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AGE AND GROWTH OF BLACK MARLIN (*Makaira indica*) IN WATERS OFF EASTERN TAIWAN

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Abstract

Age and growth of black marlin (*Makaira indica*) in the waters off eastern Taiwan was studied from the growth rings on cross sections of the third dorsal spines. Length and weight data, and the first dorsal fins were collected monthly at Shinkang Fish Market in the southeastern Taiwan from July 2004 to April 2006. In total, 923 dorsal fins were collected, of which 874 (95%) (187 males and 687 females) were aged successfully. Trends in the monthly mean marginal increment ratio indicated that growth rings formed once a year. Two methods were used to back-calculate the length of presumed ages and growth was described using the standard and generalized von Bertalanffy growth function. The most reasonable and conservative description of growth assumes that length-at-age follows the standard von Bertalanffy function and that the relationship between spine radius and lower jaw fork lengths follows a power function. Growth differed significantly between sexes, with females growing faster and reaching larger size than males. The maximum sizes in our sample were 368.2 cm LJFL for females and 261.5 cm LJFL for males.

Key words: black marlin, age and growth, dorsal spine, eastern Taiwan

Introduction

Black marlin (*Makaira indica*) is a commercially important species widely inhabiting the tropical and subtropical waters of the Pacific and Indian Oceans (Nakamura, 1985). In the Pacific, they usually inhabit between 35ºS and 40ºN, with highest densities in the warm Kuroshio Current and its branches (Nakamura, 1985). In Taiwan waters, black marlin are mainly harvested by longline, harpoon, and gill net fisheries. The annual landings of black marlin in Taiwan were around 1,000 to 2,100 mt during 1985 to 1994 although declined to around 500 mt during 1995 to 2002. The landings increased again in recent years, of which most came from the waters off eastern Taiwan.

Information on age and growth of fishes is a central element in fishery management (Brothers, 1983). However, almost no attempt have been made to age black marlin except for Speare (2003) who estimated the age and growth of black marlin in the recreational fisheries off eastern Australia using the dorsal and anal spines, although various methods have been used to study the age and growth of other billfishes, such as sailfish (de Sylva, 1957; Farber, 1981; Chiang et al., 2004), swordfish (Esteves et al., 1995; Ehrhardt et al., 1996; Sun et al., 2002), and blue marlin (Wilson et al., 1991).

The objectives of this study were to estimate the age and growth of black marlin by counting the growth rings on the cross sections of the third spine of the first dorsal fin and to compare the standard and generalized von Bertalanffy growth functions for representing the best growth model of black marlin in the waters off Taiwan. This information will allow the age composition of the catch to be determined, which in turn will allow the status of black marlin stock in the waters off Taiwan to be assessed using yield-per-recruit or sequential population analysis techniques.

Materials and methods

Field sampling and data collection

Data on lower jaw fork length (LJFL), eye fork length (EFL) (in cm) and round weight (RW) (in kg), and the first dorsal fins of male and female black marlin were collected monthly at the Shinkang Fish Market (Fig. 1) from July 2004 to April 2006. The dorsal fins were kept in cold storage until being boiled to remove tissue and to separate the third spines. Two cross sections in thickness of 0.5 and 0.7 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; Chiang et al., 2004). 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 10x to 20x depending on the sizes of sections. The more visible one of these two sections was read twice, approximately two weeks apart. When the two ring counts differed, the section was read again, and if the third ring count differed from both of the previous two ring counts, the spine was considered unreadable and was discarded. The precision of reading was evaluated using average percent error (APE) (Beamish and Fournier, 1981; Campana, 2001).

Images of the cross sections were captured using the Image-Pro Image analysis software package in combination with a dissecting microscope equipped with a charged coupled device (CCD) camera (model: Toshiba IK-630) and a computer equipped with high-resolution 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 section was estimated following Cayré and Diouf (1983) (Fig. 2B). The distances (d_i) were then converted into radii (r_i) 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 following 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 of Hill et al. (1989), Sun et al. (2002) and Chiang et al. (2004). This 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 of the samples which have missing early rings were then compared with the radius data 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 for the data 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 using the equation (Hayashi, 1976, Prince et al., 1988; Sun et al., 2002; Chiang, et al, 2004):

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

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.

Growth estimation

Growth for males and females was estimated by back-calculation of lengths at presumed ages using two methods. Method I was based on the assumption that the relationship between spine radius (R) and LJFL (L) is linear, i.e. $L = a_1 + b_1 R$ (Berkeley and Houde, 1983; Sun et al., 2002) while Method II was based on the assumption that this relationship is a power function, i.e. $L = a_2 R^{b_2}$ (Ehrhardt, 1992; Sun et al., 2002). The parameters of the relationships were estimated by maximum likelihood, assuming log-normally distributed errors.

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 generalized von Bertalanffy growth function (Generalized VB; Richards,

1959) were then fitted to the mean back-calculated male and female lengths-at-age from methods I and II assuming additive error.

Standard VB:

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

Generalizd VB:

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

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).

Results

Length and weight data were collected from 4,521 individuals (3,799 female, 586 male, 136 sex unknown; Fig. 3), of which 923 (727 female, 196 male) dorsal fins were taken. Analyses of covariance found significant difference between females and males in the relationships of LJFL versus EFL, and LJFL versus weight (P<0.05). Of the 923 dorsal spines sampled, 874 (95%; 687 females and 187 males) were read successfully. The average percent error (APE) was 9.17% for females and 6.23% for males. The aged females ranged in size from 151 to 323 cm LJFL or 31 to 302 kg RW and the males ranged from 152 to 214 cm LJFL or 26 to 85 kg RW. The females were significantly larger than the males (t-test, P<0.05).

