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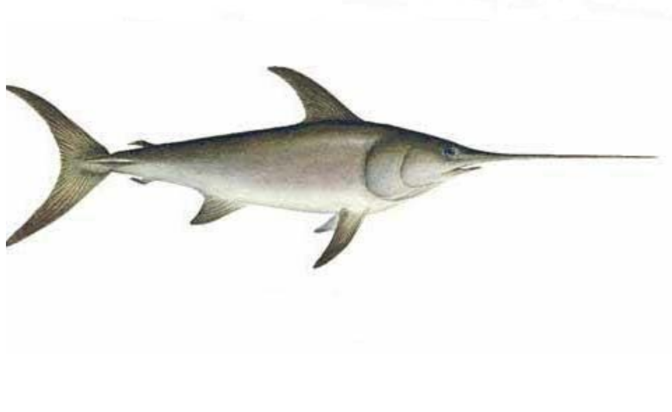

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Age and growth of striped marlin (*Kajikia audax*) in waters off Taiwan: A revision*

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Abstract

Age and growth of striped marlin in waters off Taiwan were re-examined from counts of growth rings on cross sections of the fourth spine of the first dorsal fin with length measurements on lower jaw fork length (LJFL), instead of eye fork length (EFL) that was used in the previous working paper to fit the growth model of striped marlin (Sun et al., 2011), for comparison with results of other studies. There were 241 and 206 spines aged successfully for males and females respectively. 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, $P > 0.05$). The estimated values of growth parameters of Richards function for striped marlin in waters off Taiwan are: $L_{\text{inf}} = 263.44$ cm LJFL, $t_0 = -0.40$ year, $K = 0.04$ year^{-1}, and $m = -2.05$.

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 harpoon fisheries in waters off Taiwan (Hsu, 2010).

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The objectives of this study were to re-estimate age and growth of striped marlin by counting growth rings on cross sections of the fourth spine of the first dorsal fin with length measurements on lower jaw fork length (LJFL), instead of eye fork length (EFL) that was used in the previous working paper (Sun et al., 2011), for comparison with the results of other age and growth studies for striped marlin. This study determines 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, lower jaw fork length, weight (W), and sex (determined by visual examination of gonads) was recorded for striped marlin caught in the longline, gillnet, and harpoon fisheries in waters off Taiwan monthly from November 2004 to April 2010. Spines were also collected from sampled fish. Spines were sampled, processed and aged following the protocols proposed by Sun et al. (2002), Chiang et al. (2004), Drew et al. (2006), and Kopf et al. (2009), and summarized by Sun et al. (2011).

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) and the Richards function 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: $L_t = L_{\text{inf}}\left(1 - e^{-k\,(t-t_0)}\right)$,

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

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; 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

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. 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 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 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 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 (Sun et al., 2002). Therefore the Richards function (sex-combined) was chosen to best represent the growth pattern of striped marlin in waters off Taiwan (Table 3).

The estimated sizes-at-age of striped marlin from various studies were compared in Fig. 6. 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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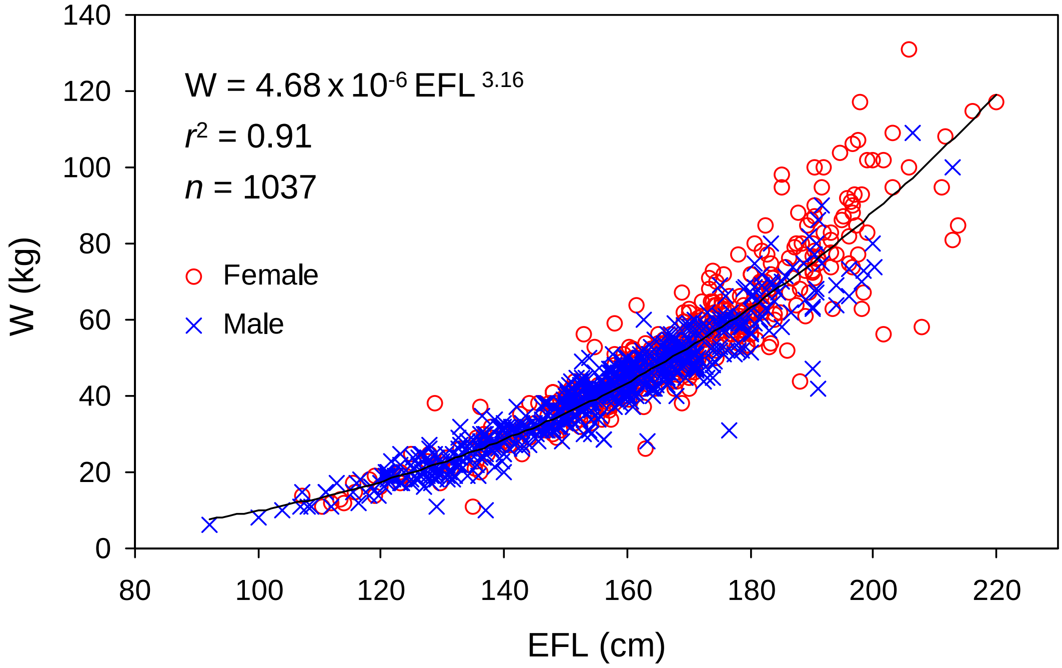

