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Research Article

Age and growth of the swordfish (*Xiphias gladius* Linnaeus, 1758) in the southeastern Pacific off Chile (2001)

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ABSTRACT. The age and growth of swordfish (*Xiphias gladius*) in the southeastern Pacific off Chile were estimated for 511 males and 632 females using samples collected from longline fisheries in 2001. Lower jaw fork length (LJFL) measurements ranged from 100 to 265 cm for males and 116 to 289 cm for females. Age estimates were obtained using cross sections of the second anal fin ray. Both the monthly average marginal increment and the analysis of the edge type indicated periodicity in the formation of growth bands, with the hyaline band forming in the summer (December-March). The relationship between the ray radius and LJFL was nonlinear. The growth was modeled using standard and generalized Von Bertalanffy equations. Swordfish growth was best described by the standard equation, with the following parameters: L_∞ = 279 cm, K = 0.158, t_0 = −2.65 for males, and L_∞ = 321 cm, K = 0.133, t_0 = −2.46 for females. The analysis of growth curves revealed that females are significantly larger than males. A comparison of growth rates between different studies shows that swordfish in the southeastern Pacific off Chile grow faster than those from the northwestern Pacific (Taiwan), southwestern Pacific (Australia), and other regions (Atlantic Ocean, Mediterranean Sea), but their growth rates are very similar to those of the swordfish from the central North Pacific (Hawaii).

Keywords: age, growth, swordfish, *Xiphias gladius*, Chile, southeastern Pacific.

Edad y crecimiento del pez espada (*Xiphias gladius* Linnaeus, 1758) en el Pacífico suroriental frente a Chile (2001)

RESUMEN. La edad y el crecimiento del pez espada (*Xiphias gladius*) en el Pacífico suroriental frente a Chile fue estimado para 511 machos y 632 hembras con muestras obtenidas en la pesquería de palangre durante el 2001. La distribución de la longitud mandíbula inferior horquilla (LMIH) varió entre 100 y 265 cm en machos y 116 y 289 cm en hembras. La edad fue estimada en secciones transversales de la segunda espina de la aleta anal. El promedio mensual del incremento marginal así como el análisis del tipo de borde indica una periodicidad en la formación de bandas de crecimiento donde la formación de la banda hialina ocurre durante el verano (diciembre a marzo). La relación entre el radio de la espina y la LMIH fue no lineal. El crecimiento fue modelado usando la ecuación de Von Bertalanffy en su forma estándar y generalizada. El crecimiento del pez espada se ajustó mejor a la ecuación estándar obteniendo los siguientes parámetros: L_∞ = 279 cm; K = 0,158; t_0 = −2,65 en machos y L_∞ = 321 cm; K = 0,133; t_0 = −2,46 en hembras. El análisis de las curvas de crecimiento revela que las hembras alcanzan mayores tamaños que los machos. Una comparación de la tasa de crecimiento entre diferentes estudios indica que el pez espada del Pacífico suroriental frente a Chile crece más rápido que en el Pacífico noroeste (Taiwán), Pacífico suroeste (Australia) y otras regiones (océano Atlántico y Mar Mediterráneo), sin embargo crece en forma muy similar al pez espada del Pacífico Norte central (Hawai).

Palabras clave: edad, crecimiento, pez espada, *Xiphias gladius*, Chile, Pacífico suroriental.

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INTRODUCTION

The swordfish (*Xiphias gladius*) is a cosmopolitan species that is found from tropical to temperate waters (between 5 and 27ºC). Commercial catch data indicate a latitudinal distribution that extends from 50ºN to 45ºS in the western Pacific and from 50ºN to 35ºS in the eastern Pacific (Nakamura, 1985). In Chile, swordfish are caught with small-scale drift gill nets and large-scale commercial longlines. Catches have been recorded since 1938, but fisheries did not experience significant growth until 1986. Total landings peaked in 1991, reaching 5,959 tons (Barbieri *et al*., 1998), and then stabilized in recent years with catches of 1,397 and 1,586 tons in 2001 and 2002, respectively (Donoso *et al*., 2002, 2003a).

