Age and growth of the swordfish (*Xiphias gladius* L.) in the waters around Taiwan determined from anal-fin rays

Chi-Lu Sun
Sheng-Ping Wang
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): chilu@ccms.ntu.edu.tw

Abstract—Age and growth of the swordfish (*Xiphias gladius*) in Taiwan waters was studied from counts of growth bands on cross sections of the second ray of the first anal fin. Data on lower jaw fork length and weight, and samples of the anal fin of male and female swordfish were collected from three offshore and coastal tuna longline fishing ports on a monthly basis between September 1997 and March 1999. In total, 685 anal fins were collected and 627 of them (293 males and 334 females) were aged successfully. The lower jaw fork lengths of the aged individuals ranged from 83.4 to 246.6 cm for the females and from 83.3 to 206 cm for the males.

The radii of the fin rays and growth bands on the cross sections were measured under a dissecting microscope equipped with an image analysis system. Trends in the monthly marginal increment ratio indicated that growth bands formed once a year. Thus, the age of each fish was determined from the number of visible growth bands. Two methods were used to estimate and compare the standard and the generalized von Bertalanffy growth parameters for both males and females. The nonlinear least square estimates of the generalized von Bertalanffy growth parameters in method II, in which a power function was used to describe the relationship between ray radius and LJFL, were recommended as most acceptable. There were significant differences in growth parameters between males and females. The growth parameters estimated for females were the following: asymptotic length (L_∞) = 300.66 cm, growth coefficient (K) = 0.040/yr, age at zero length (t_0) = –0.75 yr, and the fitted fourth parameter (m) = –0.785. The growth parameters estimated for males were the following: asymptotic length (L_∞) = 213.05 cm, growth coefficient (K) = 0.086/yr, age at zero length (t_0) = –0.626 yr, and the fitted fourth parameter (m) = –0.768.

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The swordfish (*Xiphias gladius* L.) is a cosmopolitan species found in the tropical, subtropical, and temperate waters of the world's oceans and adjacent seas (Sakagawa, 1989). In the Pacific Ocean, swordfish is generally distributed from Asia to the Americas between 50°N and 50°S (Bartoo and Coan, 1989). In the waters of Taiwan, the swordfish is an incidental bycatch of the offshore tuna longline and harpoon fisheries. Both fisheries contributed an estimated 1528 metric tons (99%) to the total swordfish landings from Taiwan waters in 1999.

Information on age and growth of fishes is a central element in fishery management (Brothers, 1983). Measurement of the age of the fish provides the key variable of time needed to estimate life history and biology factors, such as mortality and growth. Mortality and growth-rate models provide quantitative information on the status of fish stocks and at the same time may be used in more sophisticated models, such as yield-per-recruit analyses and cohort analyses (Powers, 1983), which will directly contribute to the rational exploitation of fish resources, as well as to the development of proper management plans.

Most age determination studies of swordfish have dealt with Atlantic populations and have used different hard parts, such as anal-fin rays (Berkeley and Houde, 1983; Wilson and Dean 1983; Prince et al., 1988; Ehrhardt, 1992; Esteves et al., 1995; Ehrhardt et al., 1996), otolith (Radtke and Hurley, 1983; Wilson and Dean, 1983; Esteves et al., 1995), and vertebrae (Esteves et al., 1995). In contrast, only a few attempts have been made to determine the age of swordfish in the Pacific Ocean. Yabe et al. (1959) estimated the growth of swordfish caught in the western North Pacific (140°–160°E) by longline during the period from 1948 to 1956 using the modal analysis of length frequencies. Castro-Longoria and Sosa-Nishizaki (1998) compared the age estimates of swordfish caught by drift gillnet vessels off Baja California from 1992 to 1993 based on otolith microstructure and cross sections of the second ray from the first anal fin, and highly recommended the use of cross sections of the second ray to determine the ages of swordfish in the Pacific Ocean. Uchiyama et al. (1998) evaluated various hard parts (including rays of the first dorsal and first anal fins, vertebrae, and sagittae) for aging swordfish in the central North Pacific by Hawaii longline fishery from 1991 to 1993, and provided preliminary estimates of length-at-age.

The objectives of our study were to estimate the age and growth of swordfish by counting the growth rings on the cross sections of the second ray of the first anal fin and to compare the generalized growth function proposed by Richards (1959) with the standard von Bertalanffy model for representing the best growth model of swordfish around Taiwan waters. The information is crucial because it will allow the age composition of the catch to be determined, which in turn will allow the status of the swordfish stock in the

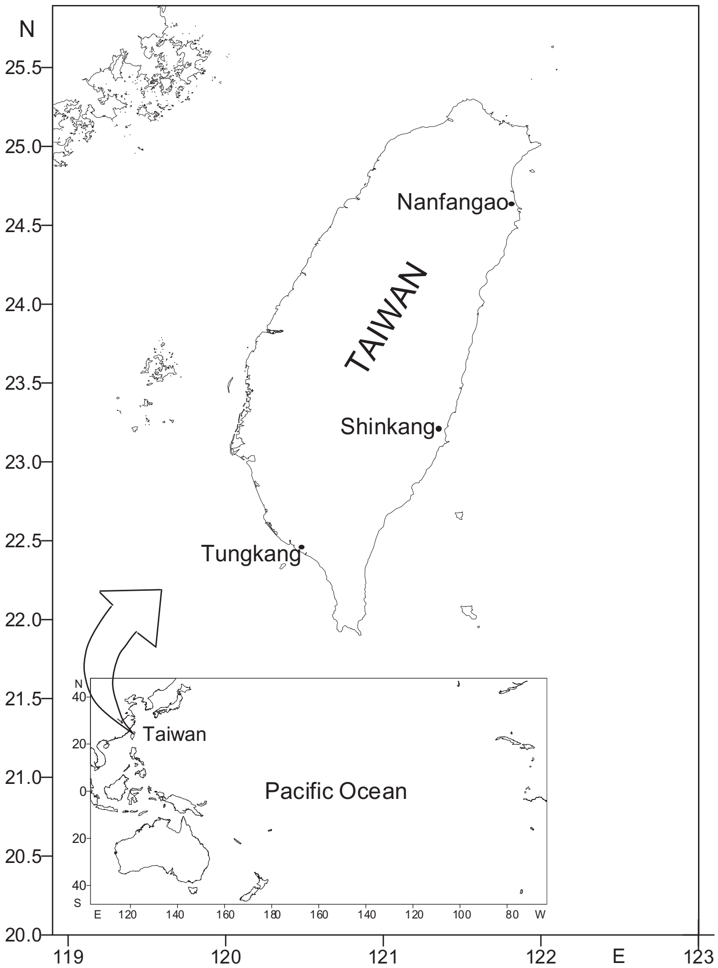

Figure 1

Three fishing ports in Taiwan where the swordfish anal-fin ray samples were collected in this study.

