Determination of age and growth of swordfish, *Xiphias gladius* L., 1758, in the eastern Mediterranean using anal-fin spines

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Estimates of growth rates of billfish are important because they are necessary elements of population dynamics models used in the assessment of stocks for this family of fish. Otoliths have been used for ageing most billfish species (Radtke, 1983; Radtke and Hurley, 1983; Wilson and Dean, 1983; Prince et al., 1984; Hill et al., 1989) but several authors have pointed out that the use of dorsal- and anal-fin spines are more practical in terms of ease of collection and processing (Berkeley and Houde, 1983; Hedgepeth and Jolley, 1983; Hill et al., 1989; Tsimenides and Tserpes, 1989). Other skeletal structures such as vertebrae have rarely been used and results have been poor (Prince et al., 1984; Hill et al., 1989).

The swordfish, *Xiphias gladius*, is a cosmopolitan billfish species that is highly exploited in the Atlantic Ocean and the Mediterranean Sea. In the Mediterranean the average size of harvested swordfish has declined over the last decade such that juveniles compose as much as 50–80% of the catch (Di Natale, 1990; Tserpes et al., 1993). However, the existence of contradictory estimates of growth parameters makes assessment of swordfish stocks difficult (Anonymous, 1990; 1993).

Age of swordfish has been estimated from otoliths (Radtke and Hurley, 1983; Wilson and Dean, 1983), and sections of anal-fin spines (Berkeley and Houde, 1983). Of these ageing methods only Ehrhardt (1992) achieved partial validation of the anal-fin method through marginal increment analysis. This analysis assumes that time of annulus formation corresponds to the time when marginal increments are minimal, and it has been widely used to determine the timing of annual increment formation in otoliths and scales of various fish species (Wenner et al., 1986; Maceina et al., 1987). Although the assumption of the analysis is valid for any ageing structure, the method has rarely been applied to structures other than otoliths and scales.

Tsimenides and Tserpes (1989) conducted growth studies on swordfish from the Aegean sea using anal-fin spines but did not attempt validation. They concluded that there was "a degree of uncertainty" in age estimates due to the loss of the first annulus in older animals.

The primary goal of this paper is to determine whether growth bands in anal-fin spines used for age determination of swordfish are deposited annually. Because Ehrhardt (1992) reported that the von Bertalanffy growth function did not adequately represent swordfish growth, we propose a second objective, namely to compare the growth function proposed by Ehrhardt (1992) with the standard von Bertalanffy model for representing growth of Mediterranean swordfish.

Materials and methods

Fish sampling and spine preparation

A total of 1,325 swordfish samples were obtained from commercial longline catches landed at the ports of Kalimnos (n=782), Kithnos (n=185), and Chania (n=358) in the Aegean sea. These ports, located on the islands of Kalimnos, Kithnos, and Crete are part of a national project addressing the fishery and biology of swordfish in the Greek seas (De Metrio et al., 1989). Samples were collected from 1987 to 1992 during alternate months from February to October. However, most were collected from May to September when the majority of catches occur.

Measurements of lower-jaw fork length (LJFL to nearest cm) were taken for all fish, sex was determined, and the anal fin removed and frozen for storage. In the laboratory, fins were thawed and sections of the second spine of the anal fin were prepared for reading according to the method described by Tsimenides and Tserpes (1989). Specifically, each anal fin was immersed in boiling water for a few minutes before the second spine was removed, freed from skin and tissue, cleaned with water, and left

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to dry completely. A section about 2 cm thick was cut with an electric saw from each dried spine at the point where the spine flares (condyle). Each section was placed in a plastic cylinder (3 cm diameter and 2 cm height) which was then filled with liquid resin. These were left to dry for at least 12 hours, the plastic case was removed, and two or three sections about 1 mm thick were cut distally with a "Stuers" accutom.

Age determination

Spine sections were read under a binocular microscope at 12× magnification by using reflected light and a dark background. The distances from the focus to the edge of the section on the dorsal rim (spine radius) and from the focus to each annulus were measured with an optical micrometer. Sections were read by two readers and identical counts were obtained in >80% of the cases; samples were considered unreadable and were excluded from the analysis if discrepancies in counts could not be resolved.

