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Age and growth of albacore (*Thunnus alalunga* Bonnaterre, 1788) from the eastern Mediterranean

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Abstract: This study was designed to characterize the growth parameters of the albacore, *Thunnus alalunga*, in the eastern Mediterranean. A total of 819 albacore specimens were collected from gillnet boats operating in Antalya Bay (in the Levantine Sea) between May and July from 2006 to 2008. Individuals were all between 55 and 101 cm in fork length (FL). The fork length was directly proportional to weight, with a relationship of $W = 0.00042FL^{2.246}$ for females, $W = 0.00022FL^{2.396}$ for males, and $W = 0.00016FL^{2.467}$ for males and females combined. Negatively allometric growth was observed in all individuals. Age and growth were estimated by assessing seasonal bands formed on the first dorsal spines of 744 specimens. Albacore samples were estimated to be between 1 and 9 years old. Von Bertalanffy growth parameters were estimated for all individuals and for males and females independently. There were significant differences between growth patterns in males and females. The von Bertalanffy growth parameters for both sexes and all years combined were $L_\infty = 93.198$ cm, $W_\infty = 11.552$, $k = 0.295$ year^{-1} and $t_o = -1.213$ years.

Key words: Albacore, *Thunnus alalunga*, age, growth, spine, eastern Mediterranean Sea

Doğu Akdeniz'de uzun kanat orkinos balığı'nın (*Thunnus alalunga* Bonnaterre, 1788) yaş ve büyümesi

Özet: Bu çalışmada, Doğu Akdeniz'de uzun kanat orkinos balığının, *Thunnus alalunga*, büyüme parametrelerinin belirlenmesi amaçlanmıştır. 2006-2008 yıllarında Antalya Körfezi'nde (Levantin Denizi) uzatma ağlarıyla yapılan avcılıkta, her yılın Mayıs, Haziran ve Temmuz aylarında, toplam 819 uzun kanat orkinos örneği toplanılmıştır. Bireylerin çatal boyları (FL) 55 ve 101 cm arasında değişmektedir. Çatal boy-toplam ağırlık arasındaki ilişki dişiler için $W = 0.00042FL^{2.246}$, erkekler için $W = 0.00022FL^{2.396}$ ve tüm bireyler için ise $W = 0.00016FL^{2.467}$ olarak hesaplanmıştır. Tüm bireylerde negatif allometrik büyüme gözlenmiştir. 744 örneğin ilk dorsal yüzgeç ışınında mevsimsel olarak oluşan bantlardan yaş ve büyüme hesaplanmıştır. Uzun kanat orkinosun hesaplanan yaşı 1 ve 9 yaş arasında değişmektedir. Von Bertalanffy büyüme parametreleri dişiler, erkekler ve tüm bireyler için hesaplanmıştır. Erkek ve dişilerin büyümeleri arasında önemli farklılıklar bulunmaktadır. Her iki cinsiyet ve tüm yılların karması olan von Bertalanffy büyüme parametreleri $L_\infty = 93.198$ cm, $W_\infty = 11.552$, $k = 0.295$ yıl^{-1} ve $t_o = -1.213$ yıldır.

Anahtar sözcükler: Uzun kanat orkinos, *Thunnus alalunga*, yaş, büyüme, diken ışın, Doğu Akdeniz

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Introduction

Albacore (*Thunnus alalunga*) is a highly migratory epi- and mesopelagic oceanic tuna species. This species has a wide geographical distribution, ranging from Nova Scotia to northern Argentina in the western Atlantic and from the Bay of Biscay to South Africa in the eastern Atlantic, and populations found in both the Indian and Pacific oceans (ICCAT, 1990).

The International Commission for the Conservation of Atlantic Tunas (ICCAT) defines 3 stocks: North Atlantic, South Atlantic (separated at 5 °N), and Mediterranean stocks (ICCAT, 2006). There are stock assessment studies for the Atlantic stocks; however, no studies so far could be made for the Mediterranean stock due to lack of information. Therefore, there are no ICCAT regulations directly aimed at managing the Mediterranean albacore stock.

