International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

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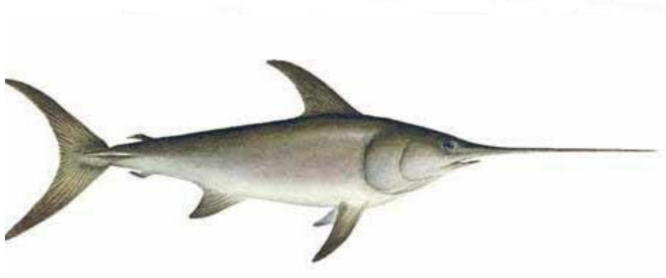

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Age and growth of striped marlin (*Kajikia audax*) in waters off Taiwan*

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Abstract

Age and growth of striped marlin in waters off 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 three major fishing ports (Tungkang, Shinkang, and Nanfangao) in Taiwan. In total, 1,037 length and weight samples of striped marlin were collected from November 2004 to April 2010. The length-weight (EFL-W) relationship were combined between the sexes ($W = 4.68 \times 10^{-6}\ EFL^{3.16}$) because of no significant difference ($P > 0.05$). There were 241 (of 291, 83%) and 206 (of 226, 91%) spines aged successfully for males and females respectively. The time of the formation of the first ring was validated by reading the daily rings on the cross section of the otolith of striped marlin. The analysis of marginal increment ratio suggested that the growth bands of striped marlin formed once a year during October to next January. The back-calculated lengths for each age were computed using the Fraser-Lee's and Monastyrsky methods, and then used to fit the standard von Bertalanffy growth function (VBGF) and Richards function. Results showed that the fits to Richards function were better than those for standard VBGF based on AIC statistics. The estimated growth equations for male and female striped marlin were not statistically different through the analysis of residual sum of squares (ARSS, $P > 0.05$).

Introduction

Striped marlin (*Kajikia audax*) are highly migratory pelagic species widely distributed in the Pacific Ocean (Nakamura, 1985). They are commercially important caught in the distant-water longline fisheries in the Pacific Ocean or the recreational fisheries in waters off New Zealand, Australia, and Mexico (Melo-Barrera et al. 2003; Kopf et al. 2005). However, striped marlin were captured in the offshore longline or coastal

* A working paper submitted to the Intercessional Workshop of the Billfish Working Groups of ISC. 19-27 January 2011, Honolulu, Hawaii, USA.

harpoon fisheries in waters off Taiwan (Hsu, 2010). McDowell and Graves (2008) suggested that several (at least four) stocks of striped marlin exist in the Pacific Ocean based on genetic studies. The growth of striped marlin in the central North Pacific Ocean was estimated by Skillman and Yong (1976) using length-frequency analysis. Kopf et al. (2009) showed that the age of striped marlin maximizes at 8 years in the southwest Pacific Ocean using both spines and otoliths. However, the biological information on age and growth of striped marlin in the northwest Pacific Ocean is still limited. The objectives of this study were to estimate age and growth of striped marlin by counting growth rings on cross sections of the fourth spine of the first dorsal fin and validating using the daily rings on otoliths, and to determine which of the and the standard von Bertalanffy growth function and Richards function best represents the growth of striped marlin in waters off Taiwan.

Material and methods

Eye fork length (EFL), lower jaw fork length (LJFL), and weight (W) of striped marlin caught in the longline, gillnet, and harpoon fisheries in waters off Taiwan were collected with sex information justified by preliminary examination of gonads every month between November 2004 and April 2010. Paired otoliths of 14 striped marlin were sampled to read the daily rings on otoliths as a validation of annuli rings forming on a yearly basis. How the spines and otoliths were sampled, processed, and read follows a protocol of age and growth study proposed by Sun et al. (2002), Chiang et al. (2004), Drew et al. (2006), and Kopf et al. (2009). The distances (d_i) were then converted into radii (r_i) by using the equation (Sun et al., 2002):

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

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), Ehrhardt et al. (1996), and Chiang et al. (2004). The precision on reading annuli was evaluated by using average percent error (APE; Beamish and Fournier, 1981) and coefficient of variation (CV; Campana, 2001).

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 for all ages combined. As suggested by Kopf et al. (2009), daily increments in otoliths of striped marlin were assumed.