Typically, broad opaque bands and narrow translucent ones could be seen alternating outwards from the central core. Translucent bands that form around the entire circumference of the spine were considered to be annuli and the total number of these bands was recorded (Fig. 1).

Age classes were assigned on the basis of the number of annuli and the following characteristics of the bands: 1) the disappearance of the first annulus from older fish and 2) the existence of multiple bands mainly in larger fish. Preliminary analysis of LJFL measurements taken in nursery areas of the Aegean sea have shown that swordfish reach a length of about 80–90 cm at one year of age. The first annulus could be seen in fish of this size at an average distance of 1.5 mm (SD=0.08) from the focus, but it was usually not visible at lengths greater than 100 cm (Fig. 1). In such cases, and if the total spine radius was greater than 1.5 mm, one year was added to the assigned age. As described by Berkeley and Houde (1983), multiple bands are those which form around the entire circumference of the spine such that the distance between them is substantially less than that of the preceding and following annual bands. In these cases, the clearest band was considered an annulus and the others were ignored. However, if it was not possible to identify such a band, the specimen was considered unreadable. When the opaque-translucent zonation was such that annuli could not be defined, such specimens were also considered unreadable.

Data analysis

The marginal increment ratio (MIR) was estimated for each specimen according to the formula:

$$MIR = (S - r_n) / S,$$

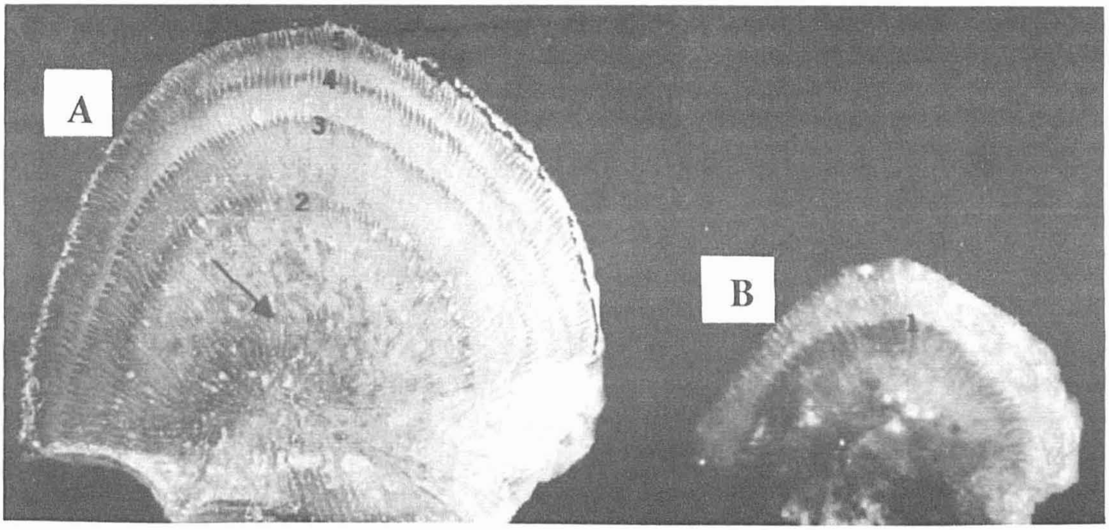

Figure 1

Sections of second anal-fin spine with five growth zones (**A**) and one growth zone (**B**) used for age determination of swordfish, *Xiphias gladius*, from the eastern Mediterranean. First annulus is missing in section (A) whereas it can be clearly seen in section (B). Estimated location of first annulus in section (A), based on its location in section (B), is indicated by an arrow. Lower-jaw fork lengths (LJFL) of animals (A) and (B) were 162 and 95 cm, respectively.

where S = spine radius; and
r_n = radius of the most recent annulus.

The mean *MIR* and the standard deviation were computed for each month and age separately. Marginal increment analysis was not performed for age 1 because the first annulus was usually missing, nor for ages greater than 5 because of a lack of sufficient number of samples.