507 (74%) of the female spines and 182 (97%) of the male spines had at least the first or second ring visible. Their ring radii statistics by sex are summarized in Fig. 4. All other specimens were assigned inner rings and final age estimates based upon these data. The maximum age of the sampled black marlin, after correction for missing early rings, was 11 years for females and 5 years for males.

The monthly means of the marginal increment ratio (MIR) for females were high during September-December but declined markedly after January and reached a minimum of 0.6 in April (Fig. 5). The monthly means of MIR did not differ significantly from each other over the period from May to August (ANOVA, P>0.05).

However, those in September through January were significantly higher than those in February through April (*t*-test, P<0.001). Also, the mean MIR in April was significantly lower than that in May (*t*-tests, P<0.001). This result suggested that one growth ring was formed each year, most likely during February to April for female black marlin. The monthly means of MIR for males, however, did not clearly validate the formation of one ring per year due to too small sample size in some months (none in January and only one in each month from February to June).

Fig. 6 shows the sex-specific relationships between LJFL and spine radius based on method I (linear regression) and method II (power function). The relationships for males and females are not significantly different for method I (P>0.05), but are significantly different for method II (P<0.05).

The mean back-calculated lengths-at-age obtained from methods I and II are listed in Table 1. After the first year of life, the growth rates of both sexes slow appreciably. However, females still grow faster and reach larger sizes than males after age 3. The standard VB and the generalized VB for females and males are shown in Fig. 7 and the corresponding parameter estimates are listed in Table 2. The growth curves for males differ significantly from those for females (ARSS, P<0.05).

Discussion

Dorsal-fin spines appear to be useful for aging black marlin. 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, 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. Spines can also be easily stored for future reexamination (Compeán-Jimenez and Bard, 1983; Sun et al., 2001, 2002).

The problems associated with the fin-spine ageing method were the possible existence of false rings and the vascularized core which can obscure early growth rings in larger fish (Berkeley and Houde, 1983; Hedgepeth and Jolley, 1983; Tserpes and Tsimenides (1995), Megalofonou (2000), Sun et al. (2001, 2002) and Chiang et al. (2004). However, 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 (Tserpes and Tsimenides, 1995; Megalofonou, 2000). The missing early growth rings in larger specimens were accounted for by compiling ring radii statistics for younger specimens which had at least the first or second ring visible and comparing the radii of the first several visible rings of the specimens which had missing early rings to the mean and standard deviation 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) and sailfish (Chiang, et al., 2004).

Marginal increment ratio (MIR) analysis is the most commonly applied method for age validation (Campana, 2001). The MIR analysis conducted for black marlin suggested that one growth ring is formed each year during February to April for females. The MIR analysis provides only partial age validation; complete validation requires either mark-recapture data or the study of known-age fish (Beamish and McFarlane, 1983; Prince et al., 1991; Tserpes and Tsimenides, 1995; Sun et al., 2001, 2002).

Female black marlin are a little smaller than males before 3 of age, but females grow faster, and finally reach larger sizes than males. Both the standard and generalized VB curves in either Method I or II appear to fit the black marlin data as well (Fig. 7). However, the standard VB curve is commonly used to describe asymptotic growth in fish and Method II provides a more realistic description of growth of age 0 (Table 2). Therefore, the parameter estimates for the standard VB with method II are recommended as the most appropriate for calculating the age composition of black marlin in the waters off eastern Taiwan.

Age and growth study of black marlin have been reported only for east coast Australian waters (Speare, 2003). The maximum ages found in our study, 11 years (323 cm LJFL) for females and 5 years (214 cm LJFL) for males, are close to those of 12 years (326 cm LJFL) for females and 6 years (255 cm LJFL) for males proposed by Speare (2003) based on dorsal and anal spines. However, the growth curve of black marlin obtained by Speare (2003) differs significantly from ours in this study (Fig. 8). This might be due to the size range difference of samples between ours (160 to 250 cm LJFL) and Speare's (120 to 180 cm LJFJ) and due to the fact that Speare's estimate was sex-combined.