Swordfish age and growth studies have been based mainly on two different methods: modal decomposition analysis of length frequency data and the analysis of hard parts such as otoliths, dorsal and anal fin rays, and vertebrae. These studies have been carried out in different geographic areas, including the Atlantic, the Mediterranean Sea, and the North Pacific (Yabe *et al*., 1959; Berkeley & Houde, 1983; Wilson & Dean, 1983; Tserpes & Tsimenides, 1995; Ehrhardt *et al*., 1996; Sun *et al*., 2002). Conversely, only one attempt has been made to estimate age and growth in the southeastern Pacific region (Donoso & Chong, 1992); this study was based on a few samples obtained at the onset of longline activities.

Assessing the growth of a species is a fundamental part of fisheries population dynamics, particularly for highly migratory species, as growth comparisons could also facilitate understanding of their life history traits. Therefore, the objective of the current study was to estimate sex-specific age and growth of swordfish by counting growth rings in cross sections of anal fin rays from the southeastern Pacific off Chile.

MATERIALS AND METHODS

Swordfish lower jaw fork length (cm), total weight (kg), and anal fin rays were sampled by sex and monthly on board longline vessels in the fishing areas of the Chilean longline fleet in 2001 (Fig. 1). A total 1,143 anal fin rays were collected and processed (511 males, 632 females). In the laboratory, anal fins ray were boiled for 5 min; the second rays were cleaned and dried at room temperature. Second anal fin rays were cross sectioned at a location equivalent to ¾ the maximum width of the condyle base (Fig. 2). Sections approximately 1.5 mm thick were obtained using an "ISOMET" saw with diamond wafering blades. These sections were immersed in 96% alcohol for 20 min and then stored dry.

Sections were analyzed under a stereomicroscope with reflected light at a magnification of 10x or higher when needed to observe details of the type of edge. Measurements from the focus to the distal edge of the section (ray radius) and from the focus to the distal edge of each annulus were measured for each specimen using an eyepiece equipped with a graduated reticule. The criteria of Berkeley & Houde (1983) and Ehrhardt (1999) were used to identify annuli. The cross section readings were conducted deliberately without prior information of the sampled fish (i.e., length, weight, date of capture). Ageing bias and band count precision between readers were assessed using age-bias plots and the coefficient of variation (Campana, 2001) and average percent error (IAPE, Beamish & Fournier, 1981).

Two methods were used to evaluate the annual periodicity in the formation of ray growth bands in swordfish. The first method considered the monthly proportion in the type of band (opaque, translucent) present on the edge of each cross section. 2) For the second method, the marginal increment ratio (MIR) was also estimated for each specimen using the following formula (Sun *et al*., 2002):

$$MIR = \frac{\left(S - S_n\right)}{\left(S_n - S_{n-1}\right)}$$

where S : distance from the section ray focus to the edge,

S_n and S_{n-1} : distance from ray focus to bands *n* and *n-1*, respectively.

Due to a lack of small-sized swordfish (age 0-1+ year old), a back-calculation procedure was used. The relationship between the ray radius and the length of the fish (LJFL) was nonlinear; therefore, the proportional method described by Bagenal & Tesch (1978 *fide* Francis, 1990) was used as follows:

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

where L : LJFL at the time of capture

L_n : LJFL when band *n* was formed

b : exponent of the nonlinear regression of fish length on ray radius at capture.

