Sex-specific Growth Parameters and Natural Mortalilty Rates for Blue Marlin (*Makaira nigricans*) in the Northwest Pacific Ocean

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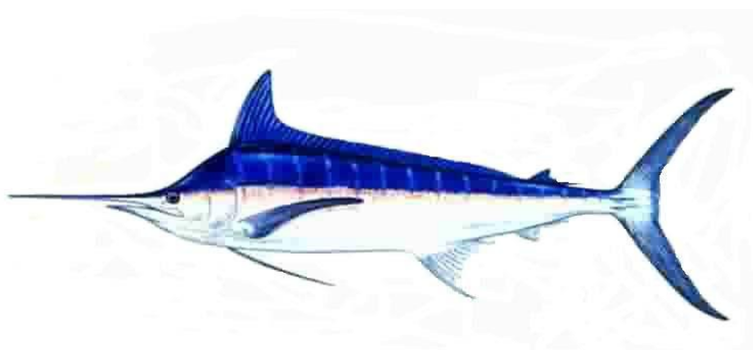

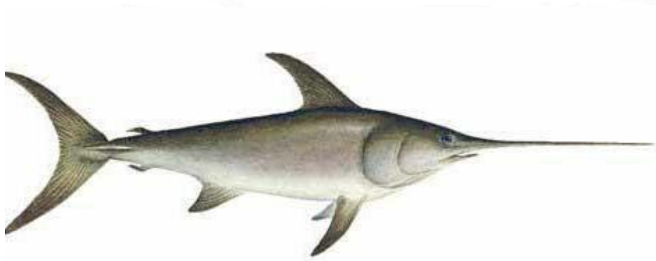

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Sex-specific growth parameters and natural mortality rates of blue marlin (*Makaira nigricans*) in the northwest Pacific Ocean*

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Abstract

Blue marlin are sexually dimorphic in size-at-age and other biological characteristics. We analyzed the sex-specific catch-at-length data for blue marlin, ranging between 100-311 cm in eye to fork length (EFL) for females and 100-236 cm EFL for males, collected from the Taiwanese offshore longline fishery in the northwest Pacific Ocean. Female blue marlin reach larger body sizes than males. Growth parameters and natural mortality rates of blue marlin were estimated to differ between males and females. We suggest that growth parameters and natural mortality rates should be sex-specific when stock assessments for sexually dimorphic species such as blue marlin are conducted.

Keywords: sexual dimorphism, catch-at-length data, population parameters.

Introduction

Blue marlin (*Makaira nigricans*) is a cosmopolitan species distributed throughout tropical and temperate waters of the Indo-Pacific and Atlantic Oceans between 45˚N and 45˚S (Su et al., 2011). Most blue marlin are caught, as an incidental bycatch of considerable economic value, by longline vessels targeting tunas, while small catches of blue marlin are taken using surface gears, such as gillnets and harpoons, as well as by recreational and purse seine fisheries in the Pacific Ocean (see Hinton, 2001; Molony, 2008).

A single stock of blue marlin in the Pacific Ocean has been assumed based on analyses of genetic divergence (Graves and McDowell, 2003) and fishery catch-rates (Kleiber et al., 2003). The assumption of a single stock is also supported by the results

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of tagging experiments, which have shown that blue marlin migrate long distances, up to more than 8000 km in some instances, and throughout the Pacific basin (Hinton, 2001). The blue marlin stock in the Pacific Ocean has previously been assessed to be overfished or near fully exploited (Kleiber et al., 2003; Su et al., 2012), indicating that this stock was under high fishing pressure.

The objectives of this study were to estimate the growth parameters and natural mortality rates by sex of blue marlin in the northwest Pacific Ocean that are poorly described in previous studies, and to provide suggestions for how the population dynamics of sexually-dimorphic species should be modeled when stock assessments are conducted.

