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Chi-Lu Sun, Sheng-Ping Wang, and Su-Zan Yeh

Institute of Oceanography
National Taiwan University
Taipei, Taiwan

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Introduction

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 America at the latitudes between 50°N and 50°S (Bartoo and Coan 1989). In the waters of Taiwan, the swordfish is an incidental species caught primarily by offshore and harpoon fisheries. These two fisheries contributed an estimate of 1,489 metric tons or 88.6% of the total Taiwan swordfish catch in 1997. A few attempts have been made to determine the age of swordfish in the Pacific Ocean using model lengths and anal spines (Yabe *et al.* 1959, Uchiyama *et al.* 1995). The purpose of this study is to provide up to date estimates of the age and growth of swordfish by counting growth rings on the cross sections of the second anal fin spines. The information will allow us to determine the age-composition of the catch, and to assess the status of the swordfish stock in the waters of Taiwan by using yield-per-recruit and sequential population analyses.

Material and Methods

Data of weight and lower jaw fork length (LJFL), and samples of the second anal fins of male and female swordfish were collected from three offshore and coastal tuna longline fishing ports (Fig. 1) on a monthly basis between December 1997 and December 1998. In total, 584 anal spines were collected. The cross section was taken along the length of each spine above condyle base (Fig. 2A) using a low-speed "ISOMAT" saw. The thickness of the sections ranged from 0.5 to 1.0 mm (Fig. 2B). The sections were then examined under a dissecting microscope with transmitted light and various magnifications depending on the size of the section.

The images of the anal spine sections were captured using the Image-Pro Plus Image Analysis Software package in combination with a dissecting microscope with a CCD camera and a high resolution computer monitor. The images were measured in microns using the software package after distance calibrations were incorporated. The distances from the focus to the edge of the section (spine radius) and from the focus to each growth band were measured and recorded (Fig. 3).

Age validation was made by observing the nature (translucent or opaque) of the edge of anal spine sections (Antoine *et al.* 1983). The proportion of translucent edges was calculated per month.

For the relationship between spine radius and LJFL, the following two cases were studied:

Case 1 -- The relationship between spine radius and LJFL was determined using the standard linear regression procedure (Berkeley and Houde, 1983). The relationship and the distance from focus to successive growth bands, which we assumed to be annual events, were used to back-calculate the lengths at presume ages:

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

where L is LJFL at time of capture, L_n is LJFL when band n was formed, a is the intercept on length axis from the regression line of length on spine radius, S_n is the distance from spine focus to band n, and S is the spine radius.

Case II. – The relationship between spine radius and LJFL was determined using a power function procedure (Ehrhardt 1992, Ehrhardt *et al.* 1996). Parameters of this function were estimated by non-linear least square fits to the observed data. This relationship and the distance from focus to successive rings were used to back-calculate the lengths at presumed ages from the following formula (Tserpes and Tsimenides 1995, Ehrhardt *et al* 1996):

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

where b is the exponent of the regression of length (L) on spine 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 Case I and Case II were then applied to the following standard von Bertalanffy growth equation (Standard VB) and 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 is the mean LJFL at age t, L_∞ is the asymptotic length, t_0 is the hypothetical age at length zero, k and K are the growth coefficients, and m is the fitted growth function parameter.

Parameters of above two equations were estimated, respectively, by fitting a curve to the observed back calculated LJFL-at-age using non-linear least square procedure.

Results and Discussion

Of the 584 swordfish sampled, 572 (264 males and 308 females) were aged successfully. The lengths of the individuals ranged from 83.4 to 253.1 cm for the females and 83.3 to 206.6 cm for the males (Fig. 4a). The proportion of the females (Fig. 4b) was variable at sizes less than 206.6 cm, then increased to 100% at 207 cm, above which all were female.

The relationship between LJFL and round weight for both sexes combined of 213 samples is shown in Fig. 5. ANCOVA revealed no significant difference in the relationship between the males and females (P>0.05). The trend of monthly percent terminal translucent edges was shown in Figure 6. It suggests that from January to June there was a long period of inhibited growth (translucent edge). From July to August, growth appears to resume (opaque edge) and later from September to December a new translucent edge appeared. This pattern suggests the formation of one ring a year during July and August.

The observed LJFL's of female and male swordfish are plotted against their corresponding spine radii in Case I and Case II, respectively (Figs. 7 and 8). The average back-calculated length-at-ages obtained in Case I and Case II are shown in Table 1. Growth rates were higher during the first year of age (mean 94.86 cm and 94.34 cm for males and females, respectively, in Case I, and 89.18 cm and 87.30 cm for males and females, respectively, in Case II). After the first year of age, the growth rates of both sexes slowed down appreciably. Fitted growth curves for males and females are shown in Fig. 9, and the estimated parameters corresponding to each curve in Case I and Case II are shown in Table 2. The generalized growth function appears to fit the data well over the range of ages and it provides more realistic growth pattern for juveniles of ages less than one year. On the other hand, the standard von Bertalanffy growth equation, commonly used to describe fish asymptotic growth, didn't fit this data well, and generated grossly overestimated expected values for individuals less than one year (Table 2 and Fig. 9) (Ehrhardt 1992, Ehrhardt *et al.* 1996).

In Table 2, the t_0 values estimated by generalized von Bertalanffy function in Case II (i.e. a power function is used to describe the relationship between spine radius and LJFL) are much smaller than those estimated by generalized growth function in Case I (i.e. a simple linear function is used to describe the relationship between spine radius and LJFL). Also, Ehrhardt (1992), Ehrhardt *et al.* (1996), and Tserpes and Tsimenides (1996) considered that the use of a power function (Case II) to describe the LJFL-radius relation is more biologically realistic and suggested to use it. Therefore, the parameter estimates for generalized von Bertalanffy model in Case II shown in Table 2 were the best estimates in this study and were recommended as most acceptable for determinating the age composition of the swordfish in the waters around Taiwan.

Fig. 10 shows the grow curves of swordfish estimated by various investigators. Most of these studies were made in the Atlantic Ocean by using anal fin spines and sagittae (Berkeley and Houde 1983, Ehrhardt 1992, Ehrhardt *et al.* 1996, Wilson and Dean 1983, Radtke and Hurley 1983), and very few studies in the Pacific Ocean (Yabe *et al.* 1959, Uchiyama *et al.* 1995). Our method is the same as Ehrhardt (1992), Tserpes and Tsimenides (1995), and Ehrhardt *et al.* (1996), but our results did not well coincide with theirs. This could be due to difference in stock and environmental factors, and a further investigation is needed.

