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Length–weight relationship, age, growth and mortality of Atlantic chub mackerel *Scomber colias* in the Adriatic Sea

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Chub mackerel, Scomber colias, *is widely distributed in the warm waters of the Atlantic Ocean including the Mediterranean and Adriatic Seas. This medium-sized pelagic fish species occurs in deeper waters during the colder part of the year and schools are found in coastal waters during the warmer parts of the year, where they spawn and feed. Atlantic chub mackerel is one of the most important commercial fish throughout its habitat and as a consequence of its wide distribution and broad commercial exploitation, biological information on the growth and mortality is required for stock assessment and management. Despite the abundance and economic importance of* S. colias *in the Adriatic Sea, knowledge about its biology and population dynamics is still limited. Studies of the age, growth, mortality and exploitation rates of* S. colias *have not been undertaken previously in the Adriatic Sea. Therefore, the exploitation status of this species' stock in the Adriatic Sea is unknown. The purpose of this study was to provide information on the age, growth and length–weight relationship as well as estimates of mortality and exploitation rate in order to define the present state of the population in the Adriatic Sea.*

Keywords: length–weight relationship, growth parameters, mortality, Scombridae

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INTRODUCTION

Chub mackerel, *Scomber colias* Gmelin, 1789, is widely distributed in the warm waters of the Atlantic Ocean including the Mediterranean and Adriatic Seas. This medium-sized pelagic fish species occurs in deeper waters during the colder part of the year and schools are found in coastal waters during the warmer parts of the year, where they spawn and feed. Atlantic chub mackerel is one of the most important commercial fish throughout its habitat (Anonymous, 2011) and as a consequence of its wide distribution and broad commercial exploitation, biological information on the growth and mortality is required for stock assessment and management (Cadima, 2000). Despite the abundance and economic importance of *S. colias* in the Adriatic Sea, knowledge about its biology and population dynamics is still limited. Studies of the age, growth, mortality, and exploitation rates of *S. colias* have not been undertaken previously in the Adriatic Sea. Therefore, the exploitation status of this species' stock in the Adriatic Sea is unknown. The purpose of this study was to provide information on the age, growth, and length–weight relationship as well as estimates of mortality and exploitation rate in order to define the present state of the population in the Adriatic Sea.

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MATERIALS AND METHODS

The studied specimens of *S. colias* were collected randomly from the commercial landings during the night with artificial lights and purse seines with a stretched mesh size of 10 mm. The purse seine with artificial light is the preferred fishing technique in the Adriatic Sea for capturing those fish species that school or aggregate close to the surface, including anchovies, sardines, mackerels, herrings and some tuna species.

A total of 4189 specimens were sampled between January 1998 and December 2007 in the eastern part of the Adriatic Sea (geographical range from 44°13.586′N 15°08.883′E to 42°48.523′N 17°51.109′E). Samples were collected once a month, with the exception of 13 months when sampling was limited by logistical problems or bad weather. The number of specimens sampled each month ranged from 20 (May 2002) to 177 (September 2007) individuals. All fish were analysed in the laboratory immediately after landing. For each specimen, fork length (FL) (±0.1 mm) and total body weight (W) (±0.01 g) were measured. Sex was determined macroscopically considering the shape, appearance and structure of the gonads. The total sample comprised 1085 males, 1611 females and 1493 specimens of undetermined sex. The latter included those specimens that were immature, in the resting phase of reproduction (i.e. the sex could not be determined by macroscopic examination), or due to the specimens not being preserved well enough.

The relationship between FL and W was calculated for each sex separately by geometric mean functional regression (Ricker, 1975) in exponential form $W = aFL^b$, where b is the regression coefficient and a is the regression constant.