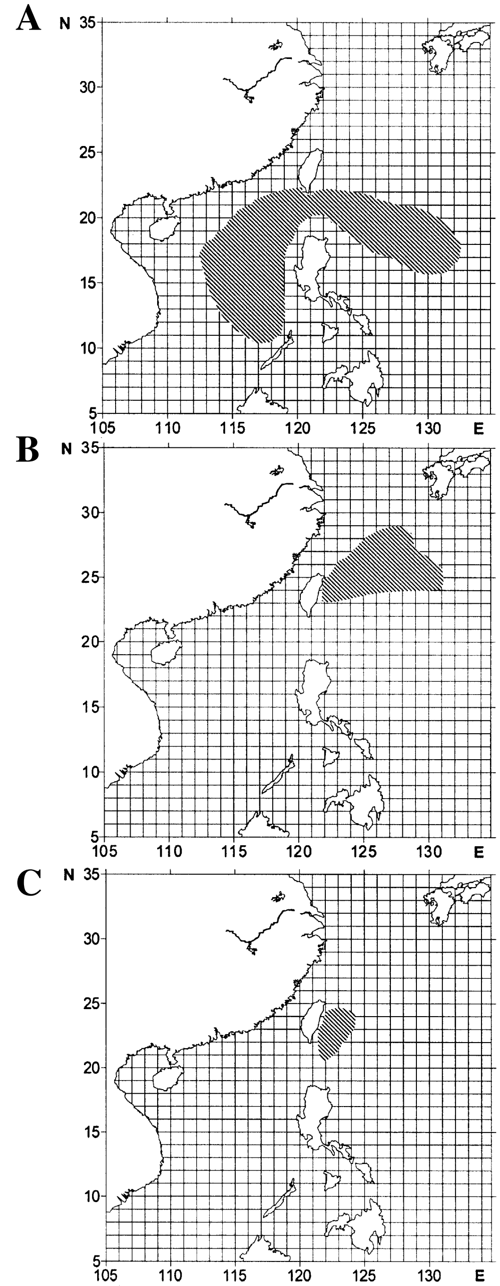

Figure 2

The fishing grounds (oblique dot lines) of the longline and harpoon fishing boats based in Tungkang (**A**), Nanfangao (**B**), and Shinkang (**C**) fishing ports.

waters around Taiwan to be assessed by using yield-per-recruit and sequential population analyses.

Material and methods

Data on lower jaw fork length (LJFL) and weight, and samples of the first anal fin of male and female swordfish were collected from three offshore tuna longline and harpoon fishing ports (Fig. 1) on a monthly basis between September 1997 and March 1999. The fishing grounds for those vessels are shown in Figure 2. In total, 769 LJFLs and 685 anal fins were collected. The anal fins were frozen for approximately one month before being thawed and boiled to remove the tissue and to separate the second rays. Three cross sections ranging in thickness from 0.5 to 0.75 to 1.0 mm were taken successively along the length of each ray 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. 3) (Ehrhardt, 1992; Ehrhardt et al., 1996). The sections were immersed in 95% ethanol for several minutes, placed in a labeled (with sampling date and a number) small plastic case to air dry, and then stored for later reading. Anal-fin ray sections were then taken from the small cases randomly and examined under a dissecting microscope (model: Leica MZ 6) with transmitted light at various

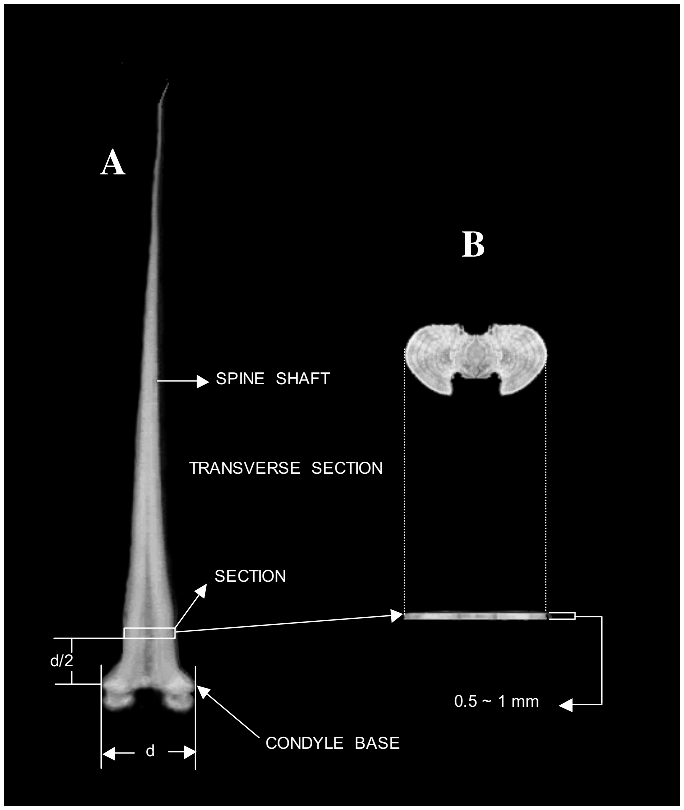

Figure 3

The second ray of the first anal fin showing the location of the cross section at a distance equal to a half of the width of the condyle base above the base (**A**), and a section of the second ray of the first anal fin (**B**).

magnifications from 8× to 16× depending on the size of the section. The clearest one of the three sections from each fin ray was read three times by one reader about one to three months apart with no knowledge of fish length. The precision of readings was evaluated as the average percent error (APE, Beamish and Fournier, 1981) and coefficient of variation (CV, Campana et al., 1995, 2001). For those sections resulting in three different readings, each section was reread by two to three readers simultaneously. Specimens whose age estimates still disagreed were omitted from further analyses.