Albacore fishing in Turkish waters is performed using purse seines and long lines and gillnets in the Mediterranean and Aegean seas. In the Aegean Sea, fishing occurs primarily during the winter months, contrasting with the spring and summer (May, June, and July) fishing season of the Mediterranean (Karakulak et al., 2007).

Despite the economic value of this species, little is known regarding its population biology. Existing studies of albacore biology generally focus on the Atlantic Ocean, where features like fin rays, vertebrae, and otolith have been used to evaluate the age and growth of this species (Bard, 1974; Bard and Compean-Jimenez, 1980; Gonzales-Garces and Farina-Perez, 1983; Fernandez, 1992; Lee and Yeh, 1993; Santiago and Arrizabalaga, 2005). Few studies have assessed the age and growth of *T. alalunga* in the Mediterranean Sea (Arena et al., 1980; Cefali et al., 1986; Megalofonou, 2000; Megalofonou et al., 2003), and we know of no studies that have examined this species in the Levantine Sea (eastern Mediterranean). There are 2 studies focusing on albacore in Turkish waters: the first focuses on Turkish fisheries (Karakulak et al., 2007) and the other assesses stomach contents (Salman and Karakulak, 2009).

The growth rate of fish is an essential input parameter into stock assessment models of fish populations with a significant impact on the outcome of the analysis. Likewise, the weight-at-length relationship is also an important component of the description of the life cycle and the population dynamic analyses. The objectives of this study were to estimate the age and growth parameters using growth rings on sections of the first dorsal spine and to formulate the length-weight relationship in order to contribute new, useful information for the stock assessment of Mediterranean albacore stock caught in Turkish waters. This paper provides new information and insight into this region, and we compare our results with those of previous studies of albacore populations.

Materials and methods

Albacore were collected from commercial tuna fishing conducted in Antalya Bay (in the Levantine Sea) in May-July, 2006-2008 (Figure 1). Fish were measured on the boat. The fork length (FL) and weight (W) of 819 fish were recorded, and the radius of the first dorsal fin of each fish was recorded for age analysis. The FL of each fish was measured to the nearest centimeter, and W was measured to the nearest gram. Sex was determined, when possible, by visual inspection of the gonads.

Spine extraction, preparation, and sectioning protocols were described by Bard and Compean-Jimenez (1980) and Cort (1991). We obtained 4 serial cross-sections, each approximately 0.7 mm thick, from each spine at the point near the condyle base using a low-speed saw and diamond wafering blades. The spine sections were observed using a binocular lens microscope under transmitted light connected to a Quantimet 500 W (Leica) image analyzer.

Growth bands were identified based on the presence of a narrow translucent zone (slow winter growth) and a wider opaque zone (rapid summer growth). The age of each fish was estimated by the number of winter hyaline (translucent) zones (Cort, 1991). All spines were interpreted twice by 2 different examiners, without prior information on FL.

Estimating age based on spine sections is relatively easy, robust, and simple to interpret, and samples may easily be stored for future reexamination (Compean-Jimenez and Bard, 1983). However, in the older specimens, as the nucleus of the spine section is reabsorbed, the first rings disappear. To solve this problem, ring diameters may be used to assign ages to the first visible/observed ring (Cort, 1991).