Estimates of theoretical growth in length were obtained by fitting mean monthly length-at-age data to two forms of the von Bertalanffy growth equation: 1) the standard form and 2) the generalized form as proposed by Chapman (1961).

$$L_t = L_\infty\left(1-e^{-k(t-t_0)}\right) \quad (1)$$

$$L_t = \left[L_\infty^{(1-\delta)} - \left(L_\infty^{(1-\delta)} - l_0^{(1-\delta)}\right)e^{-k(1-\delta)t}\right]^{1/(1-\delta)} \quad (2)$$

where L_t = LJFL at age t, L = asymptotic length, k = growth coefficient, t_0 = theoretical age at zero length, l_0 = length at zero age, and δ = fitted fourth function parameter.

Mean data were used in order to assign equal weight to all observations. Only mean values from samples of greater than five fish were used. Growth parameters of both models were estimated iteratively by using the Simplex minimization algorithm (Wilkinson, 1988). The measure of goodness of fit was the coefficient of determination (r^2). Date of birth was set at 1 June because swordfish spawn in the Mediterranean sea in early summer (Palco et al., 1981).

Growth parameters were estimated for males, females, and sexes combined, and sex differences were tested by analysis of the residual sum of squares (ARSS) as suggested by Chen et al. (1992). This method is a modification of the ARSS originally developed for the comparison of linear models (Zar, 1984).

Back calculations of length at age were estimated in two ways.

1 From a modified version of the direct proportion formula (Fraser, 1916; Lee, 1920):

$$L_n - c = (S_n / S)\,(L - c),$$

where L_n = LJFL when the annulus n was formed;
L = LJFL at time of capture;
c = intercept on length axis from linear regression of length on spine radius;
S_n = distance from spine focus to annulus n; and
S = spine radius.

2 From the formula of Monastyrsky (Bagenal and Tesch, 1978):

$$L_n = (S_n / S)^b L$$

where L_n = LJFL when the annulus n was formed;
L = LJFL at time of capture;
b = the exponent of the regression of length (L) on spine radius (S) which is assumed to be a power function of the form $L=aS^b$;
S_n = distance from spine focus to annulus n; and
S = spine radius.

The constant b was calculated from the logarithmic form of the power function.

In both cases the relation between spine radius and LJFL was determined for males and females and for sexes combined. Moreover, the regression lines for males and females were tested for equality of slopes and if significant differences were found, intercepts were tested by means of analysis of covariance (Dixon and Massey, 1985). No back calculations were attempted for age one because the first annulus was missing in the vast majority of the specimens. All statistical inferences were based on the 0.05 significance level.

Results

Of the 1,325 swordfish sampled, 1,100 were aged successfully (521 males and 579 females). The lengths of individuals ranged from 62 to 210 cm (Fig. 2). In 64 of the 225 unreadable spines, no annuli could be identified because the opaque-translucent zonation was unclear. The remaining 161 spines were considered unreadable owing to the existence of multiple bands which made the identification of annuli difficult or which resulted in ageing discrepancies between the readers, or both.

Up to 9 rings, assumed to be annuli, were visible in the anal-fin spines sampled. Sample sizes for all age classes were greater than 20, except for class 9 (15). Two-year-old fish were the dominant age class and over 80% of the fish were less than 5 years old. Differences in mean size between the successive age classes were calculated to reveal any peculiarities in growth patterns. In theory, absolute growth was expected to be rapid at first and to decrease progressively in later life. The pattern observed for swordfish generally agreed with these expectations (Table 1). Monthly means of MIR indicated that an annu-

