Int. J. Aquat. Biol. (2021) 9(5): 268-278
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com

Original Article

Age, Growth and Mortality of Atlantic chub mackerel, *Scomber colias* Gmelin, 1789 in the Mediterranean Waters of Morocco

Mohamed Techetach*[1], Hassnae Kouali[1], Hafid Achtak[1], Fatima Rafiq[1], Ahmed Lemhadri[1], Abdallah Dahbi[1], Rabia Ajana[2], Younes Saoud[2]

[1]Environment and Health Team, Department of Biology, Polydisciplinary Faculty of Safi, Cadi Ayyad University, Safi, Morocco.
[2]Applied Biology and Pathology Laboratory, Department of Biology, Faculty of Sciences, Abdelmalek Essaadi University, Tetouan, Morocco.

Abstract: This work is a study of growth aspects and mortality of the Atlantic chub mackerel, *Scomber colia,* from the Mediterranean Moroccan coast. A total of 845 specimens were collected from commercial catches in M'diq Bay, whose total length ranged between 16.4 and 35.9 cm. The length-weight relationship was $W = 0.0019\ TL^{3.4527}$ ($r = 0.97$) for the whole population. The Atlantic chub mackerel displays positive allometric growth. Otolith edge analysis indicated that opaque zones were formed between April and September and translucent ones during the remaining months of the year. The oldest individuals in the sample were 5 years old for both sexes. Von Bertalanffy growth parameters estimated for this species were: $L_\infty = 37.30$ cm, $k = 0.26$ year^{-1} and $t_0 = -2.19$ year. The difference in growth between sexes is not significant. The estimated natural mortality was 0.59 per year.

Article history:
Received 20 November 2020
Accepted 12 September 2021
Available online 25 October 2021

Keywords:
Age
Growth
Mortality
Southwestern Mediterranean Sea

Introduction

Small pelagic fishes (sardines, mackerel, horse mackerel and anchovies) represent the fishery potential of Morocco, contributing to nearly 80% of national production and ensuring domestic fish consumption and supply of processing units. The second most important species landed in Morocco in 2017 after the sardine was the Atlantic chub mackerel, *Scomber colias* Gmelin, 1789 (242 749 tons), which represent 17% of the whole catch of small pelagic. The catches from the Mediterranean waters were 2189 tones, contributing 1% to the overall Atlantic chub mackerel landings. The Moroccan fleet targeting small pelagic fish is composed by coastal purse seiners, which mainly target sardine and anchovy but also Atlantic chub mackerel depending on its availability (INRH, 2017). According to Zardoya et al. (2004), *S. colias* is considered to belong to one stock management policy in Mediterranean Sea. For assessment purposes, the GFCM (General Fisheries Commission for the Mediterranean) defined the Moroccan Mediterranean coast as southern Alboran Sea, geographical subarea 3 (FAO, 2018).

Scomber colias is a coastal pelagic species inhabiting warm and temperate waters of the Atlantic, Mediterranean and Black Sea (Collette and Nauen, 1983). Based on significant mitochondrial and nuclear DNA data and phenotypic characteristics, *S. colias* is a separate species from its Indo-Pacific congener, *S. japonicus* (Infante et al., 2007). Besides their fishery's worldwide importance, the Atlantic chub mackerel occupies an intermediate position in food web and plays an important role in connecting the lower and upper trophic levels (Cury et al., 2000).

Growth is one of the most important life history processes influencing the dynamics of a fish population. Hence, reliable estimation of growth is critical to the development of sustainable fisheries (King, 1995). In spite of the economic and ecological interest, biological information about the Atlantic chub mackerel and its fishery in Moroccan Mediterranean coast are still lacking, and there are no published studies on age structure and growth, except a recent study about its reproduction (Techetach et al.,

*Correspondence: Mohamed Techetach
E-mail: mtechetach@gmail.com
DOI: https://doi.org/10.22034/ijab.v9i5.1033

2019). By contrast, in other areas of the Mediterranean Sea, several aspects of the biology of this species has been discussed, such as length-weight relationship and mortality (Petrakis and Stergiou, 1995; Moutopoulos and Stergiou, 2002; Sinovčić et al., 2004; Karakulak et al., 2006; Özaydın and Taşkavak, 2006; Bayhan, 2007; İşmen et al., 2007; Cengiz, 2012; Allaya et al., 2013; Cikes-Kec and Zorica, 2013), age and growth (Rizkalla, 1998; Hattour, 2000; Kiparissis et al., 2000; Perrotta et al., 2005; Velasco et al., 2011), reproduction (Cikes-Kec and Zorica, 2012) and feeding habits (Hattour, 2000; Bayhan et al., 2007).

Age determination based on otoliths has been the most used method for the Atlantic chub mackerel in different areas (Castro and Santana, 2000). Otoliths grow continuously throughout ontogeny and they are not metabolically active providing an ideal structure to infer growth (Campana, 2001). In addition to the age estimation, otoliths are also used in taxonomical and biological archives of species in stock discrimination analyses, and study of the diet from partially digested stomach contents (Cottrell et al., 1996). Accurate ages are mandatory to define life-history traits applicable to management, including rates of growth and age-at-maturity (Beamish and Mcfarlane, 1983). Therefore, the knowledge about age structure and growth are fundamental to achieve certain stock assessments. Based on above mentioned background, the objectives of this study were to provide length-weight relationship, growth parameterization, validation of age interpretation and natural mortality of *S. colias* in the SW Mediterranean Sea for fisheries management purposes.

