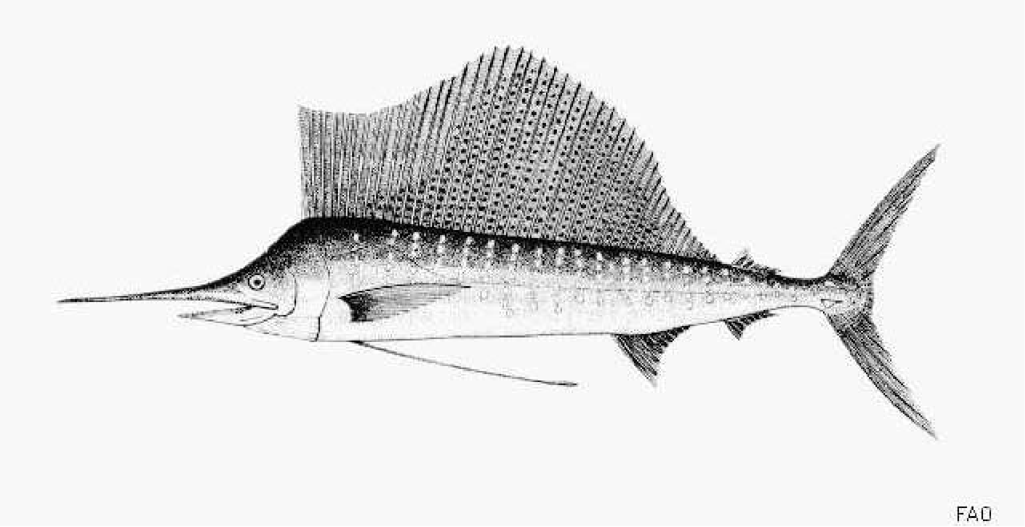
SCTB17 Working Paper

INF–BIO–1

Age and growth of sailfish (*Istiophorus platypterus*) in waters off eastern Taiwan


FAO

Wei-Chuan Chiang, Chi-Lu Sun, Su-Zan Yeh & Wei-Cheng Su

Institute of OceanographyNational Taiwan University, Taiwan
Taiwan Fisheries Research Institute, Taiwan

July 2004

Age and growth of sailfish (*Istiophorus platypterus*) in waters off eastern Taiwan

Wei-Chuan Chiang
Chi-Lu Sun
Su-Zan Yeh
Institute of Oceanography
National Taiwan University
No. 1, Sec. 4, Roosevelt Road
Taipei, Taiwan 106
E-mail address (for C. L. Sun, contact author): chilu@ntu.edu.tw

Wei-Cheng Su
Taiwan Fisheries Research Institute
No. 199, Ho-Ih Road
Keelung, Taiwan 202

Abstract—Age and growth of sailfish (*Istiophorus platypterus*) in waters off eastern Taiwan were examined from counts of growth rings on cross sections of the fourth spine of the first dorsal fin. Length and weight data and the dorsal fin spines were collected monthly at the fishing port of Shinkang (southeast of Taiwan) from July 1998 to August 1999. In total, 1166 dorsal fins were collected, of which 1135 (97%) (699 males and 436 females) were aged successfully. Trends in the monthly mean marginal increment ratio indicated that growth rings are formed once a year. Two methods were used to back-calculate the length of presumed ages, and growth was described by using the standard von Bertalanffy growth function and the Richards function. The most reasonable and conservative description of growth assumes that length-at-age follows the Richards function and that the relationship between spine radius and lower jaw fork length (LJFL) follows a power function. Growth differed significantly between the sexes; females grew faster and reached larger sizes than did males. The maximum sizes in our sample were 232 cm LJFL for female and 221 cm LJFL for male.

Manuscript approved for publication
22 December 2003 by Scientific Editor.

Manuscript received 20 January 2004
at NMFS Scientific Publications Office.

Fish. Bull. 102(2): 251–263 (2004).

The sailfish (*Istiophorus platypterus*) is distributed widely in the tropical and temperate waters of the world's oceans. According to data from longline catches, sailfish are usually distributed between 30°S and 50°N in the Pacific Ocean, and highest densities are found in the warm Kuroshio Current and its subsidiary currents. This species has a tendency to be found close to the coast and near islands (Nakamura, 1985). During the 1990s the annual landings of sailfish off Taiwan ranged between 600 and 2000 metric tons, of which approximately 54% came from waters off Taitung (eastern Taiwan). Sailfish are seasonally abundant from April to October (peak abundance from May to July) and contribute substantially to the economic importance of the eastern coast of Taiwan where this species is taken primarily by drift gill nets, although they are also caught by set nets, harpoons, and as incidental bycatch in inshore longline fisheries.

Age and growth of sailfish caught in recreational fisheries in the Atlantic Ocean have been studied by using various methods, including length-frequency analysis (de Sylva, 1957), analysis of release-recapture data (Farber[1]), and inferences from observed marks on hard parts, such as spines (Jolley, 1974, 1977; Hedgepeth and Jolley, 1983) and otoliths (Radtke and Dean, 1981; Radtke, 1983; Prince et al., 1986). In contrast, very few attempts have been made to age sailfish in the Pacific Ocean. Koto and Kodama (1962) estimated the growth of sailfish caught with longlines from 1952 to 1955 in the East China Sea using length-frequency analysis, and Alvarado-Castillo and Félix-Uraga (1996, 1998) used the fourth spine of the first dorsal fin to estimate age and growth of sailfish caught from 1989 to 1991 in the recreational fishery off Mexico. However, western Pacific sailfish have not been aged with calcified structures in any previous study.

The aging of fishes, and consequently the determination of their growth and mortality rates, is an integral component of modern fisheries science (Paul, 1992). Mortality and growth rates provide quantitative information on fish stocks and are needed for stock assessment methods such as yield-per-recruit and cohort analysis (Powers, 1983).

The objectives of this study were to estimate age and growth of sailfish by counting growth rings on cross sections of the fourth spine of the first dorsal fin and to determine which of the Richards function and the standard von Bertalanffy growth function best represents growth of sailfish in waters off eastern

---

[1] Farber, M. I. 1981. Analysis of Atlantic billfish tagging data: 1954–1980 Unpubl. manuscr. ICCAT workshop on billfish, June 1981. Southeast Fisheries Center Miami Laboratory, National Marine Fisheries Service, NOAA, 75 Virginia Beach Drive, Miami, FL 33149.