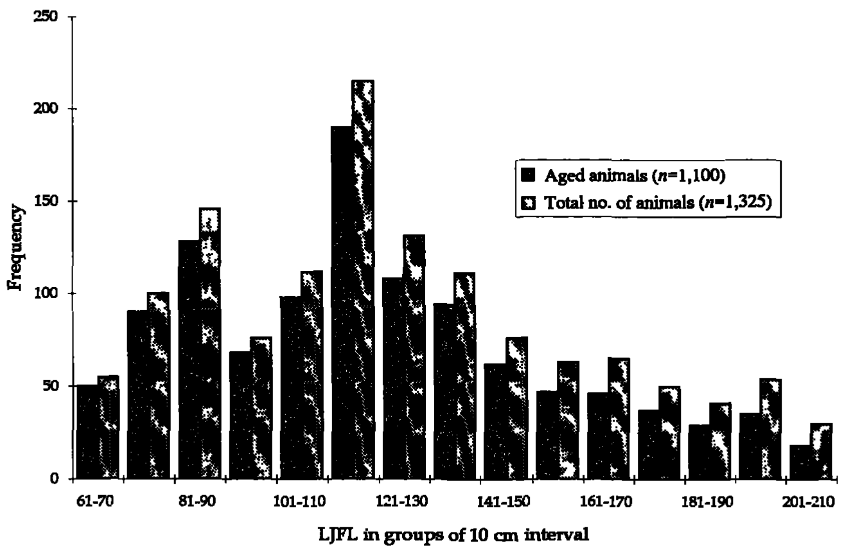

Figure 2

Length-frequency distribution of swordfish, *Xiphias gladius*, from the eastern Mediterranean indicating the total number of fish and the number of those with readable spines (aged animals). LJFL = lower-jaw fork length. n = sample size.

lus is formed from middle spring to early summer for all ages examined (Fig. 3).

Parameters of the standard von Bertalanffy growth function and the generalized model were computed for males, females, and sexes combined (Tables 2). Both models provided a good fit to the data (Fig. 4). Results of the ARSS revealed that growth differences between sexes were always highly significant (F=8.22, P<0.001 for the standard growth function; F=7.41, P<0.001 for the generalized model).

The intercept values used in the proportional formula of back calculation were obtained from the linear regression of LJFL on spine radius:

$LJFL$ = 59.09 + 18.32(S) [r^2=0.98 for males];
$LJFL$ = 62.43 + 17.02(S) [r^2=0.98 for females]; and
$LJFL$ = 61.45 + 17.39(S) [r^2=0.98 for both sexes combined],

where $LJFL$ = lower-jaw fork length (cm);
S = anal-fin spine radius (mm); and
r^2 = coefficient of determination.

Males and females had significantly different slopes (F=44.85, P<0.001).

The constant b used for the nonlinear method of back calculation was obtained from the slope values of the relation between $LJFL$ and spine radius:

Table 1

Summary statistics on sizes of aged swordfish, *Xiphias gladius*, from the eastern Mediterranean. LJFL = lower-jaw fork length.

Age	Sample size	Mean LJFL (cm)	Standard error	LJFL range (cm)	Mean size increment
0	128	72.59	0.51	62–88	—
1	232	89.71	0.52	75–115	—
2	326	114.90	0.33	102–130	25.19
3	153	134.20	0.59	119–153	19.30
4	84	150.46	0.97	126–169	16.26
5	48	162.35	1.04	148–176	11.89
6	54	174.37	0.93	159–185	12.02
7	27	186.81	1.11	179–199	12.44
8	33	198.27	1.13	190–210	11.46
9	15	199.40	1.09	193–205	1.13

ln($LJFL$) = 4.30 + 0.43(ln$S$) [r^2=0.94 for males];
ln($LJFL$) = 4.30 + 0.44(ln$S$) [r^2=0.96 for females]; and
ln($LJFL$) = 4.30 + 0.44(ln$S$) [r^2=0.96 for both sexes combined].

The slope of the relationship differed significantly between males and females (F=6.33, P=0.01).

The statistically significant differences between the sexes for the LJFL spine-radius relation are likely

Table 2

Parameter estimates for the standard von Bertalanffy and the generalized von Bertalanffy growth model for swordfish, *Xiphias gladius*, from the eastern Mediterranean. Corresponding r^2 values are shown in parenthesis. See text for parameter definitions.

	Standard von Bertalanffy			Generalized von Bertalanffy		
Parameter	Male (r^2=0.99)	Female (r^2=0.99)	Sexes combined (r^2=0.99)	Male (r^2=0.99)	Female (r^2=0.99)	Sexes combined (r^2=0.99)
L_∞	203.076	226.525	238.582	292.967	274.914	385.503
k	0.241	0.210	0.185	0.020	0.037	0.011
t_0	−1.205	−1.165	−1.404			
l_0				0.000	0.000	0.002
δ				−1.434	−1.140	−1.393

due to the small variance of the recorded values rather than to a morphometric discrimination between sexes. This can be seen by solving the equations for different spine-radius values. For example, the computed LJFL values for a spine radius of 2 mm are: 1) 95.73 for males and 96.47 cm for females from the linear method; and 2) 99.29 for males and 99.98 for females from the nonlinear method.