Fig. 1. Relationship between eye fork length (EFL) and weight (W) of striped marlin in waters off Taiwan.

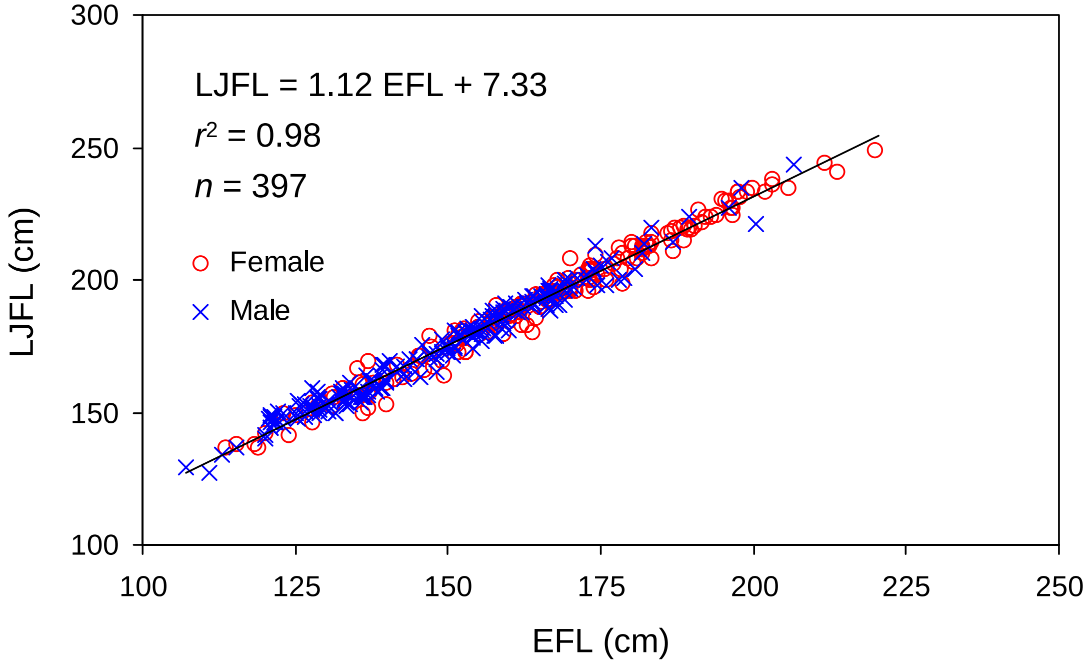

Fig. 2. Relationship between eye fork length (EFL) and lower jaw fork length (LJFL) of striped marlin in waters off Taiwan.