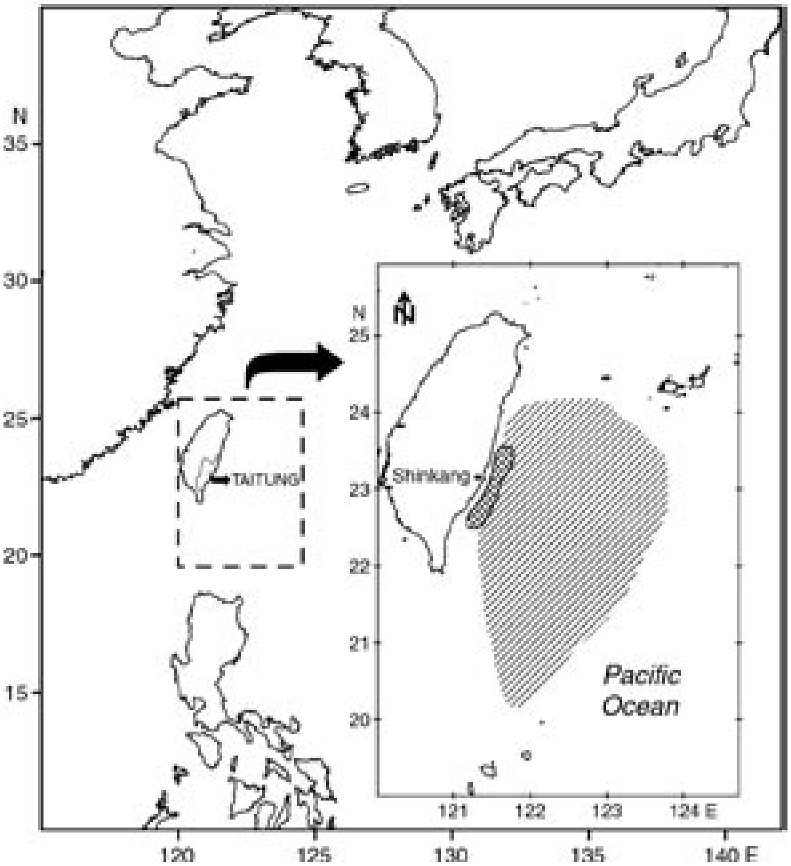


Figure 1

Fishing grounds of the gillnet (cross lines) and longline (oblique lines) fishing boats based at Shinkang fishing port.

Taiwan. This information could be used to determine the age composition of the catch and to assess the status of sailfish in these waters by using yield-per-recruit or sequential population analysis techniques.

Materials and methods

Materials

Data on total length (TL), eye fork length (EFL), lower jaw fork length (LJFL) (in cm), round weight (RW) (in kg) and the first dorsal fins of male and female sailfish were collected monthly at the fishing port of Shinkang (Fig. 1) from July 1998 to August 1999. In total, 304 TLs, 1166 LJFLs, 1166 RWs, and 1166 dorsal fins were collected. The dorsal fins were kept in cold storage before being boiled to remove surrounding tissue and to separate the fourth spines. Three cross sections (thickness 0.75 mm) were taken successively along the length of each spine with a low-speed "ISOMET" saw (model no. 11-1280) and diamond wafering blades, at a location equivalent to 1/2 of the maximum width of the condyle base measured above the line of maximum condyle width (Fig. 2A) (Ehrhardt et al., 1996; Sun et al., 2001, 2002). The sections were immersed in 95% ethanol for several minutes for cleaning, placed on disposable paper to air dry, and then stored in a labeled plastic case for later reading. Spine sections were examined with a binocular dissecting microscope (model: Leica-MZ6) under transmitted light at zoom magnifications of 10–20× depending on the sizes of the sections. The most visible one of these three sections was read twice, approximately one month apart. If the two ring counts differed, the section was read again, and if the third ring count differed from the previous two ring counts, the spine was considered unreadable and discarded. The precision of reading was evaluated by using average percent error (APE) (Beamish and Fournier, 1981; Campana, 2001) and coefficient of variation (CV) (Campana, 2001) statistics.

Images of the cross sections were captured by using the Image-Pro Image analysis software package (Media Cybernetics, Silver Spring MD, 1997) in combination with a dissecting microscope equipped with a charged coupled device (CCD) camera (model: Toshiba IK-630) and a Pentium II computer equipped with a 640×480 pixel frame grab card and a high-resolution (800×600 pixel) monitor.

The distance from the center of the spine section to the outer edge of each growth ring was measured in microns with the Image-Pro software package after calibration against an optical micrometer. The center of the spine

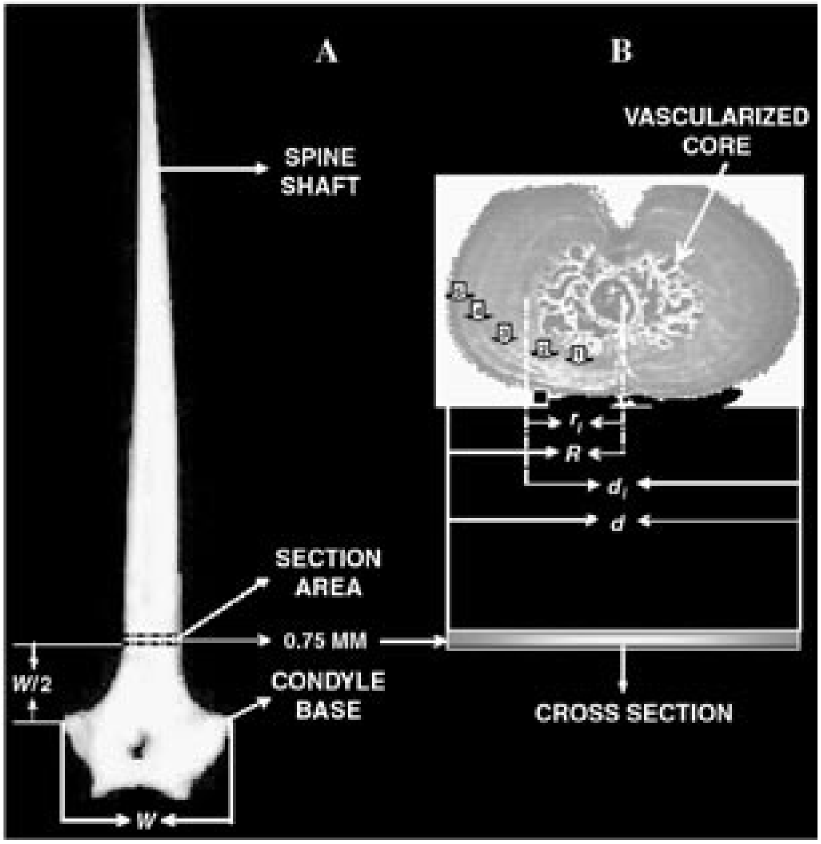


Figure 2

Schematic diagram of the fourth dorsal spine of sailfish (*I. platypterus*) and the location of the cross section (**A**), and a cross section showing the measurements taken for age determination of sailfish (**B**). W = maximum width of condyle base, R = radius of spine, r_i = radius of ring i, d = diameter of spine, d_i = diameter of ring i. The vascularized core and growth rings (1, 2, 3, 4, 5) are also shown.

section was estimated according to the methods of Cayré and Diouf (1983) (Fig. 2B). The distances (d_i) were then converted into radii (r_i) by using the equation (Megalofonou, 2000; Sun et al., 2001):

$$r_i = d_i - (d/2),$$

where r_i = radius of the ring i;
d_i = distance from the outside edge of ring i to the opposite edge of the cross section; and
d = diameter of the spine.

False growth rings were defined according to criteria of Berkeley and Houde (1983), Tserpes and Tsimenides (1995), and Ehrhardt et al. (1996).

Accounting for missing early rings

The first several growth rings of the larger specimens may be obscured because of the large size of the vascularized core of the spine. The number of early but missing growth rings was therefore estimated by the replacement method applied to Pacific blue marlin (*Makaira nigricans*) by Hill et al. (1989). This method involved first compiling ring radii statistics from younger specimens that had at least the first or second ring visible. Radii of the first four visible rings from samples that had missing early rings were then compared with the radii for these younger specimens. When the radii of at least two successive rings of the first four visible rings each fitted well within one standard deviation from the mean radii of each of two or more rings from the data compiled from the younger specimens, the number of missing rings was computed as the difference between the ring counts for the matched radii compiled from younger specimens and those for the specimen of interest.

