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The length-weight relationship of anchovy, *Engraulis encrasicolus* (L.), in the eastern Adriatic Sea

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The length-weight relationship of 7735 anchovy, Engraulis encrasicolus *(L.), specimens during 1987-1991 can be described by the following equations:* $W = 0.0038\ L_T^{\ 3.1939}$ *for anchovy from the nursery ground (Novigrad Sea),* $W = 0.0040\ L_T^{\ 3.1195}$ *for anchovy from the coastal waters (Kaštela Bay) and* $W = 0.0205\ L_T^{\ 2.7078}$ *for anchovy from the offshore waters (Vis and Biševo Islands area) of the eastern Adriatic Sea. The length-weight relationship was calculated by area, sex and gonad maturity stage.*

Key words: *Engraulis encrasicolus*, Adriatic Sea, length-weight relationship

INTRODUCTION

Length-weight relationship is a standard measurement in fish biology. It provides a means of interpreting length and weight at any given life stage. The relationship describes the weight distribution for size subpopulations and is vital for analysing population dynamics. The parameters of the length-weight equation are used in a number of practical applications: for rapidly converting the length of an individual fish to weight so as to assess the size of a population or standing stock, for estimating the mean weight of fish in a given length class, to study mortality rates, exploitation rates, and other parameters important for precise characterization of fish populations. The length-weight relationship of a fish species is typical to a given habitat and is indicative of the adequacy of the complex of synecological conditions that influence fish growth and development in that environment. Thus, the parameters of the length-weight relationship regression intercept (*a*) and length-weight exponent or allometric factor (*b*) of a fish species vary seasonally in response to fluctuating environmental conditions and physiological conditions such as reproduction and spawning (LE CREN, 1951). The present paper is an account of the length-weight relationship of anchovy, *Engraulis encrasicolus* (L.), from the nursery grounds (Novigrad Sea), coastal waters (Kaštela Bay) and offshore waters (Vis and Biševo island area) of the eastern Adriatic Sea.

MATERIAL AND METHODS

The investigated area includes the eastern Adriatic nursery grounds (Novigrad Sea), coastal waters (Kaštela Bay) and offshore waters (Vis and Biševo island area) of the anchovy, *Engraulis encrasicolus* L. (Fig. 1).

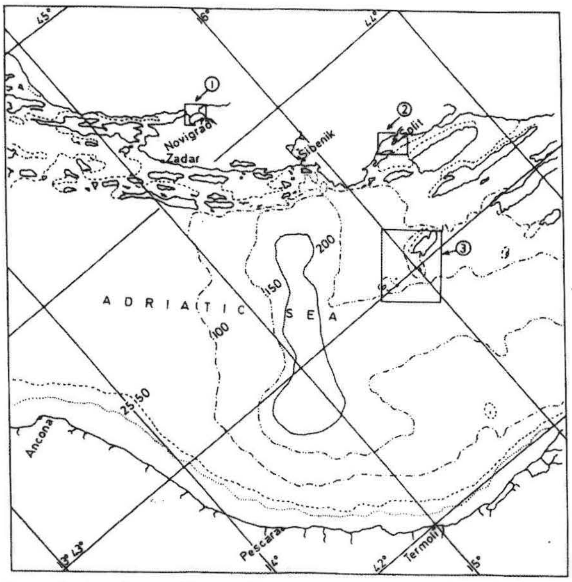

Fig. 1. Anchovy, Engraulis encrasicolus, *sampling locations in the eastern Adriatic: 1- Novigrad Sea nursing grounds, 2- Kaštela Bay coastal waters and 3- Vis and Biševo Island offshore waters*

During the investigation, the length-weight relationship of 7735 anchovy specimens, *Engraulis encrasicolus* (L.), was calculated and the length, weight, sex and gonad maturity stages were examined. Monthly samples were obtained from commercial purse seine catches in the Novigrad Sea (965♂, 1157 ♀ and 452 unidentified specimens), the Kaštela Bay (1415 ♂ and 1371 ♀), and the Vis and Biševo Island region (1179 ♂ and 1196 ♀) during 1987-1991. The total (L_T) and standard (L_S) length of each fish in mm was measured. The gonads and the gut were then removed and the fish were weighed to the nearest 0.1 g.

