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The potential use of scales for estimating age and growth of Mediterranean albacore (*Thunnus alalunga*)

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Summary

The ability to accurately estimate the age of fishes is critical for conducting stock assessments and developing fishery management policies. Scales were collected from albacore, *Thunnus alalunga,* caught in the Mediterranean Sea during the years 1989–1995 to estimate their age and growth. Ages, which ranged from 1+ to 6+ years, were estimated from the interpretation of the concentric rings on the scales of 473 individuals that ranged in fork length from 55.5 to 89 cm. Males reached a greater size and age than females. The relatively close agreement in the mean lengths at ages estimated by scales and other techniques constituted a preliminary verification of the method. The von Bertalanffy growth model was fitted to mean lengths at estimated ages, resulting in the following growth parameters for the combined sexes: $L_\infty = 86$ cm, $K = 0.4$, $t_o = -0.8$ years. Parameter estimates were in agreement with what is known about life history of the species in the Mediterranean. Moreover, the growth rates were consistent with length increment observations from five tag returns, which lend support to our working hypothesis that the scale-rings are annual structures. When the Mediterranean albacore growth parameters were compared with those of Atlantic Ocean albacore using scale age estimates, there were significant differences between the two populations, and Mediterranean albacore remain significantly smaller than Atlantic Ocean albacore.

Introduction

Albacore *Thunnus alalunga* (Bonnaterre, 1788), is a highly migratory pelagic species known to inhabit the tropical and temperate waters of all oceans including the Mediterranean Sea. This species is a seasonal migrant in the Aegean and Ionian seas and is one of the most important commercial tuna species exploited in Mediterranean. The most important Greek and Italian albacore fishing fleets target high concentrations of albacore, but the distribution is discontinuous. The fishery season is from the end of August until the end of November using long lines and troll lines gear (Cefali et al., 1986; Megalofonou, 1990). Aggregations are composed of similar size individuals, and schools can include other tuna species such as bluefin tuna. Since 1984, Mediterranean albacore landings have fluctuated between 2000 and 4000 metric tonnes (ICCAT, 1996).

Despite the high commercial value of this species, and the significance of this large predator of the open sea, relatively little is known about its population biology in the Mediterranean Sea. In the past, preliminary data for the size and age distributions of Mediterranean albacore were obtained in the Tyrrhenian and Aegean seas (Arena et al., 1980; Megalofonou, 1990). Ages were estimated by counting the concentric rings of scales, however the results from the two areas of the Mediterranean were not in close agreement. This may indicate regional growth differences but could also be due to uncertainties in the results, as the number of samples in some age groups was very limited. In both studies however, significant differences were noted between the life history characteristics of Mediterranean and Atlantic albacore. A recent study on age and growth of Mediterranean albacore, using fin spine sections to estimate age of 1136 specimens, supported the hypothesis that the Atlantic and Mediterranean albacore are separate stocks (Megalofonou, 2000). Much of the evidence used to evaluate the reliability of the observed differences in growth between Mediterranean and Atlantic albacore had come from the comparison of growth of tagged fish.

Biological studies on age and growth of fish are an integral part of stock assessment models that are necessary to formulate management recommendations. Small variations in growth rates can have significant impacts on the outcomes of the population analysis. This is especially important when it is unclear if the fish that are targeted by the fishery are of single or multiple stocks. There have been several attempts to estimate age and growth of albacore in the Atlantic and Pacific oceans using various hard parts such as scales, spiniform fin rays, vertebrae and otoliths (Partlo, 1955; Figueras, 1957; Yang, 1970; Bard, 1974; Bard and Compeán-Jimenez, 1980; Hue, 1980; Beamish, 1981; Gonzáles-Garcés and Fariña-Perez, 1983; Laurs et al., 1985; Fernandez, 1992; Labelle et al., 1993; Lee and Yeh, 1993). Most of the results obtained showed no clear agreement in the determination of mean size at various ages. These differences may be partially attributed to the diversity of methods and the geographic origin of the samples.

Comparative analysis of different calcified structures suggested that the fin rays are appropriate structures for aging adult albacore (Beamish 1981, Fernandez, 1992). In large pelagic species it appears that sections made from otoliths and spines are most reliable, whereas scales, especially those from older fish, are less reliable. Although the tendency in verification studies is to assume that the structure providing the higher age estimation is the most accurate, this may not always be the case. Otoliths (Fernandez, 1992) and spines (González-Garcés and Fariña-Perez, 1983) have been shown to contain multiple zonation, which if interpreted literally, overestimated the age of the fish.