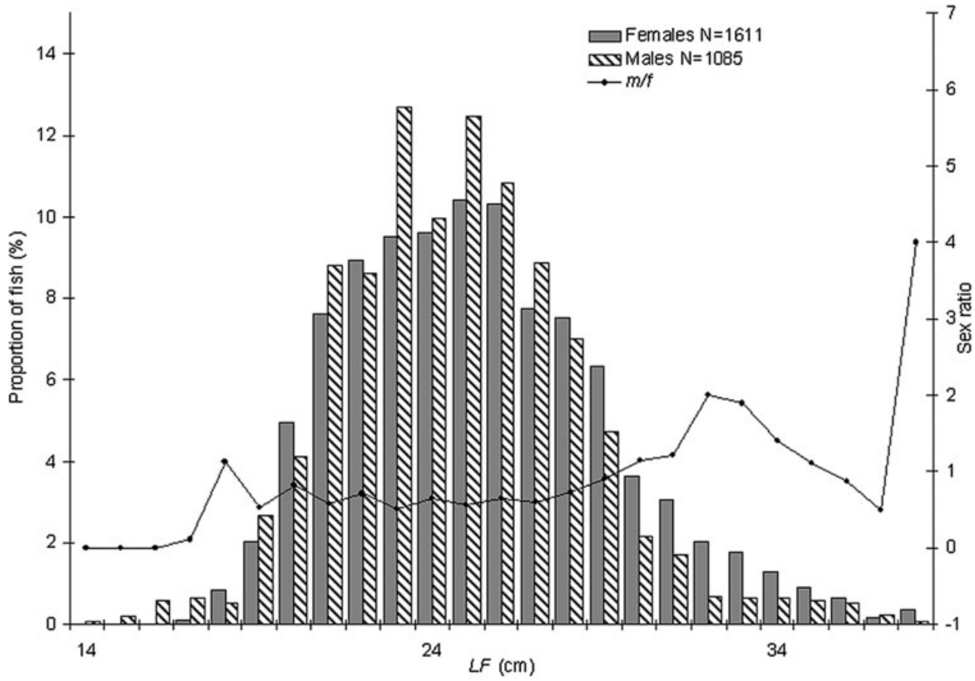

Fig. 1. Length–frequency distribution of male and female chub mackerel specimens as well as sex-ratio by length, Adriatic Sea, 1998–2007.

Length–weight regressions were tested for differences in slopes between sexes using the Mann–Whitney *U*-test.

Random subsamples of *S. colias* (10 specimens from fresh fish commercial landings sampled randomly each month) were taken during the period January 2006–December 2007; sagittal otoliths were removed from the head, cleaned, dried and stored in plastic tubes. Otoliths were immersed in alcohol and aged on three separate occasions, approximately two months apart, to reduce subjectivity. Reading was done using reflected light on a black background and a magnification of 1.6. The otolith was considered to be unreadable when two readings from the same otolith resulted in different age estimates. One opaque and one hyaline ring were considered to represent one year of life.

The weights of the undamaged and cleaned otoliths (N = 100) were measured on a Mettler analytical balance (to the nearest 0.01 mg). The relationship between fork length, weight, and age of the fish and weight of the otolith were examined with the linear, exponential regression model by the method of least squares (Sokal & Rohlf, 1995). StatSoft 5.5 software was used for the statistical analysis.

Values of L_∞ (the asymptotic length), K (the growth constant), and t_0 (the age at which FL = 0) were calculated by the Ford–Walford graphic method (Ford, 1933; Walford, 1946). The von Bertalanffy growth equation $L_t = L_\infty [1 - e^{-K(t = t_0)}]$ was fitted to length-at-age data using non-linear least squares parameter estimation (Gulland, 1983). Separate analyses were carried out for males, females and both sexes pooled together with unsexed specimens.

The growth performance index phi-prime (Φ') was estimated to compare the growth parameters obtained in the present work with those reported by other authors. This index was calculated by the equation of Munro & Pauly (1983): $\Phi' = \log K + 2 \log L_\infty$.

Natural, fishing, and total mortality were calculated for the total sample. Natural mortality (M) was defined as the mean value of three estimations using the general regression equations below:

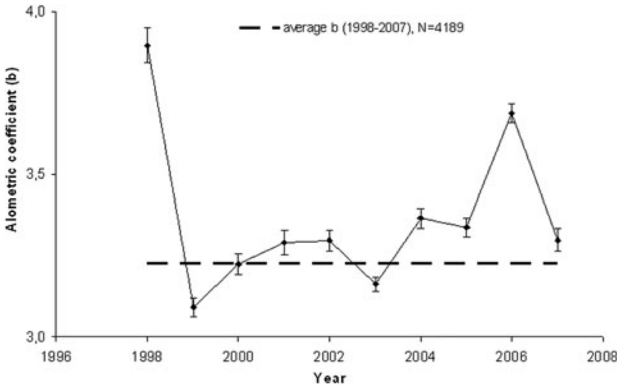

Fig. 2. Mean annual allometric coefficient (b) and its standard deviations for each year together with the average allometric coefficient for the overall investigated period, *Scomber colias*, Adriatic Sea, 1998–2007.

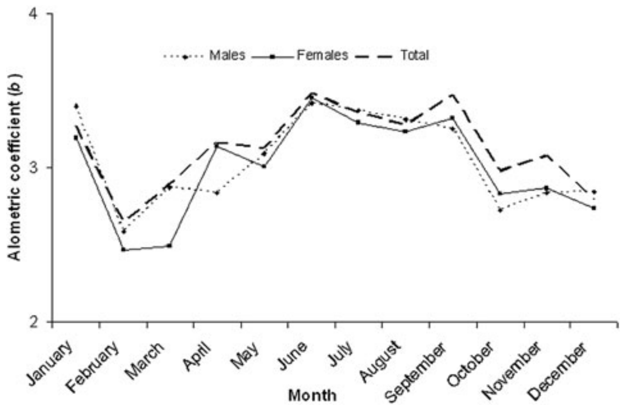

Fig. 3. Mean monthly allometric coefficient of males, females, and overall investigated specimens of *Scomber colias*, Adriatic Sea, 1998–2007.