Materials and methods

Eye fork length (EFL, in cm), lower jaw fork length (LJFL, in cm), whole weight (W, in kg), and sex information for blue marlin caught in the northwest Pacific Ocean (Fig. 1) by Taiwanese small-scale (<100 gross register tons) tuna longline vessels were collected monthly and randomly at the fishing ports (Tungkang and Shinkang) during 2000 to 2006. Sex was identified by examining the gonads. EFL-LJFL (LJFL = a + b EFL) and EFL-W (W = c EFL^d) relationships were derived to test, using analysis of covariance (ANCOVA), for differences between the sexes, and to make conversions between different length measurements (Table 1).

The parameters by sex of the von Bertalanffy growth equation (VBGE) were estimated using empirical equations for blue marlin. The asymptotic length (L_{inf}) that the fish would eventually attain should not differ too much from the average of the maximum sizes among individuals (see Froese and Binohlan, 2000). The equation developed by Froese and Binohlan (2000) was used therefore to estimate L_{inf}, based on the length of the largest fish sampled from the population (L_{max}).

The growth coefficient (K) of VBGE for blue marlin can be estimated using Beverton's (1992) equation, which relates K, L_{inf}, the length-at-first-maturity (L_m), and the mean age-at-first maturity (t_m)(Su et al., 2013). The estimates of L_m and t_m for blue marlin in the literature (Molony, 2008; Sun et al., 2009) were used in this study.

The theoretical age at zero length (t_0) for blue marlin was estimated by sex using the empirical equation of Pauly (1979), which can be expressed as:

$\log(-t_0) = -0.3922 - 0.2752 \log(L_{inf}) - 1.038 \log(K)$.

The natural mortality rates of blue marlin by sex were estimated using the empirical relationship of Pauly (1980) with growth parameters of VBGE derived in this study. The equations and the values used were summarized in Table 2.

Results and discussion

In total, 1325 female and 1943 male blue marlin were sampled, with mean lengths of 193 cm and 158 cm EFL, respectively (Fig. 2). The EFL-LJFL equations by sex were pooled because the sex-specific relationships did not differ statistically (ANCOVA, $P > 0.05$) (Fig. 3; Table 1). However, the relationships between EFL and W differed significantly between the sexes (ANCOVA, $P < 0.01$) so separate relationships are reported in Table 1 (Fig. 4).

The estimates of the VBGE parameters were listed in Table 2. As expected, the estimates of L_{inf}, K, and t_0 differ between the sexes. The theoretical age at zero length (t_0) for blue marlin were assumed to be 0 and –4 in this study, to examine the impacts of different values assuming for this parameter (t_0). The estimated sex-specific growth curves were consistent with those estimated by Dai (2002) when same values for t_0 were assumed, which illustrates the sexual dimorphism in blue marlin (Fig. 5). Hill et al. (1989) did not provide growth rates for blue marlin owing to the difficulty in ageing larger fish. However, the growth curves of blue marlin derived from this study were consistent with the mean lengths-at-age based on annual increments in spine sections from Hill et al. (1989) for both sexes (Fig. 5). The growth parameters derived in present study could be used for the stock assessment of Pacific blue marlin:

L_{inf} = 313.8 cm EFL, K = 0.102 year^{-1}, t_0 = -3.164 year for females;

L_{inf} = 239.4 cm EFL, K = 0.145 year^{-1}, t_0 = -2.366 year for males.

Su et al. (2013) have estimated the growth parameters (L_{inf} and K) for blue marlin in the northwest Pacific Ocean using the empirical equations, as those in this study. Skillman and Yong (1976) applied length-frequency analysis to estimate VBGE parameters for blue marlin. However, their estimates were not biologically reasonable, (e.g., an incredibly large estimate, over 1000 cm, for L_{inf}). Very few blue marlin larger than 400 cm were sampled in all commercial and recreational fisheries in the Pacific Ocean (Kleiber et al., 2003; Molony, 2008; Su et al., 2012).

It is often difficult to estimate *M* for exploited fish populations directly. Thus, published empirical relationships between *M* and life history parameters are used frequently to infer this parameter. However, *M* and other life history parameters are poorly described by sex for blue marlin. The estimates of natural mortality for females (Dai, 2002 and this study) were consistently lower than those for males (Table 2).