In this paper, we estimate the age and growth of albacore from the Mediterranean Sea using scales and compare these with results from an independent study using fin spine sections (Megalofonou, 2000). Moreover, using the length increment data from tagging experiments we test the assumption that scale-rings represent annual features. In a previous preliminary study of albacore (Megalofonou, 1990), growth rates were not estimated and conclusions were limited because of small sample size. Therefore, an increased sample size and expanded collection of samples was required to warrant more reliable estimates and comparisons. The main goals of the present study were to improve the existing preliminary age estimates using scales to estimate the growth parameters, which are essential for the stocks evaluation models, and to verify the use of scales for age estimation of albacore.

Materials and methods

Sampling scheme

Albacore were obtained from the catches of the Greek fishing fleets operating in the Aegean Sea, in September and October during the years 1989–1995. A total of 473 specimens were sampled from landings at the island of Alonisos of the North Sporades (Fig. 1). For each fish, scales, fork length (L_F), round weight (W), sex, as well as date and place of capture were collected. Scales were removed from the dorsal area behind the second dorsal fin after the fish was well cleaned with water. About 10 scales were obtained from each specimen using forceps and put in a small envelope with the code and the date of capture of the fish. Fork length measurements were made to the nearest centimeter (cm), fish measured in the laboratory were measured to the nearest millimeter (mm), and weight was measured to the nearest gram (g). Sex was determined, when it was possible, by visual inspection of the gonads.

Scale preparation and age estimation

Scales were cleaned by dipping in fresh water then rubbed between thumb and forefinger to remove any dirt or mucus. Scales were mounted on glass microscope slides with a spot of egg albumin with the convex side up. Slides were later examined under a binocular stereoscope. A personal computer connected to the stereoscope by means of a video camera and equipped with image analysis software was used to examine scales and to perform measurements. Checks or concentric rings on scales were distinguished as narrow structural discontinuities and have been interpreted as representing annual events (Regier, 1962; Casselman, 1983). Regenerated scales were easily detected by the confusing nature of the striations and the absence of concentric rings near the focus and were thus rejected. The total number of the rings in scales was recorded in order to assign an estimated age to each albacore and build a size–age key. Two readings of the same scale were made independently. When there was disagreement between counts of annuli, scales were read for a third time; if agreement could not be reached, these scales were not included in the analysis.

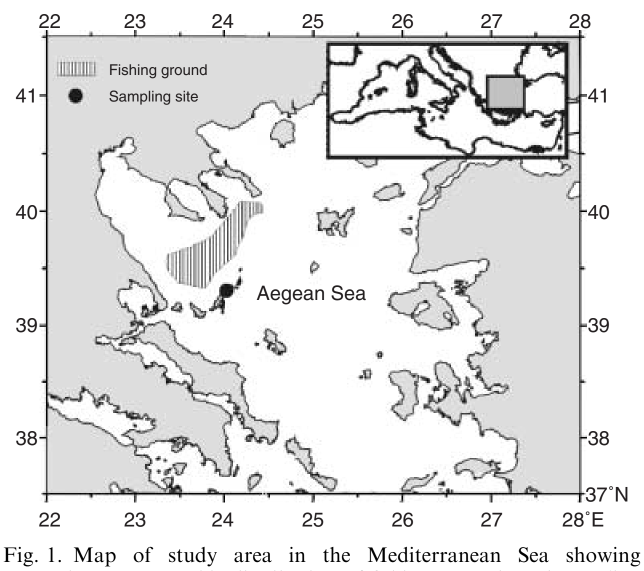

Fig. 1. Map of study area in the Mediterranean Sea showing approximate geographic distribution of fishing grounds and sampling sites of albacore, *Thunnus alalunga*

Growth

Growth parameters were estimated from scale–ring-count data and length data. Assuming June 1 is the hatch date for albacore in the Mediterranean based on the historical data on larval occurrence (Piccinetti and Piccinetti Manfrin, 1993), and that rings are formed during late winter and very early spring, which is common for many species, we considered n^+ the age of albacore caught from September to October and having n rings on the scales. We did not attempt to estimate fractional age based on the assumed hatch date; therefore for the sake of growth calculation all ages are integers. Ages were advanced to the next whole integer (n + 1) because the fish are 4–5 months 'older' than their anniversary date and they gain most of their annual growth between June and October. Mean lengths at age were used to estimate the parameters of the von Bertalanffy growth curve:

$$L_t = L_\infty (1 - e^{(-k)\cdot(t-t_o)}) \quad (1)$$

where: L_t = length at age t, L_∞ = the asymptotic length, k = constant expressing the rate at which length reaches L_∞, and t_o = hypothetical age at which fish would have zero length.