Validation

The marginal increment ratio (MIR), which was used to validate the rings as annuli, was estimated for each specimen by using the following equation (Hayashi, 1976, Prince et al., 1988; Sun et al., 2002):

$$MIR = (R - r_n)/(r_n - r_{n-1}),$$

where R = spine radius; and
r_n and r_{n-1} = radius of rings n and $n-1$.

The mean MIR and its standard error were computed for each month by sex for all ages combined, and also for the ages 1–5 and 6–11 for males and 1–5 and 6–12 for females.

Growth estimation

Growth for males and females was estimated by back-calculation of lengths at presumed ages. Two methods were used. Method 1 was based on the assumption that the relationship between spine radius (R) and LJFL (L) is linear, i.e., $L=a_1+b_1R$ (Berkeley and Houde, 1983; Sun et al., 2002), whereas method 2 was based on the assumption that this relationship is a power function, i.e., $L=a_2R^{b_2}$ (Ehrhardt, 1992; Sun et al., 2002). The parameters of the relationships were estimated by maximum likelihood, assuming log-normally distributed errors. Akaike's information criterion (AIC, Akaike, 1969) was used to select which of the linear and power functions best represented the data:

$$AIC = -2\ln L + 2p,$$

where $\ln L$ = logarithm of likelihood function evaluated at the maximum likelihood estimates for the model parameters, and
p = number of model parameters.

The equations used to back-calculate the lengths at presumed ages were

$$L_n = \begin{cases} a_1 + \left(\dfrac{r_n}{R}\right)(L - a_1) & \text{linear relationship} \\ \left(\dfrac{r_n}{R}\right)^{b_2} L & \text{power relationship} \end{cases},$$

where L_n = LJFL when ring n was formed;
L = LJFL at time of capture; and
r_n = radius of ring n.

The standard von Bertalanffy growth function (standard VB) (von Bertalanffy, 1938) and the Richards function (Richards, 1959) were then fitted to the mean back-calculated male and female lengths-at-age from methods 1 and 2, assuming additive error.

Standard VB:

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

Richards function:

$$L_t = L_\infty\left(1 - e^{-K(1-m)(t-t_0)}\right)^{\frac{1}{(1-m)}},$$

where L_t = the mean LJFL at age t;
L_∞ = the asymptotic length;
t_0 = the hypothetical age at length zero;
k and K = the growth coefficients; and
m = the fourth growth-equation parameter.

An analysis of residual sum of squares (ARSS) was used to test whether the growth curves for the two sexes were different (Chen et al., 1992; Tserpes and Tsimenides, 1995; Sun et al., 2001), and the log-likelihood ratio test was used to determine whether the Richards function provided a statistically superior fit to the data than the length-at-age standard VB growth function.

Results

Of the 1166 dorsal spines sampled, 1135 (97%) (699 males and 436 females) were read successfully. The average percent error (APE) was 6.31% (5.91% for males and 6.93% for females) and the coefficient of variation (CV) was 8.93% (8.36% for males and 9.81% for females). Of the 31 spines that could not be read, 22 were considered unreadable because the existence of multiple rings made the identification of annuli difficult or resulted in aging discrepancies between readings, and the remaining nine spines were unreadable because of abnormal growth.

The length-frequency and weight-frequency distributions for the 1166 individuals are shown in Figure 3. These individuals ranged from 78 to 221 cm LJFL (mean=177.62, SD=16.13, n=720) or 1 to 49 kg RW (mean=22.13, SD=5.68) for the males and from 80 to 232 cm LJFL (mean=179.96, SD=17.90, n=446) or 2 to 58 kg RW (mean=23.65, SD=7.34) for the females. The females were significantly larger than the males (t-test, $P<0.05$). Table 1 summarizes the relationships between EFL and LJFL and TL, and that between LJFL and weight. The latter relationship differed significantly between males and females (analysis of covariance; $P<0.05$).

At least the first or second ring in 417 (60%) of male spines and 300 (69%) of female spines was visible. The ring radii statistics by sex is summarized in Figure 4. All other specimens were assigned inner rings and final age estimates based upon these data. The mean ring radii by age group, for males and females, after correction for missing early rings, are listed in Table 2. The maximum age of the sampled sailfish, after correction for missing early rings, was 11 years for males and 12 years for females. The maximum ages before correction were 8 years for both sexes.

The monthly means of the marginal increment ratio (MIR) for males of all ages during May–August were high (~0.72) but declined markedly thereafter and reached a minimum of 0.46 in November (Fig. 5). Similarly, the MIR for females dropped from 0.71 in September to a minimum of 0.47 in November (Fig. 6). The monthly means of MIR did not differ significantly from each other over the period December–March (ANOVA, $P_{♂}=0.86$, $P_{♀}=0.96$). However, the monthly means of MIR from April through August for males and from April through September for females were

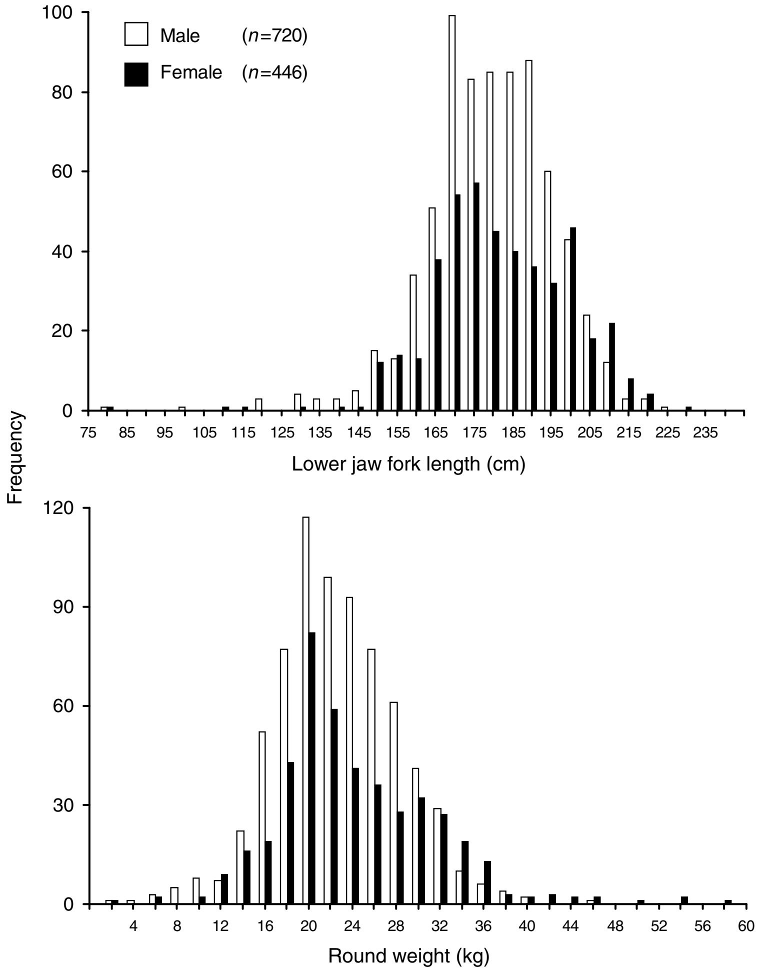


Figure 3

The size-frequency distributions by 5-cm intervals (upper figure) and by 2-kg intervals (lower figure) for male and female sailfish (*I. platypterus*) collected from the waters off eastern Taiwan.

significantly higher than those from September through November for males (t-test, $P<0.001$) and from October through November for females (t-test, $P<0.001$). Also, the mean MIR in November was significantly lower than that in December (t-tests, $P_{\text{♂}}<0.05$, $P_{\text{♀}}<0.05$). The trends in the monthly means of MIR when the data were split into ages 1–5 and 6+ were similar to those for all ages combined. The results in Figures 5 and 6 indicate that one growth ring is formed each year, most likely from September to November for males and from October to November for females.