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) and Indo-Pacific sailfish (*Istiophorus platypterus*) by Chiang et al. (2004). Additionally, the first several rings in fin spine sections was identified by comparing daily increment counts on otoliths and radius measurements of other matching sets of fin spines based on relationships between length and daily growth increments to further adjust actual age of the first rings reading in spines.

Two methods were used to compute back-calculation of lengths at presumed ages for the growth of males and females. Method Fraser-Lee's was based on the assumption that the relationship between spine radius (R) and LJFL (L) is linear (Berkeley and Houde, 1983; Sun et al., 2002):

$$L = a1 + b1\,R,$$

whereas method Monastyrsky was based on the assumption that this relationship is a power function (Ehrhardt, 1992; Sun et al., 2002):

$$L = a2\,R^{b2},$$

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. The standard von Bertalanffy growth function (standard VBGF; von Bertalanffy, 1938) and the Richards function (Richards, 1959) were then fitted to the mean back-calculated lengths-at-age for males and females using methods of Fraser-Lee's and Monaskyrsky. The growth function is expressed as:

Standard VBGF: $L_t = L_{\inf}\left(1 - e^{-k\,(t-t_0)}\right),$

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

where L_t = the mean LJFL at age t; $L_{\inf}$ = the asymptotic length; t_0 = the hypothetical age at length zero; k and K = the growth coefficients; and m = the fourth parameters of growth equation. 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 and discussion

There were in total 1,037 striped marlin measured in length and weight at the fish markets. The relationships between eye fork length (EFL) and weight (W) were not statistically different between the sexes ($P > 0.05$). The sex-combined length-weight relationship was shown in Fig. 1. This equation could be used to convert weight to length when only weight data were available at the fish market. As the bill of the fish was cut sometimes at the sea, we used the equation in Fig. 2 to convert EFL to lower jaw fork length (LJFL) if LJFL cannot be obtained and measured for the fish at the fish market. This EFL-LJFL relationship of striped marlin is sex-combined because of no statistical difference ($P > 0.05$).

The relationships between spine radius and length (LJFL) were shown by sex in Fig. 3. The method of monaskyrsky (power function) provides better fits to the data than that using the method of Fraser-Lee’s (linear regression). The monthly means of marginal increment ratio (MIR) peaked at August and declined thereafter, suggesting the growth rings were formed every year (Fig. 4). The missing early rings and the false increment were corrected according to the information from mean ring radii listed in Table 1 as well as the daily age read on the otoliths.

The first ring in spines was identified to 0.5 year using daily rings on otoliths (Table 1). The ages of sampled striped marlin estimated using otoliths were between 0.39 years (142 days) and 0.69 year (249 days). This result is consistent with the results of fin spines during the first year of life from Kopf et al. (2009). The monthly means of marginal increment ratio (MIR) peaked at August and declined thereafter, suggesting the growth rings were formed every year (Fig. 4).

The maximum age of striped marlin read from the annual rings on spines was 6 years for both sexes, whereas that was 8 years read by Kopf et al. (2009). The mean back-calculated lengths-at-age for age 0.5 and each age estimating using methods of Fraser-Lee's and Monaskyrsky were listed in Table 2. The estimated lengths by age were similar between sexes and between methods. The fitting growth functions (standard VBGF and Richards function) for male, female, and sex-combined striped marlin were shown in Fig. 5. The estimated growth parameters for both growth functions by method were listed in Table 3.

The growth curves between the sexes were not statistically different (using ARSS, $P > 0.05$), and therefore combined to unsexed growth function for striped marlin in waters off Taiwan. The Richards function with the method of monaskyrsky (power function) applied to back-calculate lengths-at-age provides a statistically superior fit (AIC) to the data. Furthermore, this suggested growth function is much more biologically realistic to observed growth pattern of juveniles of fish less than one year old (Ehrhardt, 1992; Ehrhardt et al., 1996; Sun et al., 2002). Therefore the Richards function was chosen to best represent the growth pattern of striped marlin in waters off Taiwan.

The estimated sizes-at-age of striped marlin from various studies were compared in Fig. 6. The estimated length at each age in this study is larger than that from Melo-Barrera et al. (2003) for Eastern Pacific Ocean, but smaller that those of Skillman and Yong (1976) and Kopf et al. (2009) for the central North Pacific Ocean and waters off New Zealand respectively. However, aging of younger fish could be more accurate by reading the daily rings on otoliths. The estimated size of juvenile fish (0.5 year) is 128.45 cm LJFL in present study, with a comparable value (129.15 cm LJFL) from the striped marlin age and growth study of Kopf et al. (2009). This suggested that striped marlin is a fast-growing fish reaching more than 100 cm LJLF at one year old.