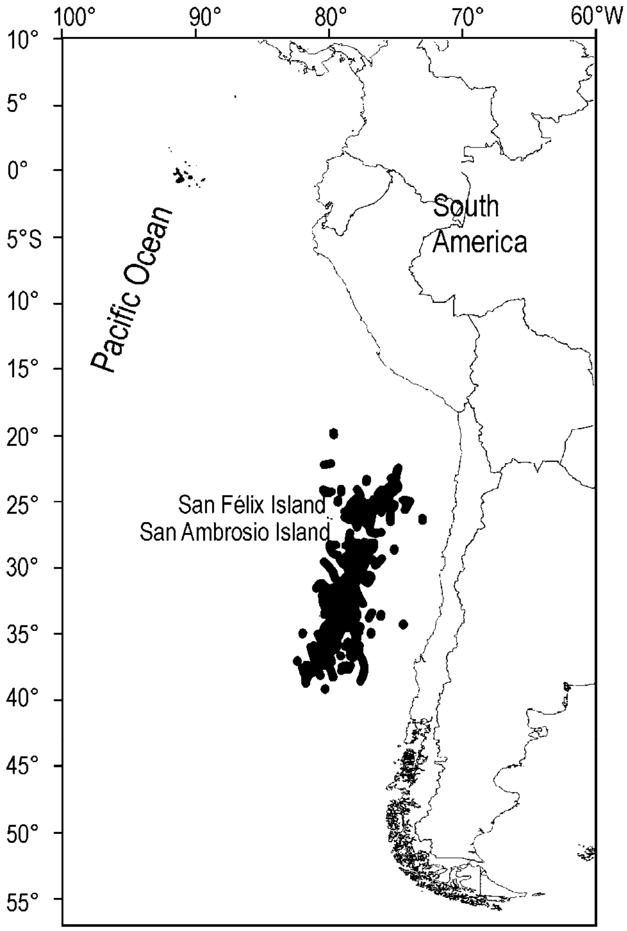

Figure 1. Geographical distribution longline set of longline swordfish fishing sets, during 2001. The samples were collected randomly for all months of this year.

Figura 1. Distribución espacial de los lances de captura de la pesquería palangrera del pez espada durante el 2001. Las muestras se obtuvieron al azar para el total de meses de este año.

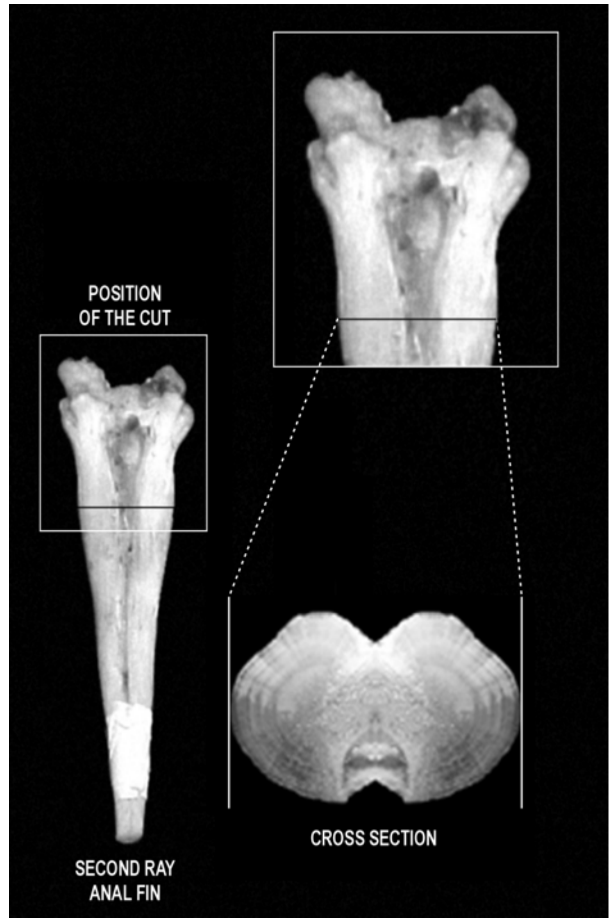

Figure 2. Typical second ray of swordfish anal fin in this study. Black line indicates the location of the cross section.

Figura 2. Segunda espina de la aleta anal: ubicación de donde se realizó el corte de la sección.

The back-calculated length-at-age data were then fitted to the Von Bertalanffy equation in its standard (Ehrhardt *et al.*, 1996; Sun *et al.*, 2002) and generalized (Richards, 1959) forms, according to the following equations:

Standard:

$$L_t = L_\infty (1 - e^{-K(t-t_0)})$$

Generalized:

$$L_t = L_\infty (1 - e^{-k(1-m)(t-t_0)})^{\frac{1}{(1-m)}}$$

where: L_t : mean lower jaw fork length at age t

L_∞ : asymptotic length or the mean maximum length of the fish

t_0 : hypothetical age at length zero

K : growth coefficient VB standard equation

k : growth coefficient VB generalized equation

m : fitted fourth growth-function parameter.

The standard and generalized Von Bertalanffy growth parameters for males, females, and combined sexes were estimated using a nonlinear least square procedure, through a Gauss-Newton algorithm (SYSTAT 7.0, Systat Software Inc., SSI). To test for significant differences in growth between males and females, Hotelling's T^2 multivariate statistical procedure was used (Bernard, 1981; Cerrato, 1990).