Otoliths (sagittae) were taken to determine age. They were extracted from 2055 specimens, washed, dried and mounted on black slides. A stereomicroscope with reflected light was used to determine the age of the anchovy from the otoliths immersed in distilled water (SINOVČIĆ, 1986). The sex was determined according to SINOVČIĆ (1992b, 2000) except for the smallest juveniles during the inactive period of the sexual cycle. The empiric scale (SINOVČIĆ, 1978, 2000) was used to estimate the gonad maturity stage.

The age, sex and gonad maturity of each specimen from each region were studied. Each group was analysed statistically. Mean values ($\bar{x}$), standard deviation (s), standard error of arithmetic mean (SE), correlation coefficient (r), and determination coefficient (r^2) were estimated. The allometric length-weight relationship of the anchovy was described by the equation: $W = a\,L^{\,b}$ or in logarithmic form: $\log W = \log a + b \log L$, where W is weight, L is length, a is regression intercept and b is the length-weight exponent or allometric factor.

Mean lengths and weights of each length class were used in the analysis.

RESULTS

Total lengths ranged 3.9-19.7 cm; weight ranged 1.71-29.70 g. The following weight-length relationships were obtained for each region:

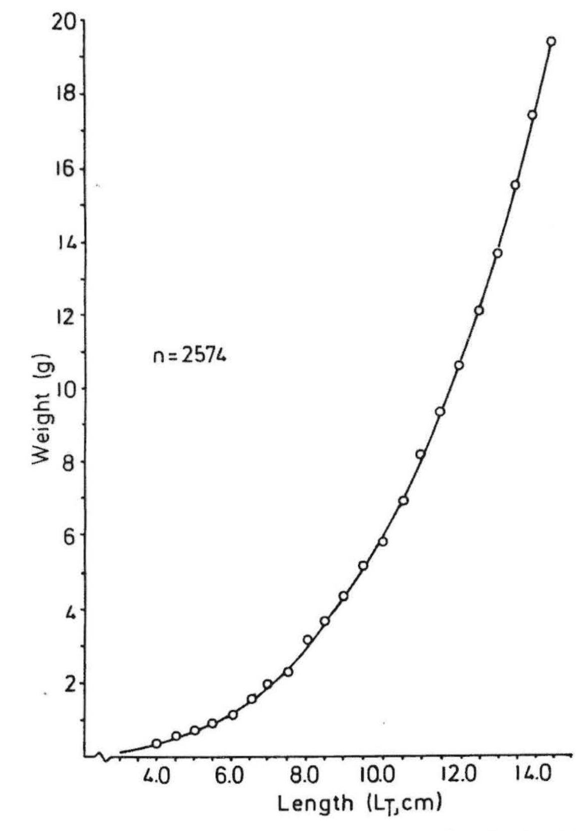

Fig. 2. Engraulis encrasicolus, *length-weight relationship in the Novigrad Sea, 1987-1991*

Novigrad Sea (Fig. 2): $W = 0.0038L_T^{3.1939}$, $r^2 = 0.980$, or $\log W = 3.1939 \log L_T$-2.4202;

Kaštela Bay (Fig. 3): $W = 0.0040L_T^{3.1195}$, $r^2 = 0.996$, or $\log W = 3.1195 \log L_T$ -2.3979;

Vis and Biševo Islands (Fig. 3): $W = 0.0205L_T^{2.7078}$, $r^2 = 0.996$, or $\log W = 2.7078$, $\log L_T$ -1.6882.

Positive allometry was noted in the length-weight relationships of anchovy from Novigrad Sea ($b = 3.1939$) and Kaštela Bay ($b = 3.1195$) while negative allometry was noted in samples from the Vis and Biševo Island area ($b = 2.7078$).

For each sex, the following standard length (L_S)-weight relationships were found (Fig. 4):

Kaštela Bay: males - $W = 0.0099\ L_s^{2.9477}$, $r^2 = 0.990$, or $\log W = 2.9477 \log L_s$-2.0044 and females - $W = 0.0095\ L_s^{2.9602}$, $r^2 = 0.992$, or $\log W = 2.9602 \log L_s$-2.0223;

Vis and Biševo Islands: males - $W = 0.0150\ L_s^{2.8261}$, $r^2 = 0.994$, or $\log W = 2.8261 \log L_s^{-1.9239}$ and females - $W = 0.0244\ L_s^{2.6440}$, $r^2 = 0.998$, or $\log W = 2.6440 \log L_s$ -1.6126.