The images of the anal-fin ray sections were captured by using an Image Analysis Software package (Media Cybernetics, 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 800 × 600 pixel monitor. The images were measured in microns after distance calibrations were incorporated. The distances from the focus to the distal edge of the section (ray radius) and from the focus to the distal edge of each growth band (annulus) were measured and recorded (Fig. 4). The focus, the growth band, and the false growth band (multiple bands) were defined according to Berkeley and Houde (1983), Tserpes and Tsimenides (1995), and Ehrhardt et al. (1996).

The marginal increment ratio (MIR), which was used to validate the reading of annuli, was estimated for each specimen by the following formula (Prince et al., 1988; Esteves et al., 1995):

$$MIR = (S - S_n)/(S_n - S_{n-1}),$$

where S = ray radius; and
S_n and S_{n-1} = the distance from ray focus to bands n and $n-1$, respectively.

The mean MIR and the standard deviation were computed for each month by sex for all ages combined and also for each age separately.

Growth was analyzed by using the back-calculation of length-at-age for each sex. For this purpose, a relationship was determined between the ray radius and the LJFL. This relationship and the distance from the focus

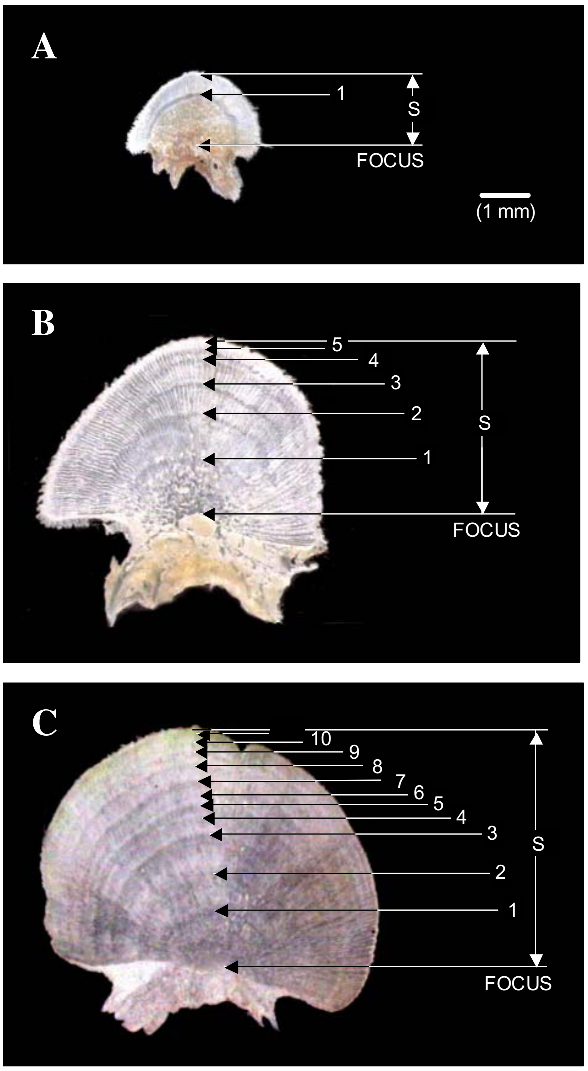

Figure 4

The section of three typical second anal fin rays of swordfish. Ray radius (S) measured from focus to edge; annuli for estimated age 1+ (**A**), age 5+ (**B**) and age 11+ (**C**).

to successive rings were used to back-calculate lengths at presumed previous ages (Ehrhardt, et al., 1996). For the relationship between ray radius and LJFL and the back-calculation of lengths-at-age, the following two methods were used.

Method I

The relationship between ray radius (S) and LJFL (L) was determined by using the standard linear regression procedure, $L = a + bS$ (Berkeley and Houde, 1983). This relationship and the distance from focus to successive growth bands, which we assumed to be based on annual growth events, were used to back-calculate the lengths at presumed ages by the following formula (Fraser, 1916):

$$L_n - a = \frac{S_n}{S}(L - a),$$

where L = LJFL at time of capture;
L_n = LJFL when band n was formed;
a = the intercept on the length axis from the regression line of length (L) on ray radius (S), e.g. $L = a + bS$; and
S_n = the distance from ray focus to band n.

Method II

The relationship between ray radius and LJFL was determined by using a power function procedure, $L = aS^b$ (Ehrhardt, 1992; Ehrhardt et. al., 1996). Parameters of this function were estimated by nonlinear least square fits to the observed data. This relationship and the distance from focus to successive growth bands were used to back-calculate the lengths at presumed ages by the following formula (Tserpes and Tsimenides, 1995; Ehrhardt et al., 1996):

$$L_n = \left(\frac{S_n}{S}\right)^b L,$$

where b = the exponent of the regression of length (L) on ray radius (S) which is assumed to be a power function of the form $L = a\,S^{\,b}$.

The data of the back-calculated length-at-age from method I and method II were then applied to the following standard von Bertalanffy growth equation (standard VB) and to the generalized growth function (generalized VB) (Richards, 1959):

Standard VB:

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

Generalized VB:

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

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 fitted fourth growth-function parameter.

Parameters of the above two equations for male and female were estimated, respectively, by fitting a curve to the observed back-calculated LJFL-at-age by using a nonlinear least square procedure (Gauss-Newton method, NLIN of SAS Institute, 1990). The measure of goodness-of-fit chosen was r^2. A multivariate statistical procedure (Hotelling's T^2) was used to test for differences in growth between males and females (Bernard, 1981) for the two growth models and two methods. The r^2 values were ranked between the two different growth functions with the smaller as 1. A nonparametric test (Friedman 1937, 1940) was then employed