For the parameters estimation, the Newton iteration method was used which is a non-linear least-squares procedure minimizing the sum of squared deviations between the observations and the estimated length at age data (Sparre, 1987). The initial values supplied for the parameters were obtained from the Ford-Walford plot (Walford, 1946). The quantity Phi prime, $\Phi' = \ln k + 2 \ln L_\infty$, was computed (Sparre et al., 1989) to compare albacore growth parameters of this study with those estimated in other similar studies from the Mediterranean Sea and Atlantic Ocean.

Comparison of growth curve with tag-recovery data

Tagging operations conducted in the Ionian Sea from 1990 to 1995 and summary statistics of the corresponding release–recapture data have been described by De Metrio et al. (1997). Differences in mean size between the successive age classes were calculated and compared with annual mean growth rate of five tagged recovered albacore in the Ionian Sea (De Metrio et al., 1997; Megalofonou, 2000). Mean growth rates were calculated directly from the lengths of tagged–recovered fish by the formula:

$$\text{growth rate} = (L_2 - L_1)\cdot(t_2 - t_1)^{-1} \quad (2)$$

where L_1 = fish length during tagging at time t_1 and L_2 = fish length during recapture at time t_2 (King, 1995).

Table 1
Mean, standard deviation (SD), and range of fork lengths (L_F) by sex for albacore, *Thunnus alalunga,* sampled in the Mediterranean Sea

		L_F (cm)			
Sex	Sample size	Mean	SD	min.	max.
Males	168	72.3	4.6	63.0	89.0
Females	82	68.2	4.3	58.5	81.5
Combined	473	69.6	5.0	55.5	89.0

The length increment data from tagging were then compared with expected increment values from the fitted von Bertalanffy growth curve (Labelle et al., 1993). This was accomplished by predicting lengths at recapture using the standard Fabens (1965) length increment model:

$$l_{ri} = l_i + (L_\infty - l_i)(1 - e^{-kDt_i}) \quad (3)$$

where l_i = length at release of individual i, Dt_i = time at liberty of marked individual i, L_{ri} = estimated length at recapture of individual i and L_∞ and k are the von Bertalanffy parameters estimated from the scales. Although this procedure is not correct in the strict statistical sense (Francis, 1988) we used it for comparative purposes because it could reveal any gross departures from our assumption that scale-rings represent annual features (Labelle et al., 1993).

Results

Age estimation

Of 473 albacore sampled, we could determine the sex of 250 specimens (Table 1). Sex ratio from all random samples dated between 1989 and 1995 was approximately 2 : 1 (male : female). Age estimations from scales were obtained from a total of 446 albacore, ranging in fork length from 55.5 to 89 cm and from 3100 to 14500 g in round weight (Fig. 2). Scales from 27 specimens, representing 5.7% of the sample, were considered unreadable and rejected from the analysis. The obtained size–age key is presented in Table 2. Estimated ages ranged from 1^+ to 6^+ years. Results of the age estimates show that the majority of fish in the commercial fishery are ages 2^+, 3^+ and 4^+ and represent 94.4% of the sample. Age 3^+ was the most abundant. No specimens equal to or younger than 1 year old were observed, and fish that had already completed their first year of life were quite rare. For males, the estimated ages ranged from 2^+ to 6^+ years, with 3^+ as the most abundant age; females ranged from 1^+ to 5^+ years, with 2^+ as the most abundant (Fig. 2). Between sexes, differences in the mean size at age were obvious and statistically significant for two age groups with sufficient sample size. However, these differences were only minor and not consistent for all age groups (Fig. 3). They were thus not further considered for growth analysis, as given below, using the full sample size. Standard deviation of the mean lengths at age ranged mostly