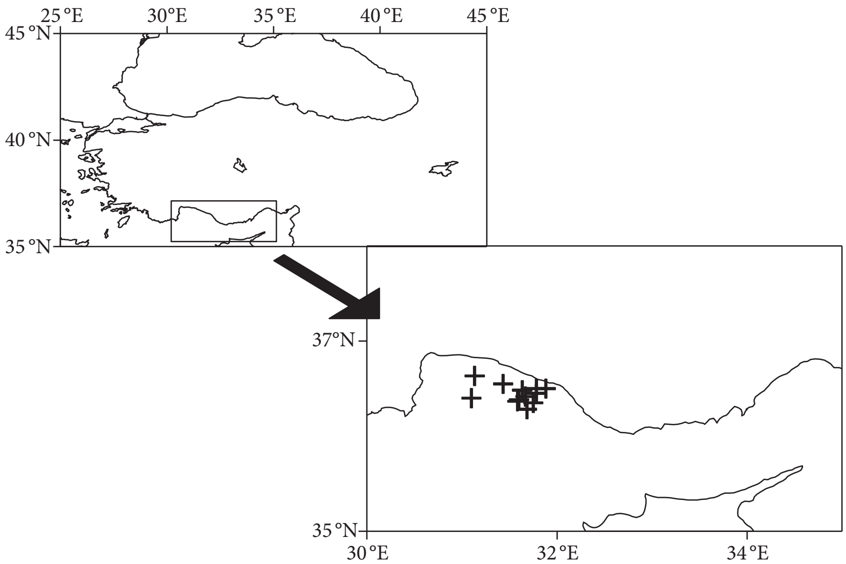

Figure 1. Albacore fishing grounds in the eastern Mediterranean Sea.

Mean FLs at different ages were used to estimate the growth parameters of the von Bertalanffy growth function, $L_t = L_\infty [1 - e^{-k(t-to)}]$, where L_t is the FL of fish at time t, L_∞ is the asymptotic FL, k is a constant expressing the rate at which the length reaches L_∞, and t_o the theoretical age at a FL of 0. Theoretical weight gain was determined by converting FL to W using the FL-weight relationship calculated for fish (Sparre and Venema, 1992). For weight gain, the same function was used: $W_t = W_\infty [1 - e^{-k(t-to)}]^b$, where W_t is the total weight and b is the power constant of the FL-W relationship. Growth performance indexes ($\Phi' = \ln k + 2 \ln L_\infty$) were calculated to compare the results obtained in this study with results published elsewhere (Sparre and Venema, 1992).

FL-W relationships were estimated for both sexes and for males and females separately. The relationships were calculated using the least squares fitting method to estimate parameters a and b of the function $W = aL^b$, and W and L data were log-transformed. W is the weight of the fish in grams, L is the FL in centimeters, a is a coefficient related to body form, and b is an exponent indicating isometric growth when equal to 3. The coefficients were analyzed using ANOVA. To test for possible significance in differences between the sexes, Student's t-test was used to compare the 2 slopes (Zar, 1996). Statistical analyses were performed with the SPSS software package and a significance level of 0.05 was accepted.

Results

A total of 819 albacore were collected during the study period. The genders of all individuals were not examined because the fish were sold as a whole. Sex was determined for 215 of these specimens: 110 were males (51.16%) and 105 were females (48.84%). The FL of all individuals ranged from 55.5 to 101 cm (average value: 76.04 ± 0.19 cm); the total weight ranged from 3.93 to 12.75 kg (average value: 6.89 ± 0.008 kg). The FL of females ranged from 55.5 to 83.5 cm (average value: 72.02 ± 0.41 cm), and that of males ranged from 64 to 91 cm (average value: 76.91 ± 0.53 cm). The dominant FL class for the entire total sample was 71-75 cm. Females dominated the classes of 65-70 cm and 71-75 cm, whereas all other classes were dominated by males (Figure 2).

Age was determined based on the first dorsal spine of 744 specimens caught during the spawning season, from May to July, 2006-2008. The number of suitable specimens for age-class determination was 734 (98.66% of the total). Age estimates ranged from 1 to 9 years old, and 3-, 4-, and 5-year-old fish dominated the population (80%). The age structure was as follows: 1-year-old fish, 0.14%; 2-year-old fish, 3.54%; 3-year-old fish, 23.43%; 4-year-old fish, 29.43%; 5-year-old fish, 27.79%; 6-year-old fish, 9.81%; 7-year-old fish, 4.22%; 8-year-old fish, 1.36%; and 9-year-old fish, 0.27%. The age-FL