We compared the length-weight relationships with mean total lengths in the range of 13.5-19.5 cm from Kaštela Bay (1393 specimens) and Vis and Biševo Islands (1187 specimens). Specimens in the most advanced gonad maturity stages for both sexes in the Vis and Biševo Islands are given separately (650 specimens). Following are the relationships for specimens from Kaštela Bay: $W = 0.0095\ L_T^{2.9591}$, $r^2 = 0.992$, or $\log W = 2.9591 \log L_T$-2.0223 and the Vis and Biševo Islands: $W = 0.0095\ L_T^{2.846}$,

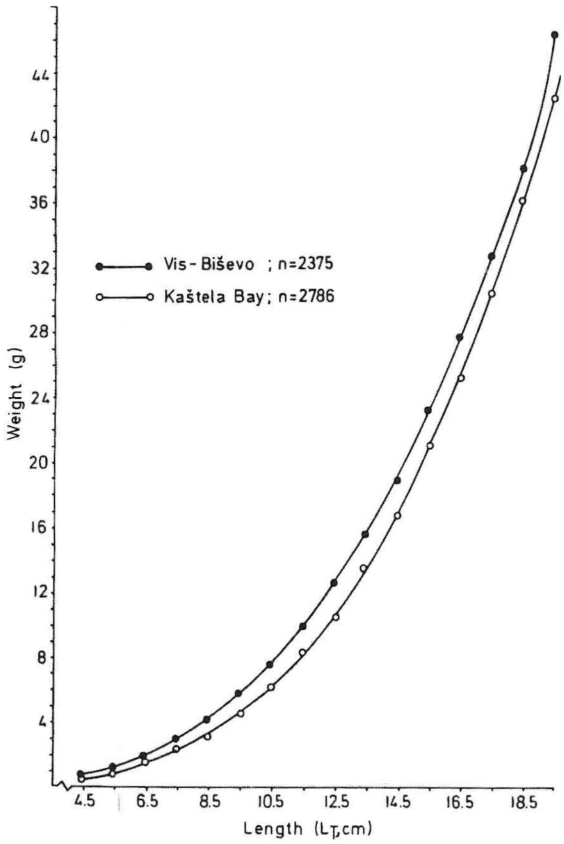

Fig. 3. Engraulis encrasicolus, *length-weight relationship in Kaštela Bay and the Vis and Biševo Island area, 1987-1991*

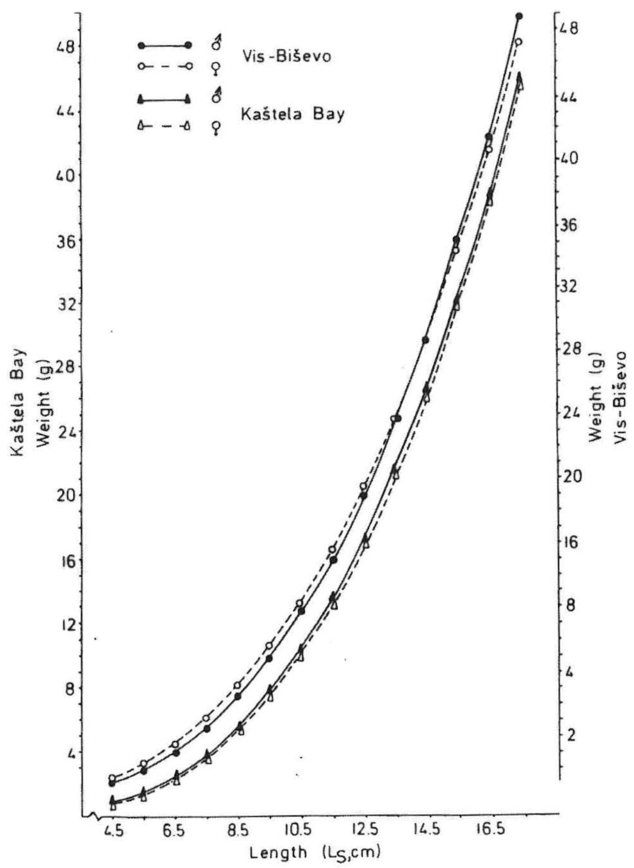

Fig. 4. Engraulis encrasicolus, *male and female length-weight relationships in Kaštela Bay and the Vis and Biševo Island area, 1987-1991*