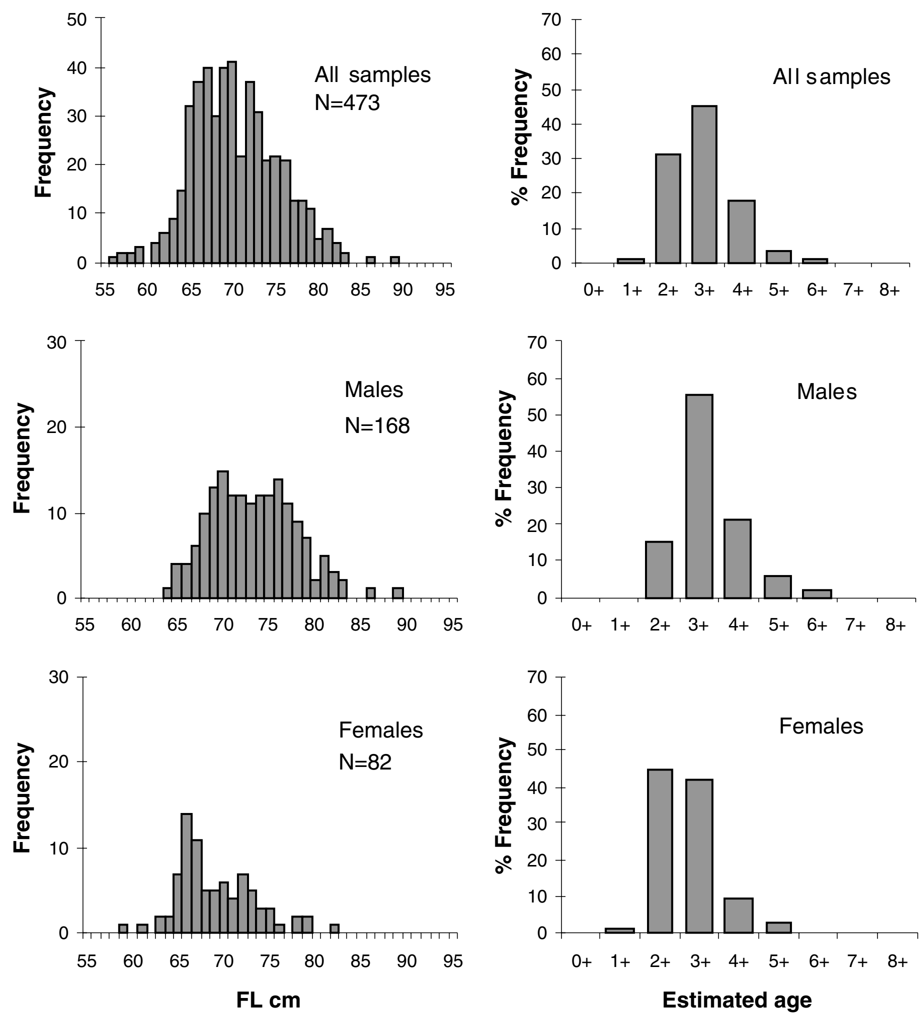

Fig. 2. Fork length and age frequency distributions of albacore, *Thunnus alalunga,* sampled in the Mediterranean Sea during 1989–1995

Table 2
Size–age key of the 446 albacore, *Thunnus alalunga,* caught in the Mediterranean Sea

Fork length L_F (cm)	Estimated age						Total number per length
	1^+	2^+	3^+	4^+	5^+	6^+	
55.5–56.5	1						1
56.5–57.5	2						2
57.5–58.5	1	1					2
58.5–59.5		2	1				3
59.5–60.5							0
60.5–61.5		3	1				4
61.5–62.5		5	1				6
62.5–63.5		8	1				9
63.5–64.5		13	1	1			15
64.5–65.5		26	5				31
65.5–66.5		23	14				37
66.5–67.5		24	14				38
67.5–68.5		10	20				30
68.5–69.5		9	27	2			38
69.5–70.5		7	30	2			39
70.5–71.5		2	18				20
71.5–72.5		3	23	9			35
72.5–73.5			16	12			28
73.5–74.5		1	10	9			20
74.5–75.5		1	4	15			20
75.5–76.5		1	9	9	2		21
76.5–77.5			2	6	1		9
77.5–78.5			2	6	4		12
78.5–79.5			1	3	3		7
79.5–80.5			1	2	1	1	5
80.5–81.5				2	3	2	7
81.5–82.5				2	2		4
82.5–83.5				1			1
83.5–84.5							
84.5–85.5							
85.5–86.5						1	1
86.5–87.5							
87.5–88.5							
88.5–89.5						1	1
89.5–90.5							
Total number per age group	4	139	201	81	16	5	446