The LJFL at the end of each year of life was backcalculated for each individual and these lengths were averaged for males and females separately to obtain mean back-calculated lengths at age. These generally agreed with lengths at age predicted by the growth models and show that females grow faster than males after an estimated age of 3 years (Table 3).

Discussion

Swordfish anal-fin spines have been used previously for ageing Atlantic swordfish (Berkeley and Houde, 1983). Ehrhardt (1992) attempted to validate the method by means of marginal increment analysis and reported that growth bands 1 to 4 were deposited annually during the winter months. Results of marginal increment analysis of the present study demonstrated that growth bands for fish 2 to 5 years of age are deposited annually. In both the previous cases, marginal increment analysis was successful in showing the seasonality of band deposition; however, although these results partially validate the method, it cannot be considered successful until all reported ages of each population are validated (Beamish and McFarlane, 1983). Marginal increment analysis has also been successful in elucidating the time of annulus formation in dorsal spines of *Tandanus tandanus* (Davis, 1977). It is unlikely, however, that application of marginal increment analysis to older ages, in which spine growth is considerably reduced, would show any seasonality in band deposition. In general, validation of ages of older fish requires either a mark-recapture study or the iden-

Table 3

Back-calculated and predicted lower jaw fork lengths (LJFL-cm) at age for swordfish, *Xiphias gladius*, from the eastern Mediterranean.

	Back-calculated (proportional formula)		Back-calculated (nonlinear method)		Predicted (standard von Bertalanffy)		Predicted (generalised von Bertalanffy)	
Age	Male	Female	Male	Female	Male	Female	Male	Female
1	—	—	—	—	83.71	82.76	83.79	82.52
2	106.85	108.84	110.82	112.98	109.28	109.99	110.30	112.03
3	126.14	128.44	131.03	136.06	129.36	132.06	129.03	133.00
4	141.34	145.48	146.28	153.79	145.15	149.96	143.81	149.48
5	153.80	159.88	158.22	167.15	157.55	164.46	156.10	163.04
6	165.06	172.64	168.19	178.00	167.30	176.21	166.65	174.52
7	173.32	182.24	177.11	186.76	174.96	185.74	175.87	184.41
8		190.17		193.10	180.98	193.47	184.05	193.04
9		195.16		196.67	185.72	199.73	191.38	200.63

tification of known-age fish in the population (Beamish and McFarlane, 1983).

The present work showed that annuli are formed from late spring to early summer which is the spawning period for swordfish in the Mediterranean (Palco et al., 1981). Since it has been suggested that swordfish use particular spawning grounds in the Mediterranean (Rey, 1988; Cavallaro et. al., 1991), annulus formation may be related to migration of fish to these grounds. A relation between annulus formation and migration has been suggested for the Atlantic swordfish as well (Berkeley and Houde, 1983).

Our findings indicate that anal-fin spines are useful for ageing swordfish. These are important because