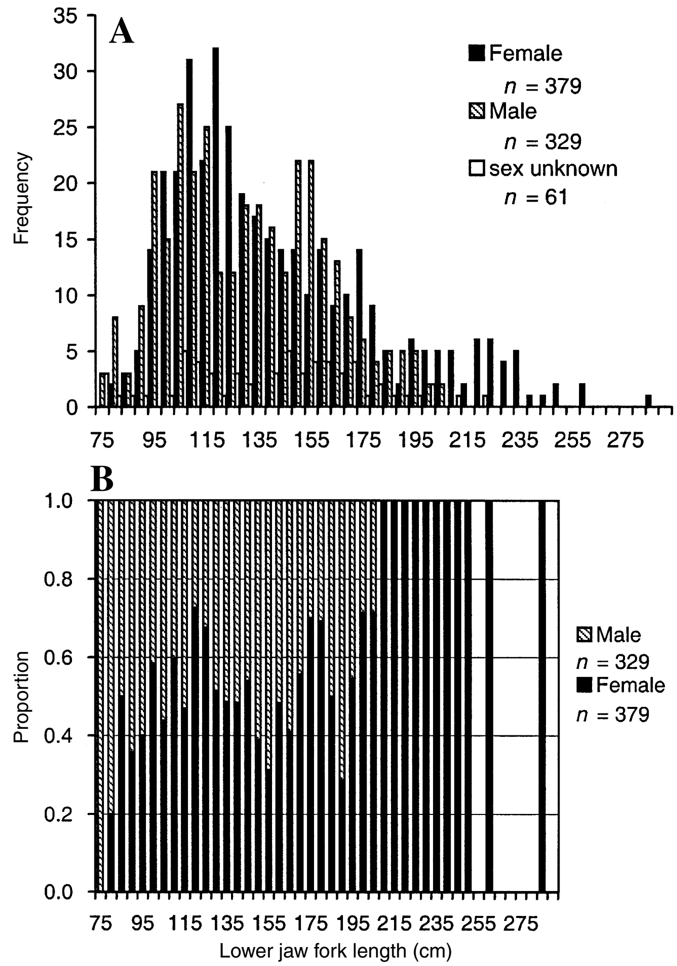

Figure 5

The size-frequency distribution by 5-cm intervals (**A**) and the proportions (**B**) of female and male swordfish collected from Tungkang, Nanfangao, and Shinkang fish markets, September 1997 to March 1999.

on the ranked results of r^2 to test the significance of the goodness-of-fit comparisons between the two growth functions (Chen et al., 1992). Friedman's test statistic χ^2_r was calculated with a correction for tied ranks (Zar, 1999). The association of rank ordering of r^2 values between the two growth functions was measured nonparametrically by using the Kendall coefficient of concordance (Kendall, 1962).

Results

Of the 685 anal fin rays sampled, 627 (334 females and 293 males) were aged successfully. The average percent error (APE) was 5.18% (5.09% for females and 5.29% for males) and the coefficient of variation (CV) was 8.50% (8.28% for female and 8.76% for males). The LJFL of the aged fish ranged from 83.4 to 246.6 cm for the females and from 83.3 to 206 cm for the males. The remaining 58 fin rays were considered unreadable mostly because the opaque-translution zonation was so unclear that annuli could not be defined (32 specimens); 7 specimens were unreadable because of the existence of multiple bands, which made the identification of annuli difficult or resulted in aging discrepancies between readings and readers; and 19 specimens were unreadable because of both the above factors.

For all the 769 swordfish with LJFL measured, individuals ranged from 83.4 to 290 cm for females and 78 to 206.6 cm for males (Fig. 5A). The proportion of the females (Fig. 5B) varied at sizes less than 195 cm, then increased to 100% at 210 cm and thereafter.

The relationship between LJFL and round weight for 227 specimens (sexes pooled) is shown in Figure 6; ANCOVA revealed no differences between males and females (P>0.05). The LJFL-EFL (eye fork length) conversion equation is $LJFL = 1.0647EFL + 7.7911$, with df = 563 and r^2=0.99.

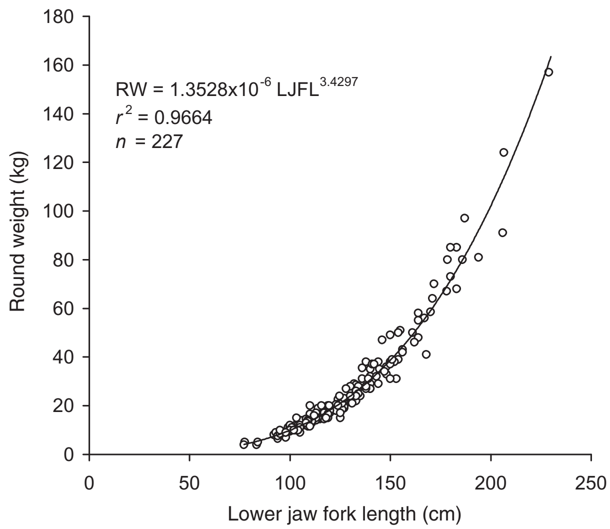

Figure 6

Relationship between round weight and lower jaw fork length for the swordfish collected from Shinkang fish market regardless of sex.

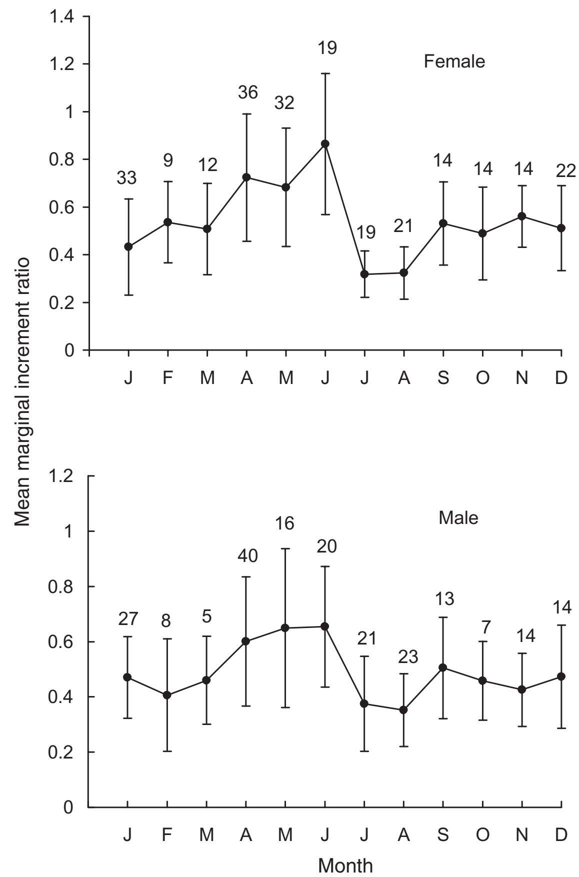

Figure 7

Monthly means of marginal increment ratio of female and male swordfish in the waters around Taiwan for all ages combined. Vertical bars are 1 SE, numbers on the top of vertical bars are sample sizes.