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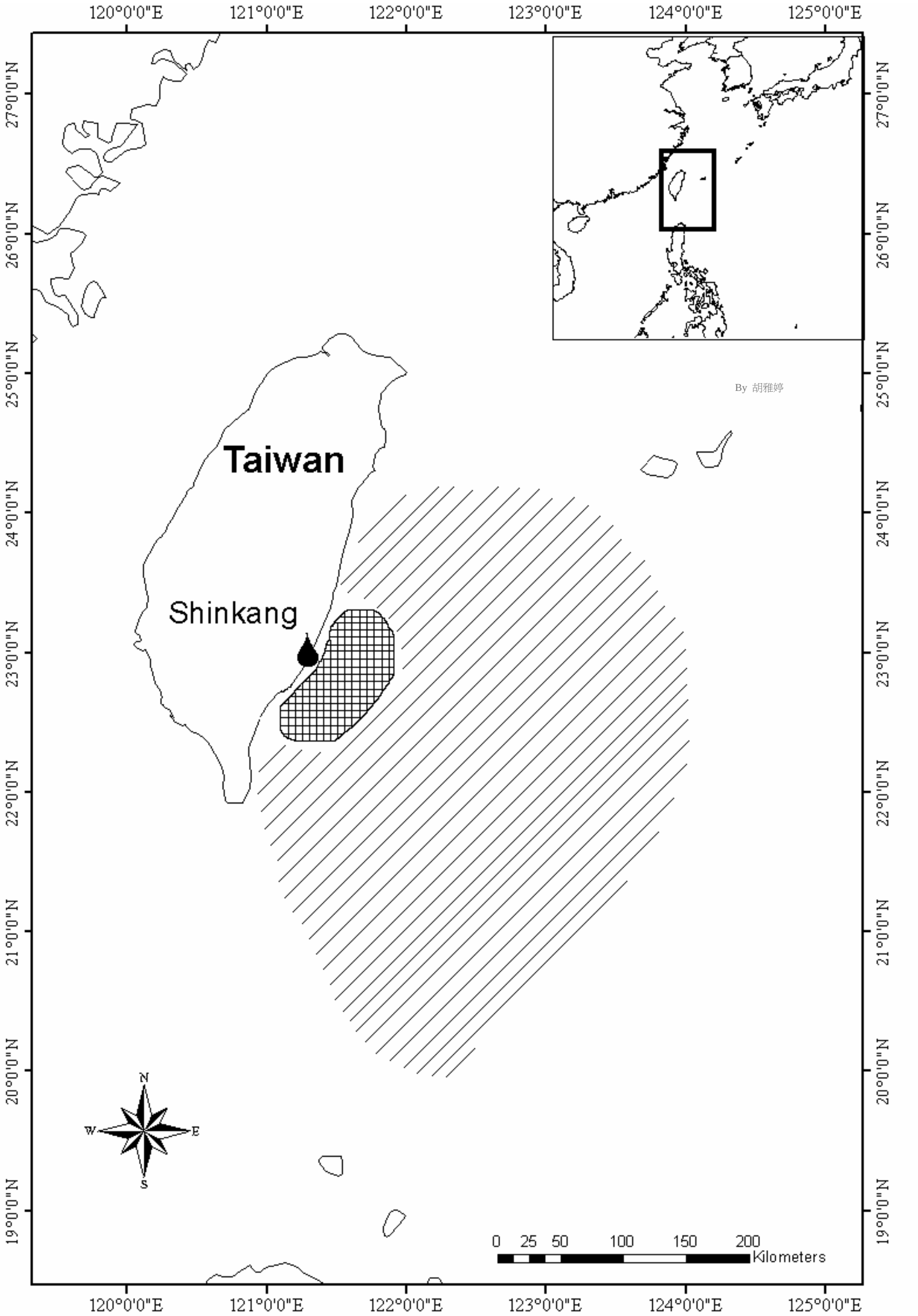


Fig. 1. The fishing grounds of gillnet and harpoon (cross lines) and longline (oblique lines) fishing boats based in Shinkang fishing port.

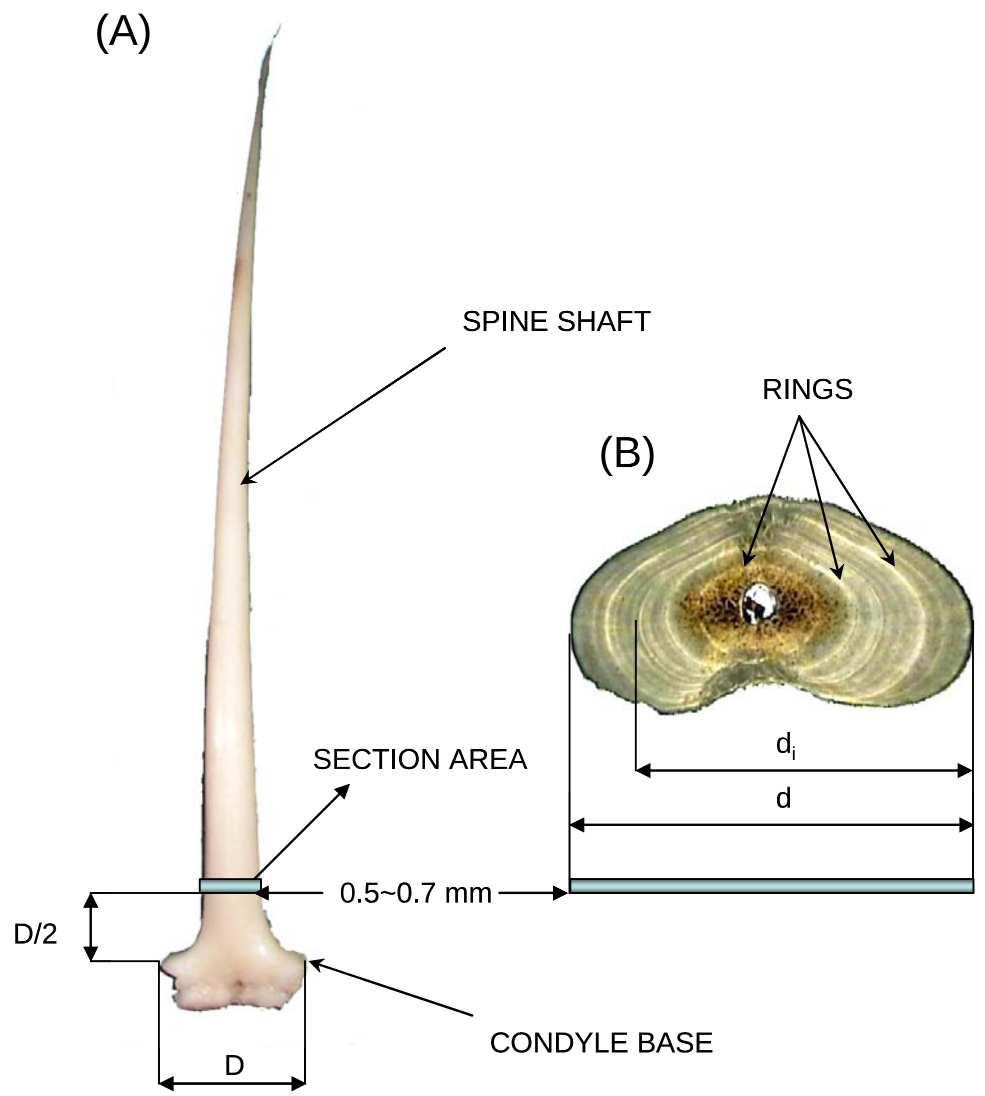


Fig. 2. The third dorsal spine and the site of cross section (A) and a cross section showing the measurements taken for age determination of black marlin, *Makaira indica*,(B). (D, width of condyle base; d, diameter of spine; d_i, diameter of ring.)