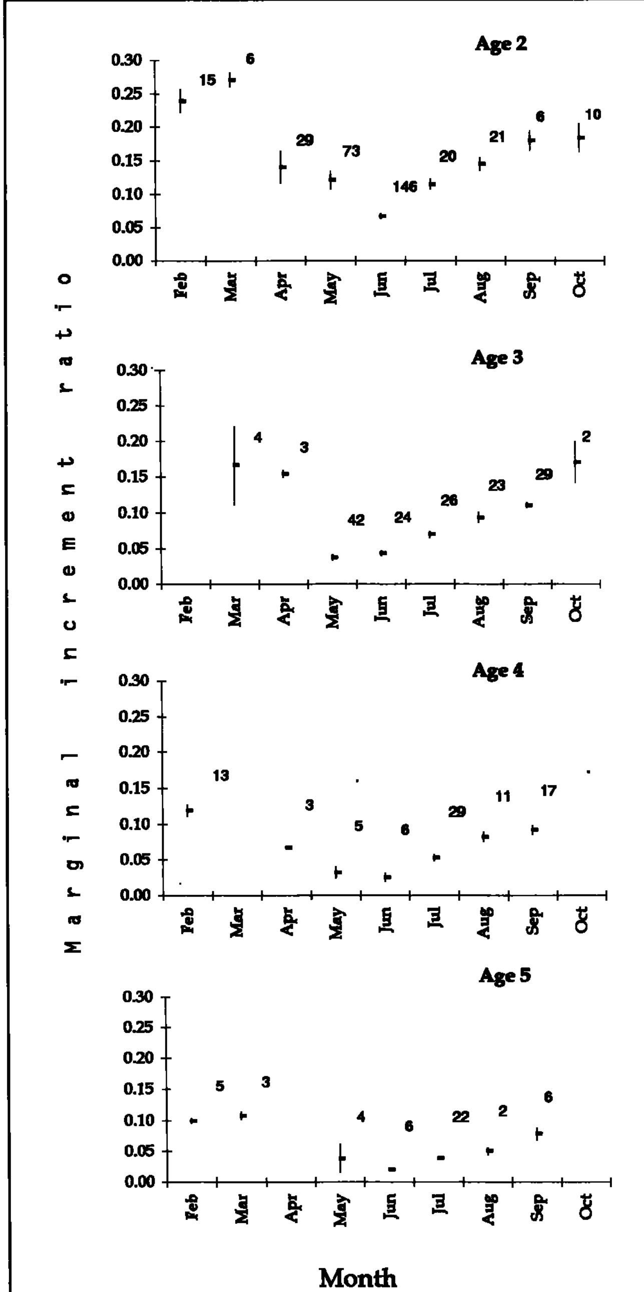

Figure 3

Mean monthly marginal increment ratio for swordfish, *Xiphias gladius*, ages 2–5 from the eastern Mediterranean. Vertical bars represent ±1 SE. Numbers are sample sizes.

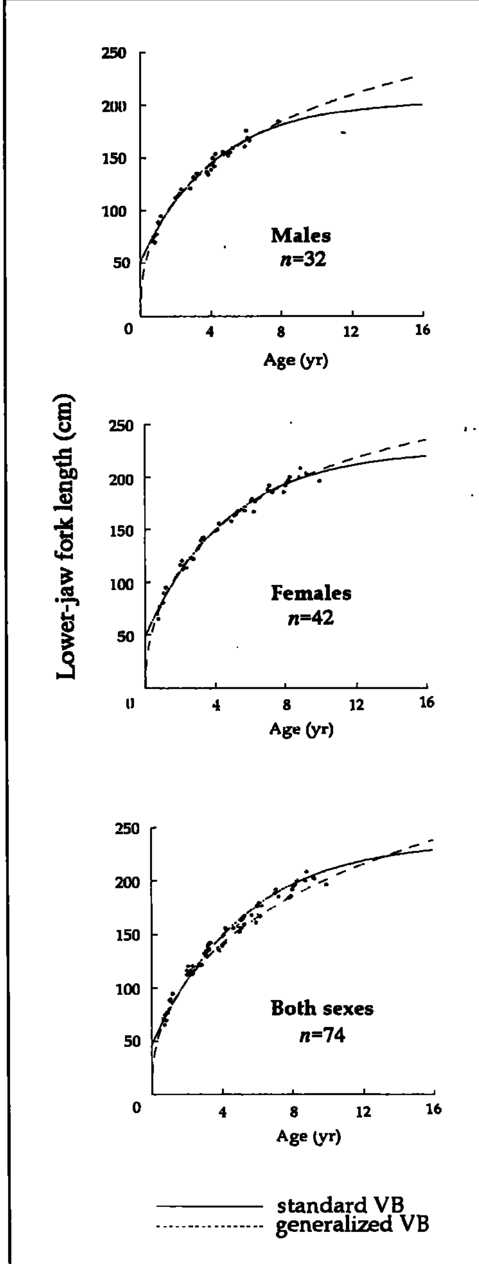

Figure 4

Standard and generalized von Bertalanffy (VB) growth curves for swordfish, *Xiphias gladius*, from the eastern Mediterranean; n = sample size.