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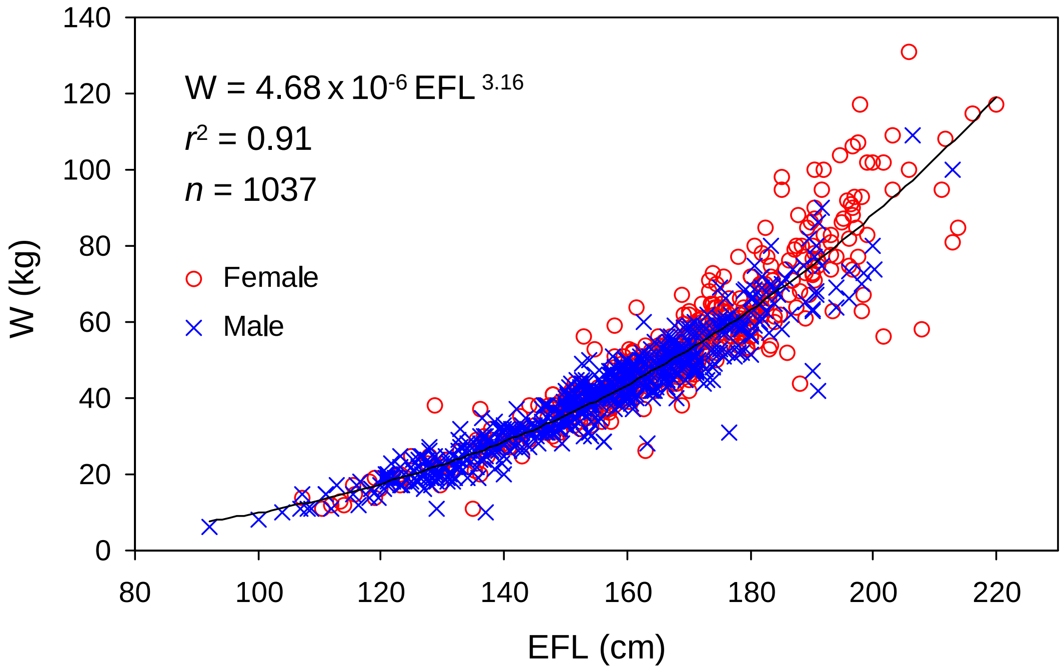

Fig. 1. Relationship between eye fork length (EFL) and weight (W) of striped marlin in waters off Taiwan.