M should consequently be assumed to differ between sexes when modeling the population dynamics of blue marlin. The results derived from this study re-emphasize the need to take sexual dimorphism into account in stock assessments for sexually-dimorphic species through, for example, the use of sex-specific parameters related to population process such as growth and natural mortality parameters.

References

Beverton, R.J.H. (1992). Patterns of reproductive strategy parameters in some marine teleost fishes. J. Fish. Biol., 41(Suppl. B): 137–160.

Dai, C.Y. (2002). Estimates of age, growth and mortality of blue marlin, *Makaira mazara*, in the western Pacific using the length-based MULTIFAN method. Master Thesis, National Taiwan University, Taipei. 80 pp.

Froese, R., Binohlan, C. (2000). Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. J. Fish. Biol., 56: 758–773.

Graves, J.E., McDowell, J.R. (2003). Stock structure of the world's istiophorid billfishes: a genetic perspective. Mar. Freshw. Res., 54: 287–298.

Hill, K.T., Cailliet, G.M., Radtke, R.L. (1989). A comparative analysis of growth zones in four calcified structures of Pacific blue marlin, *Makaira nigricans*. Fish. Bull., 87: 829–843.

Hinton, M.G. (2001). Status of blue marlin in the Pacific Ocean. Inter-American Tropical Tuna Commission (IATTC), Stock Assessment Report 1, pp. 284–319.

Kleiber, P., Hinton, M.G., Uozumi, Y. (2003). Stock assessment of blue marlin (*Makaira nigricans*) in the Pacific using MUNTIFAN-CL. Mar. Freshw. Res., 54: 349–360.

Molony, B. (2008). Fisheries biology and ecology of highly migratory species that commonly interact with industrialised longline and purse-seine fisheries in the western and central Pacific Ocean. Working Paper EB-IP-6, 4th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission (WCPFC-SC4). Port Moresby, Papua New Guinea, 11-22 August 2008.

Pauly, D. (1979). Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy growth formula. Berichte aus dem institute fuer meereskunde, Number 63, Kiel University, Kiel.

Pauly, D. (1980). On the interrelationships between natural morality, growth parameters and mean environmental temperatures in 175 fish stocks. J. Cons. Int. Explor. Mer., 39: 175–192.

Pine, W.E., Martell, S.J.D., Jensen, O.P., Walters, C.J., Kitchell, J.F. (2008). Catch-and-release and size limit regulations for blue, white, and striped marlin: the role of post-release survival in effective policy design. Can. J. Fish. Aquat. Sci., 65: 975–988.

Skillman, R.A., Yong, M.Y.Y. (1976). Von Bertalanffy growth curves for striped marlin, *Tetrapturus audax*, and blue marlin, *Makaira nigricans*, in the central North Pacific Ocean. Fish. Bull., 74: 553–66.

Su, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., DiNardo, G. (2011). Modelling the impacts of environmental variation on the distribution of blue marlin, *Makaira nigricans*, in the Pacific Ocean. ICES J. Mar. Sci., 68: 1072–1080.

Su, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., DiNardo, G. (2012). Incorporating habitat preference into the stock assessment and management of blue marlin (*Makaira nigricans*) in the Pacific Ocean. Mar. Freshw. Res., 63: 565–575.

Su, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., Chiang, W.C., Chang, Y.J., Chang, H.Y. (2013). Effects of sexual dimorphism on population parameters and exploitation ratios of blue marlin (*Makaira nigricans*) in the northwest Pacific Ocean. Aquat. Living Resour., in press.

Sun, C.L., Chang, Y.J., Tszeng, C.C., Yeh, S.Z., Su, N.J. (2009). Reproductive biology of blue marlin (*Makaira nigricans*) in the western Pacific Ocean. Fish. Bull., 107: 420–432.

Table 1. Conversion equations for eye fork length (EFL, cm), lower jaw fork length (LJFL, cm), and weight (W, kg) for blue marlin in the northwest Pacific Ocean.