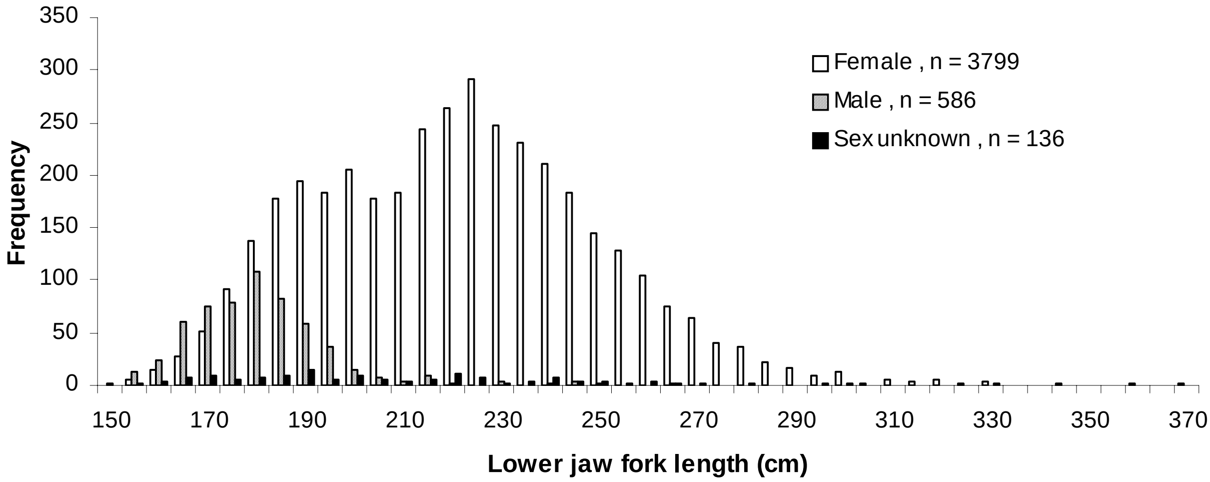


Fig. 3. The size frequency distribution (5 cm intervals) of the male and the female black marlin, *Makaira indica*, collected from the waters off eastern Taiwan, July 2004 to April 2006.