Figure 7 shows the sex-specific relationships between LJFL and spine radius based on method 1 (linear regression) and method 2 (power function). The relationships for males and females are significantly different (method 1: $F_{698,435}=56.07, P<0.01$; method 2: $F_{698,435}=59.93, P<0.01$). According to AIC, the power function provides a better fit to the data (ΔAIC=38.57 and 30.96 for males and females, respectively). Therefore, the most parsimonious representation of the data is the power function with separate parameters for males and females.

The mean back-calculated lengths-at-age obtained from methods 1 and 2 are listed in Table 3. After the first year of life, the growth rates of both sexes slow appreciably. However, females still grow faster and consequently reach larger sizes than males. The standard VB and the Richards function for males and females are shown in Figure 8 and the corresponding parameter estimates are listed in Table 4. The growth curves for males differ significantly from those for females (F=99.86 $P<0.05$ and F=107.38 $P<0.05$ for the standard VB curve [methods 1 and 2], and F=144.01 $P<0.05$ and F=48.43 $P<0.05$ for the Richards function [methods 1 and 2]). The Richards function provides a statistically superior fit to the data (log-likelihood ratio test; $P<0.001$) when method 2 is used to back-calculate length-at-age but not when method 1 is used.

Table 1

Linear relationships ($Y=a+bX$) among total length (TL, cm), lower jaw fork length (LJFL, cm) and eye fork length (EFL, cm), and the log-linear length-weight (round weight, RW, kg) relationships for sailfish in the waters off eastern Taiwan. Values in parentheses are standard errors.

Y	*X*	*a*	*b*	*n*	LJFL range (cm)	RW range (kg)	r^2
Male							
TL	LJFL	19.660 (6.334)	1.205 (0.037)	184	78–211		0.854
TL	EFL	24.782 (6.176)	1.364 (0.042)	184	78–211		0.854
EFL	LJFL	–5.196 (0.772)	0.893 (0.004)	720	78–221		0.983
$\log_{10}$RW	$\log_{10}$LJFL	–5.381 (0.080)	2.985 (0.036)	720	78–221	1–46	0.906
Female							
TL	LJFL	6.728 (9.351)	1.286 (0.055)	120	109–210		0.824
TL	EFL	6.754 (9.505)	1.489 (0.064)	120	109–210		0.820
EFL	LJFL	–2.209 (0.802)	0.876 (0.004	446	80–232		0.989
$\log_{10}$RW	$\log_{10}$LJFL	–5.338 (0.103)	2.970 (0.046)	446	80–232	2–58	0.905

Discussion

Age estimate determined from dorsal-fin spines

Dorsal-fin spines appear to be useful for aging sailfish. They are easily sampled without reducing the economic value of the fish and can also be read easily (the growth rings stand out clearly). In contrast, scales cannot be used to age sailfish because scale deposition patterns change as sailfish age (Nakumura, 1985), and otoliths are extremely small and fragile and are often difficult to locate (Radtke, 1983). Reading otoliths is more time consuming and expensive than reading spines and spines can also be easily stored for future re-examination (Compeán-Jimenez and Bard, 1983; Sun et al., 2001, 2002).

The problems associated with the fin-spine aging method used in this study were the possible existence of false rings and the presence of the vascularized core which can obscure early growth rings in larger fish. These problems were also noted by Berkeley and Houde (1983), Hedgepeth and Jolley (1983), Tserpes and Tsimenides (1995), Megalofonou (2000), and Sun et al. (2001, 2002). However, Tserpes and Tsimenides (1995) and Megalofonou (2000) noted that experienced readers can overcome the problem of multiple rings by determining whether the rings are continuous around the circumference of the entire spine section and by judging their distance from the preceding and following rings. We observed false rings in spines for all age classes larger than age two, which we read without problem by using these guidelines. The missing early growth rings in larger specimens were accounted for by compiling ring radii statistics for younger specimens for which at least the first or second ring was visible and by comparing the radii of the first several visible rings of the specimens that had missing early rings to the mean radii and standard deviations of the compiled data. Similar approaches for solving the problem of missing rings have also been used for Pacific blue marlin (Hill et al., 1989).

Marginal increment ratio (MIR) analysis is the most commonly applied method for age validation (Campana, 2001). The MIR analysis conducted for sailfish suggested that one growth ring is formed each year from September to November for males and from October to November for females. Spawning for sailfish in the waters east of Taiwan lasts from April through September (Chiang and Sun[2]). This is exactly the period when growth is low, as indicated by the narrow and translucent rings. Similar findings have been reported for skipjack tuna (Antoine et al., 1983), swordfish (Ehrhardt, 1992; Tserpes and Tsimenides, 1995), and bigeye tuna (Sun et al., 2001). Although the timing of annulus formation coincides with spawning season for sailfish in the eastern Taiwan, annulus deposition

---

[2] Chiang, W. C., and C. L. Sun. 2000. Sexual maturity and sex ratio of sailfish (*Istiophorus platypterus*) in the eastern Taiwan waters. Abstracts of contributions presented at the 2000 annual meeting of the Fisheries Society of Taiwan, Keelung, Taiwan, 16–17 December 2000, 15 p. The Fisheries Society of Taiwan, 199 Hou-Ih Road, Keelung, 202 Taiwan.