Acknowledgements

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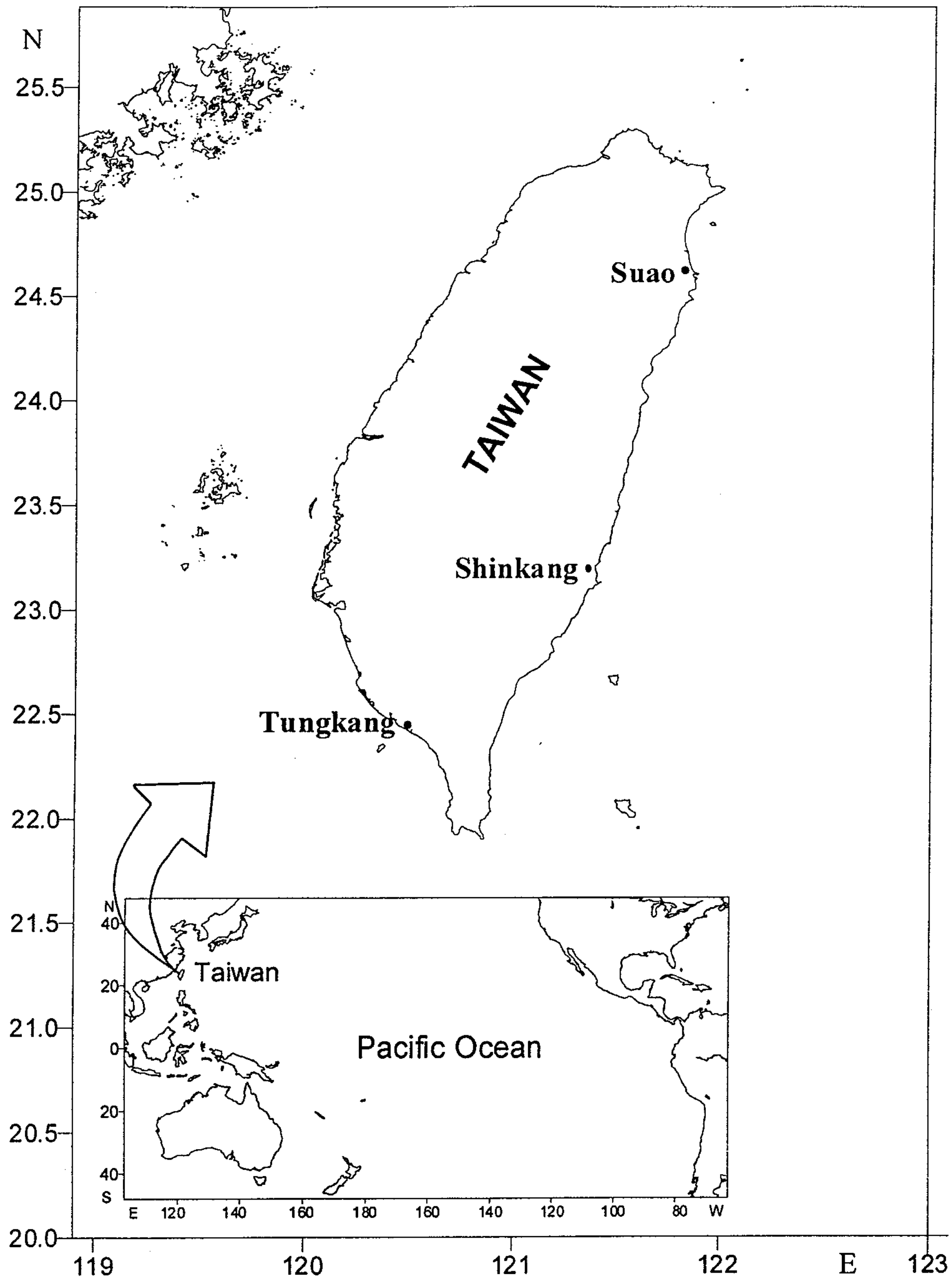

Fig. 1. Three fishing ports in Taiwan where the swordfish anal fin spine samples were collected in this study.