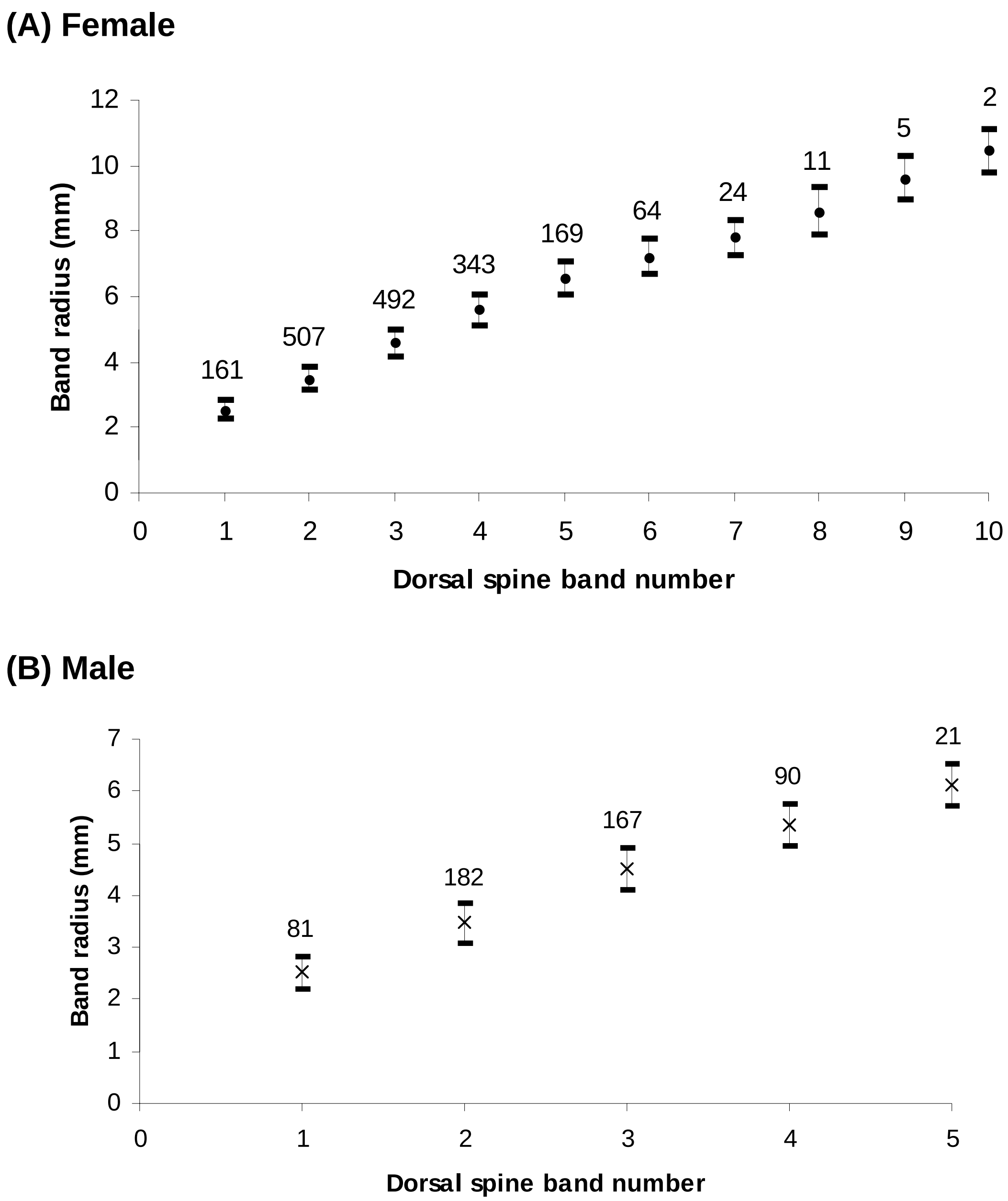
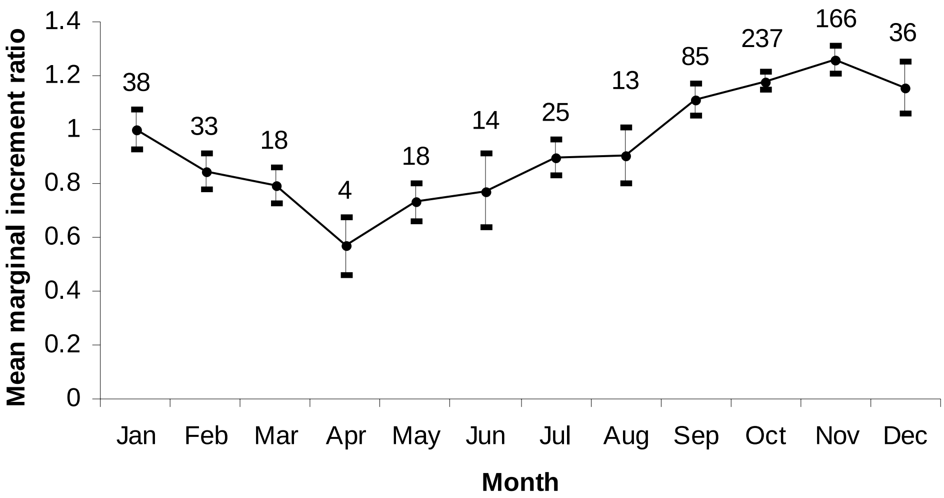


Fig. 4. Mean (±SD) ring radius for the female (A) and male (B) black marlin, *Makaira indica*, collected from the waters off eastern Taiwan which had at least the first or second ring present. The numbers above the vertical bars are sample sizes.

(A) Female



(B) Male

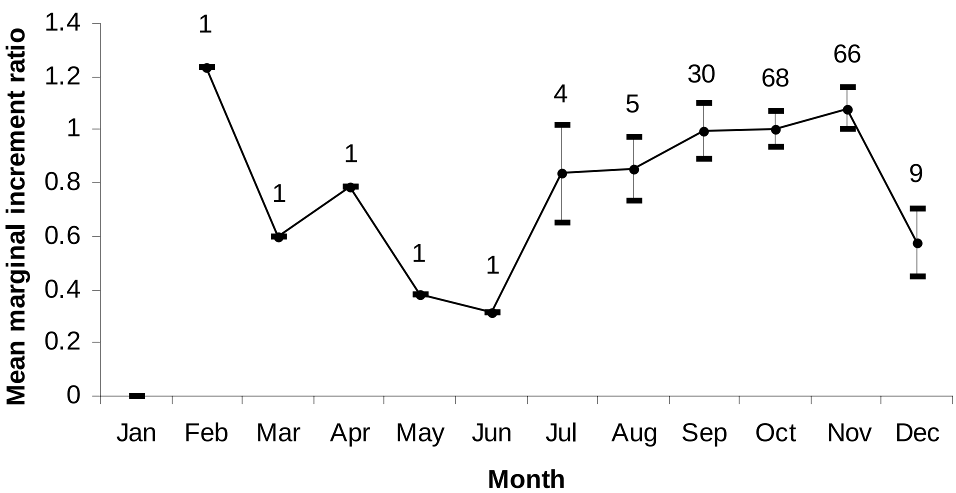
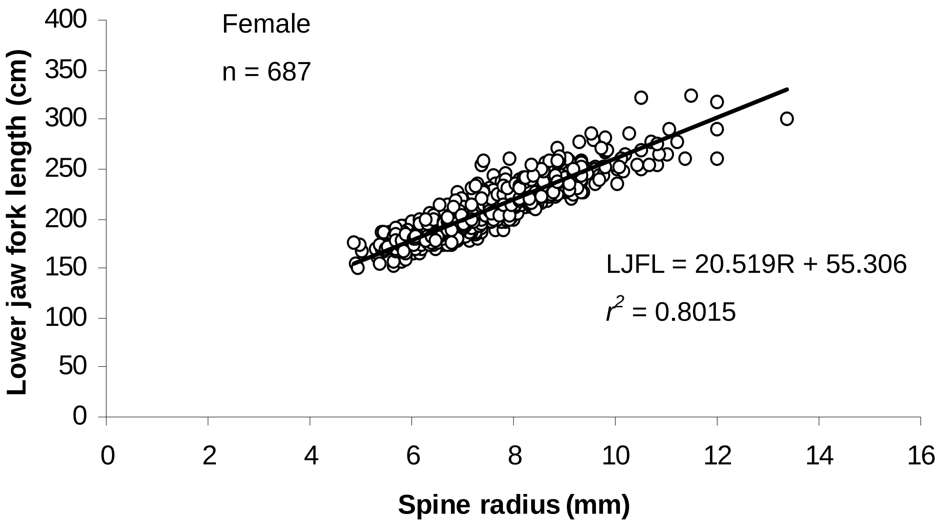


Fig. 5. Monthly means of marginal increment ratio for the female (A) and male (B) black marlin, *Makaira indica*, collected from the waters off eastern Taiwan during July 2004 to April 2006. Vertical bars are ±1 SE, numbers above the vertical bars are sample sizes.