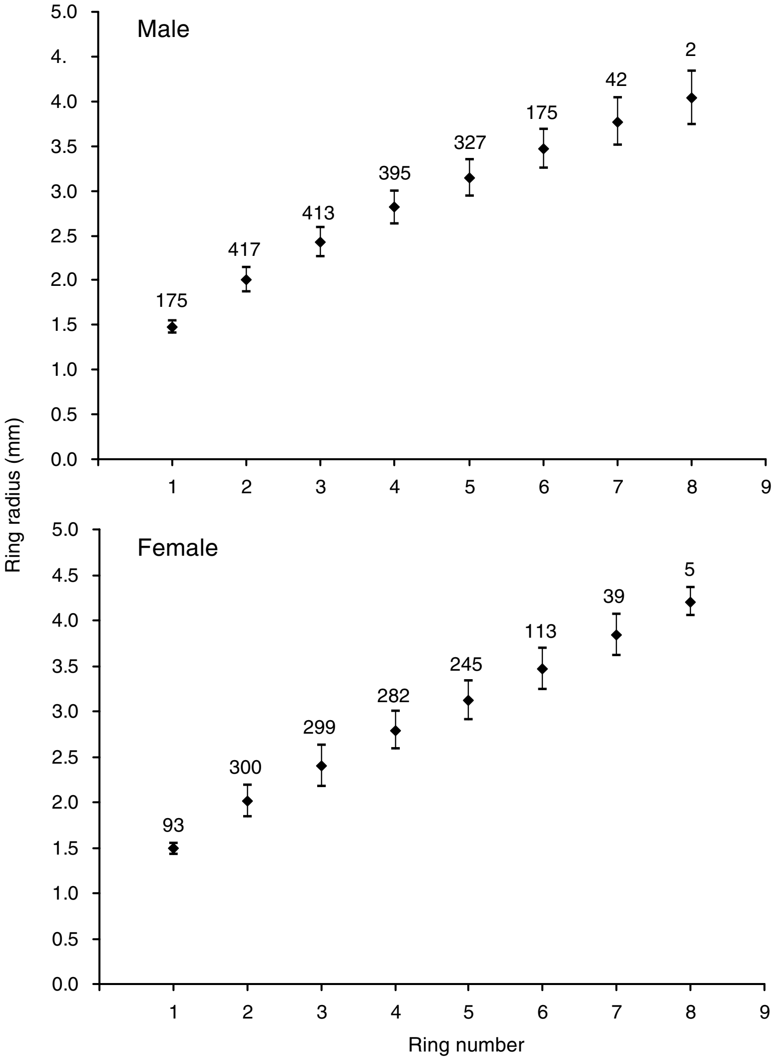


Figure 4

Mean (±1 SD) ring radius for male and female sailfish (*I. platypterus*) collected from the waters off eastern Taiwan that had at least the first or second ring present. The numbers above the vertical bars are the sample sizes.

may also be related to sailfish migration and environmental factors, as suggested by Sun et al. (2002) for swordfish. The MIR analysis provides only a partial age validation; complete validation requires either mark-recapture data or the study of known-age fish (Beamish and McFarlane, 1983; Prince et al., 1995; Tserpes and Tsimenides, 1995; Sun et al., 2001, 2002).

Selection of a growth curve

Female sailfish are typically larger for similar ages in males and grow faster than males, and the length-weight relationship differs significantly between the sexes. Similar results have been reported for east Pacific Ocean sailfish (Hernández-Herrera and Ramírez-Rodríguez, 1998), Indian Ocean sailfish (Williams, 1970) and Atlantic Ocean sailfish (Beardsley et al., 1975; Jolley, 1974, 1977; Hedgepeth and Jolley, 1983).

The Richards function appears to fit the data better than the standard VB curve (Fig. 8) and provides a more realistic description of growth for animals of age 0. The standard VB curve is commonly used to describe asymptotic growth in fish but did not fit the back-calculated lengths for fish younger than three (Table 4, Fig. 8).

Further discussion of growth curves will likely focus on method 2 (i.e., a power function relationship between spine radius and LJFL) because it provides a better fit to the data than method 1. Ehrhardt (1992), Ehrhardt et al.

Table 2

Mean radius of each ring for male and female sailfish in the waters off eastern Taiwan. Roman numerals indicate the number of rings. Numbers in parentheses are the number of specimens for which the specified ring was readable. "—"means no data owing to vascularization at core area.

Age class	Sample size	Mean radius (mm) of each ring											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Male													
1	1	1.54 (1)											
2	4	1.53 (4)	2.08 (4)										
3	18	1.45 (12)	2.02 (18)	2.51 (18)									
4	68	1.49 (45)	2.02 (68)	2.48 (68)	2.91 (68)								
5	171	1.48 (62)	2.00 (152)	2.40 (171)	2.79 (171)	3.14 (171)							
6	198	1.46 (41)	2.02 (133)	2.44 (188)	2.83 (198)	3.17 (198)	3.49 (198)						
7	130	1.42 (10)	1.96 (38)	2.42 (94)	2.80 (123)	3.18 (128)	3.50 (130)	3.82 (130)					
8	74	1.44 (1)	1.96 (4)	2.44 (36)	2.79 (62)	3.14 (72)	3.48 (74)	3.81 (74)	4.09 (74)				
9	22	—	—	—	2.69(11)	3.02 (16)	3.37 (22)	3.70 (22)	4.02 (22)	4.29 (22)			
10	9	—	—	—	—	—	3.09 (5)	3.55 (8)	3.39 (8)	4.23 (9)	4.48 (9)		
11	3	—	—	—	—	—	2.90 (2)	3.28 (2)	3.74 (3)	4.04 (3)	4.33 (3)	4.50 (3)	
Mean		1.47	2.00	2.43	2.81	3.16	3.48	3.79	4.05	4.25	4.45	4.50	
SD		0.07	0.14	0.16	0.18	0.20	0.22	0.23	0.23	0.21	0.15	0.15	
Growth increase			0.53	0.43	0.38	0.34	0.32	0.31	0.26	0.20	0.20	0.05	
Female													
1	1	1.51 (1)											
2	1	1.58 (1)	2.23 (1)										
3	17	1.44 (15)	2.00 (17)	2.47 (17)									
4	38	1.48 (17)	2.00 (37)	2.39 (38)	2.80 (38)								
5	146	1.49 (46)	1.98 (132)	2.39 (146)	2.80 (146)	3.12 (146)							
6	107	1.52 (11)	2.05 (74)	2.45 (102)	2.84 (107)	3.17 (107)	3.48 (107)						
7	64	1.52 (2)	2.08 (34)	2.55 (59)	2.95 (64)	3.29 (64)	3.60 (64)	3.89 (64)					
8	35	1.53 (1)	2.02 (4)	2.40 (10)	2.76 (29)	3.17 (33)	3.53 (34)	3.86 (35)	4.16 (35)				
9	17	—	1.91 (1)	2.36 (4)	2.79 (10)	3.07 (16)	3.40 (17)	3.76 (17)	4.07 (17)	4.38 (17)			
10	7	—	—	—	—	2.81 (4)	3.10 (7)	3.46 (7)	3.84 (7)	4.23 (7)	4.55 (7)		
11	1	—	—	—	—	—	3.31 (1)	3.82 (1)	4.25 (1)	4.44 (1)	4.74 (1)	4.95 (1)	
12	1	—	—	—	—	—	—	3.88 (1)	4.12 (1)	4.49 (1)	4.81 (1)	5.14 (1)	5.32 (1)
Mean		1.49	2.01	2.44	2.83	3.16	3.50	3.84	4.10	4.35	4.60	5.04	5.32
SD		0.06	0.17	0.25	0.23	0.24	0.27	0.27	0.29	0.32	0.41	0.13	
Growth increase			0.52	0.43	0.39	0.33	0.34	0.34	0.26	0.25	0.25	0.44	0.28