In order to assess the growth model that best fits the swordfish data, goodness-of-fit (coefficients of determination, (r^2), sum of residual squares (SSR), and standard error (SE) were considered. Akaike Information Criterion statistics (AIC, Akaike, 1973) were examined. The AIC is described by the following equation:

$$AIC = -2\ \log(L) + 2\ p$$

where, L : residual sum of squares at the maximum goodness-of-fit and p = the number of free parameters in the model.

RESULTS

The length frequency distributions of sampled fish ranged from 100 to 265 cm for males and from 116 to 289 cm for females (Fig. 3). The relationships between LJFL and total weight for males, females, and combined sexes were described by these equations: males, $TW = 4.5 \cdot 10^{-6}\ LJFL^{3.21}$ ($r^2 = 0.97$, n = 541); females, $TW = 3.7 \cdot 10^{-6}\ LJFL^{3.26}$ ($r^2 = 0.96$, n = 452), and both sexes combined, $TW = 4.1 \cdot 10^{-6}\ LJFL^{3.24}$ ($r^2 = 0.97$, n = 993) (Fig. 4). The ANCOVA of log-transformed LJFL and weight did not show significant differences in either slope (P value = 0.55) or intercepts (P value = 0.59) between males and females. However, the females become heavier than males when larger than 200 cm LJFL. Another ANCOVA indicated no significant differences in the relationship between males and females for lengths larger than or equal to 200 cm LJFL (slope; P > 0.36).

From the 1,235 ray samples, 511 males and 632 females were successfully aged; 92 (7%) fin rays were unreadable. The comparison of counts between two readers indicated no appreciable bias (Fig. 5). The IAPE and CV were 7.0 and 9.9, respectively. An analysis of same reader performance at different times showed even more precision (IAPE and CV equal at 5.17 and 7.31, respectively).

Monthly rates of translucent edge formation showed a distinctive seasonal pattern with higher values in summer months for both sexes (Fig. 6a). This pattern indicated the formation of one growth ring per year during the December-March period (Fig. 6a). The MIR also showed a trend, with higher relative values in winter. This trend is indicative of the formation of one translucent growth ring (annulus) from October to March, although it is not completely conclusive due to the absence of significant differences over months (Fig. 6b).

The relationship between LJFL and ray radius was fitted using a non-linear procedure, producing the following parameter estimates: for males, a = 87.26, b = 0.457, r^2 = 0.80, and n = 503 and, for females, a =

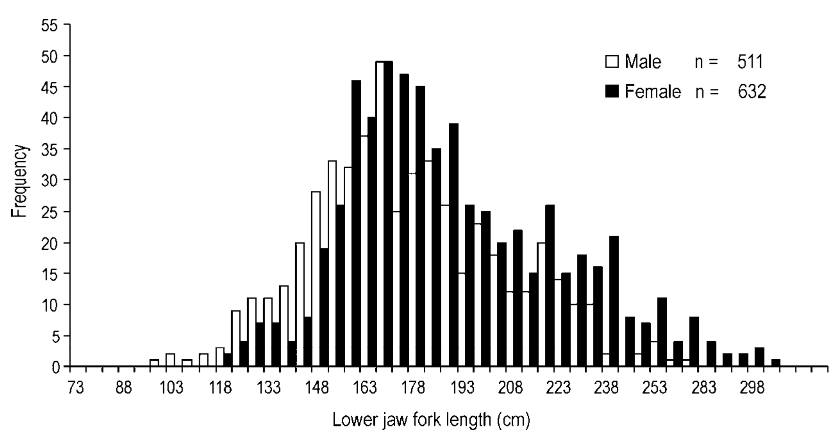

Figure 3. Length frequency distribution in 5 cm intervals for males and females swordfish collected from fishing vessels in the southeastern Pacific off Chile.

Figura 3. Distribución de frecuencia longitudes con intervalos cada 5 cm para machos y hembras de pez espada colectadas desde embarcaciones pesqueras en el Pacífico suroriental frente a Chile.