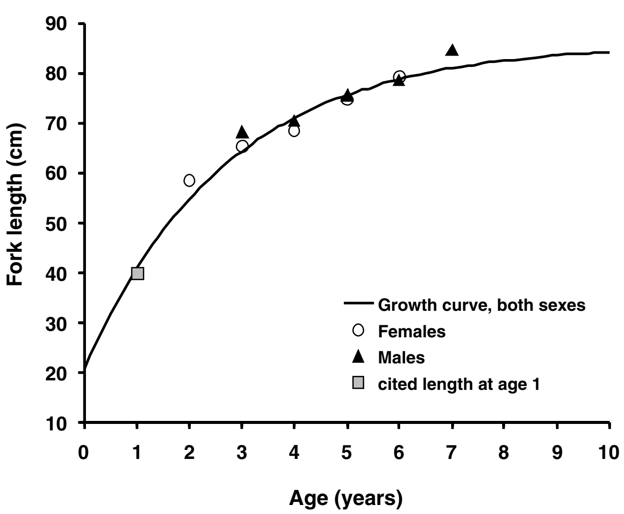

Fig. 3. von Bertalanffy growth curve for albacore, *Thunnus alalunga,* sampled in the Mediterranean Sea based on observed mean lengths at ages estimated from scale readings and an assumed length of 40 cm for age 1 (Megalofonou, 2000)

Table 3
Comparison of mean fork length (cm) at age (years) estimated using scales or spines for the Mediterranean albacore. Standard error is shown in brackets

Age group	Megalofonou (2000) Spines (n = 1087)	Present study Scales (n = 446)
0	40.0	
1	59.5	56.6 [1.5]
2	65.8	65.4 [0.3]
3	69.8	69.4 [0.2]
4	74.4	74.3 [0.3]
5	79.3	78.2 [0.8]
6	81.2	82.8 [1.4]
7	85.5	
8	92.0	

around 3 cm for age classes with a good sample size (>30), leading to standard errors around 0.3 cm and up to a maximum of 1.5 cm (Table 3).

Growth parameters

Mean lengths at ages, determined for both sexes combined, were used to estimate the von Bertalanffy growth parameters including 95% confidence limits (Table 4). Because of the difficulty in sampling young fish, a mean size at age 1 of 40 cm was taken from other studies for the Mediterranean albacore (Megalofonou, 2000). The corresponding growth curve based on the full data set is given in Fig. 3, which additionally includes the mean sizes at age for identified male and female subgroups separately to indicate the possible sex-specific difference. Compared with previously published estimates of growth parameters for albacore from the Mediterranean and Atlantic areas, some differences are obvious: L_∞ is lowest in the present study and k is in the high range; however, the calculated values of Φ' is fairly similar (Table 5).

Comparison of growth curve with tag-recover data

The five tag-recapture records included a variety of sizes (66–71 cm) and times at liberty (305–1157 days). Mean growth rates during time at liberty ranged from 1.9 to 4.1 cm year^{-1} (Table 6). In comparison, differences in mean size between the successive ages 2^+, 3^+, 4^+ and 5^+ ranged from 3.9 to 4.9 cm (Fig. 3). To compare the consistency of the von Bertalanffy model with the tag-return data, we calculated predicted recapture lengths for the five albacore using the equation (3). We also made a second set of predictions using L_∞ estimate and twice the k estimate ($L_\infty = 86$ cm and $k = 0.736$ year^{-1}). These parameters are consistent with the assumption that the

Table 4
Summary of parameter estimates for the von Bertalanffy growth equation on fork length (cm) of albacore, *Thunnus alalunga,* caught in the Mediterranean Sea. SSD = sum squares differences

Method	Parameter	Estimate	SD	95% confidence intervals Lower	Upper
Sparre	L_∞	85.95	3.45	76.34	95.56
SSD = 63.03	k	0.368	0.07	0.18	0.56
	t_o	−0.757	0.31	−1.62	0.10

Table 5
Comparison of growth parameters of Atlantic and Mediterranean albacore, *Thunnus alalunga*, estimated by different authors using scales ($\Phi' = \ln K + 2 \cdot \ln L_\infty$)

Author, method	Growth parameters L_∞	k	t_o	Area	Φ'
Yang (1970), scales	135.0	0.190		Atlantic Ocean	8.150
Bard (1974), scales	134.4	0.183	−0.350	Atlantic Ocean	8.094
Arena et al. (1980), scales	98.5	0.406	−0.626	Mediterranean	8.280
Megalofonou (2000), spines	94.7	0.258	−1.35	Mediterranean	7.746
Present study scales	86.0	0.37	−0.76	Mediterranean	7.908

Table 6
Estimated mean growth in fork length (cm year^{-1}) of five albacore tagged–recaptured in the Mediterranean Sea and observed and predicted recaptured lengths assuming that scale rings are (a) annual (Lria), and (b) semester features (Lris). MGria predicted = Mean growth assuming that rings are formed annually and MGris predicted = Mean growth assuming that rings are semestral