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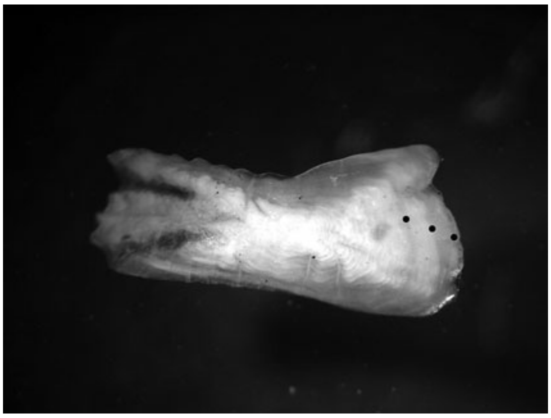

Fig. 4. *Scomber colias* sagitta otolith (W = 140.29 g, FL = 23.6 cm, age 3+, magnification 1.6 × 40), 20 April 2007, Adriatic Sea.

- $\log_{10}M = -0.0066 - 0.279\log_{10} L_\infty + 0.6543\log_{10}K + 0.4634 \log_{10}T$ (Pauly, 1980), where L_∞ and K are the parameters of the von Bertalanffy growth equation (Gulland, 1983) and parameter T is the mean value of the water temperature (17.35°C) in the investigated area (Grbec *et al.*, 2007);
- $M = 1.521/X^{0.72} - 0.155$ (Rikhter & Efanov 1976), where X is the age at which most of the population has matured (four years for males, five years for females and overall: Čikes Keč, 2009);
- $M = 0.996/A_{0.95}$ (Taylor, 1959), where $A_{0.95}$ is the age at length of 95% L_∞ (14.99 years).

The instantaneous total mortality rate (Z) was estimated using the linearized length-converted catch curve (Pauly, 1984) in the software FiSAT (Gayanilo *et al.*, 1994). The natural logarithm of the ratio between the number of fish in each length-class and the time needed for the fish to grow through the length-class ($\ln N_i/\Delta t_i$) was plotted against their corresponding relative age (t) and the total mortality was estimated from the descending slope b. The Z value obtained was used to calculate the survival rate (S) by the formula $S = e^{-Z}$ (Ricker, 1975). The instantaneous rate of fishing mortality (F) was estimated from the difference between Z and M. The exploitation rate (E) was determined according to Gulland (1983): E = F/Z. A defined limit reference point (LRP or L_{limit}) was calculated using the equation of Patterson (1992): LRP = 2/3 M in order to define the present state of the *S. colias* resource.

RESULTS

Length–weight relationship

The fork lengths and weights of all analysed specimens (N = 4189) ranged from 10.1 to 39.1 cm (mean: 23.8 ± 4.68 cm)

Table 1. Age–length key for chub mackerel with mean fork length and standard deviation ($\bar{x}$ ± SD), 2006–2008, Adriatic Sea.

FL (cm)	Age-classes								
	1+	2+	3+	4+	5+	6+	7+	8+	9+
14.0–14.9	4								
15.0–15.9	2								
16.0–16.9	10								
17.0–17.9	5								
18.0–18.9	10								
19.0–19.9	5	18							
20.0–20.9		29							
21.0–21.9		43							
22.0–22.9		32							
23.0–23.9		20	2						
24.0–24.9		7	16						
25.0–25.9		2	19						
26.0–26.9			12						
27.0–27.9			9						
28.0–28.9			1	2					
29.0–29.9				2					
30.0–30.9				2	1				
31.0–31.9				1	1				
32.0–32.9					1	2			
33.0–33.9						2			
34.0–34.9						4	1		
35.0–35.9							3		
36.0–36.9									1
37.0–37.9									
38.0–38.9									1
39.0–39.9									1
N	56	114	58	28	10	6	5	–	3
%	20.0	40.71	20.71	10.0	3.57	2.14	1.79	–	1.07
$\overline{FL}$ (cm)	17.30	21.65	25.73	28.83	31.78	33.78	35.38	–	38.23
SD	1.52	1.36	1.13	0.99	0.98	0.82	0.43	–	1.16
$\overline{W}$ (g)	52.80	107.85	192.48	285.84	414.21	522.08	599.76	–	755.27
SD	15.95	23.17	32.62	38.08	63.39	60.90	23.85	–	72.83