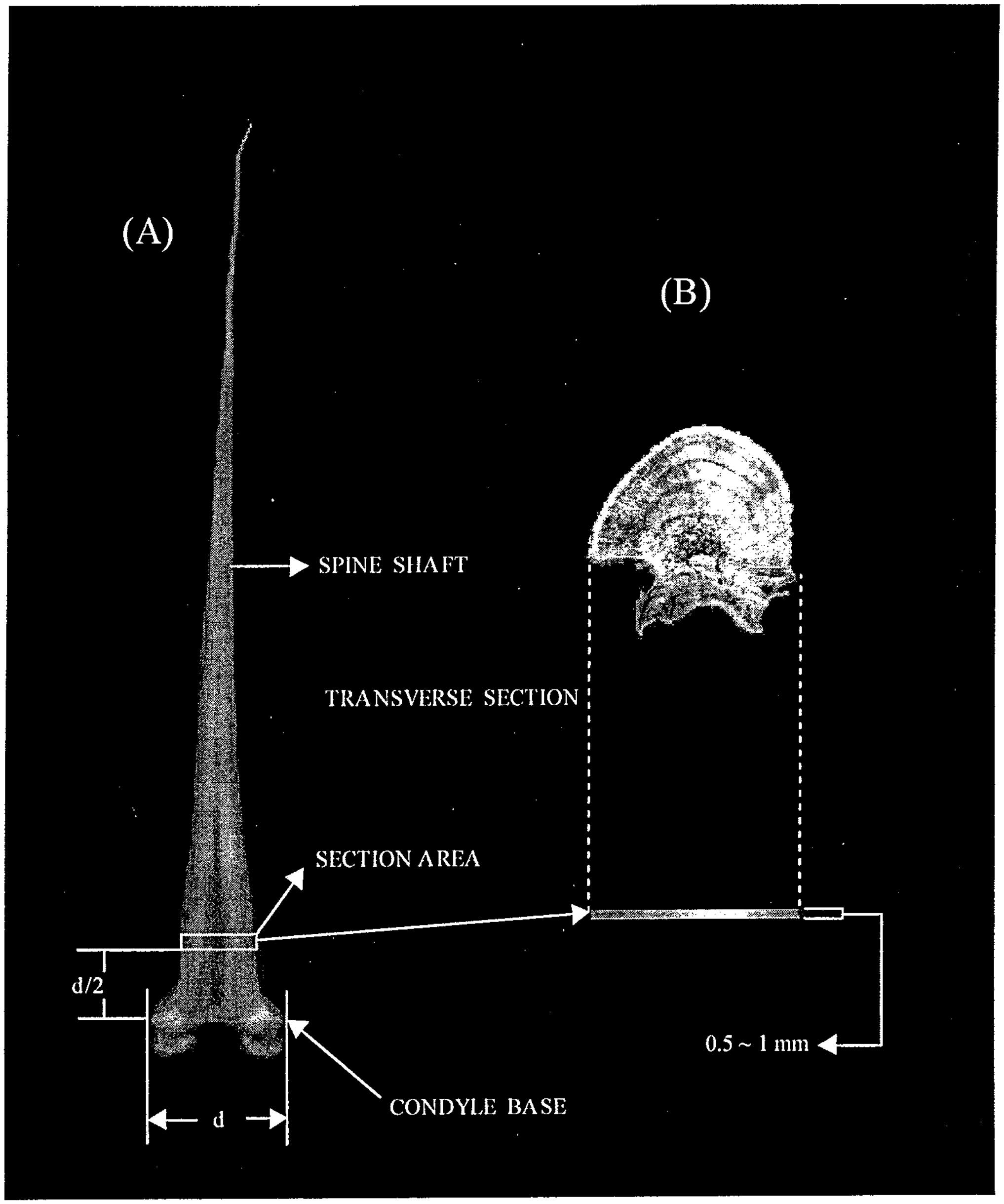

Fig. 2. The second anal fin spine showing the location of cross section at a distance equal to half the width of the condyle base above the base (A), and a section of second anal fin spine (B).

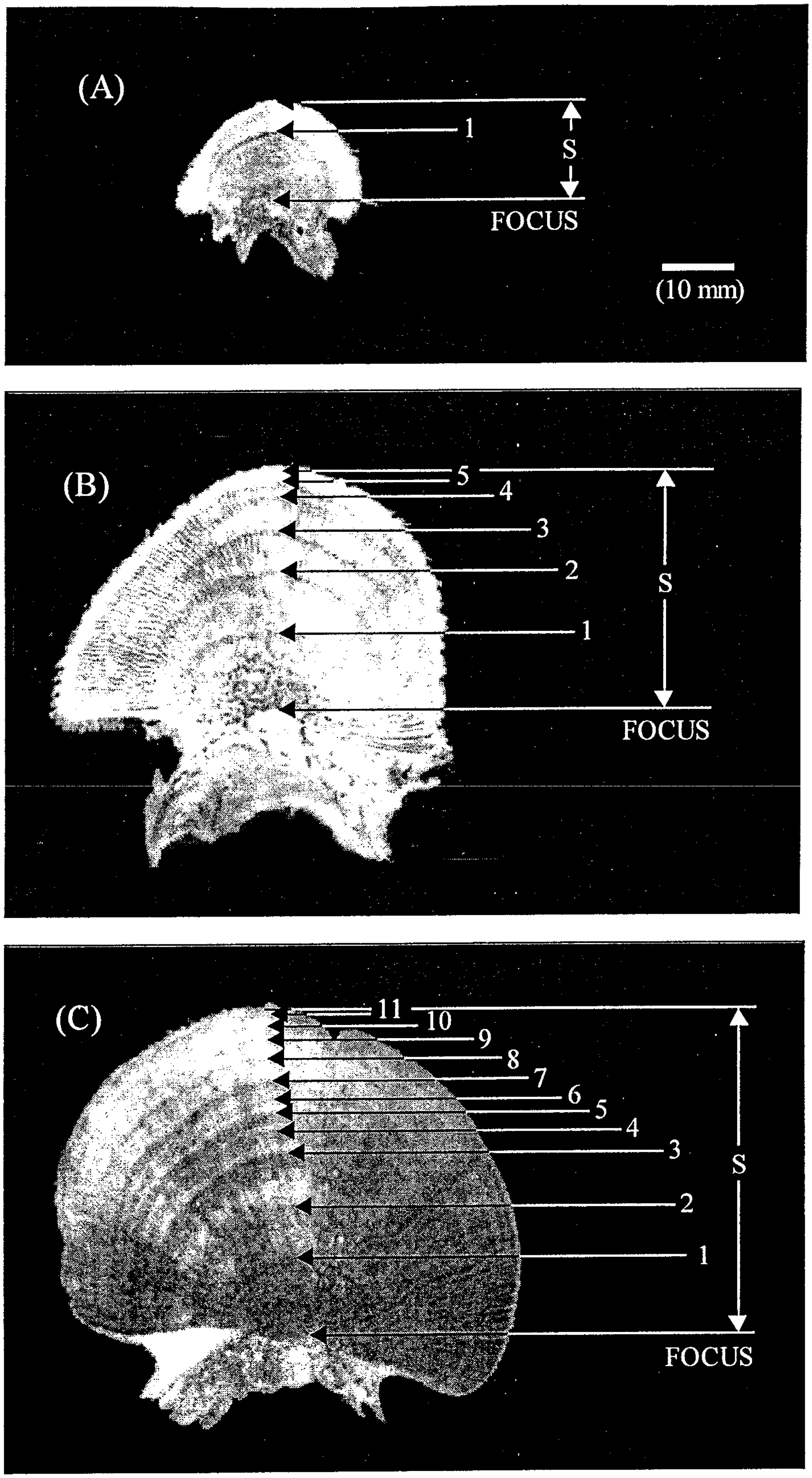

Fig. 3. Typical second anal fin spine section of swordfish (spine radius (S) measured from focus to edge; annuli for estimated age 1+ (A), age 5+ (B) and age 11+ (C)).