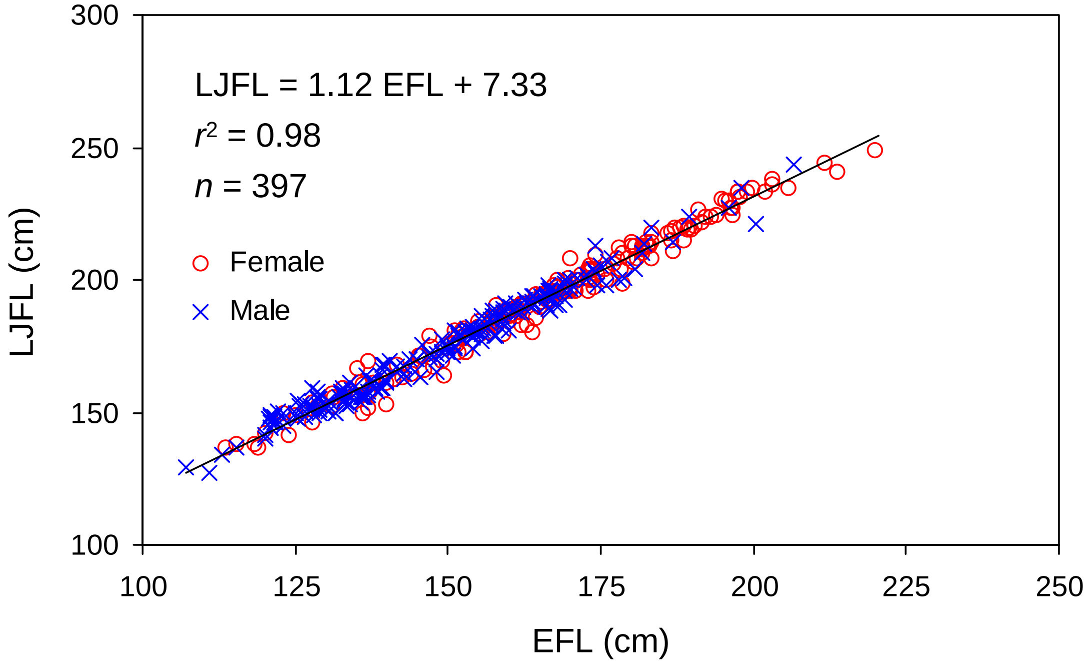

Fig. 2. Relationship between eye fork length (EFL) and lower jaw fork length (LJFL) of striped marlin in waters off Taiwan.

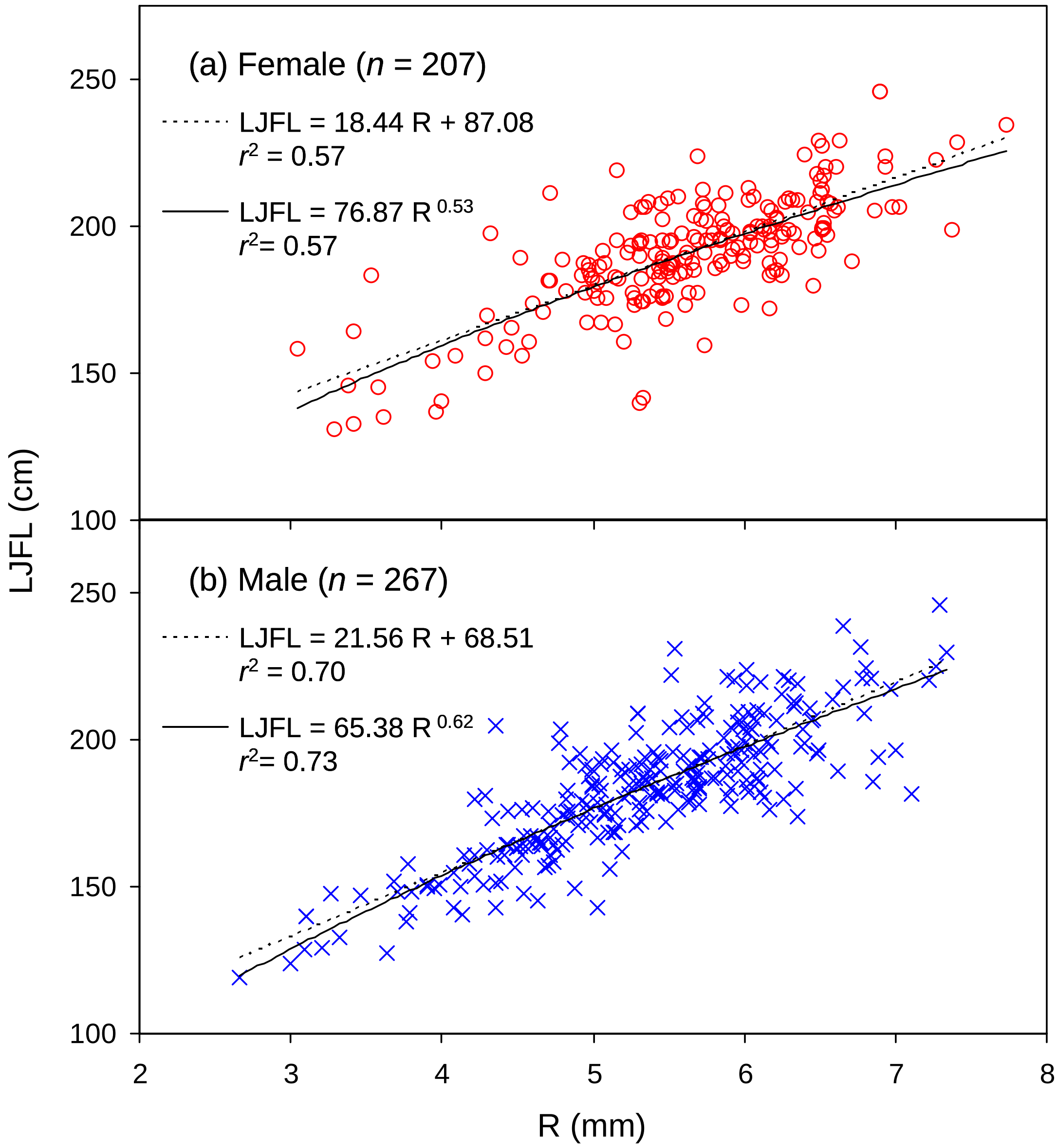

Fig. 3. Linear and power relationships between spine radius (R) and lower jaw fork length (LJFL) of (a) female and (b) male striped marlin in waters off Taiwan.