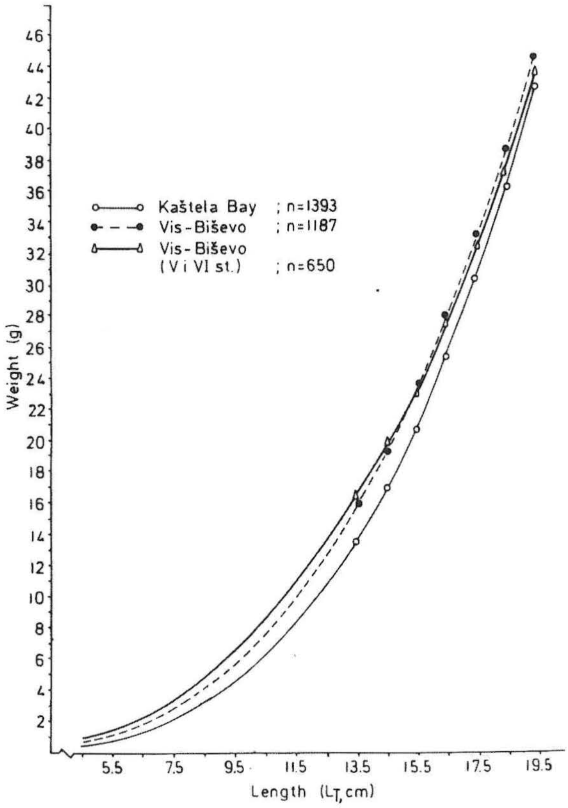

Fig. 5. Engraulis encrasicolus, *length-weight relationship of anchovy in the most advanced gonad maturity stages (V and VI) in Kaštela Bay and the Vis and Biševo Island area, 1987-1991*

$r^2 = 0.996$, or $\log W = 2.846 \log L_T -0.223$. For those in the most advanced gonad maturity stages (Fig. 5): $W = 0.01740\ L_T^{2.6334}$, $r^2 = 0.994$, or $\log W = 2.6334 \log L_T -1.7595$.

All length-weight correlation coefficients were very high and significant ($P < 0.001$). They ranged between 0.995 and 0.999. The determination coefficient ranged between 0.980 and 0.998.

This study also included observations of anchovy samples grouped according to age from the first to the fourth (0+ to 3+) year of life (Table 1). The total length (L_T) of these samples was between 3.9 (0+) and 16.8 cm (3+) while the mean lengths ranged from 8.2 (0+) to 14.94 (female 3+). The weights varied from 1.71 (0+) to 26.50 (male 3 +) with a mean of 3.30 (0+) to 19.80 (female 3+). The standard deviation of the total length (s_L) for all specimens was 1.073 and ranged between 0.036 (1+) and 1.100 (0+). The standard deviation of weight (s_W) for all specimens was 1.233 and ranged 0.114 (1+) to 1.34 (0+).

Table 1. Length-weight relationships in the anchovy, Engraulis encrasicolus, *according to sex and age class*

	Age class					
	Male			Female		
	1+	2+	3+	1+	2+	3+
n	135	415	321	147	295	290
Length range (cm)	10.2-12.8	11.3-15.1	13.1-16.8	11.0-14.1	12.0-15.4	14.0-16.1
Weight range (g)	6.71-13.98	9.58-20.69	15.04-26.50	8.55-17.40	10.77-21.89	16.75-23.08
Mean length (cm)	11.22±0.007	13.90±0.107	14.65±0.128	12.35±0.009	14.13±0.126	14.94±0.121
Mean weight (g)	9.23±0.022	17.05±0.123	19.28±0.139	12.06±0.017	16.99±0.139	19.80±0.129
s_L	0.036	1.076	1.053	0.053	1.065	1.035
s_W	0.114	1.230	1.140	0.102	1.178	1.107
$S.E._L$	0.0030	0.0530	0.0588	0.0043	0.0622	0.0608
$S.E._W$	0.0098	0.0605	0.0636	0.0084	0.0688	0.0651
a	0.0045	0.0124	0.0300	0.0106	0.0243	0.0198
b	3.150	2.747	2.403	2.800	2.470	2.560
r	0.998	0.981	0.943	0.966	0.954	0.859