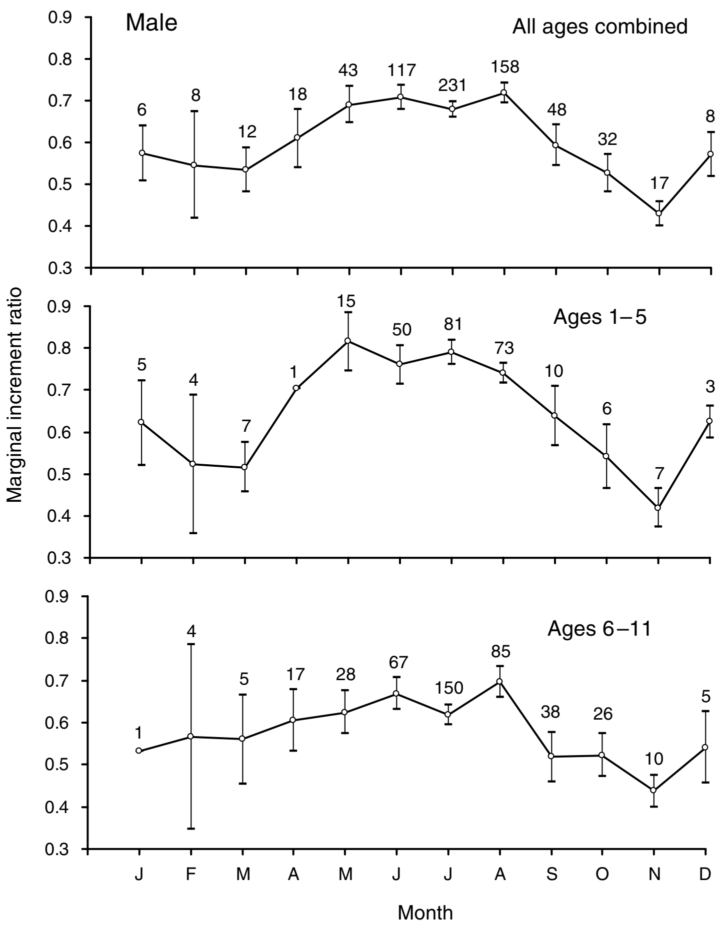


Figure 5

Monthly means of marginal increment ratio for male sailfish (*I. platypterus*) in the waters off eastern Taiwan for all ages combined and for age classes 1–5 and 6–11, respectively. Vertical bars are ±1 SE; numbers above the vertical bars are sample sizes.

Table 3

Mean back-calculated lower jaw fork lengths at age for sailfish in the waters off eastern Taiwan.

	Back-calculated length (cm)								
	Method 1		Method 2			Method 1		Method 2	
Age (yr)	Male	Female	Male	Female	Age (yr)	Male	Female	Male	Female
1	108.53	113.41	99.90	103.51	7	181.11	185.36	181.86	186.09
2	125.70	130.79	121.79	126.32	8	188.99	192.82	189.84	193.67
3	138.82	143.90	137.27	141.96	9	194.98	200.60	196.59	201.47
4	150.80	156.02	150.56	155.54	10	200.78	207.85	201.74	208.81
5	161.78	166.22	162.12	166.38	11	208.05	213.29	209.14	214.66
6	171.63	176.60	172.18	177.12	12		217.15		219.05

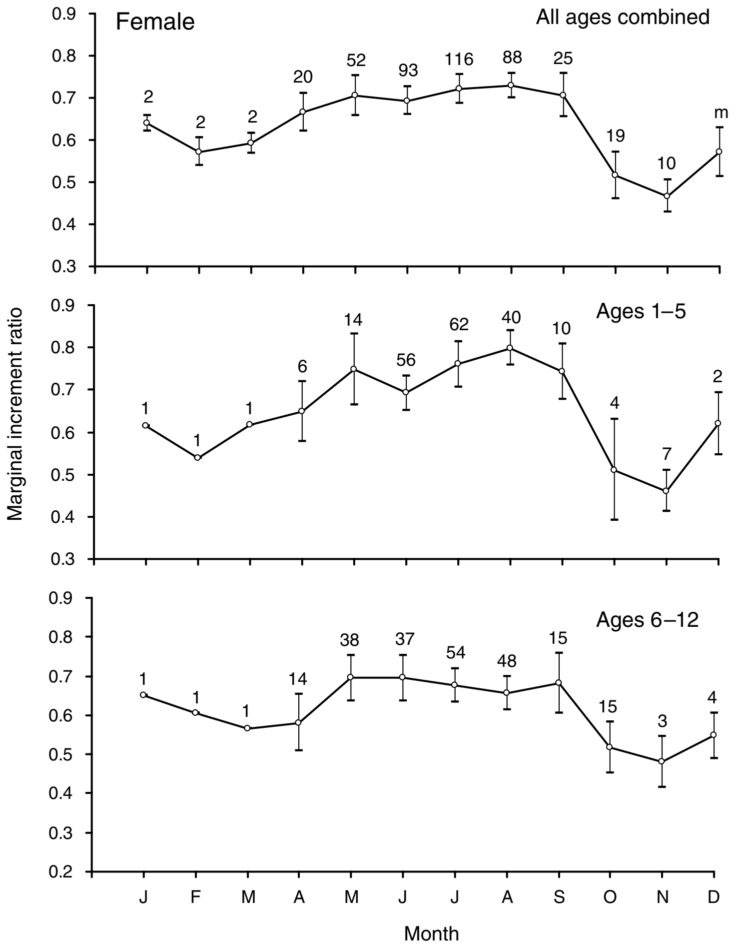


Figure 6

Monthly means of marginal increment ratio for the female sailfish (*I. platypterus*) in the waters off eastern Taiwan for all ages combined and for age classes 1–5 and 6–12, respectively. Vertical bars are ±1 SE; numbers above the vertical bars are sample sizes.

(1996), and Sun et al. (2002) favored method 2 because they believed it to be more biologically realistic. When the back-calculated lengths-at-age are generated with this method the Richards function provides a statistically superior fit to the length-at-age data. Therefore, the parameter estimates for the Richards function with method 2 listed in Table 4 are recommended as the most appropriate for calculating the age composition of sailfish in the waters to the east of Taiwan. It is perhaps worth noting that the t_0 values estimated for the Richards function with method 2 are much closer to zero than those estimated for the Richards function with method 1.

Comparison with previous studies

Figure 9 compares the age-length relationships of this paper with those for Atlantic (de Sylva, 1957; Hedgepeth and Jolley, 1983; Farber[1]) and Pacific sailfish (Koto and Kodama, 1962; Alvarado-Castillo and Félix-Uraga, 1998). De Sylva (1957) and Koto and Kodama (1962) used length-frequency analysis and concluded that sailfish are a very fast growing and short-lived species. However, they likely underestimated age and overestimated growth rate when their results are compared with those of other more recent studies.

The maximum ages found in this study (11 years for males and 12 years for females) are close to the maximum longevity of at least 13 years proposed by Prince et al. (1986) based on tagging data. Farber[1] analyzed Atlantic billfish tagging data and suggested that the asymptotic size was essentially reached by age 3 (Hedgepeth and Jolley, 1983), whereas the present study found a more gradual increase in length with age, in common with the results of Hedgepeth and Jolley (1983).