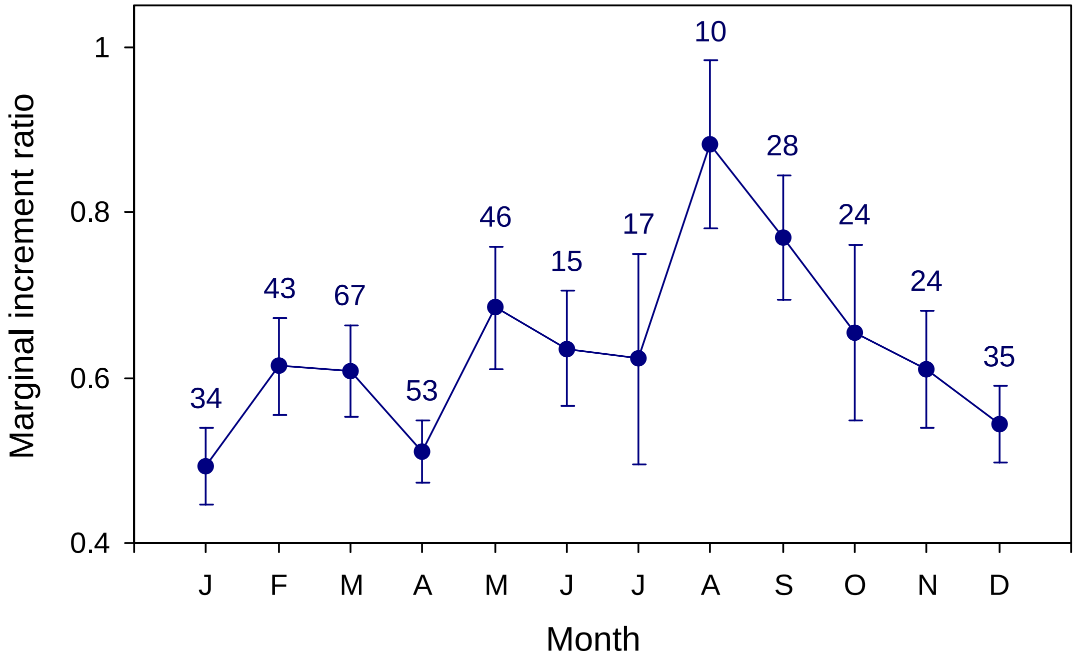

Fig. 4. Monthly means of marginal increment ratio for the striped marlin in waters off Taiwan. Vertical bars are ±1 SE. Numbers above the vertical bars are sample sizes.