The monthly means of marginal increment ratio, MIR, for females with all ages combined, dropped drastically from the maximum of 0.86 in June to the minimum of 0.32 in July and August (Fig. 7). Similarly, the monthly means of MIR value for males declined sharply from the maximum of 0.65 in June to 0.37 and 0.35 in July and August. For both females and males, the monthly means of MIR during the period from September to March were not different (ANOVA, $P_{♀}$=0.95, $P_{♂}$=0.48), but the monthly means of MIR in April, May, and June were significantly higher than that in July or August, respectively (two sample *t*-tests, P<0.001). Also, the mean MIR in August was significantly lower than that in September (*t*-tests, $P_{♀}$<0.001, $P_{♂}$<0.01). The trends exhibited by monthly means of MIR for females and males for ages 2 to 5, respectively, were the same as those just described for all ages combined (Fig. 8). These patterns indicated the formation of one ring per year during the period from July to August. The MIR analysis by age was not performed for age 1 and ages greater than 5 because the formula used to determine MIR does not apply to samples less than or equal to age 1 and there was a lack of a sufficient number of samples for ages greater than 5.

The mean band radii, by band group for female and male, are shown in Table 1. The observed LJFLs of female and male swordfish were plotted against their corresponding ray radii for method I and method II, respectively (Fig. 9). The relationships between LJFL and ray radius are described as follows:

Method I Female: $LJFL = 21.137S + 65.091$ [r^2=0.8894, n=334];

Male: $LJFL = 19.966S + 68.160$ [r^2=0.8737, n=293].

Method II Female: $LJFL = 73.754S^{0.5193}$ [r^2 = 0.8753, n=334];

Male: $LJFL = 77.075S^{0.4772}$ [r^2=0.8742, n=293].

ANCOVA revealed significant differences in the relationship between the males and females for both methods (for method I, $F_{333,\,292}$=8.36, P<0.001; for method II, $F_{333,\,292}$ =15.59, P=0.004). The average back-calculated lengths-at-age obtained using method I and method II are shown in Table 2. Growth rates were higher during the first year of age (mean 95.2 cm and 96.1 cm LJFL for males and females, respectively, for method I, compared to 88.6 cm and 90.4 cm LJFL for males and females, respectively, for method II). After the first year of age, the growth rates of both sexes slowed appreciably. Growth rates of females were always higher than those of males, especially after the age of three. Also, the growth rates were always higher for method II than for method I except for the first year of age. Fitted standard VB and generalized VB growth

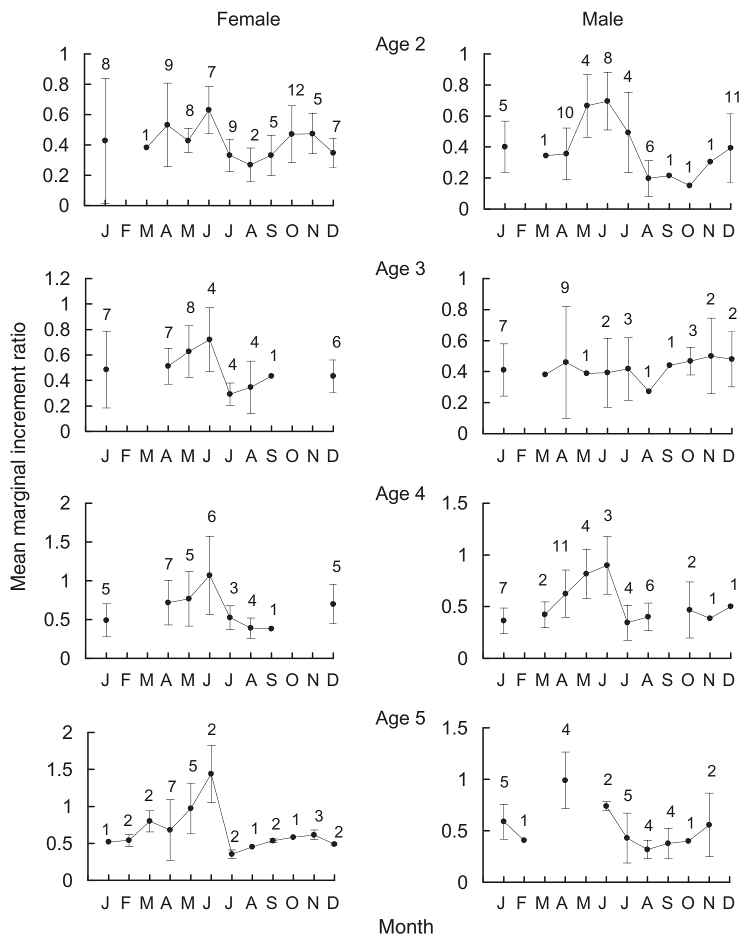

Figure 8

Monthly means of marginal increment ratio of female and male swordfish in the waters around Taiwan for ages 2 to 5 respectively. Vertical bars are 1 SE, numbers on the top of vertical bars are sample sizes.

curves for males and females with method I and method II back-calculation are shown in Figure 9, and the estimated parameters corresponding to each curve are shown in Table 3.

Hotelling's T^2 test results showed significant difference in growth parameters between female and male swordfish for either standard or generalized VB with either method I or method II back-calculation (Table 4). The calculated T^2 is considerably higher than the tabulated value in Table 4 for each case, and all the parameters, except for m of the generalized VB, significantly affect the differences in growth between male and female swordfish (The Roy-Bose simultaneous confidence intervals around differences between parameter values fail to include zero). The results of goodness-of-fit comparison showed that the generalized VB had larger r^2 ranks for method II, but had equal ranks with the standard VB for method I. Considering the tie rank groups in each sex-by-method, Friedman's χ^2_r statistics is 2 (n=4). This was not significant at the 5% level (i.e. χ^2=3.841, df=1), which indicated no significant difference in the r^2 rank ordering of the values between the two growth functions. Kendall's coefficient of concordance was 0.5 (n=4), which did not indicate a good agreement in the r^2 ranks for all sexes-by-method.

Discussion

Just as reported by Berkeley and Houde (1983), Radtke and Hurley (1983), Wilson and Dean (1983), Tsimenides and Tserpes (1989), Ehrhardt (1992), Tserpes and Tsimenides (1995), and Stone and Porter (1997), females in our study were typically larger than males although the length-weight relationship between the sexes did not differ significantly. The overall sex ratio for the sampling period in our study did not deviate significantly from 1: 1 (P<0.01) but differed substantially from the ratios of 2.3 females to 1 male and 2.7 females to 1 male reported respectively by Stone and Porter (1997) and Caton et al. (1998). This discrepancy may have been caused by the dif-

Table 1

Mean radius from focus to distal edge of each band of female (**A**) and male (**B**) swordfish in the waters around Taiwan. Roman numerals indicate the number of bands.