Materials and Methods

Samples of Atlantic chub mackerel were collected in M'diq region (35ºN, 5ºW) from purse seine commercial catches (Fig. 1). A total of 845 *S. colias* were monthly analyzed between January and December 2004; 54% (453) were females and 46% (392) males. In the laboratory, for each fish, total length (TL, to the nearest 1 mm) and total body weight (W, 0.1 g) were measured. Sex was determined by visual examination of the gonads. The sagitta otoliths

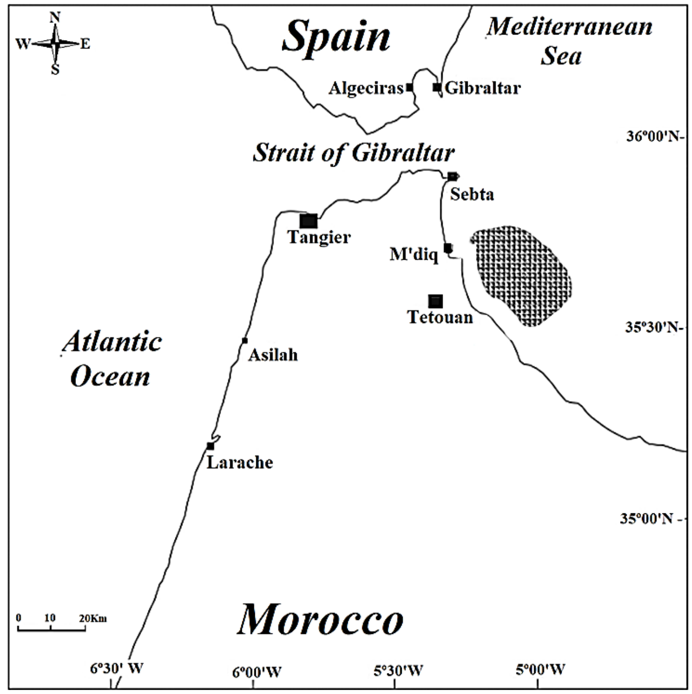

Figure 1. Location of study area in M'diq Bay (Moroccan Mediterranean coast) showing the fishing ground.

were removed, cleaned, weighted (OW, 0.1 mg) and stored dry (Table 1).

Length-weight relationships were calculated by applying the equation of W = $a\text{TL}^b$, where W is the body weight (g), TL is the total length (cm), *a* is a scaling coefficient and *b* is the allometry coefficient which usually ranges from 2.5 to 4 (Ricker, 1973). Student's t-test was used to ascertain whether the coefficient *b* was significantly different from 3, using the following formula (Morey et al., 2003): $t_s = (b - 3)\cdot t_s = (b - 3)S_b^{-1}$, where t_s is student's t-test, *b* is slope and S_b is standard error of the slope. The association degree between variables was calculated by the correlation coefficient (*r*). Analysis of variance (ANOVA) was used to check the significance of relationships and to compare the regression lines between sexes.

For age determination, whole otoliths were mounted on a black background, covered with water and examined with binocular microscope under reflected light. Each otolith was read twice at different times to limit subjective interpretations. Unreadable otoliths were excluded from the study (n = 226). The age determination criteria were (ICES, 2016): (1) the

Table 1. Statistic data from the sample of Atlantic chub mackerel collected in this study (TL = total length; W = total body weight; OW = otolith weight; SD = standard deviation; NOW = number of otoliths weighted).

Month	Number of specimens			TL range	Mean TL	Mean W (g)	NOW	Mean OW
	Males	Females	Total	(cm)	(cm) ± SD	± SD		(mg) ± SD
January	57	36	93	17.3-30.0	23.2±2.5	105.6±47.0	35	6.3±1.4
February	35	31	66	16.6-29.8	21.3±3.2	80.4±45.6	22	5.0±1.1
March	27	31	58	16.4-28.4	24.1±3.0	117.1±40.2	32	6.2±1.0
April	12	21	33	21.5-26.7	23.9±1.3	99.1±18.2	3	5.5±0.4
May	22	38	60	21.0-29.8	24.6±2.2	122.9±44.6	7	8.3±0.8
June	22	30	52	19.8-35.8	23.6±2.9	102.3±65.8	3	9.4±2.2
July	41	51	92	20.6-35.6	24.8±3.5	137.1±77.4	16	9.4±1.0
August	43	50	93	19.1-31.1	23.3±2.6	109.6±45.6	7	9.6±1.0
September	24	48	72	21.1-35.9	26.5±4.6	186.5±118.2	3	7.4±0.4
October	46	48	94	19.1-33.1	24.5±3.4	136.2±67.2	18	9.4±1.5
November	22	29	51	18.1-31.4	24.2±3.2	125.0±55.0	1	10.6
December	41	40	81	18.6-28.3	24.0±1.7	126.7±32.4	-	-

date of birth was considered to be 1 January according to the reproduction season (winter) (Lorenzo, 1992), (2) a translucent and an opaque ring were deposited on the otolith every year (Castro and Santana, 2000; Perrotta et al., 2005), and (3) the age of the fish depends on the month of capture: in otoliths taken from fish caught in the first half of the year, their age corresponds to the number of complete translucent bands, but for fish caught during the second half of the year, their age group corresponds to the number of translucent bands surrounded by opaque band (Lorenzo, 1992). To validate the annual periodicity of band formation, monthly changes in proportions of opaque and translucent rings in the otolith edge were examined. In addition, to assess that otoliths continue to grow throughout the lives of the fish, weights of 147 otoliths were regressed on age and size of fish, given that a strong positive relationship suggests that the otoliths continue to grow at a measurable rate through the lifespan of the fish (Fowler and Doherty, 1992).

To describe the growth of the Atlantic chub mackerel, the observed mean length-at-age data were fitted to the von Bertalanffy growth equation: $L_t = L_\infty[1 - e^{-k(t-t0)}]$, where L_t is the total length (cm) at age t, L_∞ is the asymptotic total length (cm), k is the growth coefficient (year^{-1}), and t_0 (year) is the hypothetical age at which $L_t = 0$. Analysis of variance was applied to compare male and female mean lengths at age. To compare the growth parameters obtained with other studies, the growth performance index (Φ') was calculated using the following formula (Pauly and Munro, 1984): $\Phi' = \log_{10} k + 2 \log_{10} L_\infty$.