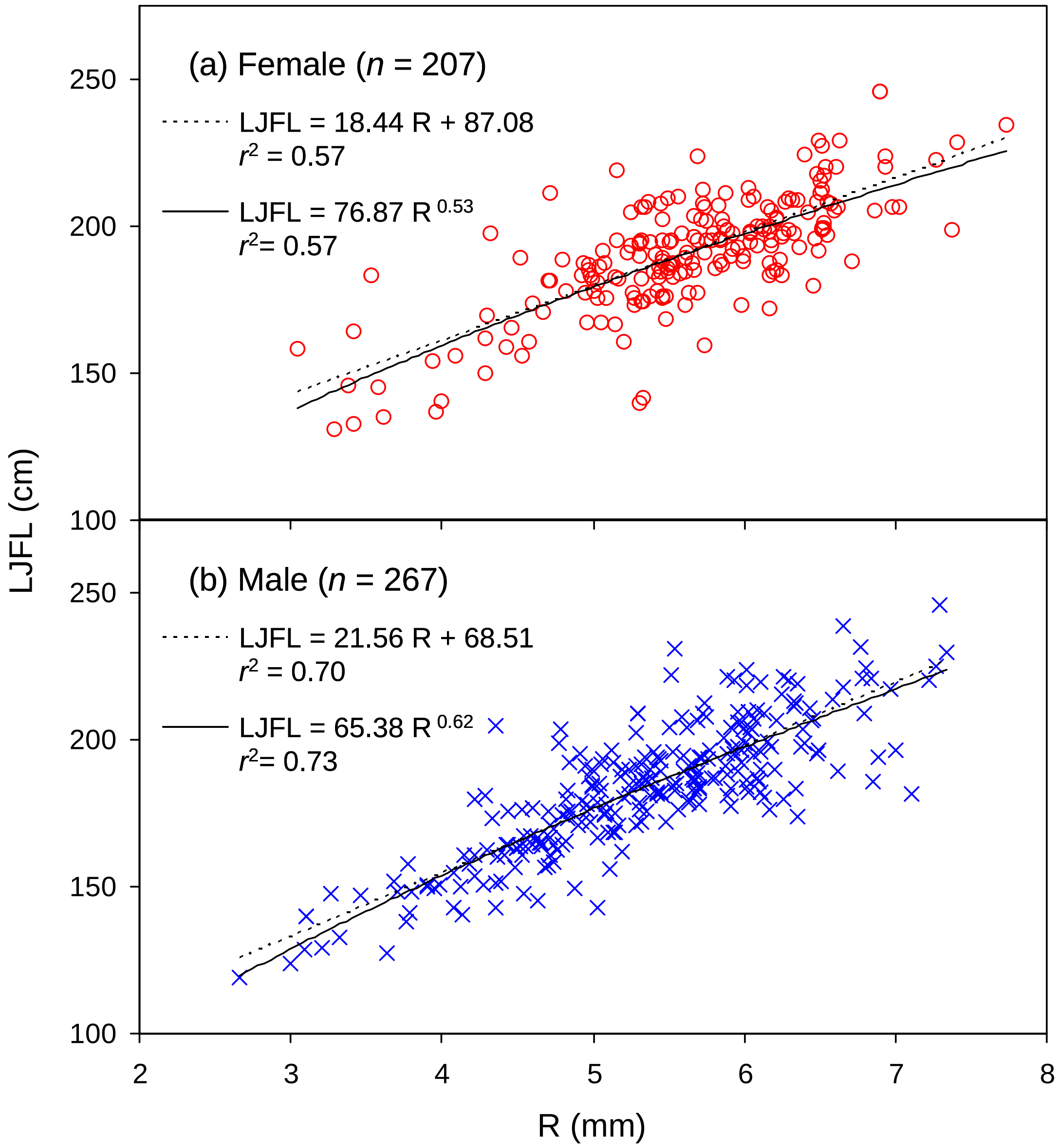

Fig. 3. Linear and power relationships between spine radius (R) and lower jaw fork length (LJFL) of (a) female and (b) male striped marlin in waters off Taiwan.