A

Band class	Sample size	Mean radius (mm) from focus to each band											
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0	2												
1	86	1.44											
2	76	1.44	2.38										
3	42	1.44	2.43	3.09									
4	39	1.51	2.34	3.08	3.52								
5	26	1.43	2.39	3.26	3.84	4.23							
6	20	1.51	2.35	3.14	3.77	4.24	4.75						
7	13	1.43	2.40	3.33	3.90	4.40	4.80	5.20					
8	13	1.58	2.60	3.47	4.10	4.52	4.95	5.39	5.84				
9	7	1.60	2.36	3.18	3.81	4.35	4.86	5.39	5.80	6.26			
10	2	1.49	2.37	3.35	3.96	4.46	4.84	5.33	5.64	6.21	6.66		
11	3	1.55	2.43	3.23	3.81	4.18	4.67	5.23	5.76	6.25	6.65	6.80	
12	5	1.50	2.44	3.30	3.88	4.41	5.02	5.39	5.94	6.29	6.69	6.98	7.24
Mean		1.49	2.41	3.24	3.84	4.35	4.84	5.32	5.80	6.25	6.66	6.89	7.24
SD		0.18	0.23	0.34	0.40	0.40	0.49	0.40	0.42	0.33	0.46	0.57	0.40
Growth increase			0.91	0.84	0.60	0.50	0.49	0.48	0.47	0.46	0.41	0.22	0.35

B

Band class	Sample size	Mean radius (mm) from focus to each band									
		I	II	III	IV	V	VI	VII	VIII	IX	X
0	2										
1	84	1.47									
2	57	1.32	2.16								
3	32	1.28	2.36	3.06							
4	43	1.31	2.32	3.04	3.51						
5	27	1.32	2.32	3.11	3.65	4.05					
6	22	1.32	2.44	3.21	3.71	4.11	4.47				
7	9	1.39	2.41	3.21	3.75	4.28	4.62	4.98			
8	8	1.33	2.52	3.24	3.82	4.26	4.66	5.02	5.37		
9	4	1.25	2.25	3.35	3.92	4.29	4.70	5.05	5.37	5.74	
10	5	1.40	2.36	3.16	3.93	4.41	4.80	5.11	5.47	5.76	6.06
Mean		1.34	2.35	3.17	3.76	4.23	4.65	5.04	5.40	5.75	6.06
SD		0.17	0.22	0.26	0.30	0.31	0.33	0.32	0.35	0.39	0.38
Growth increase			1.01	0.82	0.58	0.48	0.41	0.39	0.36	0.35	0.20

ference in size ranges of LJFL sampled for studying the sex ratio (Mejuto, et al., 1995). Most of the LJFL in our sample ranged between 100 and 185 cm, close to Arocha and Lee's (1995) middle size range within which the sex ratio was also almost 1:1 (Arocha and Lee, 1995). Besides the size range difference, the differences in geographical areas and seasons can also affect the sex ratio (Hoey, 1991; Mejuto et al., 1991). The proportion of females in our study, which increased to 100% at 210 cm and thereafter, was similar to those described by Turner et al. (1996), Stone and Porter (1997), and DeMartini et al. (2000).

Several genetic studies (Grijalva-Chon et al., 1994; Rosel and Block, 1996; Chow et al., 1997; Chow, 1998) have been unable to reject the hypothesis that swordfish comprise a single, homogenous population in the Pacific. However, from recent analyses of mtDNA, Reeb et al. (2000) concluded that swordfish are not homogenous in the Pacific. They found significantly different northern and southern populations in the western Pacific and several overlapping swordfish populations may occur in the eastern Pacific, making swordfish genetically continuous there. Gene flow between the populations occurs through

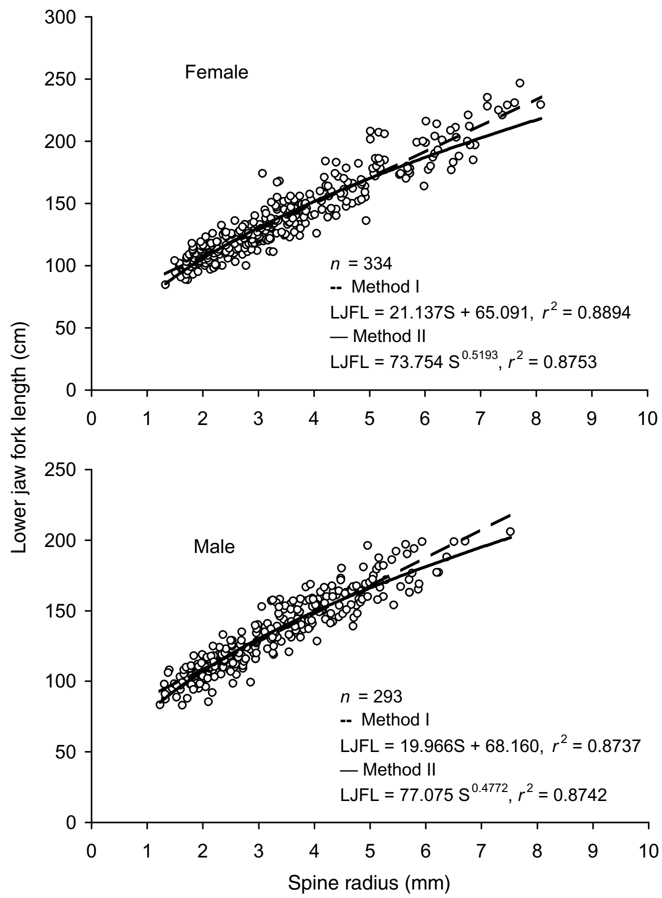

Figure 9

Relationship between LJFL and anal ray radius for female and male swordfish in the waters around Taiwan.

a horseshoe-shaped corridor, running between the northwestern Pacific, across to the eastern Pacific and back to the southwestern Pacific (Ward and Elscot, 2000). According to Reed's studies, the swordfish in our samples can be considered a part of the northern population in the western Pacific Ocean.

