearson's coefficient showed a significant correlation between values of *b* and GSI ($r = 0.62$, $N = 1136$, $p < 0.05$). The monthly variations of parameter *b* and condition factor (K) are presented in figure 3b. Condition factor (K) of horse mackerel ranged from 0.80 (July) to 0.89 (September). Pearson's coefficient showed a significant correlation between values of K and *b* ($r = 0.53$, $N = 1136$, $p < 0.05$).

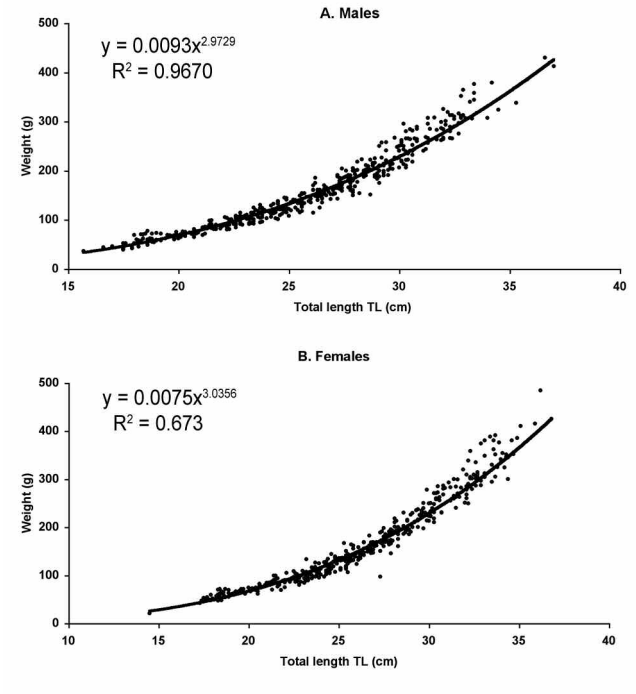

Figure 2. *Trachurus trachurus*. Total length and weight range in the eastern Adriatic Sea from January to December 2004. **A.** For 580 males. **B.** For 556 females.

Figure 2. *Trachurus trachurus*. Gamme totale de la longueur et du poids en Mer Adriatique orientale de janvier à décembre 2004. **A.** Pour 580 mâles. **B.** Pour 556 femelles.

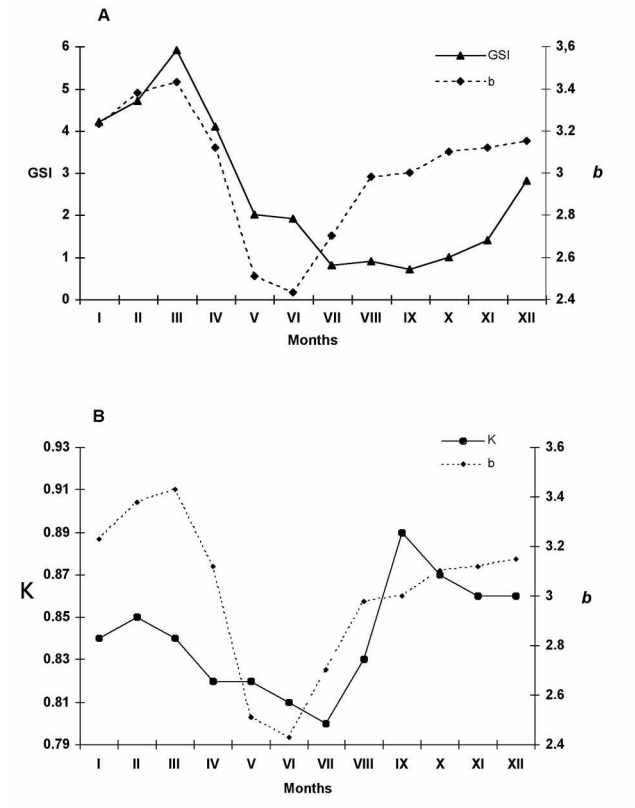

Figure 3. *Trachurus trachurus*. **A.** Temporal variations of *b* values with the gonado-somatic index. **B.** Temporal variations of *b* values with the condition factor.

Figure 3. *Trachurus trachurus*. **A.** Variations temporelles des valeurs de *b* avec l'indice gonado-somatique. **B.** Variations temporelles des valeurs de *b* avec le facteur de condition.