(A) Linear regression



(B) Power function

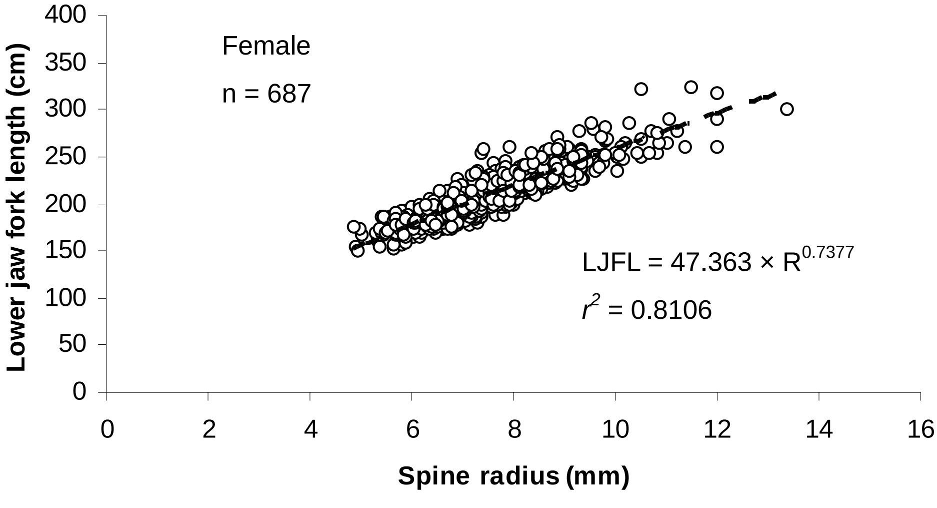
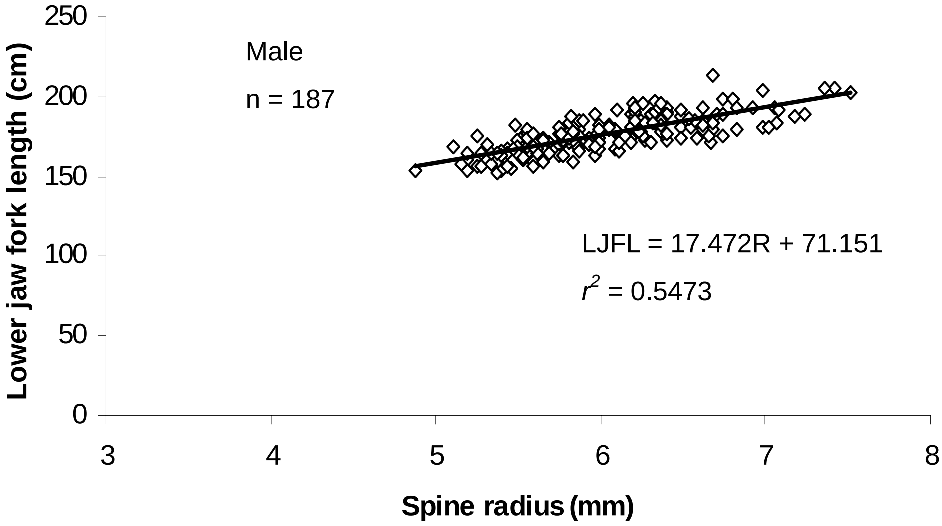


Fig. 6a. Linear regression (A) and power function (B) relationships between lower jaw fork length and spine radius for the female black marlin, *Makaira indica*, collected from Shinkang Fish Market.