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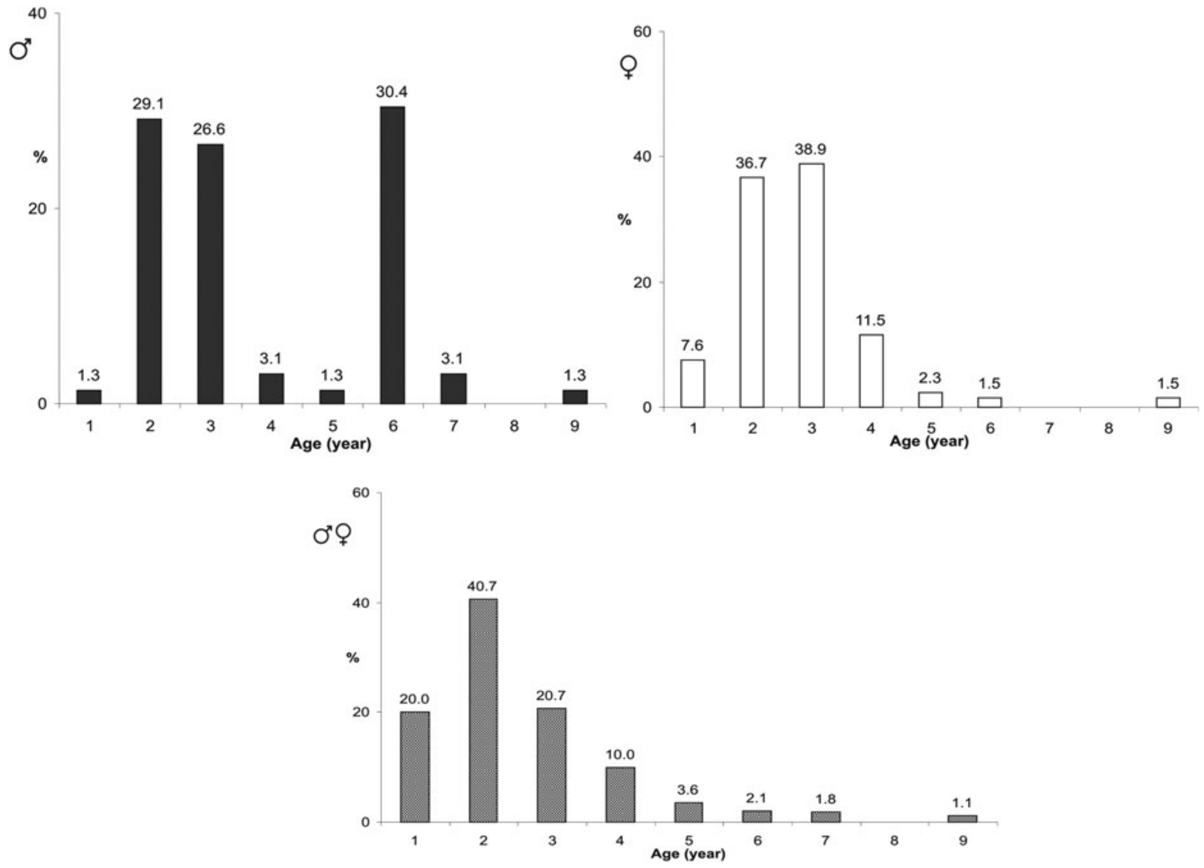

Fig. 5. Age structure of males, females and overall material, *Scomber colias*, Adriatic Sea, 2006–2008.

and from 8.90 to 804.50 g (mean: 164.49 ± 102.70 g), respectively. Females had both a wider length distribution (Figure 1) and a wider weight range than males (males ranged from 22.95 to 710.60 g and females from 16.51 to 701.66 g) and they also had lower mean values. The length frequencies of males, females, and the overall material were normally distributed (Kolmogorov–Smirnov test: d = 0.0505 males, d = 0.0375 females, and d = 0.0450 total; $P < 0.05$).

The calculated length–weight relationships were $W = 0.0061FL^{3.1836}$ ($r^2 = 0.922$) for males, $W = 0.0057FL^{3.1936}$ ($r^2 = 0.910$) for females and $W = 0.0052FL^{3.2238}$ ($r^2 = 0.969$) for all specimens. The hypothesis of isometric growth was discarded for males and females, as the obtained allometric index value (b) was significantly different from 3 (t = 0.713; t = 0.961; $P < 0.05$, respectively), but not for all the analysed material (t = 0.317; $P > 0.05$) of chub mackerel in the Adriatic Sea.

Interannual variations in the mean allometric index (b) of *S. colias* were noticed although its values stayed above the isometric value over the whole study period (Figure 2). Sharp decreases were noticed in 1998–1999 and 2007–2008. In both sexes, synchronous fluctuations of the allometric coefficient b by month were established (Figure 3). Namely, both males and females had lower b values during the colder part of the year (minimum in February, with an exception in January), while the peak was in June.