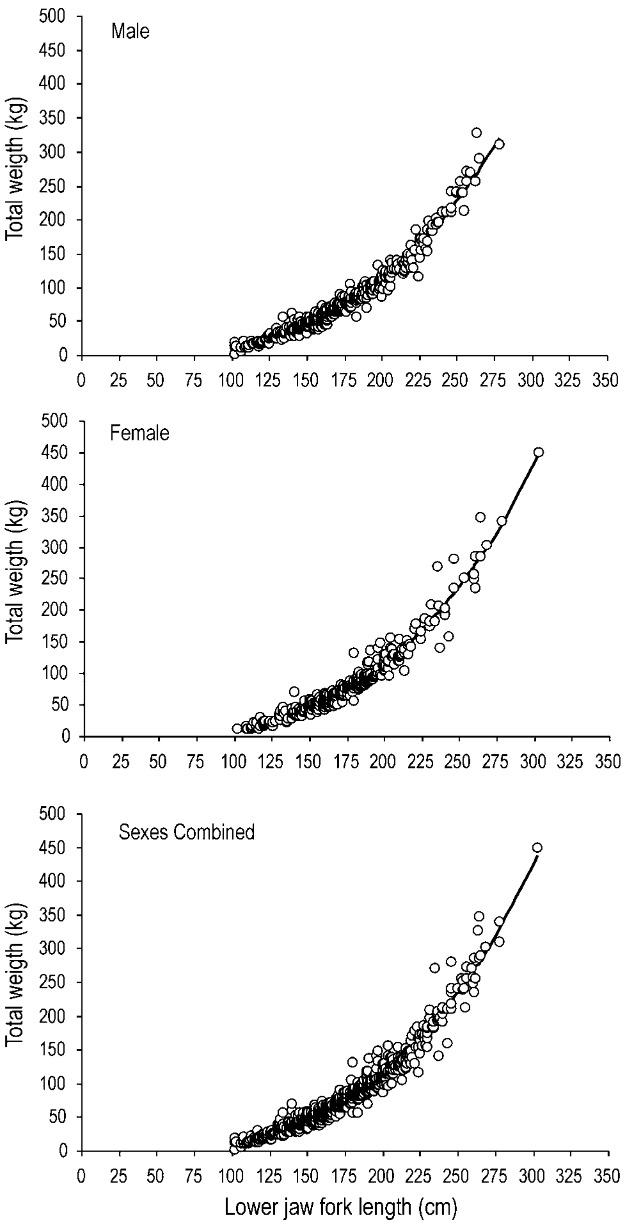

Figure 4. Relationship between total weight and lower jaw fork length for swordfish collected from fishing vessels in the southeastern Pacific off Chile.

Figura 4. Relación entre el peso total y la longitud mandíbula inferior horquilla del pez espada capturado por embarcaciones pesqueras en el Pacífico suroriental frente a Chile.

79.44, b = 0.522, r^2 = 0.84, and n = 630. Log-transformed LJFL and ray radius showed significant differences in the relationship between males and females in slope and intercept (ANCOVA; P value < 0.00012).

Growth parameter estimates for the standard and generalized Von Bertalanffy models are provided in

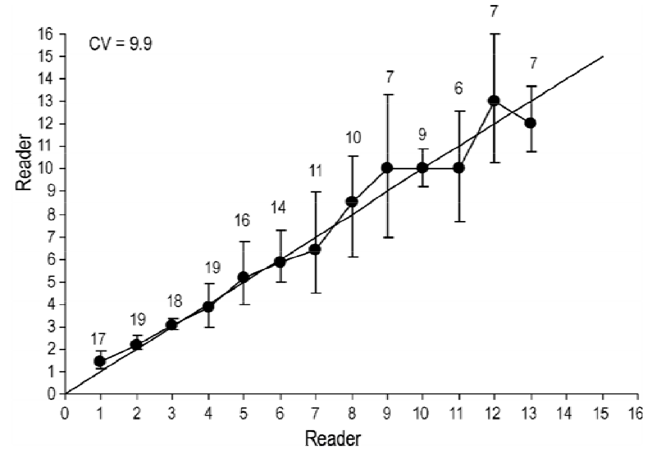

Figure 5. Mean age bias and coefficient variation (CV), for 160 counts of cross section of swordfish fin ray, made by two independent-age readers. Vertical lines indicate standard error (SE). Number of samples analyzed for age is noted above SE lines.