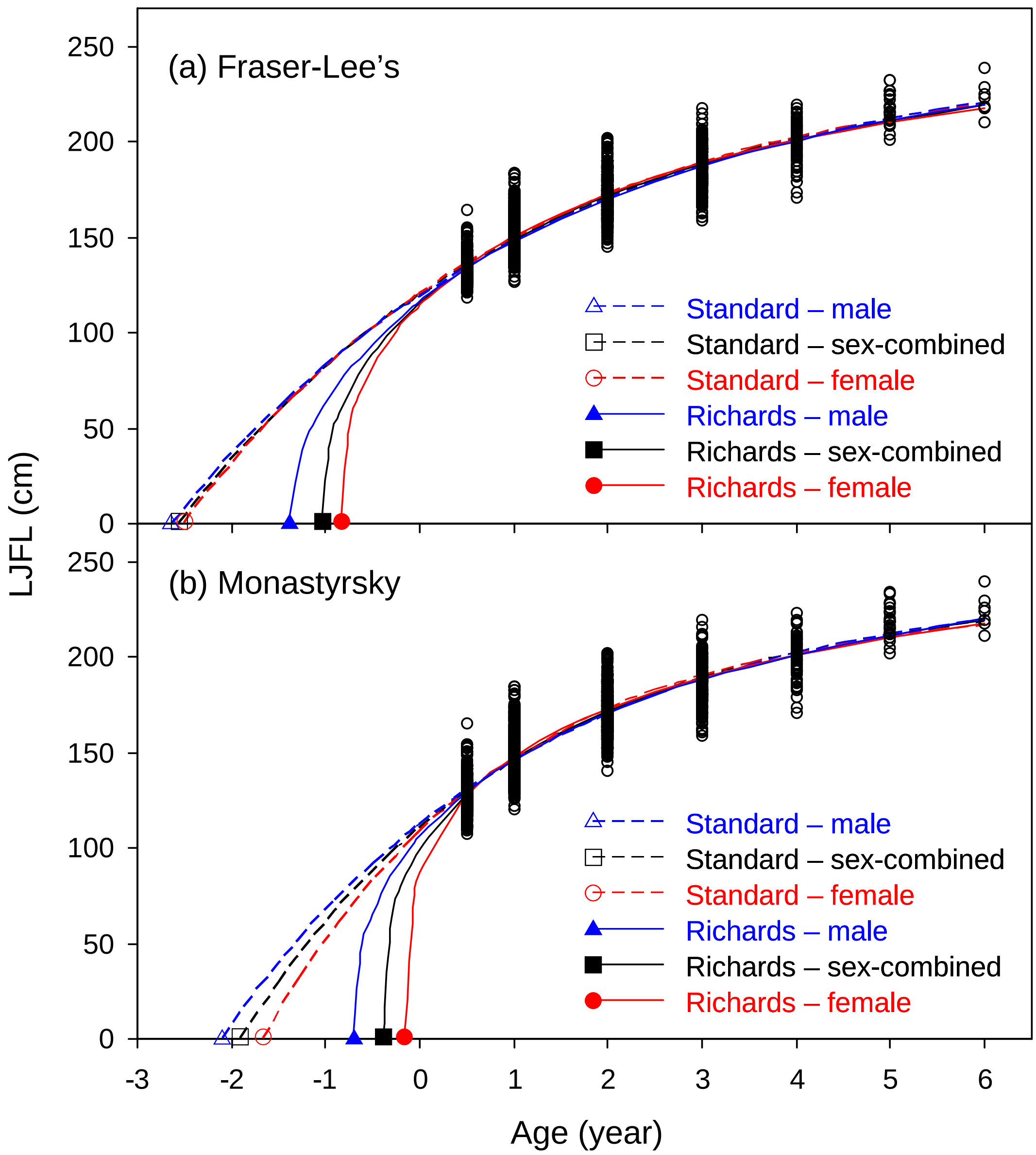

Fig. 5. Back-calculated using (a) Fraser-Lee's and (b) Monastyrsky methods and observed length-at-age and model-predicted growth curves of standard von Bertalanffy and Richards function for the striped marlin in waters off Taiwan.