Age and growth

Broader opaque and narrower hyaline zones of *S. colias* otoliths alternated outwards from the nucleus of the sagitta (Figure 4). A total of 280 otoliths were aged successfully. The fork lengths of aged specimens ranged from 14.1 to 39.0 cm (Table 1). The age-classes in the otolith sample ranged from 1+ to 9+ years, while the samples were dominated by the 2+ and 3+ age-classes (40.7% and 20.7% respectively). There appeared to be a difference between the age distributions of male and female fish, as most of the males were 6+ (30.4%) and 2+ (29.1%) years old, while females were mostly 3+ (38.9%) and 2+ (36.7%) years old. The mean lengths-at-age were more variable but generally larger for females (except in the 1+, 4+, and 9+ year olds) (Figure 5).

The weights of the otoliths were from 0.889 to 11.456 mg, with a mean of 4.252 ± 2.429 mg. The relationship between fork length and otolith weight was exponential and highly correlated (r = 0.901; Figure 6). Also, a high linear correlation was obtained between the weight of the fish and the weight of the otolith (r = 0.951). Age estimations correlated exponentially with otolith weight, as well (r = 0.907) (Figure 6).

Length-at-age data for both sexes and the total sample were very well fitted by the von Bertalanffy growth curve ($r^2 > 0.957$) (Figure 7). Overall, the relationship between age and length was described by the growth parameters $L_\infty = 45.31$ cm, $K = 0.180$ year^{-1}, $t_0 = -1.649$ year. Slight variations between sexes were established. Namely, for males the relationship was $L_\infty = 41.31$ cm, $K = 0.237$ year^{-1}, $t_0 = -1.052$ year and for females it was $L_\infty = 48.64$ cm, $K = 0.151$ year^{-1}, $t_0 = -1.943$ year. The estimated growth performance index (Φ') was 2.57 for the whole material, while for males and females the indices were 2.61 and 2.55, respectively.

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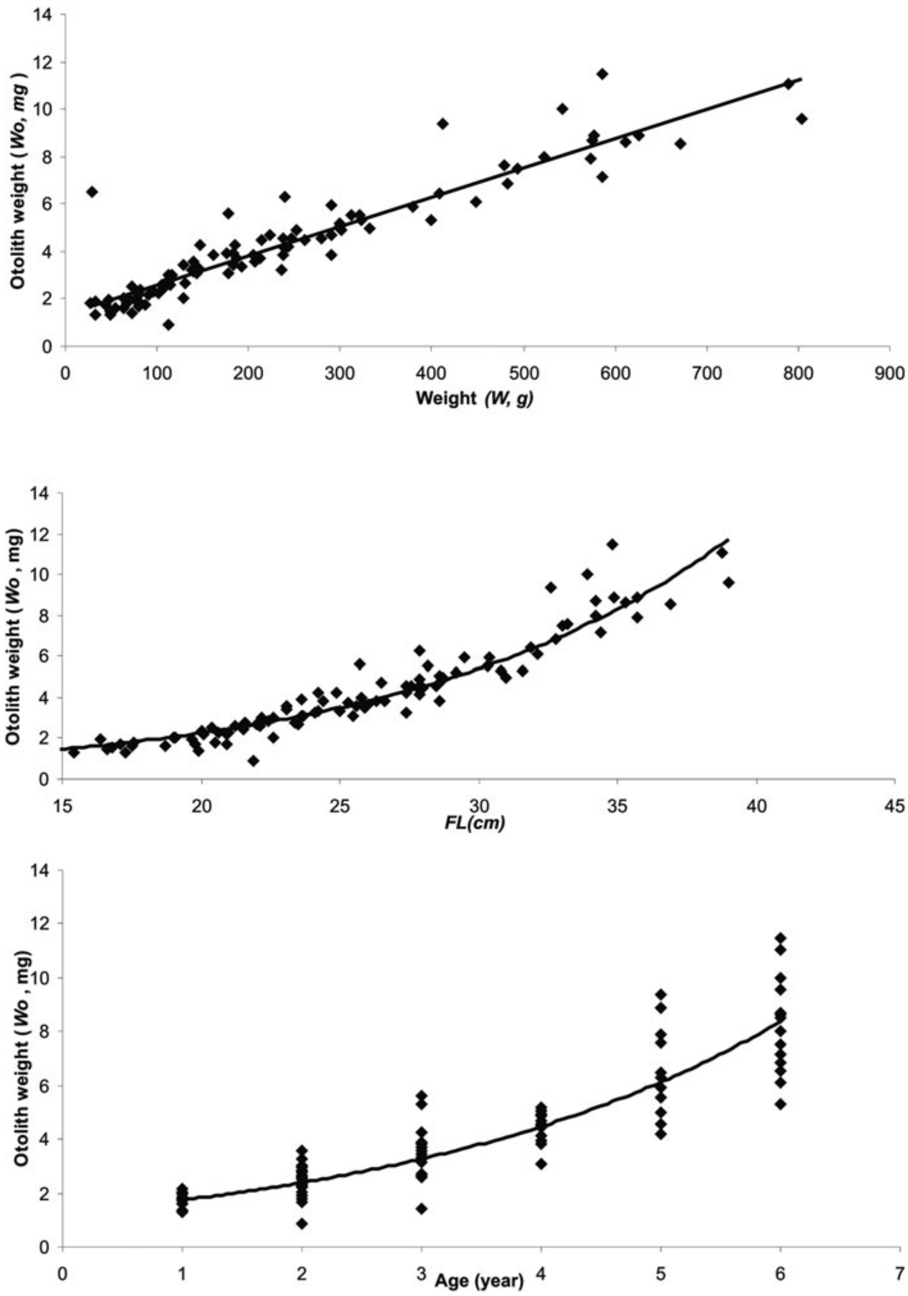