Discussion

The maximum length of the horse mackerel observed in this study (TL = 37.0 cm) was lower than the maximum record value of 41.0 cm in the eastern Adriatic Sea (Jardas, 1996). Bini (1968) reported a maximum length of 50.0 cm in the Italian waters. In the southern part of Mediterranean Sea, maximum noted length of the horse mackerel was 35.6 cm (Tunisian waters) and 28.7 cm (Algerian coast) (Ben-Salem & Daget, 1991; Sannai Cheniti, 2003). Maximum length of the horse mackerel in the eastern Atlantic was 60.0 cm (Smith-Vaniz, 1986) while in the Black Sea maximum record value was 37.0 cm TL (Banarescu, 1964). Regional differences in the total length of the horse mackerel probably depend on the ecological conditions in the areas of investigation (Shepherd & Grimes, 1983). Effects of water temperature can be directly related to rates of biological production, food availability as well as nekton and plankton species composition both of which influence on fish growth (Colerbook, 1982; Weatherley & Gill, 1987).

Including all collected specimens during the year, the *b* values for males, females and sex combined showed that growth was isometric i.e. proportional in length and weight. Isometric growth of the horse mackerel was also recorded in the central Adriatic (Alegria-Hernadez, 1984) and Mediterranean Sea (Carillo, 1978; Karlou-Riga & Sinis, 1997), see Table 2. On the other hand, in the northeast Atlantic, the values of *b* decrease more or less steadily from approximately 20°N to 41°N, where negative allometric growth occurs (Carasco, 1980; Farina-Perez, 1983; Arruda, 1984). From 41°N to higher latitudes, an opposite trend indicating positive allometric growth (Nazarov, 1978; Kerstan, 1985; Coull et al., 1989) occurs (Table 2). These variations could be due to the availability of food (Margalef, 1974). Along a large part of the eastern Atlantic coast, upwelling is a typical phenomenon during the spring-summer season (Santos et al., 2001). The intensity of upwelling is almost related to the production of zooplankton, which is the main food for the horse mackerel (Ben-Salem, 1988a; Olaso et al., 1999; Cabral & Murta, 2002). However, the northern European waters are characterized

Table 2. *Trachurus trachurus*. Previously reported length-weight relationships from the Adriatic, Mediterranean Sea and NE Atlantic. Number of specimens (N), length range (TL), *a* and *b* values. * Values of *b* significantly different from 3 ($p < 0.01$).

Tableau 2. *Trachurus trachurus* Relations taille-poids publiées à partir d'études réalisée en Mer Adriatique et Méditerranée et dans l'Océan atlantique nord-est. Nombre des spécimens (N), gamme de longueur (TL), valeurs de *a* et de *b*. * Valeurs de *b* significativement différentes de 3 ($p < 0,01$).

Authors	Areas	N	Length range (cm)		*a*	*b*
Carillo (1978)	NW Mediterranenan	1250	TL	14.1 – 37.2	0.0102	2.945
Nazarov (1978)	North Sea	1110	TL	24.5 – 40.5	0.0054	3.114*
Carasco (1980)	Cantabrian Sea	1215	TL	13.7 – 38.7	0.0145	2.812*
Farina-Perez (1983)	NW Spain	1238	TL	7.4 – 51.0	0.0129	2.854*
Alegria-Hernadez (1984)	Adriatic Sea	1726	TL	14.0 – 35.0	0.0002	2.918
Arruda (1984)	Portuguese coast	1519	TL	17.2 – 25.5	0.0199	2.885*
Kerstan (1985)	Ireland and UK	1281	TL	5.5 – 45.5	0.0043	3.125*
Coull (1989)	North Sea	283	TL	16.0 – 41.0	0.0034	3.294*
Karlou-Riga & Sinis (1997)	Greek waters	1139	TL	6.5 – 33.9	0.0061	3.070
This study	Adriatic Sea	1136	TL	14.5 – 37.0	0.0084	3.003

by the presence of extensive shelves with areas of high productivity, which support rich benthic communities (Ware, 2001). These conditions could be related with increase values of *b* observed in northern areas compared to respective values of *b* at 41°N. In addition, variation in the *b* exponents for the same species could be attributed to differences in sampling, sample size or length ranges as well as differences in age and environmental conditions (Shepherd & Grimes, 1983; Weatherley & Gill, 1987, Dulčić & Kraljević, 1996).

In the present study, allometric parameters of *b* values showed no difference between males and females. Similarly, Lucio & Martin (1989) and Karlou-Riga & Sinis (1997) reported that no differences in the LWRs between sexes of the horse mackerel in northeastern Atlantic (Bay of Biscay) and Mediterranean Sea (Greek waters).