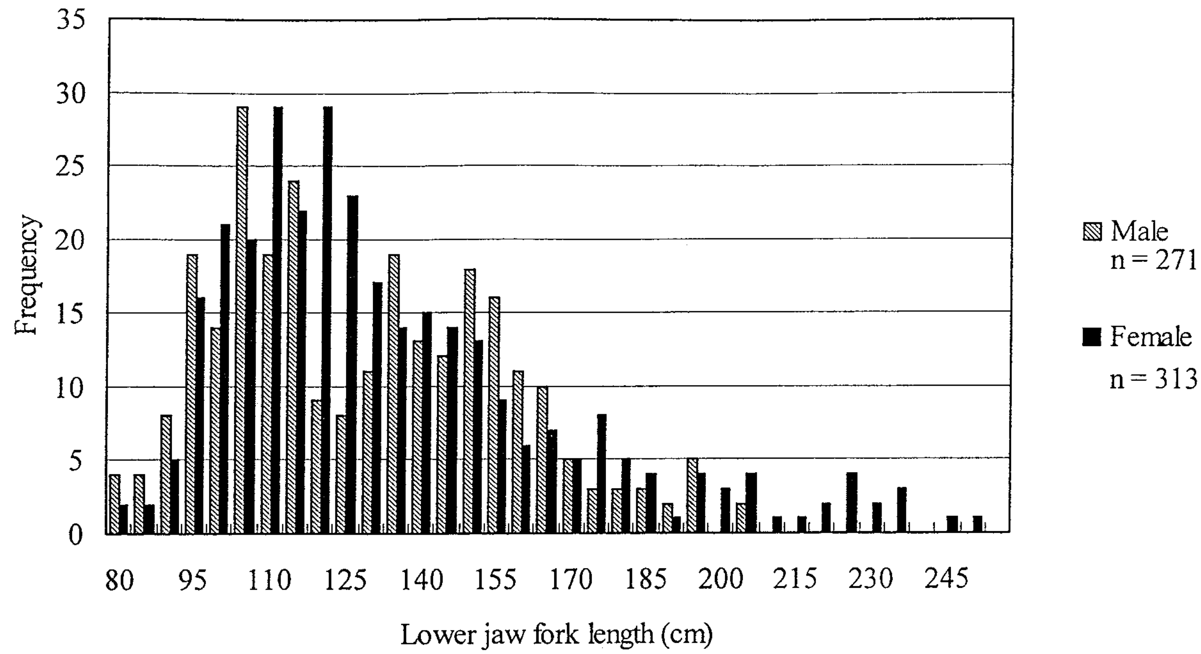

Fig. 4a. The size frequency distribution (5cm intervals) of male and female swordfish collected from the waters of Taiwan, Dec 1997 to Dec 1998.

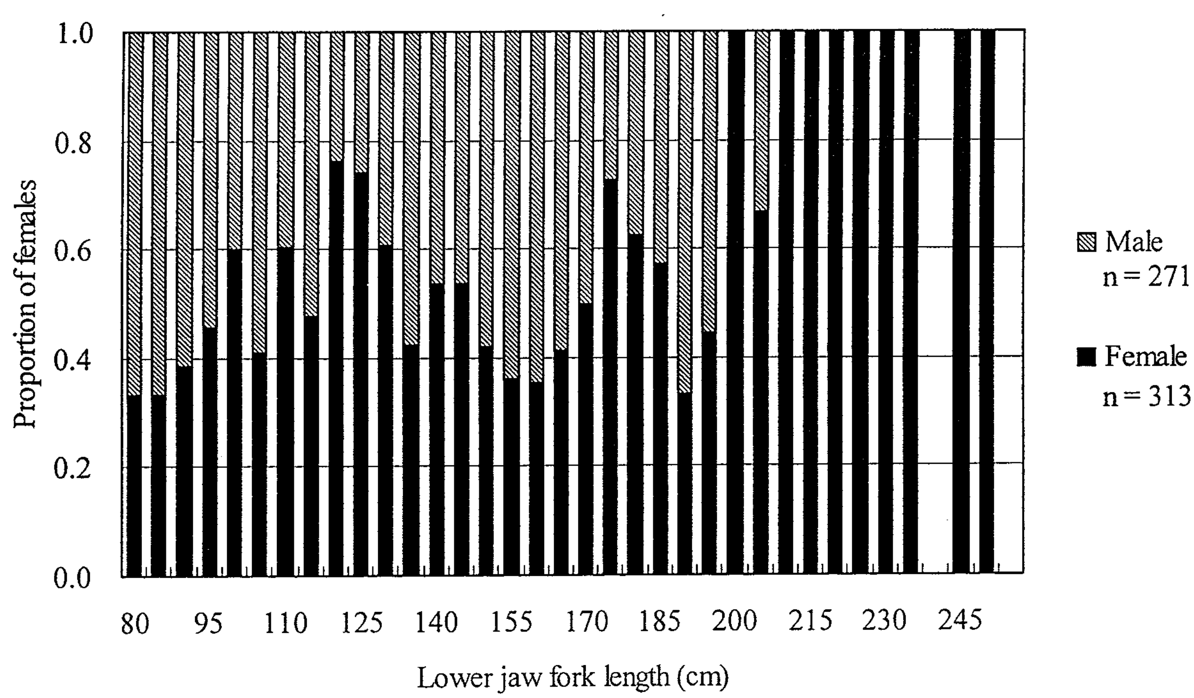

Fig. 4b. Proportions of female swordfish in the samples collected from the waters of Taiwan, Dec 1997- Dec 1998.

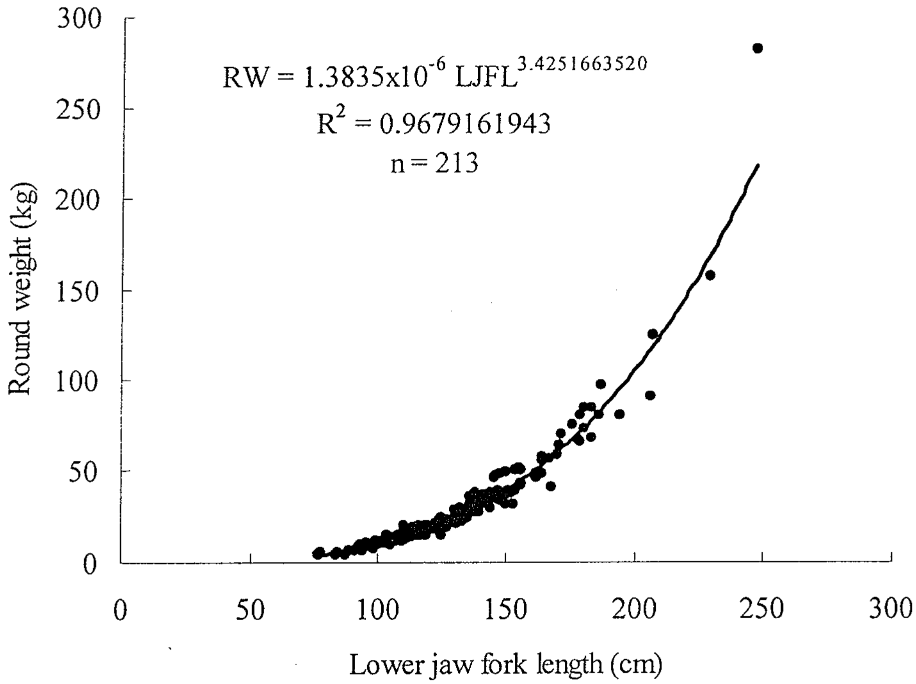

Fig. 5. Relationship between lower jaw fork length and round weight for the swordfish of both sexes combined.