Days at liberty	Length at tagging Li	Length at recapture (cm) Lri observed	Lria predicted	Lris predicted	Mean growth (cm year^{-1}) MGri observed	MGria predicted	MGris predicted
305	71	73.5	74.97	77.88	3.0	4.73	8.21
312	67	70.5	72.13	75.87	4.1	5.98	10.34
316	70	72.5	74.36	77.53	2.9	5.02	8.67
740	66	70.5	76.51	81.48	2.2	5.17	7.62
1157	71	77.0	81.31	84.51	1.9	3.24	4.25

rings are half-year features. Predicted recapture length are consistently higher than observed values: when assuming that the rings are annual features, the deviations are within the range of expected individual variation; when assuming that there are two rings formed per year, the predicted values noticeably overestimated the recapture lengths (Table 6).

Discussion

The scale method has been used widely in fishery research, and involves a systematic interpretation of the checks (breaks or changes) in the configurations of the concentric rings located on the outer surface of the scale (Regier, 1962; Casselman, 1983). Interpretations have appeared to be straightforward and simple; however, some verification studies indicated that in older and slow-growing fish, scales underestimate the true age and can be unreliable (Mills and Beamish, 1980). Beamish and Harvey (1969) reported that the spine method gives higher and more precise age estimates than the scale method for some species. The comparison of the scale and the spine aging methods for the species *Catostomus commersoni* confirmed that the scale method underestimated ages mainly after the fifth year of age (Beamish, 1973). We chose scales for age estimation of albacore because they present several advantages: they are easily accessible for sampling, their collection does not interfere with the market value of the fish, and their preparation does not require special equipment.

Our present results on mean fork lengths at age based on scale readings were similar to those based on spine sections, obtained in part from the same collection of fish from the same area (Table 3; Megalofonou, 2000). The close agreement between the mean lengths at estimated ages by scales and other techniques constitutes a preliminary verification of the method. Nevertheless, more research effort should be directed toward verification studies that will compare ages assessed independently from different calcified structures from the same fish.

Growth parameter estimates obtained in our aging study are roughly consistent with what is known about the life history of this species in the Mediterranean. Considering that the longest albacore was 89 cm in fork length, the L_∞ estimate of 86 cm seems realistic, although somewhat low, also compared with other studies for the Mediterranean albacore (Arena et al., 1980; Megalofonou, 2000). The length increment values from five tag returns presented in this study were consistently lower than results from the predicted recapture lengths but still within the range of individual variation. It should be pointed out that the growth curve is critically dependent on the assumed mean length at age 1. A somewhat higher value would result in lower k and higher L_∞ values and would improve the comparability. In any case, the possibility of two-ring formation per year is clearly ruled out by this comparison which rather supports the hypothesis of annual ring formation. Similar results were obtained for the vertebrae of the Pacific albacore (Labelle et al., 1993).

Individual length-at-age estimates show some wide range and overlap for successive age groups. This may be due to errors generated in the reading technique or may reflect real variability in the growth rate of this species. Actually, at such a rapid growth rate, especially during the first years of life, small changes in individual growth rates can produce significant differences in absolute size achieved at a certain age. In addition, an extended period of reproduction can produce similar results. Information on the spawning period of albacore in the Mediterranean Sea has been derived from icthtyoplankton studies. Piccinetti and Piccinetti Manfrin (1993) reported that albacore spawn during summer months as larvae concentrations occur from June to September. Thus, an early-spawned fish can have as much as 3–4 months growth stanza longer than a late-spawned fish from the same year class. Similar studies in the Atlantic and Pacific oceans reported that spawning of albacore may be protracted (Leis et al., 1991; Nishikawa et al., 1985).

In conclusion, there is strong evidence that annual marks do appear in scales of albacore and that they can be used to estimate the age of this species with reliability, although some underestimation of older age cannot be excluded. The factors responsible for their formation are not yet known. Further investigation is therefore needed especially to determine the time and cause of ring formation on scales. Analysis of hard parts from tagged fish in marking experiments and comparison of the various hard part aging methods could provide significant advances in albacore age assessment. These results demonstrate that scales can be used for age estimation, particularly of younger fish. They are easier to obtain and prepare and can be read with accuracy and precision by calibrated readers. Such attributes enable us to develop significantly better data on the age structure of the catch in the fishery, annual cohort production and better population dynamic models.

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