Table 1. Cont'd

	Age class Unidentified sex and both sexes together				Total
	0+	1+	2+	3+	
n	452	282	710	611	2055
Length range (cm)	3.9-11.0	10.2-14.1	11.3-15.4	13.1-16.8	7.5-16.8
Weight range (g)	1.71-8.65	6.71-20.69	9.58-21.89	15.04-26.50	6.71-26.50
Mean length (cm)	8.20±0.103	12.02±0.138	14.02±0.083	14.81±0.089	12.39±0.049
Mean weight (g)	3.30±0.126	11.20±0.162	17.02±0.094	19.55±0.096	12.77±0.056
s_L	1.100	1.080	1.070	1.045	1.073
s_W	1.340	1.260	1.210	1.125	1.233
$S.E._L$	0.0518	0.0646	0.0375	0.0423	0.0236
$S.E._W$	0.0632	0.0754	0.0454	0.0453	0.0272
a	0.0049	0.0082	0.0174	0.0303	0.0152
b	3.010	2.904	2.611	2.400	2.731
r	0.999	0.984	0.963	0.907	0.970

The greatest aberration in standard deviation was in the 0+ age group while the smallest was in 1+. The length-weight relationship for all the anchovy can be written in the following equation:

$W = 0.0186\ L_T^{\ 2.5801}$, $s_L = 1.0983$, $s_W = 1.\ 2861$, $r^2 = 0.9249$ or $\log W = 2.5801 \log L_T - 1.7304$.

Negative allometry (b = 2.5801) was confirmed for the total anchovy specimens with a proportionately higher increase in anchovy length compared to weight. For individual age classes, the length-weight relationship for both sexes can be expressed using the following equations:

for 0+: $W = 0.0049\ L_T^{\ 3.010}$, $s_L = 1.100$, $s_W = 1.340$, $r^2 = 0.998$, or $\log W = 3.010 \log L_T - 2.3098$

for 1+: $W = 0.082\ L_T^{\ 2.904}$, $s_L = 1.080$, $s_W = 1.260$, $r^2 = 0.968$, or $\log W = 2.904 \log L_T - 2.0862$

for 2+: $W = 0.0174\ L_T^{\ 2.611}$, $s_L = 1.070$, $s_W = 1.210$, $r^2 = 0.927$, or $\log W = 2.611 \log L_T - 1.7954$

for 3+: $W = 0.0325\ L_T^{\ 2400}$, $s_L = 1.045$, $s_W = 1.125$, $r^2 = 0.822$, or $\log W = 2.400 \log L_T - 1.4881$

The following length-weight relationship equations were found for each sex:

males 1+: $W = 0.045\ L_T^{3.150}$, $s_L = 0.036$, $s_W = 0.114$, $r^2 = 0.996$, or $\log W = 3.150 \log L_T - 2.3468$

males 2+: $W = 0.0124\ L_T^{2.747}$, $s_L = 1.076$, $s_W = 1.230$, $r^2 = 0.962$, or $\log W = 2.747 \log L_T - 1.9066$

males 3+: $W = 1.0300\ L_t^{2.403}$, $s_L = 1.053$, $s_W = 1.140$, $r^2 = 0.889$, or $\log W = 2.403 \log L_T - 0.0128$

females 1+: $W = 0.0106\ L_T^{2.800}$, $s_L = 0.053$, $s_W = 0.102$, $r^2 = 0.933$, or $\log W = 2.800 \log L_T - 1.9747$

females 2+: $W = 0.0243\ L_T^{2.470}$, $s_L = 1.0652$, $s_W = 1.777$, $r^2 = 0.910$, or $\log W = 2.470 \log L_T - 1.6144$

females 3+: $W = 0.0198\ L_T^{\ 2.560}$, $s_L = 1.0349$, $s_W = 1.1074$, $r^2 = 0.737$, or $\log W = 2.560 \log L_T - 1.7033$

Values in Table 1 show that the coefficient of the length-weight relationship decreases in older anchovy. The same goes for correlation coefficient values, which are significantly very high and theoretically approach the ideal value of 1.0, indicating that only a small number of samples cannot be explained by this relationship. The correlation coefficient (*r*) ranged between 0.859 for female 3+ and 0.998 for male 1+ or 0.999 for both sexes 0+.