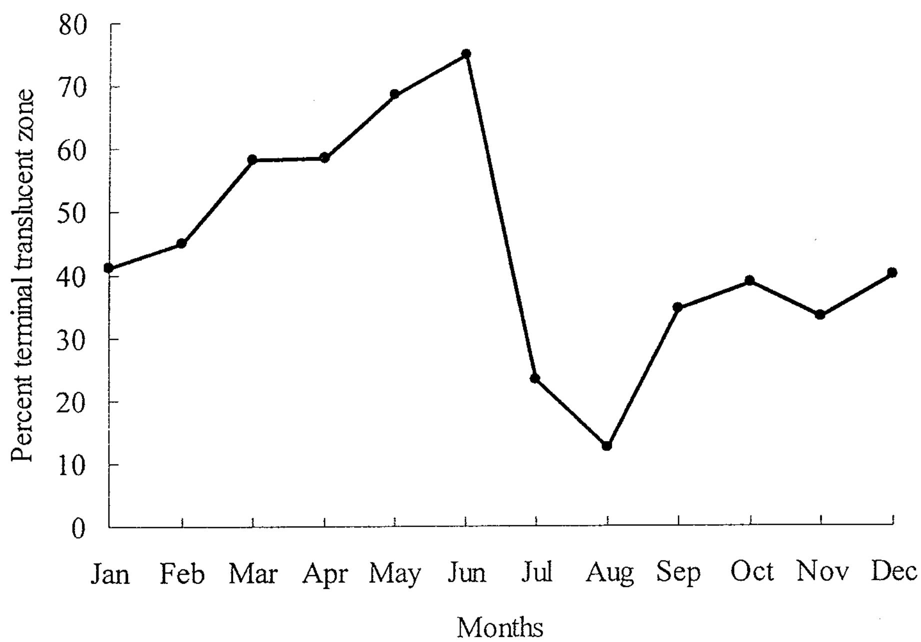

Fig. 6. Percent terminal translucent zone by month for the swordfish from the waters of Taiwan during the year 1998.

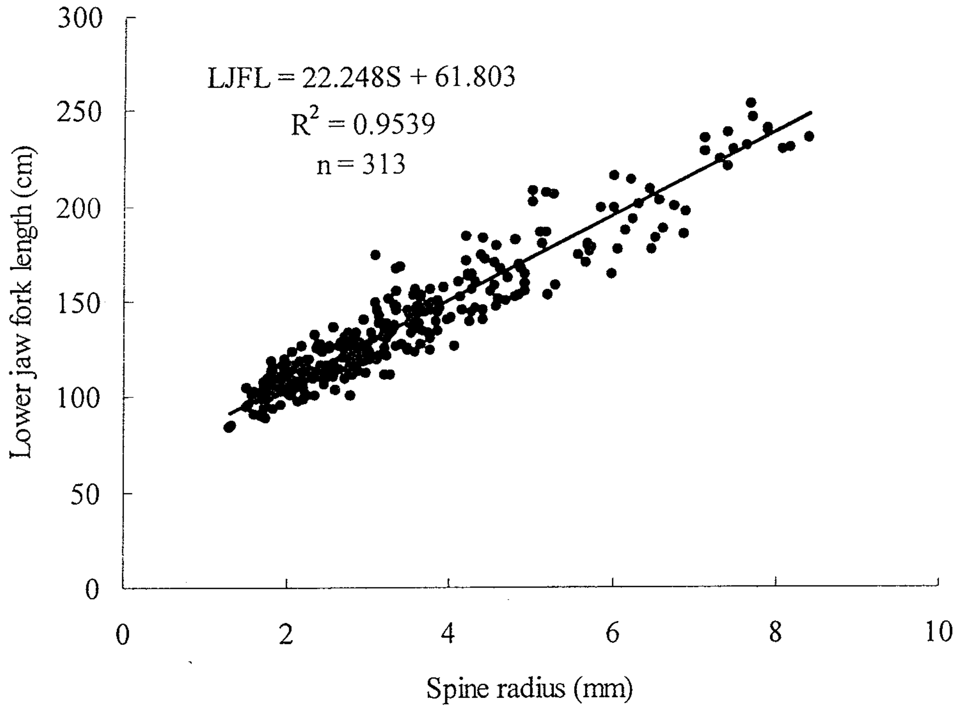

Fig. 7a. Relationship between lower jaw fork length and anal spine radius (S) for female swordfish in the waters of Taiwan.