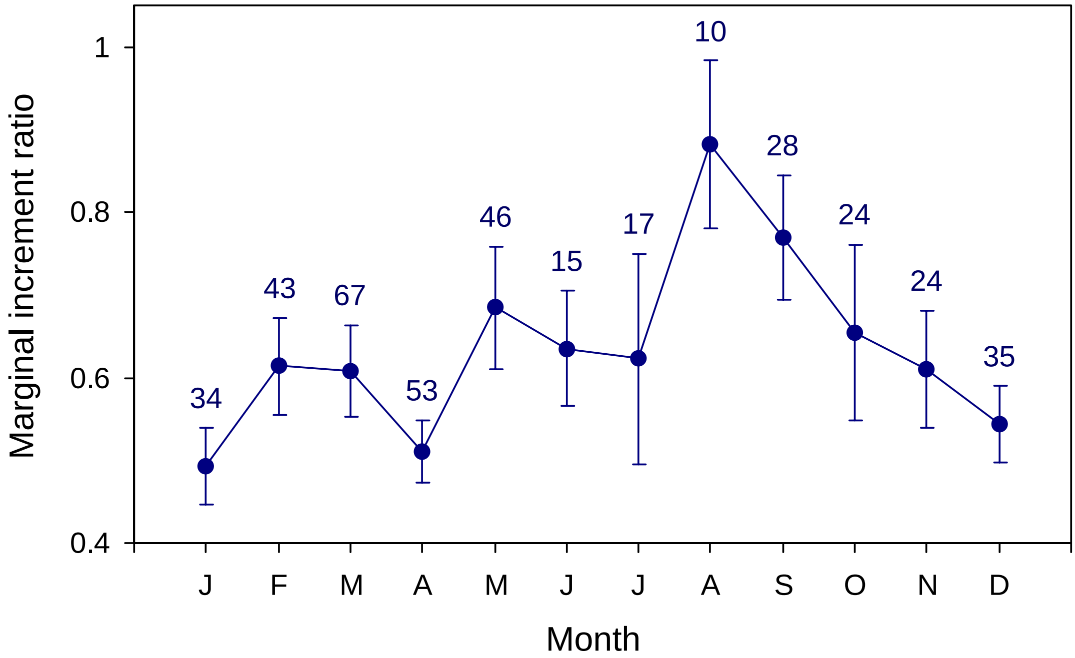

Fig. 4. Monthly means of marginal increment ratio for the striped marlin in waters off Taiwan. Vertical bars are ±1 SE. Numbers above the vertical bars are sample sizes.