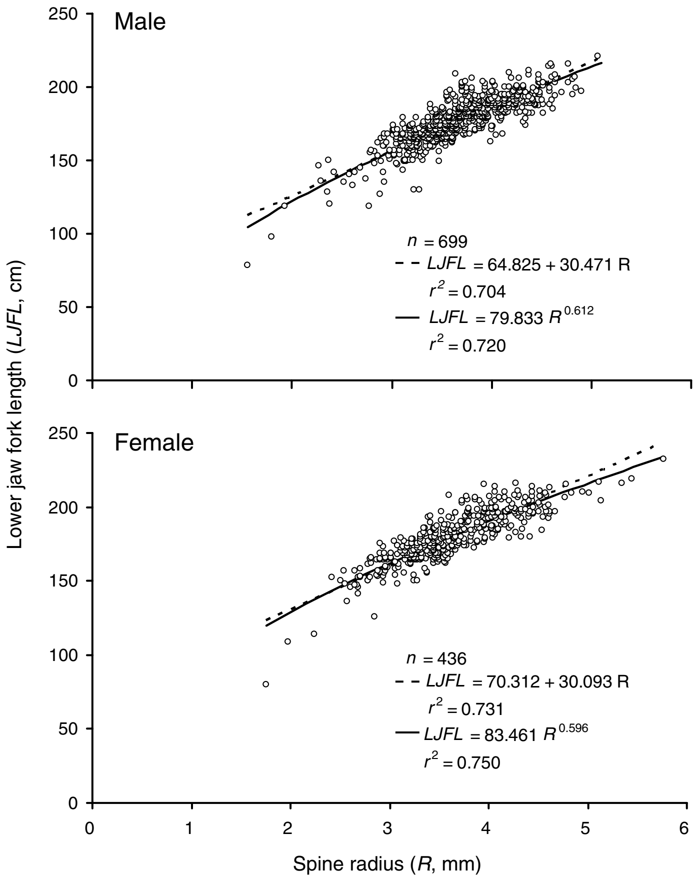


Figure 7

Relationship between lower jaw fork length and spine radius for male and female sailfish (*I. platypterus*) in the waters off eastern Taiwan.

Table 4

Parameter estimates and standard errors (in parenthesis) for the standard von Bertalanffy growth function and the Richards function for sailfish in the waters off eastern Taiwan.

	Standard von Bertalanffy growth function				Richards function			
	Method 1		Method 2		Method 1		Method 2	
Parameter	Male	Female	Male	Female	Male	Female	Male	Female
L_∞	252.6	261.4	240.4	250.3	271.8	280.4	294.0	343.8
	(3.652)	(3.397)	(3.794)	(4.278)	(22.713)	(19.882)	(29.607)	(47.921)
k	0.115	0.110	0.145	0.138				
	(0.005)	(0.004)	(0.008)	(0.008)				
t_0	–3.916	–4.207	–2.781	–2.990	–2.473	–2.608	–0.704	–0.468
	(0.143)	(0.147)	(0.154)	(0.186)	(0.931)	(0.896)	(0.279)	(0.186)
K					0.051	0.049	0.023	0.011
					(0.034)	(0.030)	(0.013)	(0.007)
m					–0.551	–0.578	–1.288	–1.639
					(0.472)	(0.436)	(0.308)	(0.243)

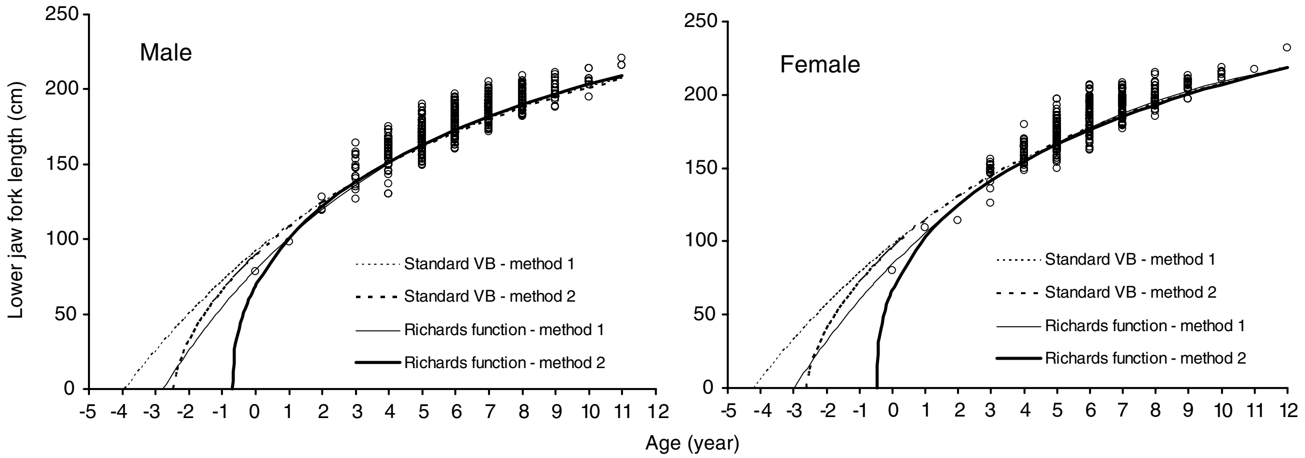


Figure 8

Observed and back-calculated length-at-age and standard von Bertalanffy and Richards function model-predicted growth curves for male and female sailfish (*I. platypterus*) in the waters off eastern Taiwan.

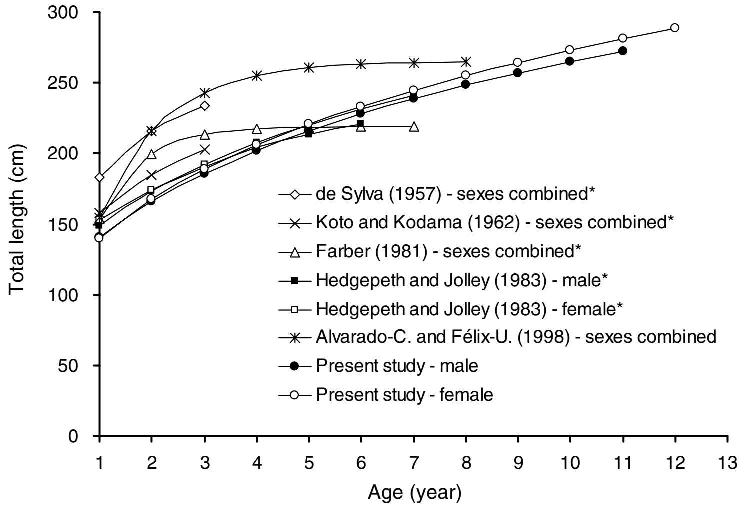


Figure 9

A comparison of the growth curves for sailfish (*I. platypterus*) estimated by different authors. (* Data from Table 1 of Hedgepeth and Jolley, 1983.)

Even though the aging method used in the present study is the same as that of Hedgepeth and Jolley (1983) and Alvarado-Castillo and Félix-Uraga (1998), there are nevertheless differences in the estimated length-at-age. This difference could be due to spatial differences in growth, the range of ages and sizes used in the analysis, or the form of the growth model applied. The size range in the present study is broader than those in previous studies and the growth curve is based on the Richards function rather than the standard VB function. Therefore, we believe that our growth parameter estimates are more appropriate for use in stock assessments of the sailfish population in the western Pacific Ocean.

Acknowledgments

The authors express sincere gratitude to André Punt, School of Aquatic and Fishery Sciences, University of Washington, for his valuable comments and comprehensive editing of the manuscript. This study was in part supported financially by the “Fisheries Agency, Council of Agriculture, Taiwan,” through grant 91AS-2.5.1-F1(7) to Chi-Lu Sun.

Literature cited

Akaike, H.
1969. Fitting autoregressive models for prediction. Ann. Inst. Stat. Math. 21:243–247.