The condition factor (*Kn*) was used for comparing the condition or well-being of fish and could be used as an indicator of seasonal energy investment, related to changes between somatic growth and reproductive processes. The *Kn* was calculated using formula (Fulton, 1904) of $Kn = W (g) TL^{-3} (cm) 100$.

Natural mortality (M) was calculated by applying the Pauly (1980) formula as $\log_{10}M = -0.0066 - 0.279 \times \log_{10}L_\infty + 0.6543 \times \log_{10}k + 0.4634 \times \log_{10}T$, where L_∞ and k are the parameters of the von Bertalanffy growth equation and T is the mean annual sea water temperature, which was 19.8°C in M'diq Bay (https://www.seatemperature.org/africa/morocco/). Averaged temperature was obtained for the area and the study time period. Additionally, based on the results published in Techetach et al. (2019), the age at first maturity (A_{50}) was estimated using von Bertalanffy growth equation. All the statistical analyses were conducted in Statistica software v.6.0.

Results

Size composition: The length of fish ranged between 16.4 and 35.9 cm TL (mean length = 24.07, standard deviation (SD) = 3.25). Males ranged 16.6-35.9 cm (23.97±3.26) and females varied from 16.4 to 35.8 cm (24.15±3.25). Most of the fish sampled ranged 20-27 cm, representing 79.27% of the whole capture, and the modal was 22-23 cm (Fig. 2). The ANOVA showed

Table 2. Parameters of length–weight relationship for Atlantic chub mackerel (*N* = number of fish; *a* = scaling coefficient; *b* = allometry coefficient; *r* = correlation coefficient; t_s = t-test).

Sex	*N*	*a*	*b*	*r*	t_s	Significance	Allometry
Males	392	0.0017	3.48	0.98	14.10	$P<0.05$	Positive
Females	453	0.0020	3.42	0.97	11.33	$P<0.05$	Positive
All fish	845	0.0019	3.45	0.97	17.54	$P<0.05$	Positive

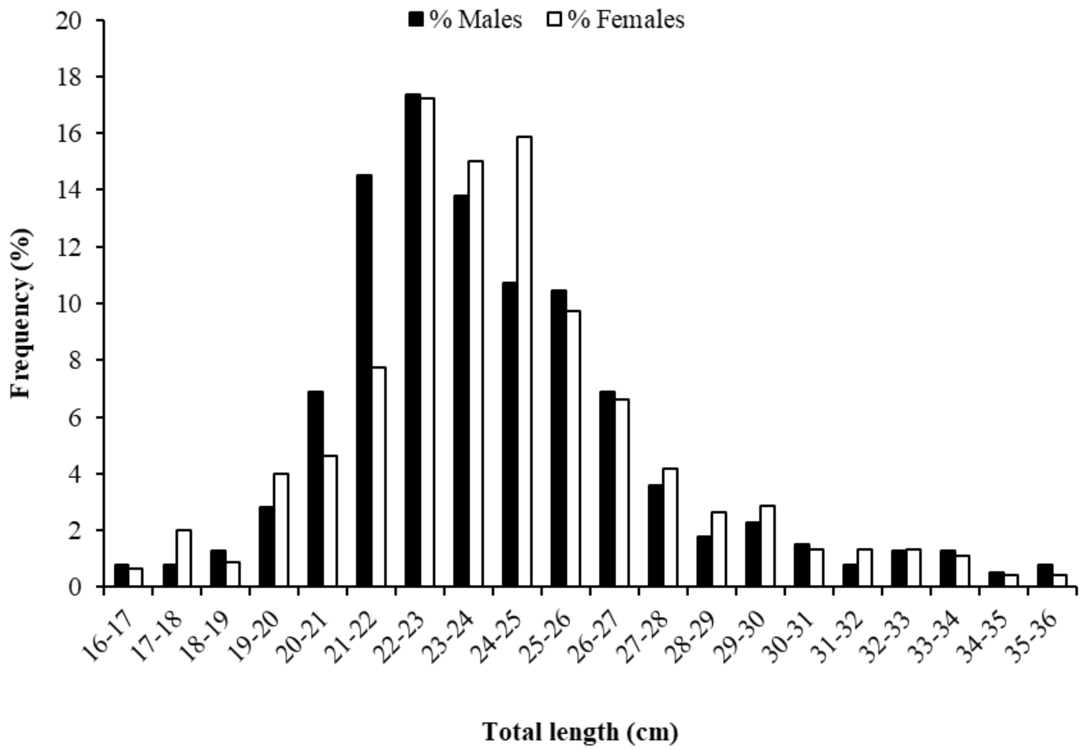

Figure 2. Size frequency distributions by sex for Atlantic chub mackerel caught in M'diq Bay.

that difference between mean TL by sex not significant ($F = 0.69$, $P>0.05$).

Length-weight relationship: The relationship between length and weight was highly significant for all fish combined and per sex ($P<0.001$). In addition, high value of the correlation coefficient ($r>0.97$) indicated that variables were strongly correlated. The *b*-values showed significance difference from isometric growth for both sexes and all fishes (Table 2). Therefore, the Atlantic chub mackerel displays positive allometric growth ($b>3$). The slopes of the length-weight regressions lines were not significantly different between sexes ($F = 1.6$; $P = 0.2$).

Age validation: Otolith analysis showed two types of edges (opaque and translucent). Monthly changes in the frequency of opaque and translucent bands on the otolith edge seemed to show a seasonal variation in the formation of these bands during the study period (Fig. 3). Opaque edges were more frequent in spring and summer months (April-September), while translucent edges dominated during autumn and winter (October-March), thus confirming the expected annual pattern of deposition of two rings: one opaque and one translucent.

The weights of 147 otoliths varied from 3.4 to 12.8 mg, with a mean value of 7.19±2.06 mg. A positive linear relationship was observed between otolith weight and age ($r = 0.88$) (Fig. 4). A high linear correlation was also obtained between the total length of the fish and the otolith weight ($r = 0.88$) (Fig. 5).