(A) Linear regression



(B) Power function

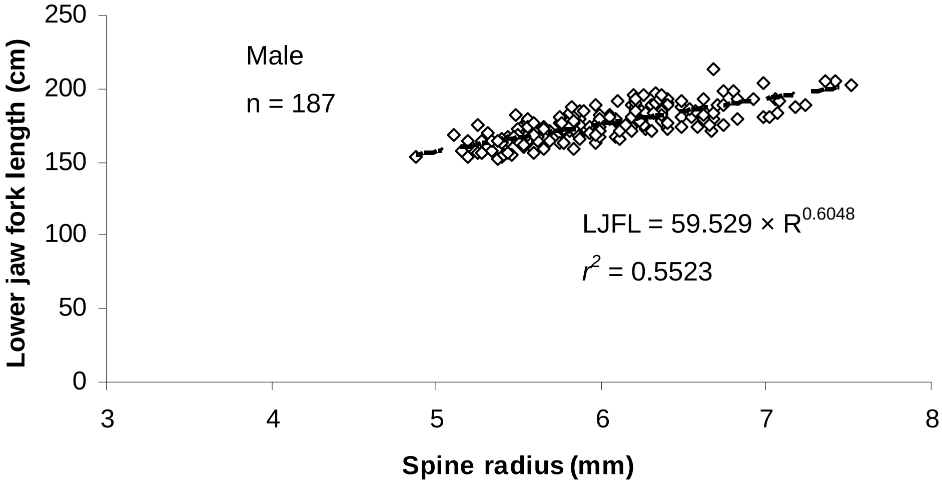
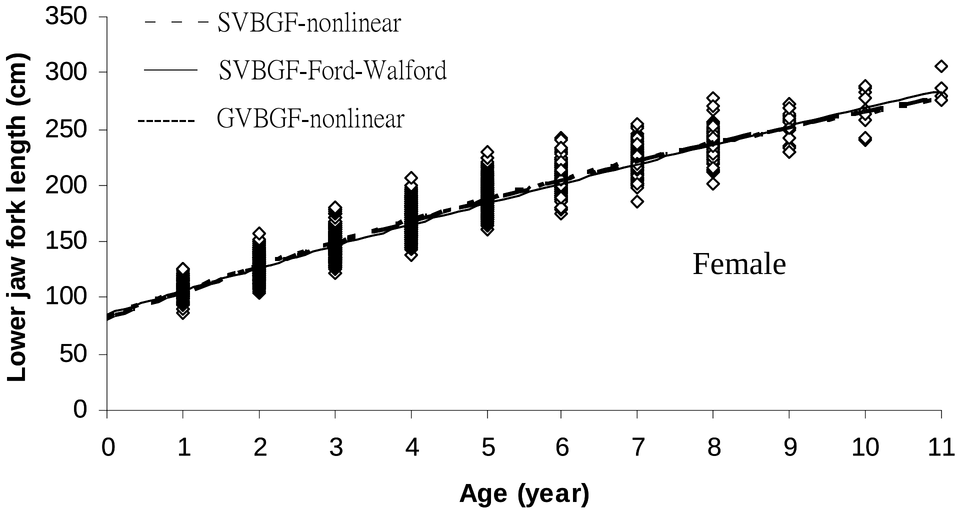


Fig. 6b. Linear regression (A) and power function (B) relationships between lower jaw fork length and spine radius for the male black marlin, *Makaira indica*, collected from Shinkang Fish Market.

(A) Fraser-Lee's method (Method I)



(B) Monastyrsky method (Method II)

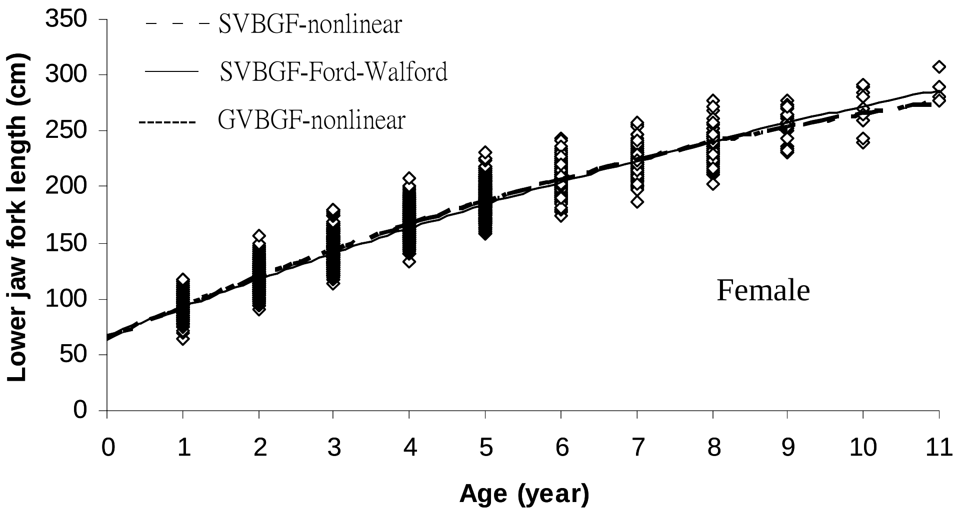
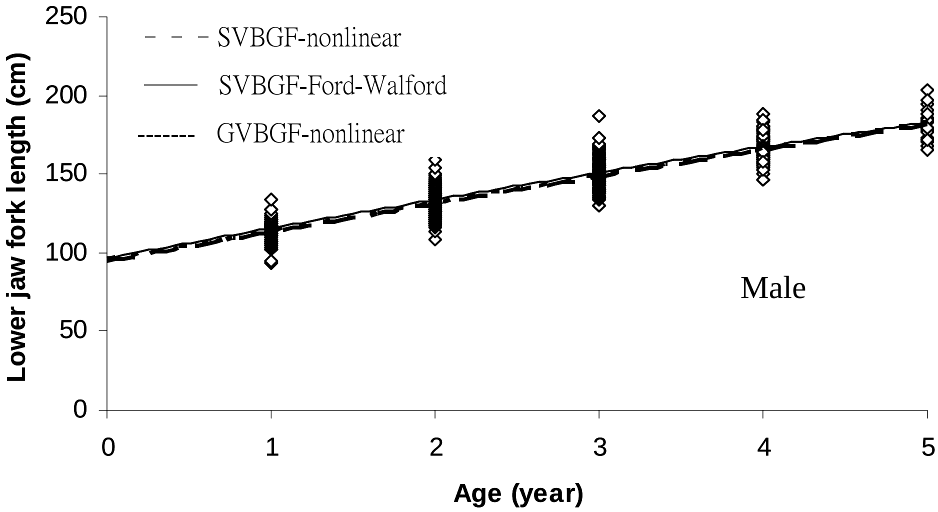


Fig. 7a. Standard and generalized von Bertalanffy growth curves estimated by Fraser-Lee's method (A) and Monastyrsky method (B) for the female black marlin, *Makaira indica*, in the waters off eastern Taiwan.