Fig. 6. Correlations between otolith weight (Wo) and total body weight (W), fork length (FL), and age, *Scomber colias*, Adriatic Sea, 2006–2008.

Mortality

The natural mortality (M), total mortality rate (Z) (Figure 8), fishing mortality coefficient (F), exploitation (E), and survivor (S) rate were estimated (Table 2). The value of the M/K ratio was 1.94, while the limit reference point (LRP) for *S. colias* was estimated as 0.23.

DISCUSSION

The length–weight relationship is a key biological parameter (Martin, 1949; Bagenal & Tech, 1978; Ricker, 1978) and data from this and earlier studies are presented in Table 3. Isometric growth of *S. colias* determined in this study was in accordance with results reported in earlier studies (Stergiou & Moutopoluos, 2001; Sinovčić *et al.*, 2004) and elsewhere in its range. Length–weight investigations of *S. colias* throughout its habitat revealed allometric coefficients (b) ranging from 3.227 (Portuguese coast: Goncalves *et al.*, 1997) to 3.704 (Aegean Sea: Moutopoulos & Stergiou, 2002). Negative allometry was recorded in the northern part of the Atlantic (Magnusson & Magnusson, 1987: b = 2.880). As previously recorded by other researchers (Huxley, 1932; Frost, 1945; Martin, 1949; Bagenal & Tesch, 1978; Ricker, 1978), changes in the length–weight relationship by year and by sex were noted during this investigation as well. Namely, positive allometry was established for males and females, and intra- and inter-annual variations of the mentioned allometric coefficient were noted; higher values of b were observed

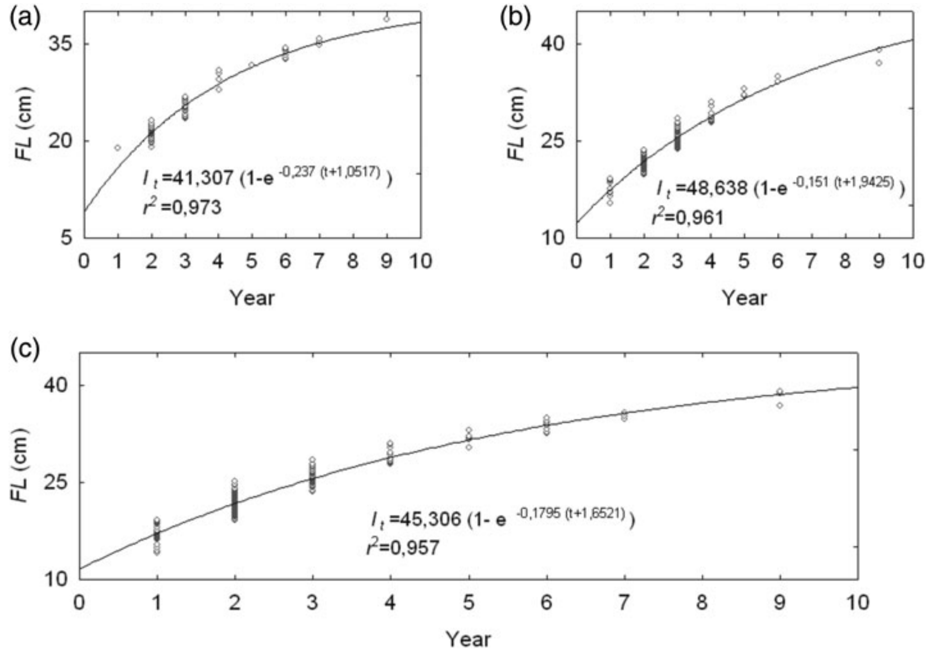

Fig. 7. Von Bertalanffy growth equations for (a) males, (b) females and (c) overall specimens, *Scomber colias*, Adriatic Sea, 2006–2008 (l_t is the length at time *t*).

during the warmer part of the year. Therefore, the deviations between the results obtained in this study and those from other areas are probably due to differences in the time/area of investigations, sample size and/or sex-ratios.