Condition factor: The *Kn* ranged from 0.51 to 1.1 for males and from 0.46 to 1.072 for females. A similar monthly trend was observed for male and female fish (Fig. 6). The highest values were recorded in

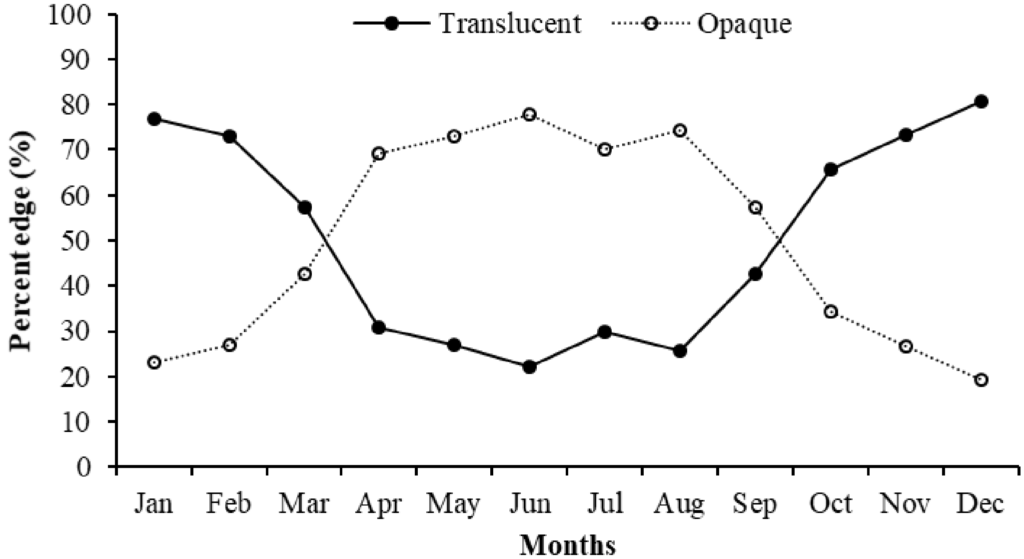

Figure 3. Monthly changes in the occurrence frequency of edge type in otoliths of Atlantic chub mackerel.

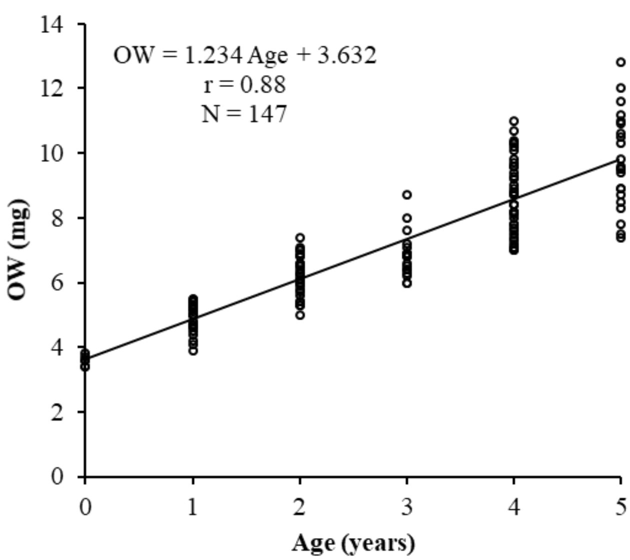

Figure 4. Relationship between age and otolith weight (OW) for Atlantic chub mackerel in M'diq Bay (N = number of fish; r = correlation coefficient.

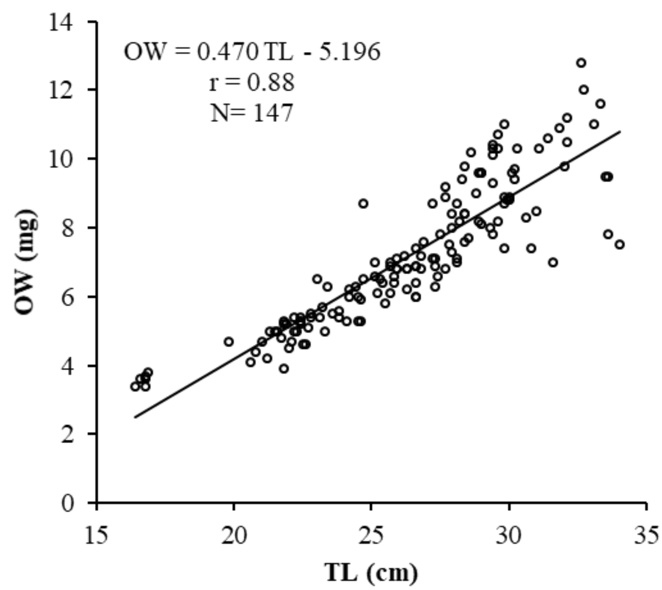

Figure 5. Relationship between total length (TL) and otolith weight (OW) for Atlantic chub mackerel in M'diq Bay (N = number of fish; r = correlation coefficient).

September and December, while the lowest ones were occurred in April and June.

Age and growth: The estimated ages of *S. colias* varied from 0 to 5 years both for males and females. Age class 1 (37.16%) was dominant, followed by 2 (32.47%) and 3 (12.92%). Juvenile specimens (age class 0) were poorly represented in the sample. The age-length key per sex including totals is shown in Table 3. The von Bertalanffy growth curve fitted well to the mean length at age data of Atlantic chub mackerel (Table 4). The growth performance index (Φ') was calculated as 2.56 for males, females and all samples. No significant differences were found in the mean length at age between males and females (P>0.05). There were no differences in the growth between both sexes, thus data can be pooled (Fig. 7). The estimated natural mortality was 0.59 per year.

Age at first maturity: In M'diq Bay, the size at first maturity has been estimated at 19.19 cm (Techetach et al., 2019), which corresponds to an age at first

Table 3. Age-length key per sex and total of *Scomber colias* from M'diq Bay (N = number of fish; TL = total length; Min = minimum; Max = maximum; SD = standard deviation).