The range of variation in total length is greater for older individuals, which also were most abundant. The length-weight coefficient (*b*) varied from 2.400 (both sexes 3+) to 3.150 (male 1+). Positive allometry was found in the 0+ and males 1+ age groups while negative allometry was found in the other age groups. In these cases, anchovy samples showed relatively more rapid growth in length compared to weight.

When shown in the logarithmic form (Fig. 6), the tendency towards alternating growth is evident. The first point at which the length-weight relationship changes appears at the average anchovy length of 8.5 cm. This growth model is retained to 12.0 cm. The following intersection appears at 14.0 cm.

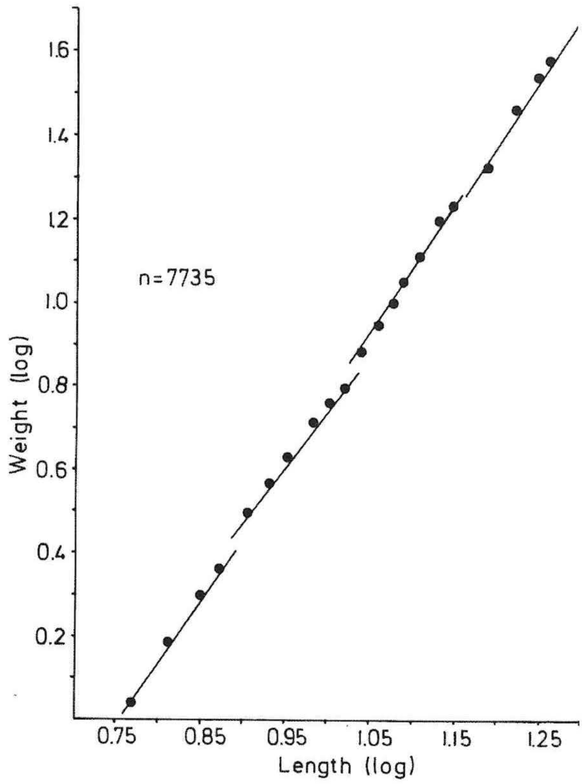

Fig. 6. Engraulis encrasicolus, *regression straight lines of anchovy length and weight values (logs. eastern Adriatic), 1987-1991*

DISCUSSION AND CONCLUSION

Changes in body shape, physiology, environmental factors, food supply and availability during life and biological cycles, growth increment or stagnation influence the allometric factor (FROST, 1945; LE CREN, 1951). The allometric coefficient also depends on the feeding location of the fish population, sex, length, age and gonad maturity. This value does not change as long as the factors remain unchanged (MARTIN, 1949; RICKER, 1979). Therefore, the relationship between length and weight can be used as any other morphometric characteristic (LE CREN, 1951). For the same reason, the results of this study were classed into groups according to region, age, sex and stage of gonad maturity.

The increase in length was very expressive from the onset. The anchovy retained this growth characteristic until it reached a total mean length of 8.5 cm. Afterward, the anchovy grew almost isometrically to approximately 12.0 cm. Above 12.0 cm, the anchovy increased in weight; the weight gain was larger than the gain in length in anchovy longer than 14.0 cm.

These values correspond with results obtained when the empirical values of length (*L*) and weight (*W*) are shown in the logarithmic form. The points of intersection between *W* and *L* illustrate the alternating relationship of these two parameters as they change during growth. The first intersection appears at the average length of 8.5 cm, growth is retained to 12.0 cm and the following intersection appears at 14.0 cm, coinciding with the above-mentioned values.