In natural populations the younger age-classes are expected to be more abundant than the older ones. The absence of 0+ age-class specimens as well as the rather poorly presented age-class 1+ might be explained by the selectivity of the fishing gear and ability of the smaller fish to escape the net and/or a different spatial distribution of young fish. Regarding the age-class proportions in the investigated sample, it seemed that specimens of age-class 2+ were fully fished while the rest of the age-classes in this area followed the expected fishing pattern (Figure 8). The same underrepresentation of the younger ages was also noticed in the Hellenic Seas (Kiparissis *et al.*, 2000).

The results of otolith weight in comparision with length, weight and age of the fish indicate that otolith weight could be an accurate indicator of somatic growth. This could be explained by the fact that otolith weight is the most sensitive to variations in growth rates and best related to changes in fish metabolism (Boehlert, 1985; Reznik *et al.*, 1989; Secor & Dean, 1989; Pawson, 1990; Fletcher, 1991).

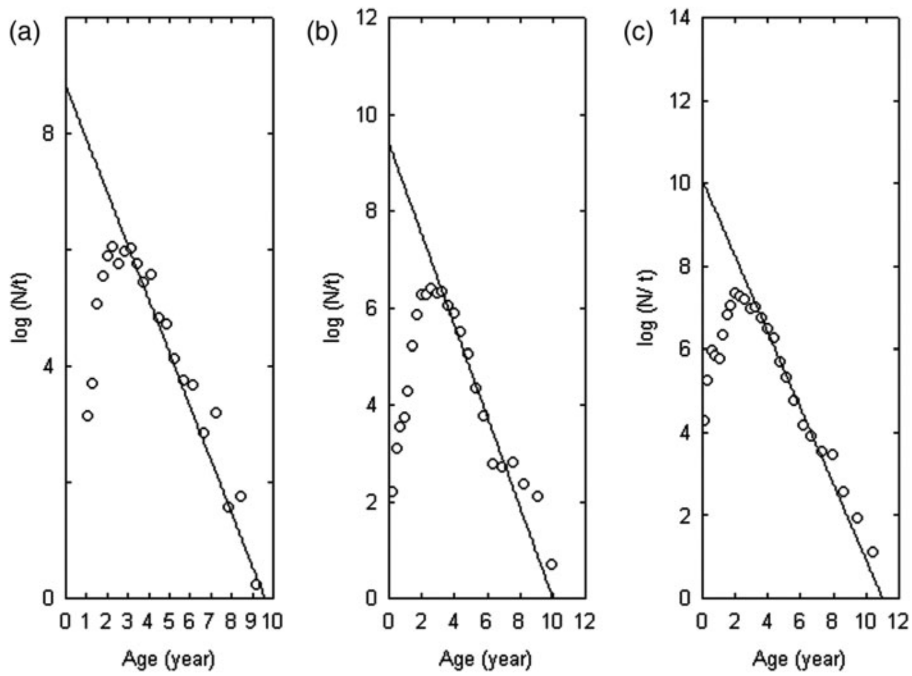

Fig. 8. Total mortality coefficients (Z) for (a) males, (b) females and (c) overall specimens, *Scomber colias*, Adriatic Sea, 1998–2007.

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Table 2. Mortality coefficients of *Scomber colias* for males, females and overall material (total) in the eastern Adriatic Sea during the investigation period from January 2006 to December 2008.

		Male	Female	Total
Natural mortality (M)	Pauly, 1980	0.511	0.363	0.414
	Taylor, 1959	0.454	0.272	0.319
	Rikhter & Efanov, 1976	0.406	0.322	0.322
	Mean M	0.457	0.319	0.352
Fishing mortality (F)		0.46	0.71	0.56
Total mortality (Z)		0.93	1.03	0.91
Exploitation rate (E)		0.50	0.69	0.61
Survivor rate (S)		0.40	0.36	0.40