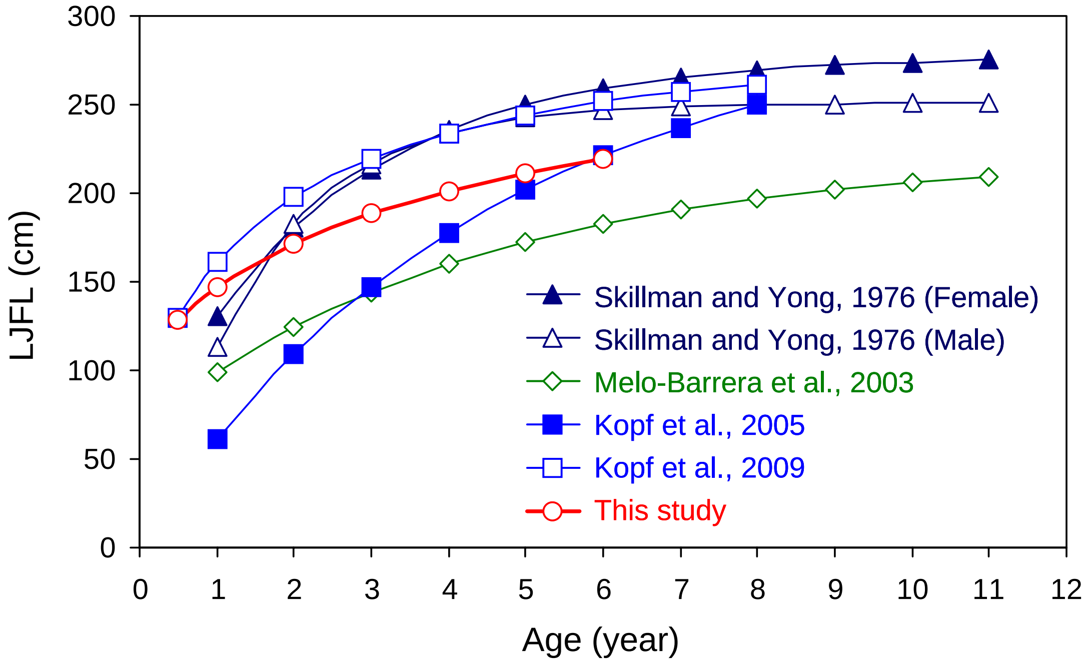

Fig. 6. A comparison of the growth curves for striped marlin in the Pacific Ocean estimated by various authors.

Table 1. Mean radius of each ring for (a) female and (b) male striped marlin caught in waters off Taiwan. Numbers in parentheses are the sample sizes for which the specified rings were readable. "-" means no data owing to vascularization at core areas.

(a) Female

Sample size	Age class	0.5	1	2	3	4	5	6
14	0.5	2.82 (14)	-	-	-	-	-	-
14	1	2.69 (11)	3.68 (14)	-	-	-	-	-
66	2	2.58 (46)	3.60 (66)	4.84 (66)	-	-	-	-
81	3	2.54 (51)	3.54 (80)	4.56 (81)	5.40 (81)	-	-	-
22	4	2.55 (5)	3.43 (16)	4.26 (21)	5.16 (22)	5.79 (22)	-	-
7	5	-	3.1 (1)	4.28 (5)	5.06 (6)	5.83 (7)	6.46 (7)	-
2	6	-	-	-	5.00 (1)	6.15 (2)	6.60 (2)	6.84 (2)
Mean		2.61	3.55	4.62	5.33	5.82	6.49	6.84
SD		0.34	0.41	0.50	0.49	0.56	0.43	0.78

(b) Male

Sample size	Age class	0.5	1	2	3	4	5	6
23	0.5	3.38 (23)	-	-	-	-	-	-
35	1	3.23 (34)	4.12 (35)	-	-	-	-	-
83	2	3.04 (64)	3.85 (83)	4.80 (83)	-	-	-	-
61	3	2.86 (31)	3.61 (55)	4.56 (61)	5.28 (61)	-	-	-
26	4	2.82 (6)	3.63 (18)	4.45 (25)	5.20 (26)	5.79 (26)	-	-
8	5	-	3.37 (2)	4.42 (6)	5.05 (8)	5.77 (8)	6.32 (8)	-
5	6	-	-	-	5.30 (5)	6.06 (5)	6.49 (5)	6.88 (5)
Mean		3.09	3.81	4.91	5.40	5.82	6.39	6.88
SD		0.47	0.55	0.48	0.40	0.44	0.39	0.17

Table 2. Mean back-calculated lower jaw fork lengths at each age for striped marlin in waters off Taiwan.

	Fraser-Lee's		Monastyrsky	
Age	Male	Female	Male	Female
0.5	133.55	134.14	129.60	126.87
1	150.67	152.53	149.22	149.93
2	170.53	173.06	170.65	172.97
3	186.57	187.12	187.27	187.65
4	201.27	199.06	202.14	200.10
5	215.65	219.26	216.50	220.41
6	222.01	226.98	222.67	227.75

Table 3. Estimated parameters of the standard von Bertalanffy and Richards growth models for the striped marlin in waters off Taiwan.

(a) Fraser-Lee's

	Standard VB			Richards function		
	Female	Male	Sex-combined	Female	Male	Sex-combined
L_{inf}	243.98	250.19	246.60	255.41	262.38	262.41
k	0.27	0.25	0.26	-	-	-
t_0	-2.50	-2.62	-2.55	-0.84	-1.39	-1.05
K	-	-	-	0.06	0.09	0.07
m	-	-	-	-1.59	-0.93	-1.33

(b) Monastyrsky

	Standard VB			Richards function		
	Female	Male	Sex-combined	Female	Male	Sex-combined
L_{inf}	228.33	240.92	234.94	257.79	263.41	263.44
k	0.38	0.30	0.34	-	-	-
t_0	-1.67	-2.09	-1.89	-0.17	-0.71	-0.40
K	-	-	-	0.04	0.06	0.04
m	-	-	-	-2.55	-1.52	-2.05