Length class (cm)	Age (year)					
	0	1	2	3	4	5
16-17	6					
17-18						
18-19						
19-20		1				
20-21		8				
21-22		43	1			
22-23		110	8			
23-24		61	46			
24-25		7	84	8		
25-26			45	17		
26-27			17	38	1	
27-28				16	16	
28-29				1	17	
29-30					20	2
30-31					6	6
31-32					3	6
32-33					3	8
33-34						10
34-35						4
N	6	230	201	80	66	36
Mean TL	16.68	22.51	24.51	26.32	28.93	32.16
Min. TL	16.40	19.60	21.70	24.30	26.80	29.80
Max. TL	16.90	24.40	26.90	28.10	32.40	34.50
SD TL	0.18	0.82	0.99	0.85	1.34	1.41
%	0.97	37.16	32.47	12.92	10.66	5.82

Table 4. Parameters of the von Bertalanffy growth equation for *Scomber colias* (L_∞ = asymptotic total length; k = growth coefficient; t_0 = hypothetical age at which size fish is zero; r = correlation coefficient).

Sex	L_∞ (cm)	k (year^{-1})	t_0 (year)	r
Males	36.65	0.27	- 2.15	0.94
Females	38.10	0.25	- 2.19	0.94
All fish	37.30	0.26	- 2.19	0.94

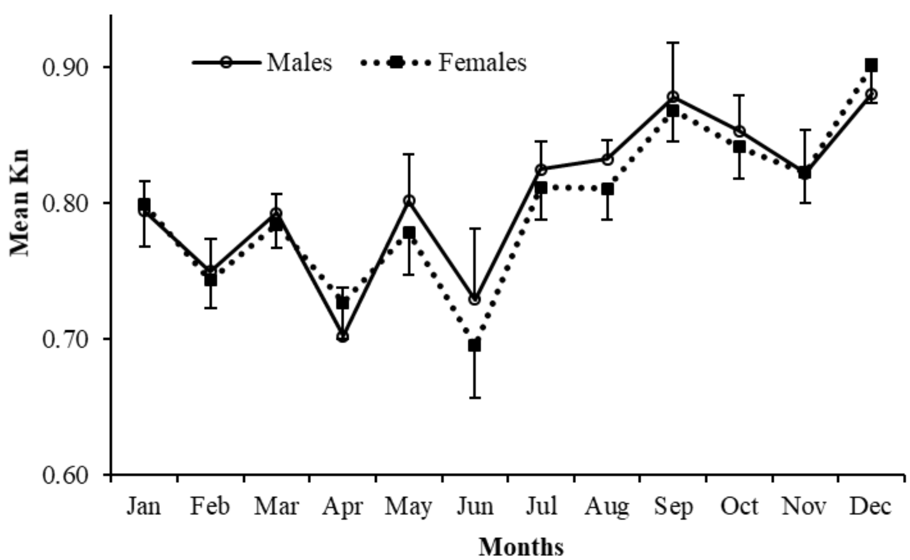

Figure 6. Relationship between total length (TL) and otolith weight (OW) for Atlantic chub mackerel in M'diq Bay (N = number of fish; r = correlation coefficient).

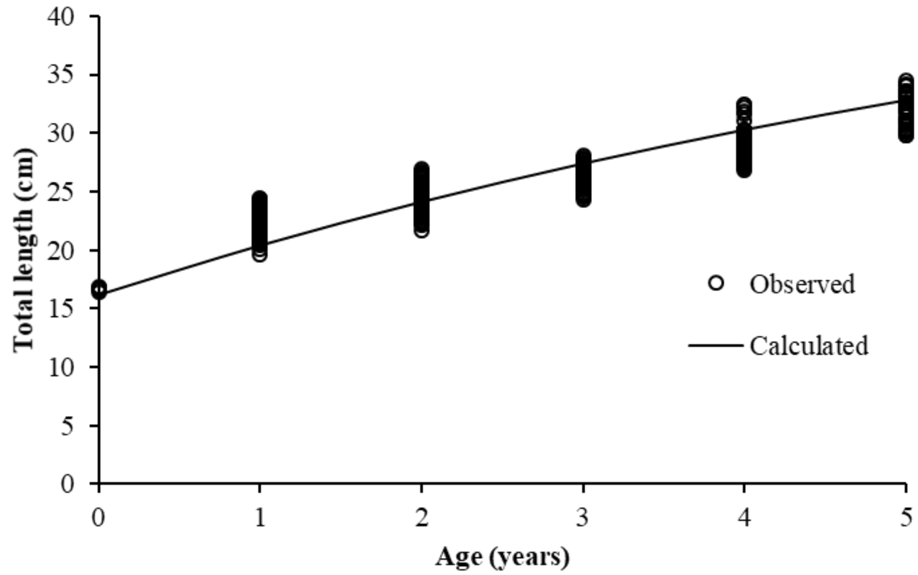

Figure 7. The von Bertalanffy growth curve for the whole sample of Atlantic chub mackerel.

maturity (A_{50}) of 0.61 year, based on the present study.

Discussions

Positive allometric growth of *S. colias* observed in this study is in agreement with results reported in other studies in Mediterranean Sea (Kiparissis et al., 2000 in the Hellenic Seas; Moutopoulos and Stergiou, 2002 in the Aegean Sea; Bayhan, 2007 in Izmir Bay; Velasco et al., 2011 in Alboran Sea; Cengiz, 2012 in Saros Bay). However, isometric growth was obtained by Allaya et al. (2013) in Tunisian coasts, Cikes-Kec and Zorica (2013) in Adriatic Sea, and Özaydın and Taşkavak (2006) in Izmir Bay. There is no significant difference in length-weight relationship parameters between sexes, which indicated a similar relative weight growth between males and females. This result is in concordance with those revealed in the Gulf of Cadiz and the Alboran Sea (Velasco et al., 2011), Madeira Island (Vasconcelos et al., 2011), and Canary Islands (Lorenzo and Pajuelo, 1996). Variation in parameters of length-weight relationship for Atlantic chub mackerel might be related to sampling area, sampling strategy, fish feeding, sexual maturity, sex, size-range and health (Tesch, 1971; Ricker, 1975).