Table 4

Estimated lower-jaw fork lengths (LJFL to nearest cm) at age for swordfish, *Xiphias gladius*, from studies in the Atlantic (A) and the Mediterranean (M).

	Berkeley and Houde (1983) (A)		Radtke and Hurley (1983) (A)		Wilson and Dean (1983) (A)		Ehrhardt (1992) (A)		Tsimenides and Tserpes (1989) (M)	
Age	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
1	97.2	98.0	84	73	116.9	122.9	89.7	89.8	103.2	103.1
2	118.5	119.9	98	85	123.3	130.6	117.0	118.9	129.5	129.1
3	136.0	139.7	110	114	130.2	138.8	137.3	142.9	148.1	149.3
4	150.4	157.8	122	131	137.4	147.5	153.4	161.3	161.4	165.0
5	162.3	174.3	133	147	145.0	156.8	168.9	177.2	170.8	177.3
6	172.0	189.3	143	160	153.0	166.6	181.8	189.6	177.5	186.8
7	180.0	202.9	153	172	161.5	177.1	195.3	204.4	185.2	194.2
8	186.6	215.3	161	183	170.4	188.2	206.1	214.7		

swordfish have no scales and otoliths are not amenable to traditional ageing techniques owing to their small size (Ovchinnikov, 1970; Becket, 1974). Successful otolith readings have been performed only through the application of scanning electron microscopy (Radtke and Hurley, 1983; Wilson and Dean, 1983). Moreover, the use of spines has the advantage that the material can be obtained relatively easily without reducing the economic value of the fish. The main problems associated with the spine method are the existence of multiple bands and the missing first annulus. An experienced reader can overcome the problem of multiple bands by determining whether they continue around the entire circumference of the spine and by recording their distance from the preceding and following annuli. The problem of the missing first annulus in larger fish can be resolved by identifying its position on sections from younger specimens where the annulus is visible. Difficulties in defining the location of the first annulus in older animals have also been reported for Atlantic swordfish (Berkeley and Houde, 1983) and Pacific blue marlin, *Makaira nigricans* (Hill et al., 1989).

Ehrhardt (1992) suggested that the standard von Bertalanffy growth function does not adequately represent the growth of swordfish and proposed the use of the generalized growth function of Chapman (1961). The present estimates of r^2 indicate that both models describe swordfish growth equally well over the age ranges considered and give almost identical results for the first eight years of growth (Fig. 4). Although the extrapolation of regression curves beyond the data is not advisable, it is interesting to note that the generalized model gives much more realistic results for ages less than one because it forces the growth curve to pass close to the origin of both axes. On the other hand, estimates of asymptotic length from this model are questionable because it is unlikely that females have lower asymptotic lengths than males, given that all the large animals in the sample were female. Therefore, the generalized model appears to overestimate asymptotic length (especially that of males).

Although results of both back-calculation methods generally agreed with the values predicted by the growth equations, the estimates of the nonlinear method are in slightly closer agreement (Table 3). The use of a nonlinear function for the LJFL spine-radius relation is preferable because it is more realistic for small animals, which have near zero spine-radius values and very small LJFL values. Ehrhardt (1992) also suggested the use of a nonlinear function to describe the LJFL spine-radius relation.

Growth studies carried out in the Atlantic together with previous work (Tsimenides and Tserpes, 1989) have shown that females grow faster than males (Table 4). Therefore, the calculation of a common growth equation is not valid and may be useful for management purposes only under certain circumstances. However, it should be noted that in previous work (Tsimenides and Tserpes, 1989), lengths at age were overestimated because the position of the first annulus was misidentified.

In the case of swordfish it seems that the use of a relatively wide range of size data and mean values for fitting the growth curves has resulted in relatively unbiased estimates of swordfish growth parameters in the eastern Mediterranean. Since all Mediterranean swordfish are proposed to belong to the same stock (Magoulas et al., 1993), our findings are appropriate for assessment studies of this stock. The use of the standard von Bertalanffy growth model is recommended for such studies because the generalized model overestimates the asymptotic length, an essential parameter for population dynamics models.

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