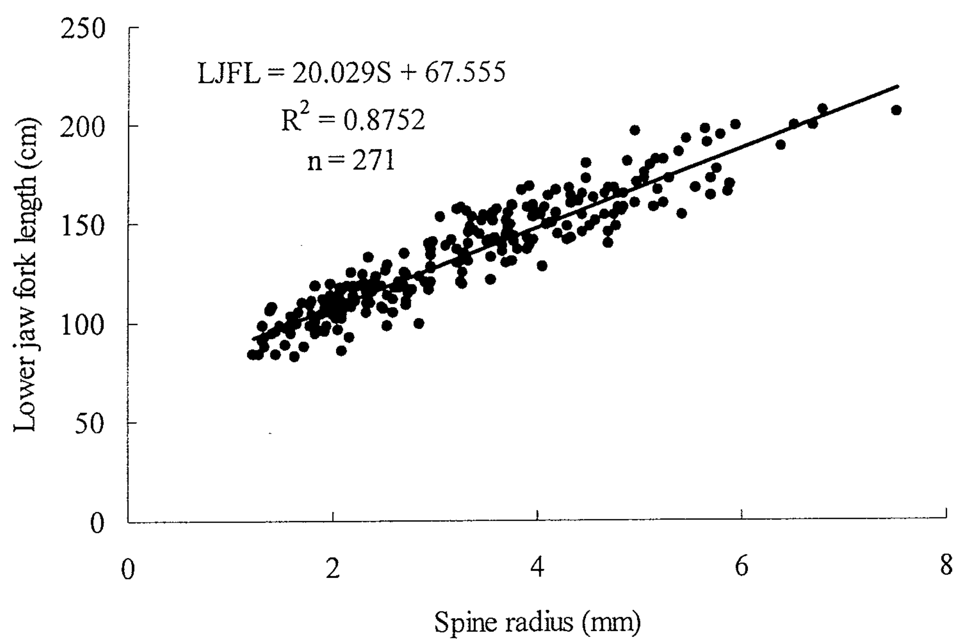

Fig. 7b. Relationship between lower jaw fork length and spine radius (S) for the male swordfish in the waters of Taiwan.

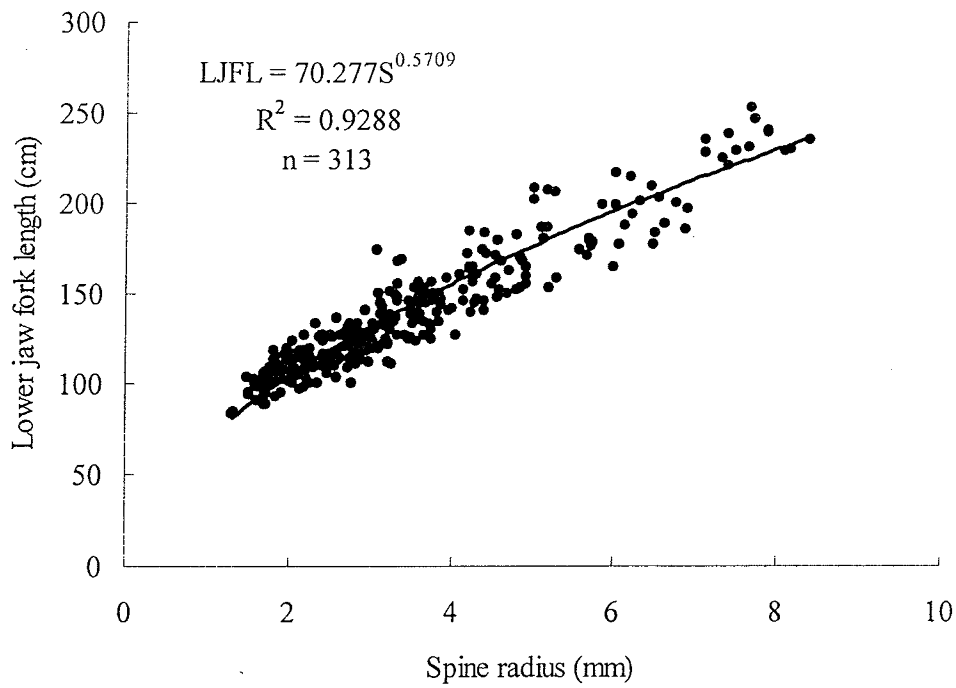

Fig. 8a. Relationship between lower jaw fork length and anal spine radius for the female swordfish in the waters of Taiwan.

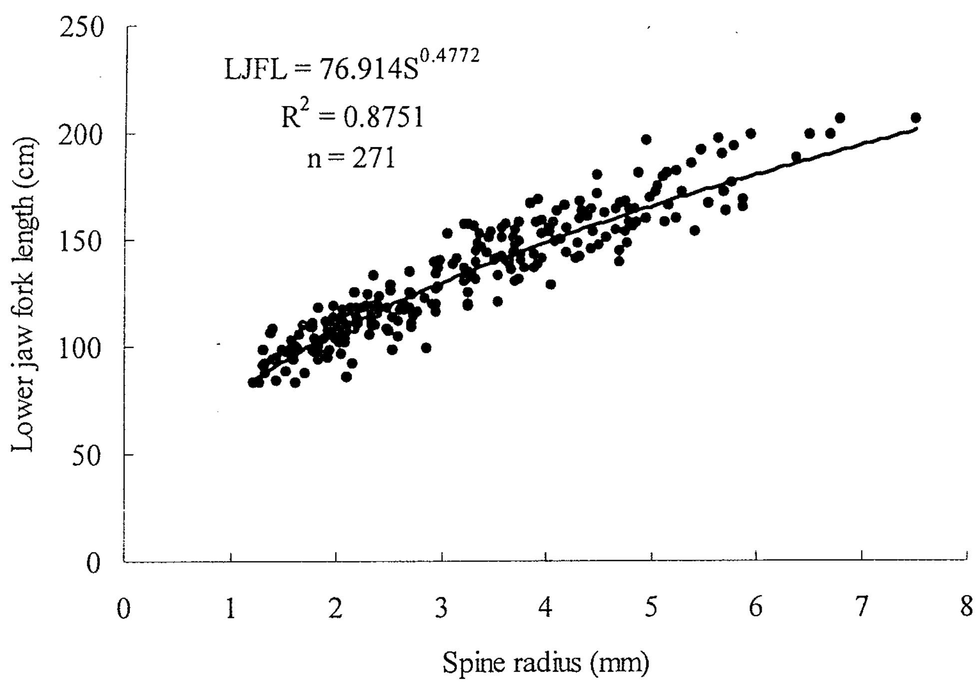

Fig. 8b. Relationship between lower jaw fork length and spine radius (S) for the male swordfish in waters of Taiwan.