Age validation is critical process to accurately determine age. Monthly evolution of the nature of the otolith edges presented a clear annual pattern of the annuli deposition with opaque and hyaline rings being laid down during warm and cold months, respectively. It matches with the results of Velasco et al. (2011) in the same area. The same pattern has been also obtained in other areas (Lorenzo, 1992; Kiparissis et al., 2000). The formation of an opaque zone, which corresponds to rapid growth, was related to food resource abundance, increase of temperature, and best condition. In contrast, translucent zone formation coincides with the spawning period in this area (Lorenzo and Pajuelo, 1996). Indeed, the otolith growth depends on local environmental factors, which influence the otolith deposition pattern (Campana and Neilson, 1985).

The Atlantic chub mackerel gets the energy required for gonad growth from food that explained the maximum values of *Kn* recorded in summer-autumn, whereas, the stored energy is devoted to somatic growth. Accordingly, the feeding activity of *S. colias* does not change during the reproductive period. The phase of slimming will take place after the spawning, due to the release of genital products (Kartas, 1981; Aristizabal, 2007). Similar results have been found in sardines, which do not stop feeding during the spawning period (Somarakis et al., 2004). Species that allocate ingested food directly to reproduction seem to be income breeder (Stephens et al., 2009; McBride et al., 2015). In addition, the condition of a species is the consequence of the

Table 5. Comparison of growth parameters from different regions for Atlantic chub mackerel (L_∞=asymptotic total length; *k*=growth coefficient; *t0*=hypothetical age at which size fish is zero; *Φ'*=growth performance index).

Area	L_∞	*k*	*t0*	*Φ'*	Reference
M'diq Bay	37.30	0.26	-2.19	2.56	This study
Alboran Sea	40	0.37	-0.10	2.77	Velasco et al. (2011)
Adriatica Sea	45.31	0.18	-1.65	2.57	Cikes-Kec and Zorica (2013)
Hellenic Seas	47.60	0.15	-2.18	2.53	Kiparissis et al. (2000)
Saros Bay (Turkey)	39	0.20	-2.13	2.48	Cengiz (2012)
Egypt	39.42	0.31	-1.39	2.68	Rizkalla (1998)
Gulf of Cadiz	43	0.27	-1.10	2.69	Velasco et al. (2011)
Canary Islands	49.20	0.21	-1.40	2.71	Lorenzo et al. (1995)
Madeira Island	50.08	0.25	-1.33	2.80	Vasconcelos et al. (2011)
Azores	57.52	0.20	-1.09	2.82	Carvalho et al. (2002)
Mauritania	48.40	0 .24	-1.51	2.76	Jurado-Ruzafa et al. (2017)

interaction of biotic and abiotic factors (Vazzoler, 1981).

The present study is the first work on age and growth pattern of Atlantic chub mackerel, *S. colias* in the west Mediterranean coast of Morocco. The age of Atlantic chub mackerel can be estimated from whole otoliths. This is supported by all results presented in this study, especially the positive relationship between otolith weight and length and age of fish, thus, suggesting the increase of otolith weight throughout the lifespan of fish. The otolith weight would be an accurate indicator of somatic growth, since it is sensitive to variations in growth rate and closely related to changes in fish metabolism (Pawson, 1990; Fletcher, 1995; Zorica et al., 2010).

As commented, the maximum age observed in the present study was 5 years. This longevity is similar to that obtained by Kiparissis et al. (2000), and slightly lower than the 6 years recorded in Alboran Sea (Velasco et al., 2011). However, Cikes-Kec and Zorica (2013) reported the maximum age as 9 years in the Adriatic Sea. Growth of Atlantic chub mackerel is rapid during the first year of their life reaching the 60.35% of its maximum length, which seems to be closer to the value reported by Velasco et al. (2011; 59%). The similar growth patterns between sexes noted in this study was in accordance with the results of Vasconcelos et al. (2011) and Velasco et al. (2011).

Growth parameters (L_∞, k and t_0) and growth performance index (*Φ*') from the present study and previously published studies are shown in Table 5. Our estimate of the growth parameters (k, L_∞) was in agreement with previous studies. The growth performance indices ranged from 2.48 to 2.82 for chub mackerel in their area of distribution. The lowest one corresponds to Saros Bay and the highest in Azorean waters. The obtained performance index was similar to the values in Adriatic Sea (Cikes-Kec and Zorica, 2013) and in Hellenic Seas (Kiparissis et al., 2000) although different from all the other studies (Table 5). The geographic differences in growth parameters could be due to variations in environmental conditions such as water temperature, food quality and availability might lead to different results for growth parameters (Weatherley, 1976; Perrotta et al., 2005).

The natural mortality in this study was similar to that found by Jurado-Ruzafa et al. (2017, M = 0.57 year^{-1}) but different to those of Cengiz (2012, M = 0.34 year^{-1}) and Cikes-Kec and Zorica (2013, M = 0.35 year^{-1}). Disparity of mortality rates between different localities could be explained by ecological conditions and fishing pressures (Vetter, 1988), as well as on the growth estimation method, the sample size, the sampling strategy and the ageing methodology.

The first maturity of the Atlantic chub mackerel obtained in this work is early (0.61 year) compared to previous studies in other areas. In fact, this species achieved maturity at 27 cm and 3 years in Portuguese coast (Martins, 1996). In the Azores, Carvalho et al. (2002) estimated size at maturity at 27.78 cm and 2.23 years. The trend of reduction in age and size at first maturity could be explained by the result of genetic changes as an effect of intense and prolonged exploitation and also the effect of global climate change (Jennings et al., 2001).

The information gathered in this study contributes to the life history traits of Atlantic chub mackerel *S. colias* in M'diq, Moroccan Mediterranean coast. Information on age, growth parameters and mortality rate are fundamental to improve the assessment and management of this important resource.