We found that anal-fin rays are useful for aging swordfish; they are easily sampled without reducing the economic value of the fish and can be read easily (the growth rings stand out clearly). This aging tool is especially important because swordfish lack scales and their very small otoliths are not amenable to traditional aging techniques (Ovchinnikov, 1971; Beckett, 1974; Tserpes and Tsimenides, 1995). Moreover, fin rays can be easily stored for future reexamination (Compeán-Jimenez and Bard, 1983). One problem associated with the fin-ray method used in our study, also indicated by Berkeley and Houde (1983) and Tserpes and Tsimenides (1995), was the possible existence of multiple bands and the missing first annulus in larger fish. However, González-Garcés and Fariña-Perez (1983) and Tserpes and Tsimenides (1995) noted that experienced readers could overcome the prob-

Table 2

Mean back-calculated lower jaw fork lengths at age for swordfish in the waters around Taiwan.

	Back-calculated length (cm)			
	Method I		Method II	
Age (yr)	Male	Female	Male	Female
1	95.19	96.07	88.60	90.35
2	114.86	115.70	114.96	116.18
3	131.88	133.41	133.80	136.47
4	143.12	146.30	145.22	150.35
5	152.14	157.99	154.40	162.91
6	159.15	169.95	161.36	175.34
7	165.60	180.48	167.84	186.40
8	174.76	190.14	176.87	195.83
9	184.00	198.40	185.23	204.62
10	190.89	207.79	191.58	214.15
11		215.06		220.58
12		222.15		226.62

Table 3

Parameter estimates for the standard von Bertalanffy and the generalized von Bertalanffy growth models for swordfish in the waters around Taiwan. Numbers in parentheses are standard errors.

	Standard von Bertalanffy growth model				Generalized von Bertalanffy growth model			
	Method I		Method II		Method I		Method II	
Parameter	Male	Female	Male	Female	Male	Female	Male	Female
L_∞	224.170 (12.802)	281.809 (6.805)	207.520 (8.465)	267.441 (6.517)	231.772 (26.937)	301.877 (11.068)	213.052 (19.153)	300.656 (38.869)
k	0.140 (0.025)	0.101 (0.006)	0.198 (0.031)	0.130 (0.009)				
K					0.066 (0.103)	0.060 (0.055)	0.086 (0.035)	0.040 (0.116)
t_0	–3.089 (0.523)	–3.204 (0.171)	–1.955 (0.406)	–2.302 (0.190)	–1.556 (2.942)	–2.036 (1.263)	–0.626 (1.196)	–0.750 (2.272)
m					–0.625 (2.388)	–0.409 (0.943)	–0.768 (1.730)	–0.785 (1.324)

Table 4

Results of the multivariate (Hotelling's T^2) tests for difference between the estimated von Bertalanffy growth parameters of female and male swordfish in the waters around Taiwan.

	Standard von Bertalanffy growth model		Generalized von Bertalanffy growth model	
	Method I	Method II	Method I	Method II
T^2	20715.1	56005.2	1614630	6782.34
df	3, 623	3, 623	4, 623	4,623
$T^2_{0.01,\mathrm{df}}$	11.48	11.48	13.46	13.46
99% CI for[1]				
$L_{\infty♀}–L_{\infty♂}$	53.842 ~ 61.436**	56.452 ~ 63.390**	68.845 ~ 71.365**	85.621 ~ 89.587**
$k_♀–k_♂$	–0.044 ~ –0.034**	–0.071 ~ –0.065**		
$K_♀–K_♂$			–0.008 ~ –0.004**	–0.050 ~ –0.042**
$t_{0♀}–t_{0♂}$	–0.216 ~ –0.014**	–0.406 ~ –0.288**	–0.542 ~ –0.418**	–0.163 ~ –0.085**
$m_♀–m_♂$			0.205 ~ 0.227**	–0.062 ~ 0.028

[1] Roy-Bose simultaneous confidence intervals around differences between parameter values.

** Indicates the parameter tested that significantly affects differences in growth between the females and the males at a significant level of 0.01.

lem of multiple bands by determining whether the bands were continuous around the circumference of the entire ray section and by judging their distance from preceding and following bands. In our study, 91 out of the 627 readable specimens had "multiple bands" that were read without a problem by using these criteria. Of the 26 discarded specimens that had multiple unreadable bands, most were found in swordfish larger than 200 cm in size. The missing first band in larger fish can be estimated from observations of its position on young specimens where the first band is visible. Similar approaches for solving the problem of missing band have also been used for Atlantic swordfish (Berkeley and Houde, 1983) and eastern Mediterranean swordfish (Tserpes and Tsimenides, 1995).

Results of marginal increment ratio analysis (Figs. 7 and 8) suggest one growth ring (annulus) is formed each year from July to August, which is toward the end of the spawning period for the swordfish in the north Pacific (Yabe et al., 1959). Although the timing of annulus deposition coincides with the swordfish's spawning season in the north Pacific, it may also be related to swordfish migration, as suggested by Berkeley and Houde (1983) for Atlantic swordfish and by Tserpe and Tsimenides (1995) for eastern Mediterranean swordfish. The relationship between annulus formation and migration for the western Pacific swordfish should be investigated. Others (Nelson and Manooch, 1982; Beckman et al., 1990; Sturm and Salter, 1990; Ferreira and Russ, 1994; Franks et al., 1999) have commented on the physiological nature of annulus formation and the importance of environmental factors, suggesting that reproduction may not be the sole determining factor in annulus deposition. Our results only partially validated age. Validation of ages requires either a mark-recapture study or the identification of known-age fish in the population (Beamish and McFarlane, 1983; Prince et al., 1995; Tserpes and Tsimenides, 1995; Sun et al., 2001).

According to Hotelling's T^2 analysis, the female and male swordfish in either method I or method II of both standard VB and generalized VB grew differently. Those of the generalized VB had a little larger r^2 ranks than those of the standard VB, although the goodness-of-fit of nonparametric analysis of r^2 ranks did not show a significant difference between two growth equations (P=0.22). In addition, the generalized VB appeared to fit the data well over the range of ages and it provided more realistic growth patterns for juveniles less than one year. However, the standard VB, commonly used to describe fish asymptotic growth, did not fit these data well, and generated grossly overestimated values for individuals less than one year (Table 3 and Fig. 10) (Ehrhardt, 1992; Ehrhardt et al., 1996).