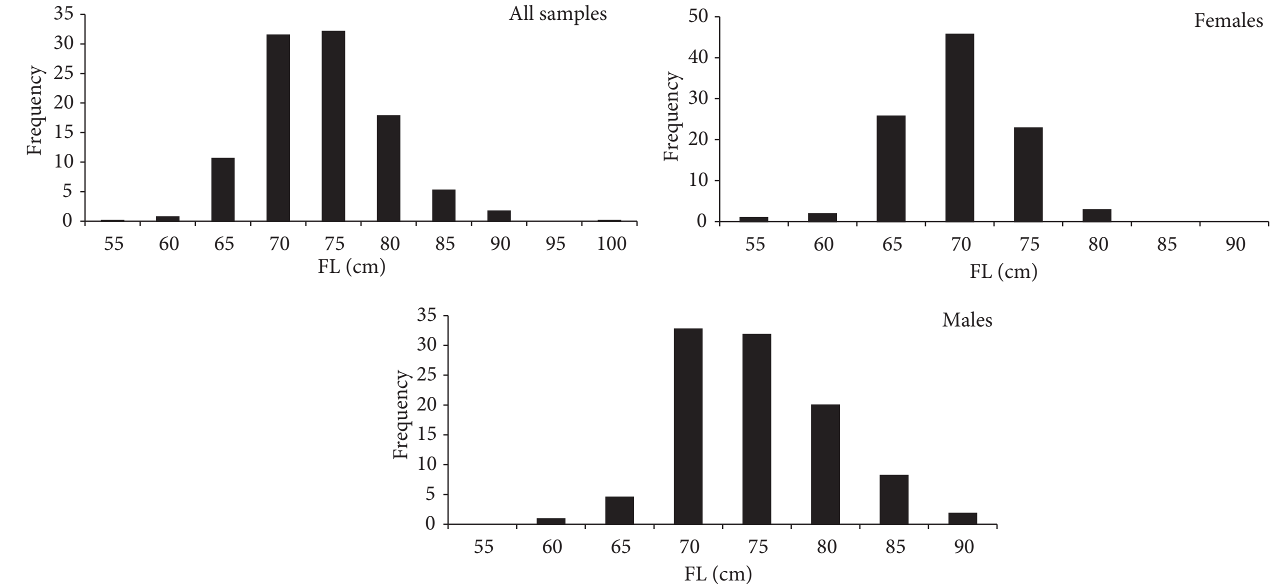

Figure 2. The FL (cm) frequency of all samples, females, and males of albacore from the eastern Mediterranean Sea.

key for albacore is presented in Table 1, showing a considerable range in FL for each age group and a large amount of overlap between adjacent age groups.

The mean fork lengths of individuals assigned to each age group were used to fit the von Bertalanffy growth model, presented in Figure 3. The von Bertalanffy equation for the theoretical growth of albacore in fork length was: $L_t = 78.927\ [1 - e^{-0.687(t + 1.195)}]$ for females, $L_t = 104.836\ [1 - e^{-0.160(t + 4.110)}]$ for males, and $L_t = 93.198\ [1 - e^{-0.295(t + 0.295)}]$ for all individuals (Table 2). Asymptotic values of fork length (L_∞) were higher for males than for females. The growth performance index (Φ') was calculated as 7.849.

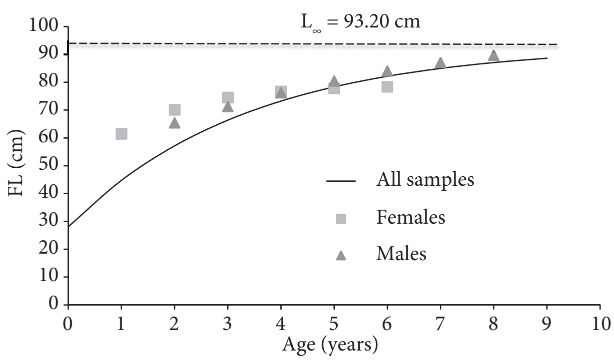

Figure 3. Von Bertalanffy growth curve in FL of albacore in the eastern Mediterranean Sea.