References

Allaya H., Hattour A., Hajjej G., Trabelsi M. (2013). Biologic characteristics of *Scomber japonicus* (Houttuyn, 1782) in Tunisian waters (Central Mediterranean Sea). Africain Journal of Biotechnology, 12(20): 3040-3048.

Aristizabal E.O. (2007). Energy investment in the annual reproduction cycle of female red porgy, *Pagrus pagrus* (L.). Marine Biology, 152(3): 713-724.

Bayhan B. (2007). Growth characteristics of the chub mackerel (*Scomber japonicus* Houttuyn, 1782) in Izmir Bay (Aegean Sea, Turkiye). Journal of Animal and Veterinary Advances, 6(5): 627-634.

Bayhan B., Sever T.M., Kaya M. (2007). Diet composition of the chub mackerel, *Scomber japonicus* (Pisces: Scombridae), in Candarli Bay (Aegean Sea, Turkey). Rapport Commission International pour l'exploration scientifique de la Mer Méditerranée, 38: 427.

Beamish R.J., McFarlane G.A. (1983). The forgotten requirement for age validation in fisheries biology. Transactions of the American Fisheries Society, 112(6): 735-743.

Campana S.E., Neilson J.D. (1985). Microstructure of fish otoliths. Canadian Journal of Fisheries and Aquatic Science, 42(5): 1014-1032.

Campana S.E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology, 59(2): 197-242.

Carvalho N., Perrotta R.G., Isidro E. (2002). Age, growth and maturity in chub mackerel (*Scomber japonicus* Houttuyn, 1782) from the Azores. Arquipelago. Life and Marine Sciences, 19: 93-99.

Castro J.J., Santana A.T. (2000). Synopsis of biological data on the chub mackerel (*Scomber japonicus* Houttuyn, 1782). FAO Fisheries Synopsis No. 157. FAO, Rome. 77 p.

Cengiz Ö. (2012). Age, growth, mortality and reproduction of the chub mackerel (*Scomber japonicus* Houttuyn, 1782) from Saros Bay (Northern Aegean Sea, Turkey). Turkish Journal of Fisheries and Aquatic Sciences, 12(4): 799-809.

Cikes-Kec V., Zorica B. (2012). The reproductive traits of *Scomber japonicus* (Houttuyn, 1782) in the Eastern Adriatic Sea. Journal of Applied Ichthyology, 28(1): 15-21.

Cikes-Kec V., Zorica B. (2013). Length-weight relationship, age, growth and mortality of Atlantic chub mackerel *Scomber colias* in the Adriatic Sea. Journal of the Marine Biological Association of the United Kingdom, 93(2): 341-349.

Collette B.B., Nauen C.E. (1983). FAO Species Catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fisheries Synopsis No. 125. FAO, Rome. 130 p.

Cottrell P.E., Miller E.H., Trites A.W. (1996). Assessing the use of hard parts in faeces to identify harbour seal prey: results of captive-feeding trials. Canadian Journal of Zoology, 74(5): 875-880.

Cury P., Bakun A., Crawford R.J.M., Jarre A., Quinones R.A., Shannon L.J.H., Verheye M. (2000). Small pelagic in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. ICES Journal of Marine Science, 57(3): 603-618.

FAO. (2018). The State of Mediterranean and Black Sea Fisheries. General Fisheries Commission for the Mediterranean. Rome. 172 p.

Fletcher W.J. (1995). Application of the otolith weight-age relationship for the pilchard, *Sardinops sagax neopilchardus*. Canadian Journal of Fisheries and Aquatic Science, 52(4): 657-664.

Fowler A., Doherty P. (1992). Validation of annual growth increments in the Otoliths of two species of Damselfish from the Southern Great Barrier Reef. Marine and Freshwater Research, 43(5): 1057-1068.

Fulton T.W. (1904). The rate of growth of fishes. Twenty-second Annual Report of the Fisheries Board for Scotland, 3: 141-241.

Hattour A. (2000). Contribution à l'étude des poissons pélagiques des eaux tunisiennes. Ph.D. Thesis, University of Tunis II. 344 p.

ICES. (2016). Report of the workshop on age reading of chub mackerel (*Scomber colias*) (WKARCM), 2–6 November 2015, Lisbon, Portugal. ICES CM 2015\SSGEIOM:11. 81 p.

Infante C., Blanco E., Zuasti E., Crespo A., Manchado M.

(2007). Phylogenetic differentiation between Atlantic *Scomber colias* and Pacific *Scomber japonicus* based on nuclear DNA sequences. Genetica, 130(1): 1-8.

INRH. (2017). Rapport annuel de l'état des stocks et des pêcheries marocaines. Casablanca: Institut National de Recherche Halieutique, DP. 287 p.

İşmen A., Özen Ö., Altınağaç U., Özekinci U., Ayaz A. (2007). Weight-length relationships of 63 fish species in Saros Bay, Turkey. Journal of Applied Ichthyology, 23(6): 707-708.

Jurado-Ruzafa A., Hernández E., Santamaría T.G. (2017). Age, growth and natural mortality of Atlantic chub mackerel *Scomber colias* Gmelin 1789 (Perciformes: Scombridae), from Mauritania (NW Africa). Vieraea, 45: 53-64.

Karakulak F.S., Erk H., Bilgin B. (2006). Length-weight relationships for 47 coastal fish species from the northern Aegean Sea, Turkey. Journal of Applied Ichthyology, 22(4): 274-278.

Kartas F. (1981). Les Clupéidés de Tunisie. Caractéristiques biométriques et biologiques, étude comparée des populations de l'Atlantique et de la Méditerranée. Ph.D. Thesis, Faculty of Sciences of Tunis. 608 p.

Jennings S., Kaiser M.J., Reynolds J.D. (2001). Marine fisheries ecology. Blackwell Science, London. 417 p.