Figure 5. Gráfico que muestra el sesgo a la edad con su respectivo coeficiente de variación (CV), para comparaciones pareadas de 160 muestras de secciones de espina de pez espada, realizada por dos lectores en forma independiente. La línea vertical indica el error estándar (ES). El número de muestras analizado por edad es indicado sobre la línea de error estándar.

Table 1. The findings between sexes for both standard and generalized models differed significantly (Fig. 7); the standard VB model shows greater sexual dimorphism in growth (Table 2). The curves of the size-at-age von Bertalanffy model fits are shown for different regions in Figure 8.

Comparisons between the standard and generalized growth models showed equal R^2 and similar SSR. Never theless, the standard Von Bertalanffy model showed a lower AIC (2 points) for males and females than did the generalized Von Bertalanffy model. According to significant criteria for comparing AIC values (Sakamoto *et al.*, 1986), this result is enough to conclude that the standard model is more appropriate for representing swordfish growth in the southeastern Pacific off Chile (Table 3).

Table 4 shows mean size-at-age estimated by back-calculating and the standard and generalized von Bertalanffy models.

DISCUSSION

As Berkeley & Houde (1983) mentioned in an early study, the main problems with ageing swordfish are the missing first band in large specimens and the pres-

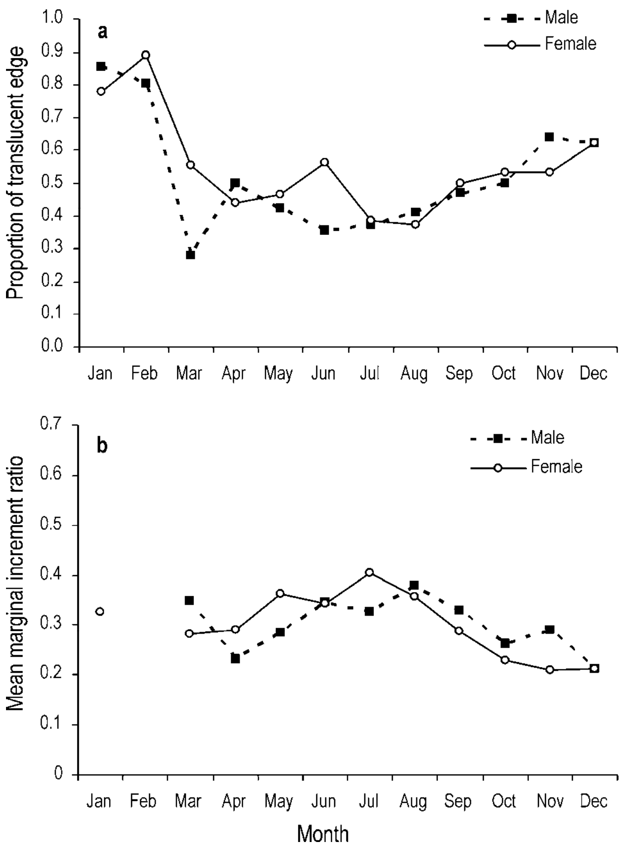

Figure 6. Monthly proportion of translucent edge (a) and monthly means of marginal increment ratio (b) of swordfish in the southeastern Pacific off Chile.

Figura 6. Proporción mensual del borde translucido (a) y promedio mensual del incremento marginal (b) del pez espada en el Pacífico suroriental frente a Chile.

ence of multiple bands or false rings. Other authors have confirmed those observations (Tsimenides & Tserpes, 1989; Tserpes & Tsimenides, 1995; Ehrhardt *et al*., 1996). However, the problem of multiple bands can be overcome by experienced readers, and the problem of the missing band in some large fish can be solved by estimating its position at a distance that is comparable to its position in small specimens (Ehrhardt, 1999).

Precision in age estimation was evaluated for different readers, and both IAPE and bias statistics indicated acceptable indices of precision. Furthermore, the precision indices obtained here (IAPE 7.0 and CV 9.9) agree with the information provided by the European Fish Ageing Network (EFAN). In addition, in a recent initiative, no significant differences were reported in age estimations of swordfish between the NMFS Honolulu Laboratory, CICESE laboratory (Mexico), NRIFSF laboratory (Japan), and IFOP (Chile) (De Martini, unpublished). All this evidence suggests that the age estimates in the current study were reliable.