Table 3 shows the FL-W relationship and FL and W characteristics for albacore. This relationship was highly significant ($P < 0.001$). Negatively allometric growth was observed for all groups (females, males, and all individuals). T-tests indicated that there were no significant differences ($P > 0.05$) between the slopes (b) of the FL-W relationship for females and males. The values of b for females, males, and both sexes were significantly different from 3 (isometric growth) ($P < 0.05$). The FL-W relationships are shown in Figure 4.

The relationship between spine diameter and FL is shown in Figure 5. The fork length of the 744 specimens varied from 55.5 to 101 cm, and spine diameters varied from 2.126 to 4.564 mm. The regression function was significant ($r^2 = 0.665$, $P < 0.001$) and the equation obtained was $R = -0.647 + 0.05306FL$.

Discussion

In this study, a total of 819 specimens were examined to determine the age and growth parameters of the albacore caught in Turkish waters. In many fish species (including tunas), males dominate the largest size groups due to sexual difference in growth and death rates (Schaefer, 2001). Wild (1986) and Schaefer

Table 1. Age-FL key for all individuals of albacore.

FL (cm)	1+	2+	3+	4+	5+	6+	7+	8+	9+	Total
55.0-55.9	1									1
56.0-56.9										0
57.0-57.9										0
58.0-58.9										0
59.0-59.9										0
60.0-60.9										0
61.0-61.9										0
62.0-62.9		1								1
63.0-63.9										0
64.0-64.9		1	3							4
65.0-65.9		2	2							4
66.0-66.9		1	4	1						6
67.0-67.9		2	10	2						14
68.0-68.9		5	12	5						22
69.0-69.9		4	14	15						33
70.0-70.9		5	22	14						41
71.0-71.9		1	19	15	2					37
72.0-72.9		1	18	16	6					41
73.0-73.9		3	27	20	6					56
74.0-74.9			17	24	14	1				56
75.0-75.9			12	19	27	1				59
76.0-76.9			5	25	22					52
77.0-77.9			4	17	19	4				44
78.0-78.9				19	25	5				49
79.0-79.9			3	6	19	6				34
80.0-80.9				10	27	8	1			46
81.0-81.9				5	9	8	1			23
82.0-82.9				2	14	7	3			26
83.0-83.9				1	9	8	3			21
84.0-84.9					1	8	3			12
85.0-85.9					1	6	4			11
86.0-86.9					3	7	4			14
87.0-87.9							2	1		3
88.0-88.9						2	2	2		6
89.0-89.9							2	3		5
90.0-90.9						1	2	1		4
91.0-91.9							2	2	2	6
92.0-92.9								1		1
93.0-93.9							1			1
94.0-94.9							1			1
Total	1	26	172	216	204	72	31	10	2	734

Table 2. The von Bertalanffy growth parameters for albacore.

Sex	N	k	t_o	L_∞	W_∞
All samples	734	0.295	−1.213	93.198	11.552
Females	105	0.687	−1.195	78.927	7.663
Males	110	0.160	−4.110	104.836	15.260

Table 3. FL-W relationships for albacore ($W = aFL^b$).

Sex	FL (cm)			TW (kg)		Parameters of the L-W relationship			
	N	Min.	Max.	Min.	Max.	a	b	S.E (b)	r^2
All samples	336	64.00	94.00	3.92	12.75	0.00016	2.467	0.07	0.788
Females	87	64.00	83.50	3.92	8.42	0.00042	2.246	0.20	0.609
Males	89	67.00	91.00	5.01	12.75	0.00022	2.396	0.18	0.683

N is the sample size; min. and max. are minimum and maximum fork lengths in cm; a and b are the parameters of the fork length-weight relationship; SE (b) is the standard error of the slope b; and r^2 is the coefficient of determination.