The first point at which the *W*/*L* relationship changes, at 8.5 cm, corresponds with the earliest sexual maturity of anchovy in the Adriatic Sea (SINOVČIĆ, 1978, 1992b, 1998a,b, 1999) and the transformation from the juvenile to adult phase (SINOVČIĆ, 1992b, 1999). This growth model is retained up to 12.0 cm when the secondary anchovy maturation occurs. The intersection at

14.0 cm marks the third maturation (SINOVČIĆ, 1992b). Since gonad maturation reflects developmental progress by either slowing down or accelerating development according to the proportion of energy spent on reproduction, changes in anchovy growth are even more noticeable. The beginning of the spawning season in the Adriatic Sea occurs in the spring (KARLOVAC, 1963; VARAGNOLO, 1968; VUČETIĆ, 1971; REGNER, 1972; SINOVČIĆ, 1978, 1992b, 1998a,b, 2000; GAMULIN & HURE, 1983) and overlaps environmental changes, which are most prevalent at this time. Therefore, the cessation in growth is more noticeable during spring.

Anchovy of the same length were heavier in the off-shore area than in the coastal waters, confirming that trophic offshore regions are more suitable to this species (SINOVČIĆ, 1992a,b).

Length-weight coefficients were higher in males than in females of the same age, and males had a higher weight than females of the same length in the largest length class (13.0 cm and up). This can be explained by the greater weight loss in females at this age due to more expressed metabolic processes during intensive spawning (SINOVČIĆ, 1978). The lower correlation coefficient in females is probably due to the same reason. In smaller anchovy specimens (<13.0 cm), weight loss was greater in males than in females, perhaps because of greater mobility and increased activity in males at the onset of sexual maturation (TEMPLEMAN, 1967). Initial sexual maturity occurs earlier in males than in females (SINOVČIĆ, 1978, 1999, 2000).

Comparison of the length-weight relationships presented in this paper with those of anchovy from other regions shows that the coefficient of the length-weight relationship changes from negative allometry through isometric to positive allometry depending on the period of the year, the physiological state of the anchovy and the length range analysed. RODRIGUEZ-RODA (1977) analysed 2915 anchovy specimens with a total length of 7.5-14.5 cm caught near Cadiz in several months between June 1969 and June 1971. This author confirmed the total negative allometry (b = 2.86) in anchovy from this region. Meanwhile, PERTIERRA (1987) analysed 1970 anchovy specimens from the coastal region of the western Mediterranean near Barcelona from April 1984 to August 1985 and found that the coefficient of the length-weight relationship of anchovy in a nearly identical length range as in our study (5.0-18.5 cm) varied in a range similar to that in our study (2.40-3.19).

Comparison of the allometric coefficient values between males and females of the same age demonstrates the differences. All coefficients of regression (b), except that of the male 0+ age group, had allometric coefficient values below 3. The value decreased with age, showing an even proportionately lower weight increment than length increase in older anchovy. Since the lowest allometric coefficient values were noted in the oldest anchovy specimens, this fact could be connected to spawning intensity. Anchovy in the 2+ age group and, especially, 3+ spawned intensively during our research, resulting in the exhaustion of fat reserves from the fish tissue (SINOVČIĆ, 1992a,b). This is most obvious when comparing the length-weight relationships of specimens in the most advanced gonad maturity stages with all other specimens from the offshore region (Vis and Biševo Islands) of the eastern Adriatic Sea. In anchovy larger than 13.5 cm, the length-weight relationship changes show greater loss in females, probably as the result of greater exhaustion of females during spawning, which is seen in the weight values of the specimens in the most advanced gonad maturity stages.

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Dužinsko-maseni odnos brgljuna, *Engraulis encrasicolus* (L.), u istočnom Jadranu

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SAŽETAK

Proučavan je dužinsko-maseni odnos u 7735 jedinki brgljuna, *Engraulis encrasicolus* (L.), u razdoblju od 1987 do 1991 godine. Taj odnos može se izraziti sljedećim jednadžbama: $W = 0.0038\ L_T^{\ 3.1939}$ za mlađ brgljuna (Novigradsko more); $W = 0.0040\ L_T^{\ 3.1195}$ za brgljuna iz obalnog područja (Kaštelanski zaljev) i $W = 0.0205\ L_T^{\ 2.7078}$ za brgljun otovrenih voda (otoci Vis i Biševo) istočnog Jadrana. Dužinsko-maseni odnos je izračunat s obzirom na područje, spol i stadij zrelosti gonada.

Ključne riječi: *Engraulis encrasicolus*, Jadransko more, dužinsko-maseni odnos