The analysis of the distribution of the monthly proportion of edge types indicated the formation of an annual translucent ring between December and March with a maximum in January and February. The translucent ring deposition coincides with the spawning season of the swordfish in the southeastern Pacific (Donoso *et al*., 2003b). This could be because, when spawning, fish use more energy to produce gametes than for growth, resulting in a less calcified ring. Alternatively, deposition of the translucent zone over summer could also be related to swordfish migration to reproductive areas as suggested by Berkeley & Houde (1983), Tserpe & Tsimenides (1995), and Sun *et al*. (2002). The current study provides the first evidence that an annual growth ring formation occurs in the swordfish of the southeastern Pacific. Further studies using techniques such as tag-recapture and oxytetracycline tagging (Campana, 2001; Sun *et al*., 2002) are needed to validate this evidence.

Swordfish growth did not differ between the estimates made by the standard and generalized Von Bertalanffy equations for males and females. Such results show both equations provide similar explanations for the age-size relationship of fish between the ages of zero and seven years. However, estimates from the generalized equation showed a higher L_∞ in males than in females, which differs from previous studies with higher growth in females (Berkeley & Houde, 1983; Ehrhardt, 1992; Tserpes & Tsimenides, 1995; Ehrhardt *et al*., 1996; Sun *et al*., 2002). If both equations are compared using AIC, the standard equation is the most appropriate according to Sakamoto *et al*. (1986), because two points of difference in the AIC are enough to conclude that the model is correct. In addition, the incorporation of a fourth parameter in the generalized Von Bertalanffy equation did not provide a better fit to the age-size relationship, which, biologically, is meaningless (Ehrhardt, 1992). The generalized VBGF would be appropriate for describing swordfish size-at-age only if there was a compelling reason to fit the growth curve through zero length at zero age (De Martini *et al*., 2007). Consequently, the standard Von Bertalanffy growth equation seems to be more appropriate, statistically and biologically, to represent the growth of the swordfish in the southeastern Pacific off Chile.

A comparison of the growth in males and females revealed significant differences that were more marked in the standard growth equation. In general, females grew more quickly than males during their second year, reaching larger sizes than males. This response has also been observed in other regions

Table 1. Parameter estimates of standard and generalized Von Bertalanffy growth models for swordfish in the southeastern Pacific off Chile. Standard errors in parenthesis.

Tabla 1. Parámetros de crecimiento del pez espada en el Pacífico suroriental estimados con la ecuación de crecimiento de Von Bertalanffy estándar y generalizada. Error estándar entre paréntesis.

	Von Bertalanffy growth model					
	Standard			Generalized		
Parameter	Male	Female	Combined sexes	Male	Female	Combined sexes
L_∞	279	321	327	365	344	396
	(9.11)	(8.30)	(6.75)	(158.47)	(39.69)	(80.94)
K	0.158	0.133	0.126			
	(0.0127)	(0.0075)	(0.0056)			
k				0.027	0.077	0.033
				(0.0512)	(0.0546)	(0.0292)
t_0	-2.65	-2.46	-2.59	-1.14	-1.81	-1.4
	(0.1529)	(0.0987)	(0.0790)	(0.7544)	(0.6815)	(0.4506)
m				-1.023	-0.307	-0.706
				(0.8068)	(0.3880)	(0.3606)
r^2	0.85	0.89	0.89	0.85	0.89	0.87

(Tserpes & Tsimenides, 1995; Ehrhardt *et al*., 1996; Sun *et al*., 2002, De Martini *et al*., 2007). When comparing overall growth curves of swordfish, we found lower growth rates and lower L_∞ in the current study than those recorded for the North Atlantic (Berkeley & Houde, 1983; Ehrhardt, 1992; Ehrhardt *et al*., 1996), the Mediterranean (Tsimenides & Tserpes, 1989; Tserpes & Tsimenides, 1995), and the northwestern Pacific (Sun *et al*., 2002). In general, the Chilean fisheries were aged as younger at given body lengths than in other studies.