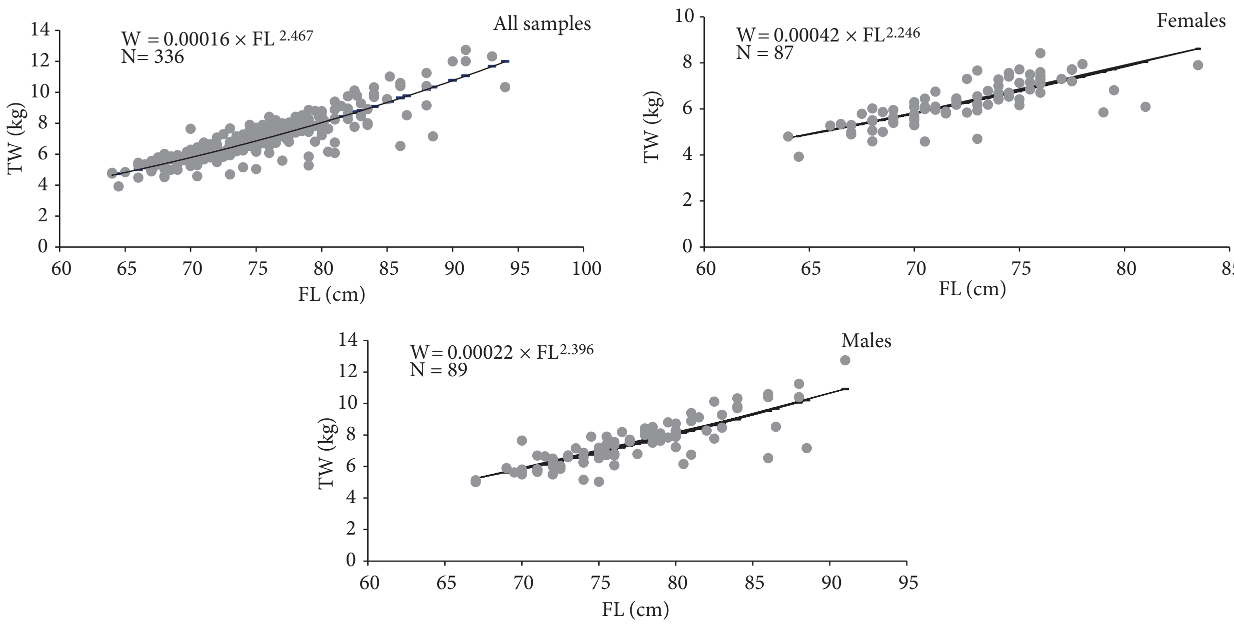

Figure 4. Relationships between W and FL of albacore from the eastern Mediterranean Sea.

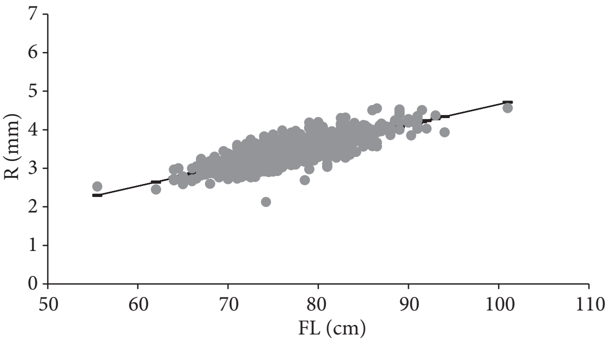

Figure 5. Relationships between FL of the fish and diameter of the first dorsal spine.

(1987, 1998) showed that the low abundance of large *Thunnus albacares* and *Euthynnus lineatus* females was caused by sexual differences in natural mortality rather than by differences in growth or fishing exposure. Similarly, we found that male *Thunnus alalunga* individuals dominated the largest size group (>75 cm). The dominance of females in the FL classes of 65-70 cm and 71-75 cm may be due to a cessation of growth in females at smaller sizes.