King M. (1995). Fisheries biology, assessment and management. Blackwell Science, Oxford, UK. 341 p.

Kiparissis S., Tserpes G., Tsimenidis N. (2000). Aspects on the demography of Chub Mackerel (*Scomber japonicus* Houltuyn, 1782) in the Hellenic Seas. Belgian Journal of Zoology, 130(1): 3-7.

Lorenzo J.M. (1992). Crecimiento de la caballa *Scomber japonicus* Houttuyn, 1782 en aguas del Archipiélago Canario. Ph.D. Thesis, University of La Laguna. 199 p.

Lorenzo J.M., Pajuelo G.J., Ramos A.G. (1995). Growth of the chub mackerel *Scomber japonicus* (Pisces: Scombridae) off the Canary Islands. Scientia Marina, 59: 287-291.

Lorenzo J.M., Pajuelo J.G. (1996). Growth and reproductive biology of chub mackerel *Scomber japonicus* off the Canary Islands. South African Journal of Marine Science, 17(1): 275-280.

Martins M.M. (1996). New biological data on growth and maturity of Spanish mackerel (*Scomber japonicus*) off the Portuguese coast (ICES Division IXa). ICES C.M. 1996/H: 23. 17 p.

McBride R.S., Somarakis S., Fitzhugh G.R., Albert A., Yaragina N.A., Wuenschel M.J., Alonso-Fernández A., Basilone G. (2015). Energy acquisition and allocation to egg production in relation to fish reproductive strategies. Fish and Fisheries, 16(1): 23-57.

Morey G., Moranta J., Massuti E., Grau A., Linde M., Riera F., Morales-Nin B. (2003). Weight-length relationships of littoral to lower slope fishes from the western Mediterranean. Fisheries Research, 62(1): 89-96.

Moutopoulos D.K., Stergiou K.I. (2002). Length-weight and length-length relationships of fish species from the Aegean Sea (Greece). Journal of Applied Ichthyology, 18(3): 200-203.

Özaydın O., Taşkavak E. (2006). Length-weight relationships for 47 fish species from Izmir Bay (eastern Aegean Sea, Turkey). Acta Adriatica, 47(2): 211-216.

Pauly D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. ICES Journal of Marine Science, 39(2): 175-192.

Pauly D., Munro J.L. (1984). Once more on the comparison of growth in fish and invertebrates. Fishbyte, 2(1): 1-21.

Pawson M.G. (1990). Using otolith weight to age fish. Journal of Fish Biology, 36(4): 521-531.

Perrotta G.R., Carvalho N., Isidro E. (2005). Comparative study on growth of chub mackerel (*Scomber japonicus* Houttuyn, 1782) from three different regions: NW Mediterranean, NE and SW Atlantic. Revista de Investigación y Desarrollo Pesquero, 17: 67-79.

Petrakis G., Stergiou K.I. (1995). Weight-length relationships for 33 fish species in Greek waters. Fisheries Research, 21: 465-469.

Ricker W.E. (1973). Linear regressions in fishery research. Journal of the Fisheries Research Board of Canada, 30(3): 409-434.

Ricker W.E. (1975). Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, 191: 1-382.

Rizkalla S.I. (1998). Some biological characters of chub mackerel (*Scomber japonicus*, Houttuyn, 1782) from the Mediterranean waters of Egypt. Egyptian Journal of Aquatic Biology and Fisheries, 2(2): 101-116.

Sinovčić G., Franičević M., Zorica B., Cikeš-Keč V. (2004). Length-weight and length-length relationships for 10 pelagic fish species from the Adriatic Sea (Croatia). Journal of Applied Ichthyology, 20(2): 156-158.

Somarakis S., Ganias K., Tserpes G., Koutsikopoulos C. (2004). Ovarian allometry and the use of the gonosomatic index: a case study in the Mediterranean sardine, *Sardina pilchardus*. Marine Biology, 146(1): 181-189.

Stephens P.A., Boyd I.L., McNamara J.M., Houston A.I. (2009). Capital breeding and income breeding: their meaning, measurement, and worth. Ecology, 90(8): 2057-2067.

Techetach M., Ajana R., Saoud Y. (2019). Reproductive parameters of Atlantic chub mackerel *Scomber colias* in M'diq Bay, Morocco. Journal of the Marine Biological Association of the United Kingdom, 99(4): 957-962.

Tesch F.W. (1971). Age and growth. In: W.E. Ricker (Ed.). Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford. pp: 99-130.

Vasconcelos J., Dias M.A., Faria G. (2011). Age and growth of the Atlantic chub mackerel *Scomber colias* Gmelin, 1789 off Madeira Island. Arquipelago. Life and Marine Sciences, 28: 57-70.

Vazzoler A.E.A. de M. (1981). Manual de métodos para estudos biológicos de populações de peixes: reprodução e crescimento. Brasília, CNPQ. 106 p.

Velasco E.M., Del Árbol J., Baro J., Sobrino I. (2011). Age and growth of the Spanish chub mackerel *Scomber colias* off southern Spain: a comparison between samples from the NE Atlantic and the SW Mediterranean. Revista de Biologia Marina y Oceanografia, 46(1): 27-34.

Vetter E.F. (1988). Estimation of natural mortality in fish stocks: a review. Fishery Bulletin, 86(1): 25-43.

Weatherley A.H. (1976). Factors affecting maximization of fish growth. Journal of the Fisheries Research Board of Canada, 33(4): 1046-1058.

Zardoya R., Castilho R., Grande C., Favre-Krey L., Caetano S., Marcato S., Krey G., Patarnello, T. (2004). Differential population structuring of two closely related fish species, the mackerel (*Scomber scombrus*) and the chub mackerel (*Scomber japonicus*), in the Mediterranean Sea. Molecular Ecology, 13(7): 1785-1798.

Zorica B., Sinovcic G., Cikes-Kec V. (2010). Preliminary data on the study of otolith morphology of five pelagic fish species from the Adriatic Sea (Croatia). Acta Adriatica, 51(1): 89-96.