Equation	Sex	Coefficient	r^2	n^*
LJFL = a + b EFL	Pooled	a = 9.550; b = 1.080	0.986	312
$W = c\,EFL^d$	Female	$c = 1.427\times10^{-5}$; d = 2.996	0.878	717
	Male	$c = 1.116\times10^{-5}$; d = 3.033	0.871	1043

* *n* denotes the sample sizes.

Table 2. Estimates of population parameters for blue marlin in the northwest Pacific Ocean and the equations used to estimate them (see Materials and methods section for the definitions of the symbols).

Parameter	Female	Male	Equation	Reference
L_{max} (cm)	310.8	236.1		This study
L_m (cm)	158	131		Sun et al., 2009
t_m (year)	4	3		Molony, 2008
L_{inf} (cm)	313.8	239.4	$10^{0.044+0.984\log(L_{max})}$	Froese and Binohlan, 2000
K (year^{-1})	0.102	0.145	$\ln(1+L_m/L_{inf})/t_m$	Beverton, 1992
t_0 (year)	-3.164	-2.366	$-1\times10^{-0.3922-0.2752\log(L_{inf})-1.038\log(K)}$	Pauly, 1979
M_1 (year^{-1})	0.201	0.274	$e^{-0.015-0.279\ln(L_{inf})+0.654\ln(K)+0.463\ln(T)}$	Pauly, 1980*
M_2 (year^{-1})	0.213	0.258		Dai, 2002

* A mean temperature of 26°C (Pine et al., 2008) was used when applying Pauly's (1980) method.

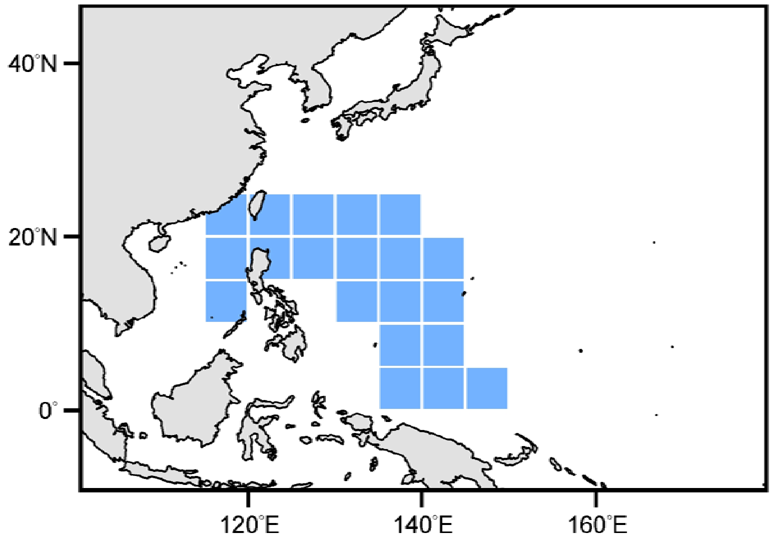

Fig. 1. Map of the northwest Pacific Ocean showing the area where blue marlin were caught based on logbooks.