In many marine fish species, sexual dimorphism has been documented in growth patterns, but females generally show more rapid growth rates and larger sizes than males (Dwyer et al., 2003). However, in long-lived tuna species, such as *Thunnus thynnus* (Butler et al., 1977; Hurley et al., 1981), *Thunnus obesus* (Shomura and Keala, 1963; Kume and Joseph, 1966), *Thunnus maccoyii* (Farley et al., 2007), and *Thunnus alalunga* (Santiago and Arrizabalaga, 2005), males tend to grow faster than females. Our results confirm that the growth of the male *Thunnus alalunga* is faster than that of the female.

Table 4 shows a comparison between growth parameters and growth performance indexes estimated in the present study and those described in previous studies. The results of this study and other studies realized in the Mediterranean Sea are similar. Compared to the Mediterranean population, North and South Atlantic populations showed a higher fitted L_∞ (122.8-147.5 cm) and a relatively lower k (0.126-0.230 year^{-1}). However, the calculated values of Φ' were fairly similar. There were significant differences between Atlantic and Mediterranean populations, and Mediterranean albacore remain significantly smaller than Atlantic populations.

In a northern Atlantic albacore tagging experiment with oxytetracycline, Ortiz de Zarate et al. (1996) reported single, double, and triple bands forming during a single year. Similar results have been reported

Table 4. Von Bertalanffy growth parameters and growth performance indexes (Φ') for *Thunnus alalunga* from different regions.

Reference	Stock	Methodology	L_∞	K	t_o	Φ'
Beardsley (1971)	Atlantic	LFA	140.0	0.141	−1.630	7.924
Bard (1974)	North Atlantic	scales	134.4	0.183	−0.350	8.103
Bard (1981)	North Atlantic	dorsal spines	124.7	0.230	−0.989	8.182
Gonzalez-Garces and Farina-Perez (1983)	North Atlantic	dorsal spines	140.1	0.129	−1.570	7.837
Fernandez (1992)	North Atlantic		125.0	0.170	−1.120	7.885
ICCAT (1996)	North Atlantic	LFA (multifan)	122.8	0.217	-	8.093
Santiago and Arrizabalaga (2005)	North Atlantic	dorsal spines	127.0	0.183	−1.616	7.990
Lee and Yeh (1993)	South Atlantic	dorsal spines	142.3	0.145	−0.674	7.985
Lee and Yeh (2007)	South Atlantic	dorsal spines vertebra	147.5	0.126	−1.890	7.916
Arena et al. (1980)	Mediterranean	scales	98.5	0.406	−0.626	8.280
Megalofonou (2000)	Mediterranean	dorsal spines	94.7	0.258	−1.354	7.746
Megalofonou (2003)	Mediterranean	scales	86.0	0.370	−0.760	7.908
Present study	Mediterranean	dorsal spines	93.198	0.295	−1.213	7.849

LFA: length frequency analysis; L_∞: asymptotic mean length; k: constant expressing the rate at which length reaches L_∞; t_o: hypothetic age at zero length.

in the Mediterranean albacore (Megalofonou, 2000) and in other tuna species (Compean-Jimenez and Bard, 1983; Cort, 1991). Indeed, we also observed that single, double, and triple bands can occur within 1 year (Figure 6). Santiago and Arrizabalaga (2005) reported that the appearance of single, double, and triple bands could be due to variability in migration routes from year to year.

The absence of 0- and 1-year-old individuals in the gillnet fisheries of the Turkish waters may be associated with the habitat and behavior of these young fish. The migration route of this species in the Mediterranean is also not fully known. Bard (1981) reported that albacore between the ages of 3 and 4 use