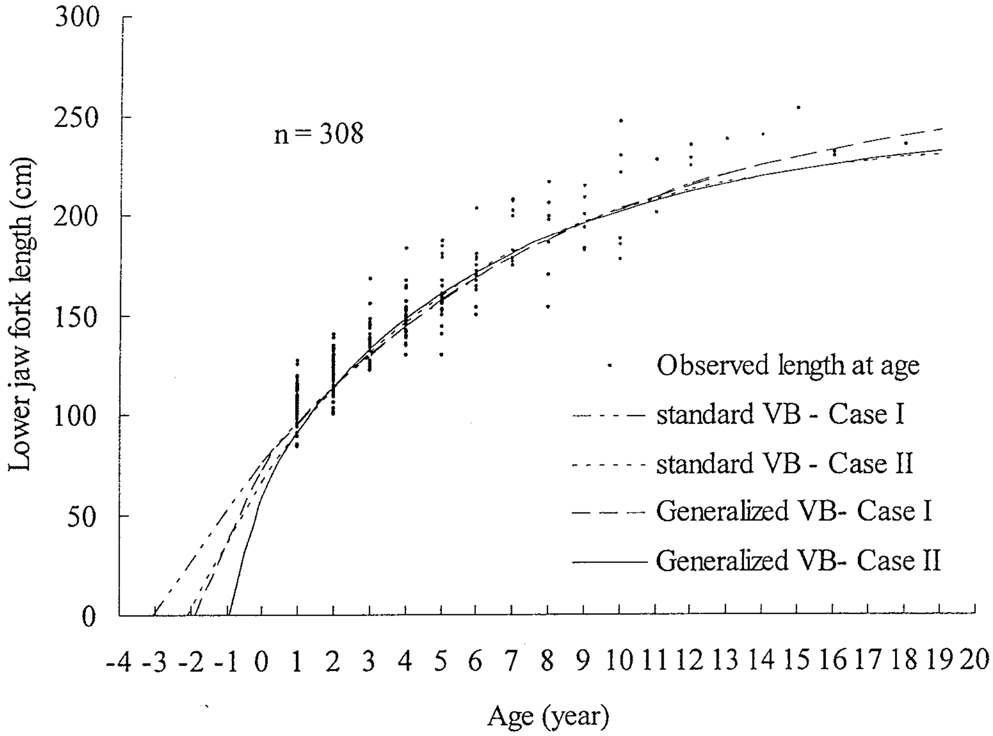

Fig. 9a. Standard von Bertalanffy and generalized von Bertalanffy growth curves for the female swordfish in the waters of Taiwan.

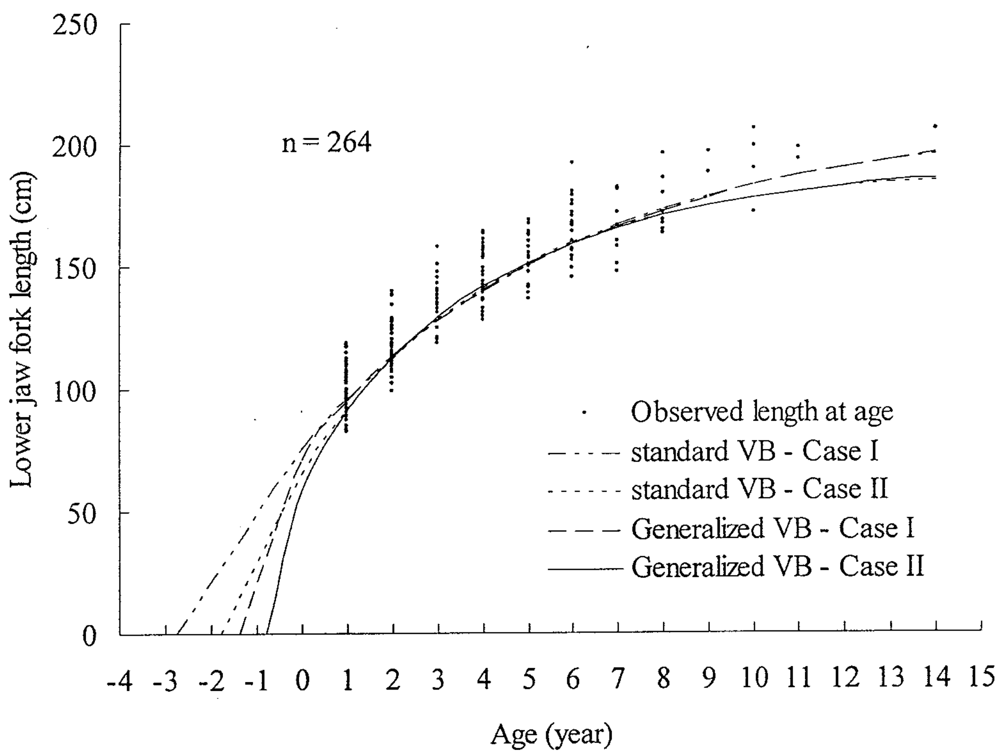

Fig. 9b. Standard von Bertalanffy and generalized von Bertalanffy growth curves for the male swordfish in the waters of Taiwan.