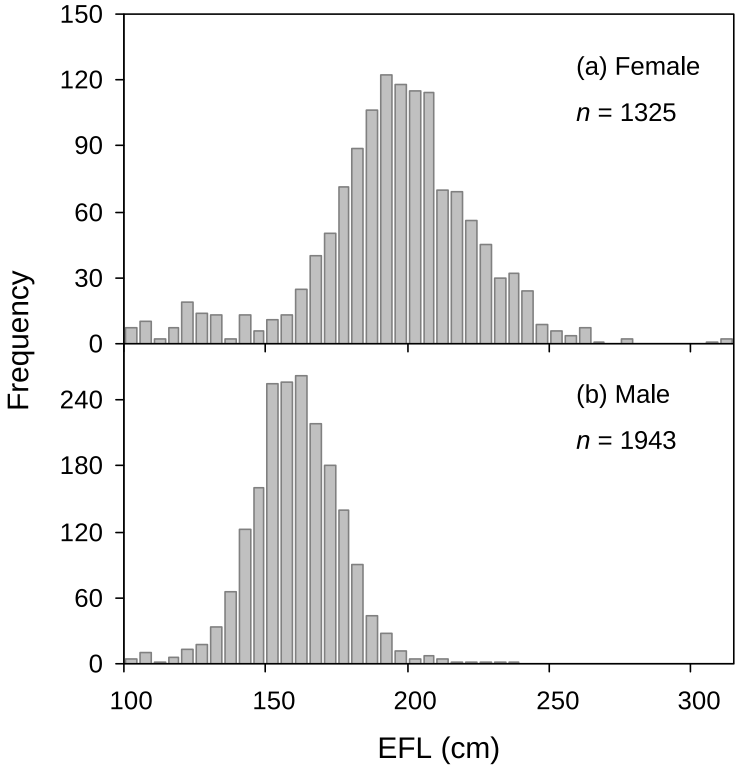

Fig. 2. Length-frequency distributions for blue marlin captured by the Taiwanese tuna longline vessels in the northwest Pacific Ocean.

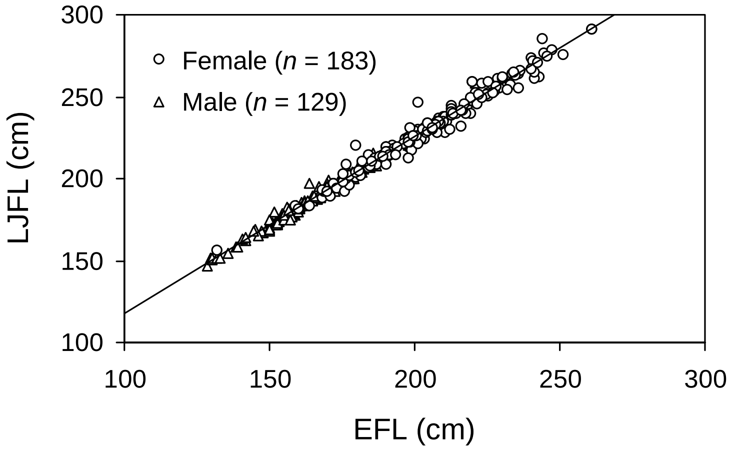

Fig. 3. The relationship between eye to fork length (EFL) and lower jaw to fork length (LJFL) for blue marlin in the northwest Pacific Ocean (sex-pooled; ANCOVA, $p > 0.05$).

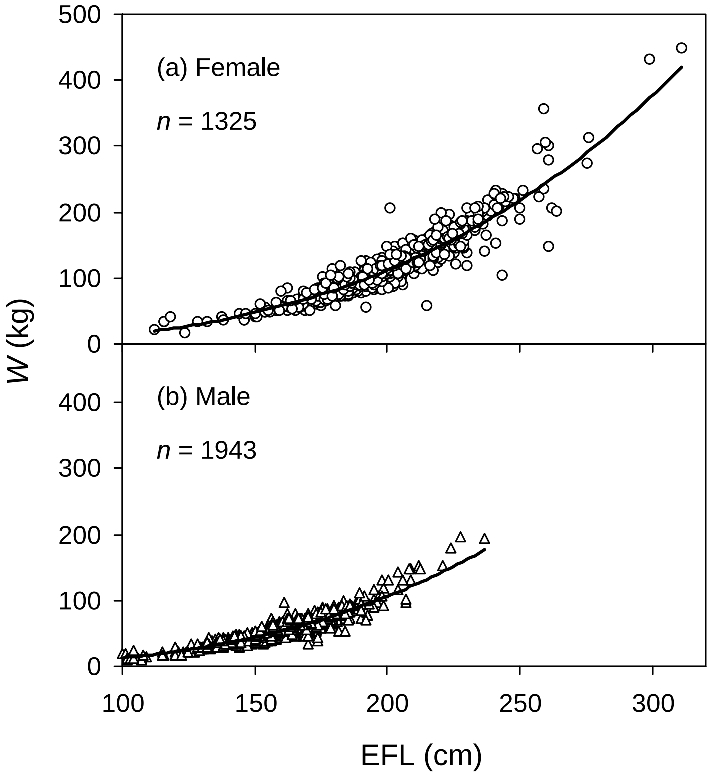

Fig. 4. Relationships between eye to fork length (EFL) and weight (W) for blue marlin in the northwest Pacific Ocean.