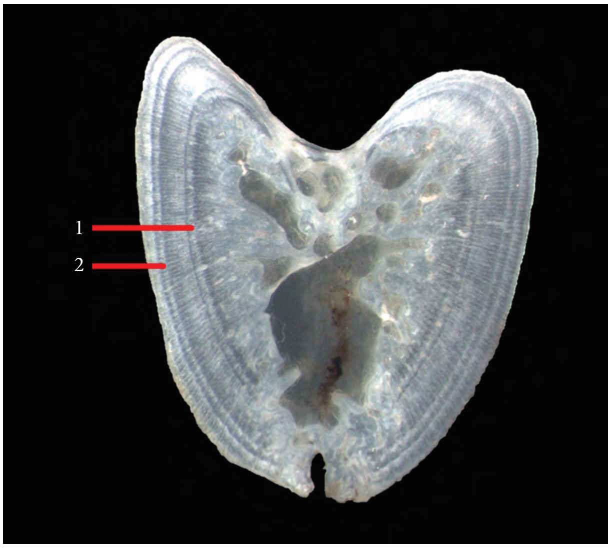

Figure 6. Spine cross-section of *Thunnus alalunga*: 1) a double band in the first year, 2) a triple band in the second year.

deeper ecological niches with more abundant trophic resources below the seasonal thermocline. There is little information available regarding the biology of albacore under 2 years old (ICCAT, 2001).

The length of each fish was estimated using back-calculation (Francis, 1990) based on the linear relationship of band diameter and fish length (Campana, 1990). The number of reabsorbed bands was inferred and the age of each albacore was estimated, relative to the first visible band. In this study, a highly significant linear relationship was found between spine diameter and FL. Linear relationships between these factors were similarly described by Bard (1981), Gonzalez-Garces and Farina-Perez (1983), Megalofonou (2000), and Santiago and Arrizabalaga (2005).

The FL-W relationship of albacore in the eastern Mediterranean displayed negative allometry. The value of exponent b is often close to 3, but can vary between 2 and 4 (Tesch, 1971). A value of 3 indicates that growth proceeds symmetrically or isometrically; values higher or lower than 3 indicate allometric growth (Tesch, 1971).

These differences in b-values may be attributed to seasonal and regional effects, changes in water temperature, salinity, sex, food availability, differences in the number of specimens examined, and differences in the observed FL ranges of the specimens caught (Tesch, 1971). Comparing the b-values derived here with those from previous studies (Table 5), our values were similar to those reported by Megalofonou (1990, 2000), but were different from those of Santiago (1993) and Penney

Table 5. Some representatives of the FL-W relationship of *Thunnus alalunga*.

Equation	Reference	N	FL (cm)	Stock
$W = 1.339 \times 10^{-5} \times FL^{3.1066}$	Santiago (1993)	714	42-117	North Atlantic
$W = 1.3718 \times 10^{-5} \times FL^{3.0793}$	Penney (1994)	1008	46-118	South Atlantic
$W = 3.119 \times 10^{-5} \times FL^{2.88}$	Megalofonou (1990)	1742	55-89	Mediterranean
$W = 5.312 \times 10^{-5} \times FL^{2.74}$	Megalofonou (2000)	998	57-92	Mediterranean
$W = 0.00016 \times FL^{2.467}$	Present study	336	64-94	Mediterranean

(1994). As a result, the FL-W relationship described for the Mediterranean Sea shows that there is no significant difference (P > 0.05), and the FL-W relationship of Mediterranean albacore differs from those found for Atlantic albacore.

The North Atlantic stock is considered to be independent from the Mediterranean stock based on the existence of an independent spawning area in the Mediterranean (Duclerc et al., 1973), different morphometric characteristics (Bard, 1981), different growth rates (Megalofonou, 2000; Megalofonou et al., 2003), and age at maturity (Arena et al., 1980). The main arguments for considering different stocks are tagging studies and genetic studies (Arrizabalaga, 2003; Arrizabalaga et al., 2004). The FL-W relationship and growth parameters described in our study further confirm that the Mediterranean *T. alalunga* stocks are distinct from the North Atlantic stocks.

Stock assessments for Mediterranean albacore were not available due to lack of catch data integration, biological characteristic parameter estimations, and fundamental fisheries knowledge. The results of this research can be used in future stock assessment studies.

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