In this study, estimate of *b* for the horse mackerel showed seasonal variations. Positive allometric growth was noted in winter, while in late spring (May) and summer (June and July) negative allometric growth was observed. The horse mackerel showed isometric growth in the other months. Also, Lucio & Martin (1989) found significant differences in these parameters between autumn-winter and spring-summer periods in the Bay of Biscay. In Portuguese waters, differences are also evident between spring and rest of the year (Borges & Gordo, 1991).

The seasonal variation of *b* values was probably connected with the reproductive cycle of this species on the basis of gonado-somatic index observed throughout the year. Development of gonads and annual curve of gonado-somatic index indicate pre-spawning period from November to February, spawning period, from March to June (most intensive at end of March and April) and post-spawning period from July to October. The maximum *b* values in both sexes were observed during the period when the gonado-somatic index showed a pronounced peak (February and March) as the testis and ovaries were developed and massive. On the contrary, gonadal regression during the spawning stage decreased GSI and probably influenced *b* values in males and females. Also, negative allometric grow of horse mackerel during the spawning period noted Borges & Gordo (1991) and Karlou-Riga (1995). The allocation of energy to the reproductive activities suggested that fishes become lighter for its length. Conversion of the gonad tissue, with high water content, into fat will decrease the body weight (Viette et al., 1997). This process should be the reason of the negative allometry from May to July in both sexes. In contrast, after the spawning season, the fish can use more energy for growth. This interperatation is corroborated by evidence that the highest fat content in the flash of the horse mackerel is found after the spawning period (Bandarra et al., 2001). A high correlation between values of *b* and GSI probably support connects of these parameters.

The condition factor based on the LWRs is an indicator of the changes in food reserves and therefore an indicator of the general fish condition. Variation in the horse mackerel condition suggested possible relation to gonadal changes. Greater drop in condition factor immediately after spawning suggested that cost of reproduction in this fish was very high (Alegria-Hernandez, 1994). The horse mackerel is a multiple spawning fish with a relatively long reproductive season (Alegria-Hernandez, 1994; Karlou-Riga & Economidis, 1997) that probably caused loss of a lot of energy stored in muscle and mesenteric fat. Fat and energy content of horse mackerel is lowest during and immediately after spawning (Sahrhage, 1970). These statements probably explain decreased condition factor

after long spawning period. Expended energy is replaced by intensified feeding of this species in the period after spawning (Jardas et al., 2004). This finding is confirmed by data for *Trachurus mediterraneus ponticus* from the Black Sea, which increased feeding intensity by about 80% after its spawning period (Sirotenko & Istomin, 1978). Specimens were in best condition in September when they were at resting phase with minimum reproductive activity. Probably, increased feeding in post-spawning period and recovery phase of gonads can explain the highest condition of fish obtained in September. Similar to the result of the present study, Alegria-Hernandez (1994) reported that condition of the horse mackerel was lowest immediately after spawning between June and July and highest in September at the end of the recovery phase. Also, Karlou-Riga (1995) noted increased condition in the horse mackerel during post-spawning period. Relative stable condition of the horse mackerel during the gonad maturation to the advanced stage was observed. This observation indicated possibility of simultaneous energy expenditure for reproduction process and somatic growth. This distribution of energy expenditure allows maximization of gonad capacity and therefore of reproductive potential (Alegria-Hernandez, 1994). On the contrary, Lucio & Martin (1989) noted that different maturity stages did not influenced on the condition of the horse mackerel in the northeastern Atlantic waters (Bay of Biscay). This would in principle be unexpected (Weatherley & Gill, 1987). Increased values of condition factor for fish in fully spent stage and when atresia rates are high could be explained by physiological processes (energy demands), avoiding the weight depletion due to reproductive effort (Lucio & Martin, 1989; Karlou-Riga, 1995).

In conclusion, in the eastern Adriatic Sea, the horse mackerel grows isometrically. The allometric parameter *b* varies throughout the year and its value is lower during the spawning season due to allocation of energy to reporoductive activities. The maximum *b* values were observed during the period when the gonado-somatic index showed a pronounced peak as the testis and ovaries were developed and massive. Variation of condition factor probaly were connected with the reproductive cycle. Condition of horse mackerel was lowest immediately after spawning period and highest at resting phase with minimum reproductive activity.

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