In Table 3, the t_0 values estimated for the generalized VB with method II (i.e. a power function was used to describe the relationship between ray radius and LJFL) were much closer to zero than those estimated for the generalized VB with method I (i.e. a simple linear function was used to describe the relationship between ray radius and LJFL). Also, Ehrhardt (1992), Ehrhardt et al. (1996), and Tserpes and Tsimenides (1995) favored the power function (method II) because they believed its description to be more biologically realistic. Therefore, the parameter estimates for the generalized VB model with method II shown in Table 3 are recommended as the most acceptable for determining the age composition of swordfish in the waters around Taiwan.

Age-length relationships of swordfish (Fig. 11) are mostly based on Atlantic specimens (Berkeley and Houde, 1983; Radtke and Hurley, 1983; Wilson and Dean, 1983; Ehrhardt, 1992; Ehrhardt et al., 1996), and a few on Pacific samples (Yabe et al., 1959; Castro-Longoria and Sosa-Nishizaki, 1998; Uchiyama et al., 1998; Castro-Longoria[1]; Uchiyama[2]). Differences in estimates of growth parameters for males and females arise from the use of different hard parts, e.g. anal-fin rays (our study) versus otoliths (Radtke and Hurley, 1983; Wilson and Dean, 1983) or vertebrae (Esteves et al., 1995), artifacts of preparation, or interpretation. Even though we used the same method as Ehrhardt (1992), Tserpes and Tsimenides (1995), and Ehrhardt et al. (1996), observed difference could be related to geographical coverage of the studies. Our results were in the mid-range of previous estimates, well within the range of variation that might be expected due to the somewhat subjective nature of the processing, measuring, and interpreting of growth rings on fin rays. Therefore, we believe our growth parameter estimates are appropriate for use in assessment studies of the northern swordfish population in the western Pacific Ocean.

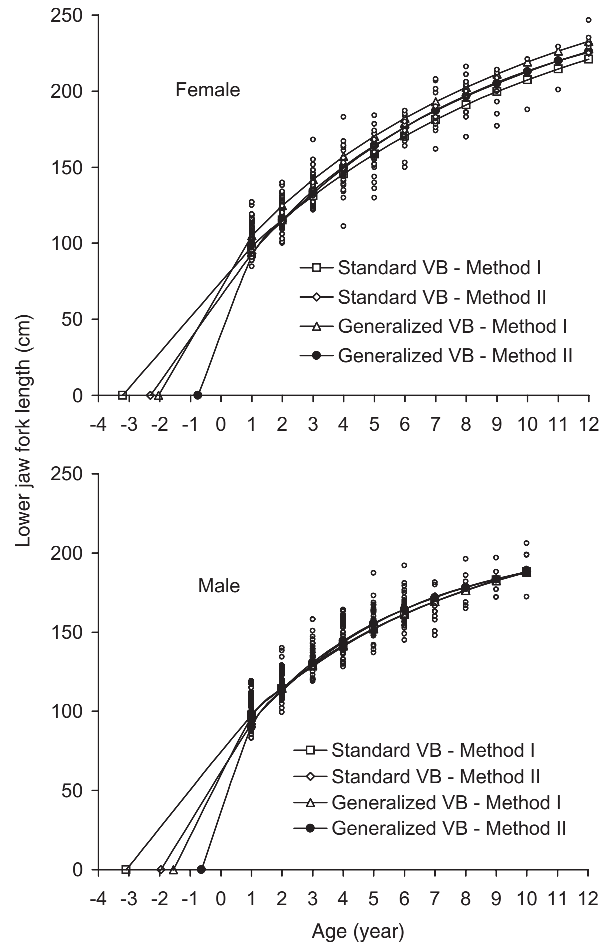

Figure 10

Standard and generalized von Bertalanffy growth curves for female and male swordfish in the waters around Taiwan.

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[1] Castro-Longoria, R. 2000. Personal communication of the length-at-age estimates mentioned in Castro-Longoria and Sosa-Nishizaki, 1998. Departmento de Investigaciones Científicas y Tecnológicas de la Universidad de Sonora, Rosales y Niños Héroes S/N, Hermosillo, Sonora, 83000 Mexico.

[2] Uchiyama, J. H. 2000. Personal communication of the length-at-age estimates mentioned in Uchiyama et al., 1998. Honolulu Laboratory, Southwest Fisheries Service Center, NOAA, 2570 Dole Street, Honolulu, Hawaii 96822-2396.

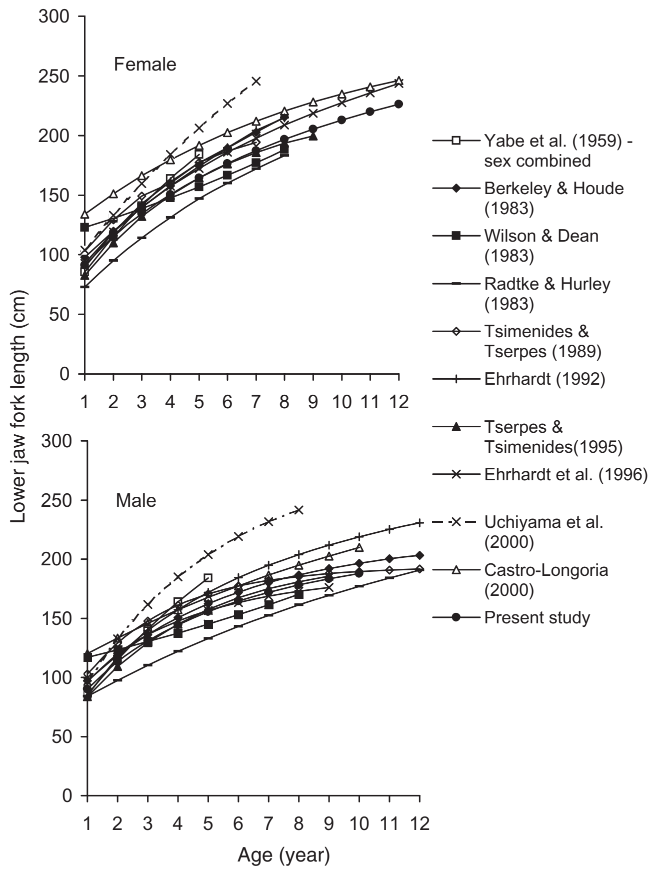

Figure 11

A comparison of the growth curves of female and male swordfish estimated by different authors.

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