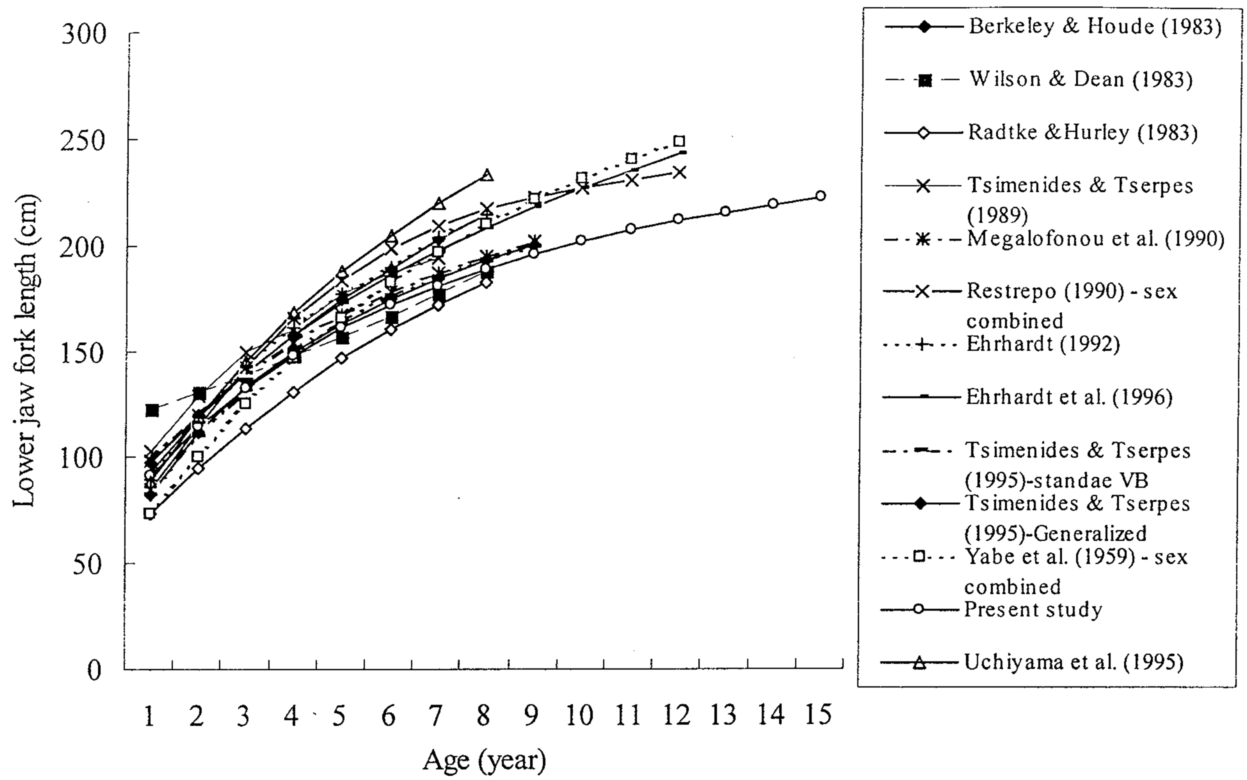

Fig. 10a. A comparison of the growth curves for the female swordfish by different authors.

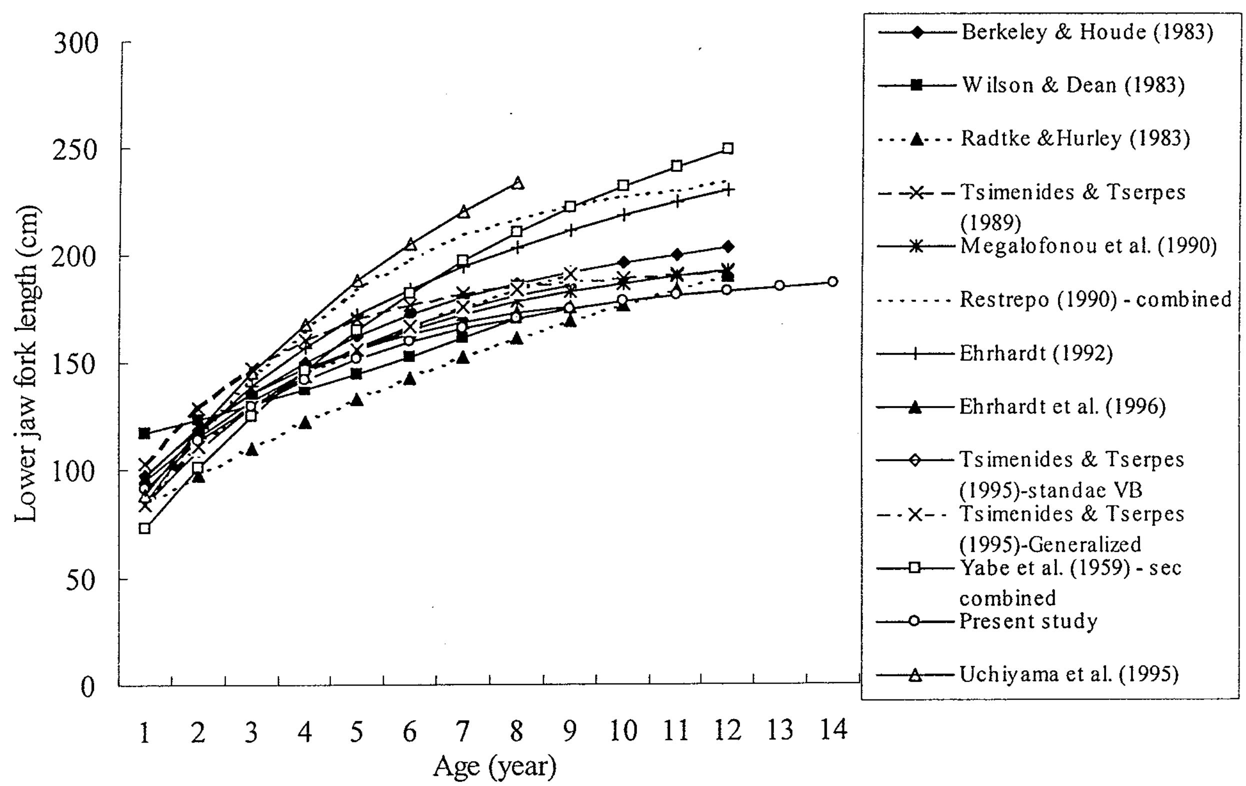

Fig. 10b. A comparison of the growth curves for the male swordfish by different authors.

Table. 1. Mean back-calculated lower jaw fork lengths (cm) at various ages for swordfish in the waters of Taiwan.

Age	Case I		Case II	
	Male	Female	Male	Female
1	94.86	94.34	89.18	87.30
2	113.85	115.00	114.72	115.60
3	129.90	132.17	132.23	135.61
4	140.15	144.47	142.19	148.68
5	149.93	156.35	151.03	160.53
6	158.38	167.65	158.24	171.21
7	166.64	177.61	164.95	180.23
8	173.33	187.43	170.17	188.80
9	181.23	196.79	176.12	196.71
10	185.63	205.58	179.34	203.93
11	185.79	211.18	179.46	208.42
12	184.82	216.83	178.76	212.89
13	194.34	219.43	185.54	214.92
14	200.15	224.73	189.55	219.02
15		226.77		220.58
16		232.37		224.82
17		235.11		226.88
18		240.90		231.17

Table. 2. Parameter estimates for the standard von Bertalanffy and the generalized von Bertalanffy growth models for swordfish in the waters of Taiwan.

Parameter	Standard von Bertalaffy model				Generalized von Bertalanffy model			
	Case I		Case II		Case I		Case II	
	Male	Female	Male	Female	Male	Female	Male	Female
L_∞	209.921	264.936	190.058	239.711	217.327	272.918	192.870	246.780
k	0.163	0.112	0.236	0.156				
K					0.073	0.066	0.121	0.075
t_0	-2.765	-3.021	-1.795	-2.106	-1.372	-1.866	-0.793	-0.914
m					-0.676	-0.389	-0.623	-0.590