(A) Fraser-Lee’s method (Method I)



(B) Monastyrsky method (Method II)

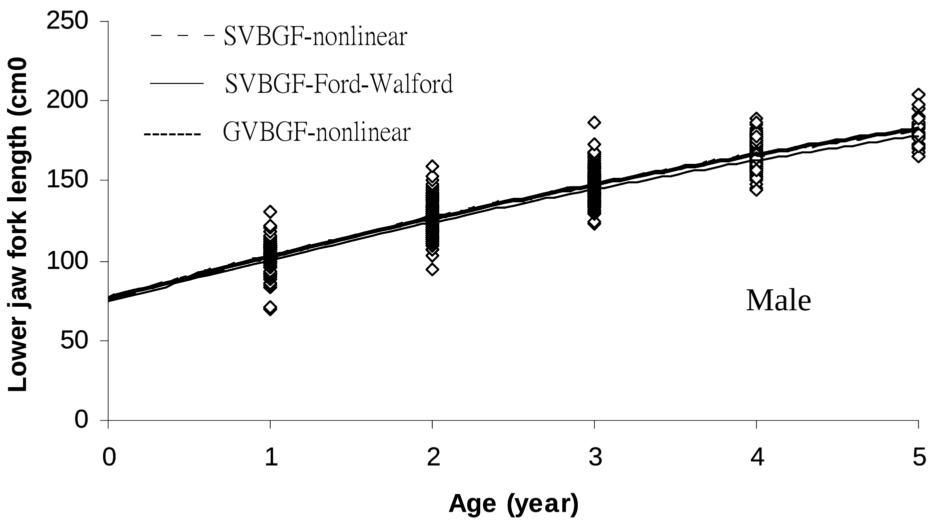


Fig. 7b. Standard and generalized von Bertalanffy growth curves estimated by Fraser-Lee's method (A) and Monastyrsky method (B) for the male black marlin, *Makaira indica*, in the waters off eastern Taiwan.

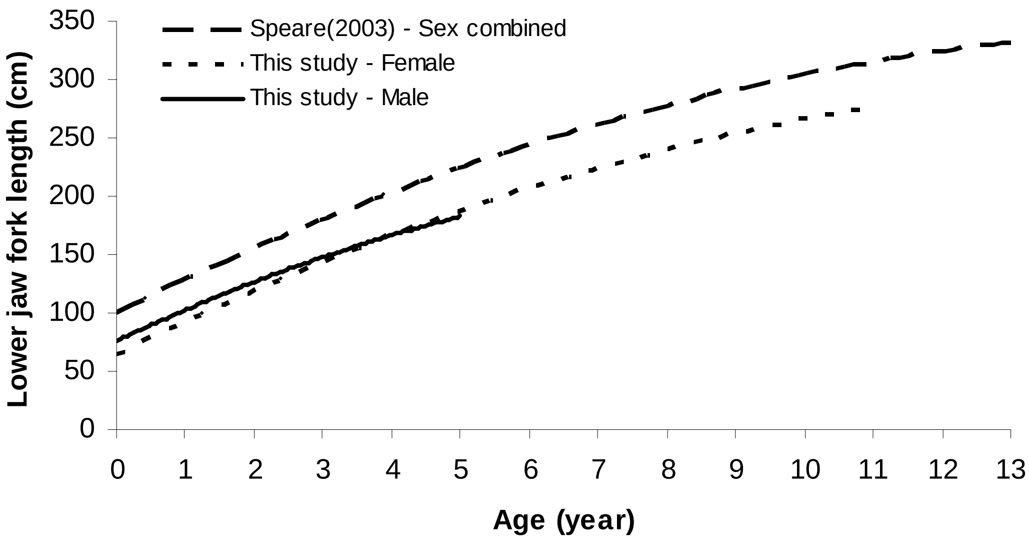


Fig. 8. A comparison of the growth curves of Pacific black marlin estimated by two authors.

Table 1. Mean back-calculated lower jaw fork lengths at age for black marlin, *Makaira indica*, in the waters off eastern Taiwan.

	Back-calculated length (cm)			
	Fraser-Lee's method		Monastyrsky method	
Age(yr)	Male	Female	Male	Female
1	119.294	107.742	109.278	94.1282
2	135.395	127.117	130.775	119.014
3	153.566	148.385	152.114	144.417
4	170.696	169.244	170.567	167.692
5	184.267	189.692	184.557	189.543
6		205.429		206.025
7		220.501		221.493
8		236.478		237.569
9		253.541		255.299
10		267.127		269.156
11		286.882		288.775

Table 2. Parameter estimates for standard von Bertalanffy and generalized von Bertalanffy growth models for a black marlin, *Makaira indica*, in the waters off eastern Taiwan.

	Standard von Bertalanffy growth model								Generalized von Bertalanffy growth model			
	Nonlinear regression				Ford-Walford plot				Nonlinear regression			
	Fraser-Lee's method		Monastyrsky method		Fraser-Lee's method		Monastyrsky method		Fraser-Lee's method		Monastyrsky method	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
L_∞	609.117	500.648	305.828	396.569	472.996	791.57	292.283	529.01	345.559	484.011	301.889	366.526
k	0.037	0.058	0.125	0.094	0.052	0.03	0.13	0.059				
K									0.39	0.346	0.142	0.147
t_o	-4.558	-3.057	-2.274	-1.825	-4.367	-3.802	-2.249	-2.268	-9.2662	-6.7889	-2.461	-2.38
m									0.691	0.631	0.069	0.193