Alvarado-Castillo, R. M., and R. Félix-Uraga.
1996. Age determination in *Istiophorus platypterus* (Pisces: Istiophoridae) in the south of the Gulf of California, Mexico. Rev. Biol. Trop. 44:233–239.
1998. Growth of *Istiophorus platypterus* (Pisces: Istiophoridae) from the south of the Gulf of California. Rev. Biol. Trop. 46:115–118.

Antoine, L. M., J. J. Mendoza, and P. M. Cayré.
1983. Progress of age and growth assessment of Atlantic skipjack tuna, *Euthynnus pelamis*, from dorsal fin spines. NOAA Tech. Rep. NMFS 8:91–97.

Beamish, R. J., and D. A. Fournier.
1981. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci. 38:982–983.

Beamish, R. J., and G. A. McFarlane.
1983. Validation of age determination estimates, the forgotten requirement. NOAA Tech. Rep. NMFS 8:29–33.

Beardsley, G. L., N. R. Merrett, and W. J. Richards.
1975. Synopsis of the biology of sailfish, *Istiophorus platypterus* (Shaw and Nodder, 1791). NOAA Tech. Rep. NMFS SSRF 675:95–120.

Berkeley, S. A., and E. D. Houde.
1983. Age determination of broadbill swordfish, *Xiphias gladius*, from the Straits of Florida, using anal fin spine sections. NOAA Tech. Rep. NMFS 8:137–146.

Campana, S. E.
2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. J. Fish. Biol. 59:197–242.

Cayré, P. M., and T. Diouf.
1983. Estimated age and growth of little tunny, *Euthynnus alletteratus*, off the coast of Senegal, using dorsal find spine sections. NOAA Tech. Rep. NMFS 8:105–110.

Chen, Y., D. A. Jackson, and H. H. Harvey.
1992. A comparison of von Bertalanffy and polynomial functions in modelling fish growth data. Can. J. Fish. Aquat. Sci. 49:1228–1235.

Compeán-Jimenez, G., and F. X. Bard.
1983. Growth of increments on dorsal spines of eastern Atlantic bluefin tuna, *Thunnus thynnus,* and their possible relation to migratory patterns. NOAA Tech. Rep. NMFS 8:77–86.

de Sylva, D. P.
1957. Studies on the age and growth of the Atlantic sailfish, *Istiophorus americanus* (Cuvier), using length-frequency curves. Bull. Mar. Sci. Gulf Caribb. 7:1–20.

Ehrhardt, N. M.
1992. Age and growth of swordfish, *Xiphias gladius*, in the northwestern Atlantic. Bull. Mar. Sci. 50:292–301.

Ehrhardt, N. M., R. J. Robbins, and F. Arocha.
1996. Age validation and estimation of growth of swordfish, *Xiphias gladius*, in the northwest Atlantic. ICCAT (International Commission for the Conservation of Tunas) Col. Vol. Sci. Pap. 45(2):358–367.

Hayashi, Y.
1976. Studies on the red tilefish in the east China sea—I. A fundamental consideration for age determination from otoliths. Bull. Jap. Soc. Sci. Fish. 42:1237–1242.

Hedgepeth, M. Y., and J. W. Jolley Jr.
1983. Age and growth of sailfish, *Istiophorus platypterus*, using cross section from the fourth dorsal spine. NOAA Tech. Rep. NMFS 8:131–135.

Hernández-Herrera, A., and M. Ramírez-Rodríguez.
1998. Spawning seasonality and length at maturity of sailfish (*Istiophorus platypterus*) off the Pacific coast of Mexico. Bull. Mar. Sci. 63:459–467.

Hill, K. T., G. M. Cailliet, and R. L. Radtke.
1989. A comparative analysis of growth zones in four calcified structures of Pacific blue marlin, *Makaira nigricans*. Fish. Bull. 87:829–843.

Jolley, J. W., Jr.
1974. On the biology of Florida east coast Atlantic sailfish, (*Istiophorus platypterus*). NOAA Tech. Rep. NMFS SSRF 675:81–88.
1977. The biology and fishery of Atlantic sailfish, *Istiophorus platypterus,* from southeast Florida. Fla. Mar. Res. Publ. 28, 31 p.

Koto, T., and K. Kodama.
1962. Some considerations on the growth of marlins, using size-frequencies in commercial catches. I. Attempts to estimate the growth of sailfish. Rep. Nankai. Reg. Fish. Res. Lab. 15:97–108.

Megalofonou, P.
2000. Age and growth of Mediterranean albacore. J. Fish. Biol. 57:700–715.

Nakamura, I.
1985. FAO species catalogue. Billfish of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes, and swordfishes known to date. FAO Fish. Synop. 125(5), 65 p

Paul, L. J.
1992. Age and growth studies of New Zealand marine fisheries, 1921–90: a review and bibliography. Aust. J. Mar. Freshw. Res. 43:879–912.

Powers, J. E.
1983. Some statistical characteristics of ageing data and their ramification in population analysis of oceanic pelagic fishes. NOAA Tech. Rep. NMFS 8:19–24.

Prince, E. D., D. W. Lee, C. A. Wilson, and S. A. Berkeley.
1988. Use of marginal increment analysis to validate the anal spine method for ageing Atlantic swordfish and other alternatives for age determination. ICCAT Col. Vol. Sci. Pap. 27:194–201.

Prince, E. D., D. W. Lee, C. A. Wilson, and J. M. Dean.
1986. Longevity and age validation of a tag-recaptured Atlantic sailfish, *Istiophorus platypterus*, using dorsal spines and otoliths. Fish. Bull. 84:493–502.

Prince, E. D., D. W. Lee, C. J. Cort, G. A. McFarlane, and A. Wild.
1995. Age validation evidence for two tag-recaptured Atlantic albacore, *Thunnus alalunga*, based on dorsal, anal, and pectoral finrays, vertebrae, and otoliths. *In* Recent developments in fish otolith research (D. H. Sector, J. M. Dean, and S. E. Campana, eds.), p. 375–396. Univ. South Carolina Press, Columbia, SC.

Radtke, R. L.
1983. Istiophorid otoliths: extraction, morphology, and possible use as ageing structures. NOAA Tech. Rep. NMFS 8:123–129.

Radtke, R. L., and J. M. Dean.
1981. Morphological features of the otoliths of the sailfish, *Istiophorus platypterus*, useful in age determination. Fish. Bull. 79:360–367.

Richards, F. J.
1959. A flexible growth function for empirical use. J. Exp. Bot. 10:290–300.

Sun, C. L., C. L. Huang, and S. Z. Yeh.
2001. Age and growth of the bigeye tuna, *Thunnus obesus*, in the western Pacific Ocean. Fish. Bull. 99:502–509.

Sun, C. L., S. P. Wang, and S. Z. Yeh.
2002. Age and growth of swordfish (*Xiphias gladius* L.,) in the waters around Taiwan determined from anal-fin rays. Fish. Bull. 100:822–835.

Tserpes, G., and N. Tsimenides.
1995. Determination of age and growth of swordfish, *Xiphias gladius* L., 1758, in the eastern Mediterranean using anal-fin spines. Fish. Bull. 93:549–602.

von Bertalanffy, L.
1938. A quantitative theory of organic growth (Inquiries on growth laws. II). Hum. Biol. 10:181–213.

Williams, F.
1970. The sport fishery for sailfish at Malindi, Kenya, 1958–1968, with some biological notes. Bull. Mar. Sci. 20(4):830–852.