Scomber colias growth rates rather similar to those revealed in this study have also been observed for both sexes in the other regions of this species distribution (Gagliardi & Cousseau, 1970; Perrotta & Forciniti, 1989). Growth parameters for all analysed material given in this paper were compared with the results of the other authors in other study areas (Table 4). It was obvious that *S. colias* grow differently in the different geographical areas. Generally, the growth coefficient (K) is considered a genetic feature of a species, whilst L_∞ is phenotypic and can be limited by environmental conditions. Temperature is stated by many authors (Gunter, 1950; Bull, 1952; Taylor, 1959) to be the most limiting factor as a higher temperature stimulates a premature onset of sexual maturity and therefore slower growth and smaller maximum length. Also, Beverton & Holt (1959) considered that the changes in growth intensity are directly connected with fishing effort. As fishing effort increases, the abundance of a species decreaseas, which can lead to faster growth of the species. Nevertheless, there was a similarity between the results obtained in this study and those reported for *S. colias* populations in the Mediterranean (Kipparissis *et al*., 2000). This was expected since genetic and morphological data revealed the clear existence of Mediterranean and Southern Atlantic chub mackerel groups (Scoles *et al*., 1998; Roldan *et al*., 2000). Furthermore, similarity was also found in the parameter Φ' evaluation of errors in estimations of the fish growth parameters. Namely, Moreau *et al.* (1986) established that species within the same family are expected to have similar Φ' values. Hence, Φ' values from this investigation were almost the same as that obtained in Greece (Kiparissis *et al*., 2000).

Table 3. Results of previously reported length–weight relationship parameters (regression coefficient b, regression constant a) of *Scomber colias* in different areas of habitat together with results for chub mackerel in the eastern Adriatic Sea during the investigation period from January 2006 to December 2008.

Reference	Area	b	a
This paper	Adriatic Sea	3.224	0.0052
Magnusson & Magnusson, 1987	North Atlantic	2.880	0.0196
Van der Elst & Adkin, 1991	South Africa	3.311	0.0049
Do Chi, 1994	Senegal	3.362	0.0039
Goncalves *et al*., 1997	Portugal	3.227	0.0035
Stergiou & Moutopoulos, 2001	Greece	2.967	0.0130
Moutopoulos & Stergiou, 2002	Aegean Sea	3.704	0.0009
Santos *et al*., 2002	North-western Atlantic	3.408	0.0021
Mendes *et al*., 2004	Portuguese west coast	3.442	0.0020
Sinovčić *et al*., 2004	Adriatic Sea	3.140	0.0066
Rosa *et al*., 2006	Azores	3.284	0.0046

Table 4. Results of previously reported growth parameters (L_∞, the asymptotic length; K, the growth constant; t_o, the 'age' at which LT = 0; growth performance index phi-prime Φ') of *Scomber colias* in different areas of habitat together with results for chub mackerel in the eastern Adriatic Sea during the investigation period from January 2006 to December 2008.

Reference	Area	L_∞	K	Φ'	t_o
This paper	Adriatic Sea	45.31	0.180	2.57	−1.65
Tuggac, 1957	Marmora Sea	33.00	0.473	2.71	
Krivospitchenko, 1979	Morocco	44.10	0.326	2.80	−0.83
Camarena Luhrs, 1986	Senegal	51.70	0.217	2.76	−0.89
Kiparissis *et al*., 2000	Greece	47.60	0.154	2.54	−2.18
Carvalho *et al*., 2002	Azores	57.52	0.201	2.82	−1.09

The ideal situation for a population is when the fishing mortality is equal to the natural mortality, meaning that fishing activities exploit the part of the population which is lost anyway by natural mortality. With knowledge of these parameters, one can control the population stock and determine the right exploitation rate which permits the optimum catch whilst saving the reproductive proportion of the population. *Scomber colias* males during this investigation had an ideal ratio of M = F = 0.46. On the contrary, females as well as the overall material did not (M = 0.32, F = 0.71 and M = 0.35, F = 0.56, respectively). This may indicate that the females are more harvested than the males in this area, which could lead to a reduction in the number of females which could threaten the reproductive advantage of the population (Murua *et al*., 2003).

The natural mortality of 0.35 estimated in this study was not in agreement with the natural mortality of 0.19 found in the area of the Azores for the same species (Carvalho *et al*., 2002). Observed differences might be due to the fact that natural mortality varies with age, density, disease, parasites, food supply, predator abundance, water temperature, fishing pressure, sex and size (Vetter, 1988).

The limit reference point (LRP) for *S. colias* in this area of investigation was estimated to be 0.23, which indicated that only approximately 23% of the available stock of chub mackerel is harvested on an annual basis, and since this is lower than the threshold for pelagic fish species (0.4: Patterson, 1992), an increase in the fishing effort can be cautiously recommended for *S. colias* in this area.

The present data provide a necessary foundation for determining the growth and mortality of *S. colias* in the Adriatic Sea. However, this stock needs to be further investigated as *S. colias* is often caught as a by-catch of purse seiners targeting sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*). Since sardine and anchovy are the most commercially important fish species in the whole of the Mediterranean and Adriatic Seas, their exploitation could affect the chub mackerel population. So, management of these commercially important species should take into account its impact on the management of *S. colias*, which should be based on this species' population dynamics.

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