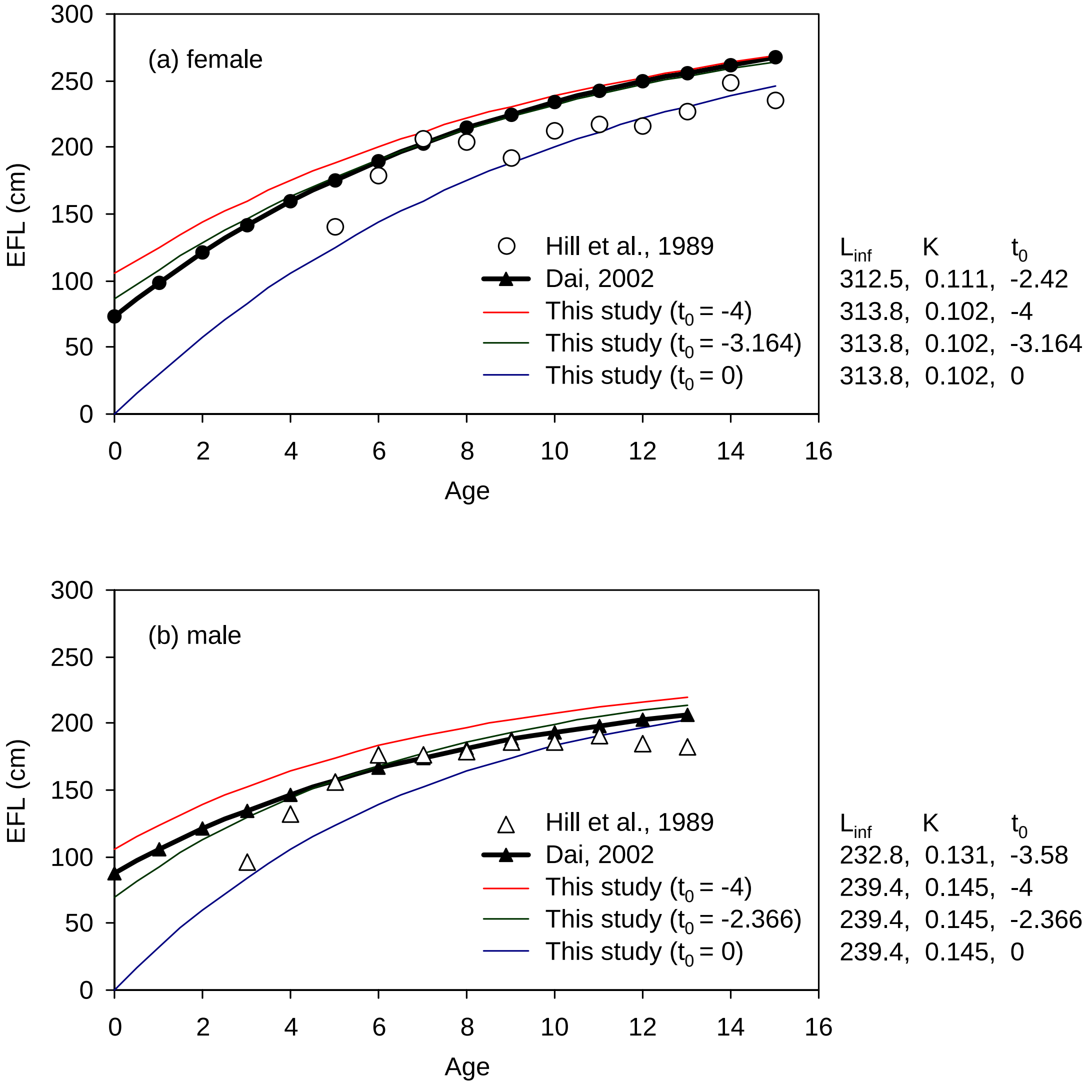

Fig. 5. Mean lengths-at-age (open points) and growth curves (lines) for blue marlin estimated by different authors.