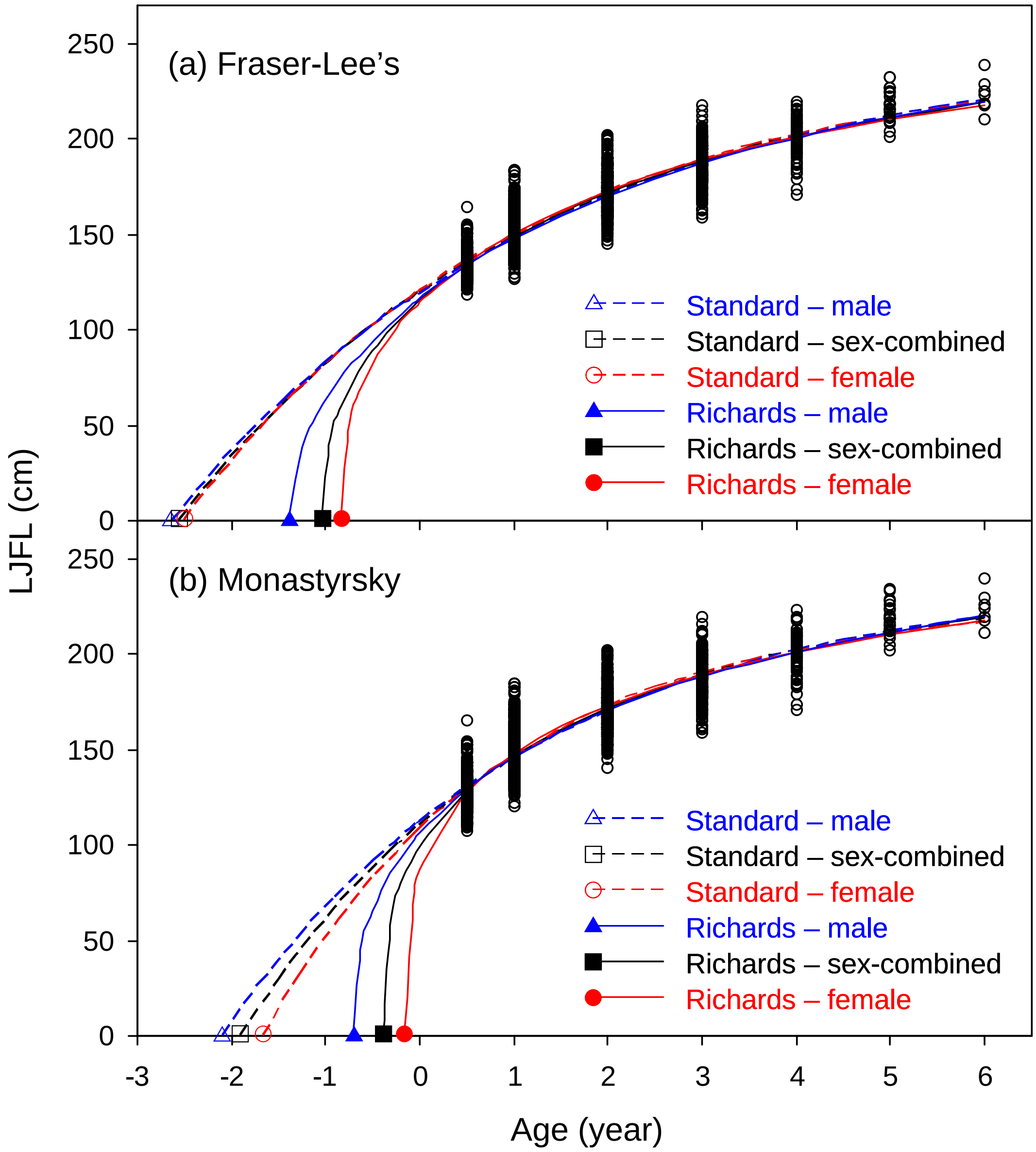

Fig. 5. Back-calculated using (a) Fraser-Lee's and (b) Monastyrsky methods and observed length-at-age and model-predicted growth curves of standard von Bertalanffy and Richards function for the striped marlin in waters off Taiwan.

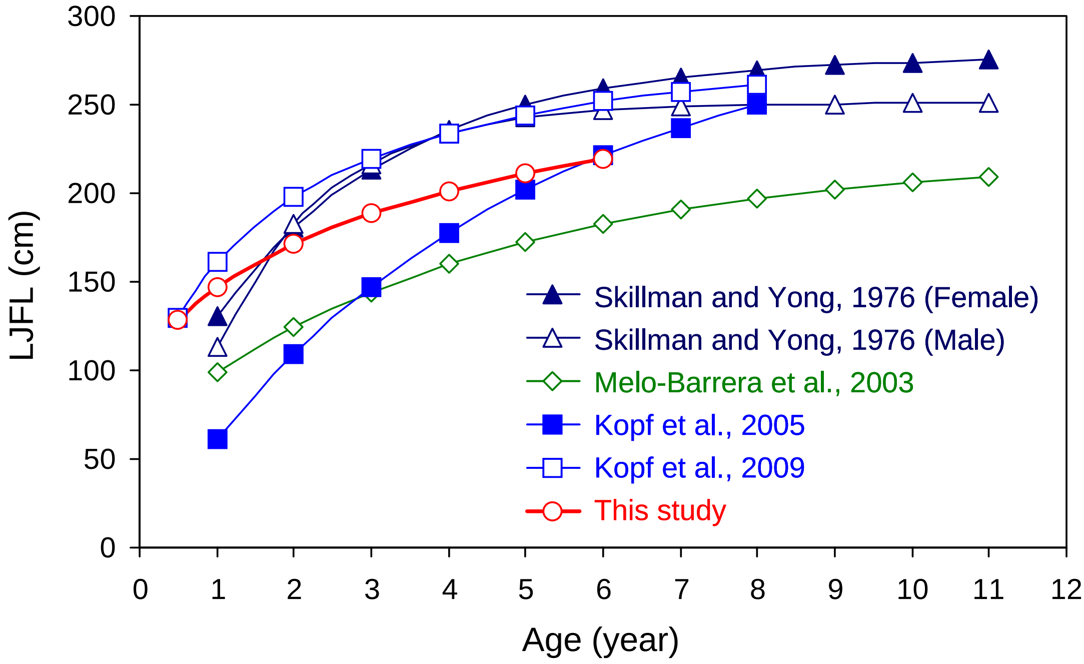

Fig. 6. A comparison of the growth curves for striped marlin in the Pacific Ocean estimated by various authors.

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