Table 2. Results of the multivariate test (Hotelling's T^2) to determine sex specific differences between the estimated Von Bertalanffy growth parameters.

Tabla 2. Resultados del test multivariado (Hotelling's T^2) que determina las diferencias entre sexos para los parámetros de Von Bertalanffy.

	Von Bertalanffy model	
	Standard	Generalizaded
T^2	222.48	24.95
df	6.66	6.66
$T^2_{(0.01, df)}$	19.99	19.99

Differences in mean size-at-age observed in the Atlantic, Pacific, and Mediterranean regions could be due to variations in growth patterns, given that these regions have been identified as different population units based on genetic studies. Chow *et al*. (1997) proposed that at least four large stocks exist: North Atlantic, South Atlantic, Mediterranean, and Indo Pacific. In the Pacific, although the differences seem to be less marked, the population is not homogeneous (Rosel & Block, 1996; Chow, 1998; Ward *et al*., 2001). According to Reeb *et al*. (2000), the north and south populations of the western Pacific appear to diverge although, in the eastern Pacific, the populations seem to be interconnected by a corridor along the equator. Galleguillos *et al*. (2001) also proposes two population groups: one formed by genetically similar fish corresponding to Chile, Ecuador, and Mexico, which is assumed to include fish from Peru and Co lombia as well, and another in the area of Hawaii and Australia, which differs significantly from the first group.

Growth rate differences were observed among the northwestern Pacific (Taiwan) (Sun *et al*., 2002), southwestern Pacific (Australia) (Young *et al*., 2004), and southeastern Pacific (Chile). The swordfish caught in the southeastern Pacific (Chile) grow in length fas-

Table 3. Results of the Akaike information criteria (AIC) to determine which model best fits the length-at-age data for swordfish in the southeastern Pacific off Chile.

Tabla 3. Resultados del Akaike information criteria (AIC) que determina cual es el mejor ajuste de los datas talla-edad para el pez espada del Pacífico suroriental frente a Chile.

	Akaike information criteria (AIC)			
	Male		Female	
	Standard V-B	Generalized V-B	Standard V-B	Generalized V-B
RSS	186,124	185,928	313,636	313,555
No. parameters	3	4	3	4
No. samples	1,421	1,421	2,171	2,171
AIC	− 4.45	− 2.45	− 5.5	− 3.50

Table 4. Average lower jaw fork length-at-age (LJFL-cm) estimated by back calculation and standard and generalized Von Bertalanffy equations for swordfish in the southeastern Pacific off Chile.

Tabla 4. Promedio de la longitud mandíbula inferior horquilla por edad (LMIH-cm) estimada por retrocálculo y a través de la ecuación de Von Bertalanffy estándar y generalizada para el pez espada en el Pacífico suroriental frente a Chile.

	Lower jaw fork length estimates (cm)					
	Back-calculated		Standard Von Bertalanffy		Generalized Von Bertalanffy	
Age (years)	Male	Female	Male	Female	Male	Female
1	122	117	119	118	122	118
2	146	145	142	144	146	144
3	164	164	161	166	165	166
4	182	183	178	185	182	185
5	197	202	192	202	196	202
6	206	218	205	217	208	216
7	217	230	215	230	220	230
8	228	244	224	241	230	241
9	244	252	232	251	239	252
10		251	239	260	247	261
11		255	244	267	255	269
12		259	249	274	262	277
13			254	280	268	283

ter than those caught in the northwestern Pacific (Taiwan) and southwestern Pacific (Australia). On the other hand, the growth rate of Chilean swordfish is similar to the swordfish caught in the central North Pacific (Hawaii). For example, the mean length at age 1 of swordfish in the Hawaii fishery is about 99 cm eye-fork length (EFL), which is equivalent to 114 cm LJFL (De Martini *et al*., 2007), whereas the mean length at age 1 of swordfish in the Chilean fishery is 118 for females and 119 for males cm LJFL. This was confirmed by readers from other laboratories during the inter-laboratory exercise (De Martini *et al*., 2007).

This faster growth in the southeastern Pacific (Chile) and North Pacific (Hawaii) suggests similar environmental conditions reflected in the high productivity of Humboldt Current ecosystem and Subtropical Convergence Zone. Although the genetic evidence shows

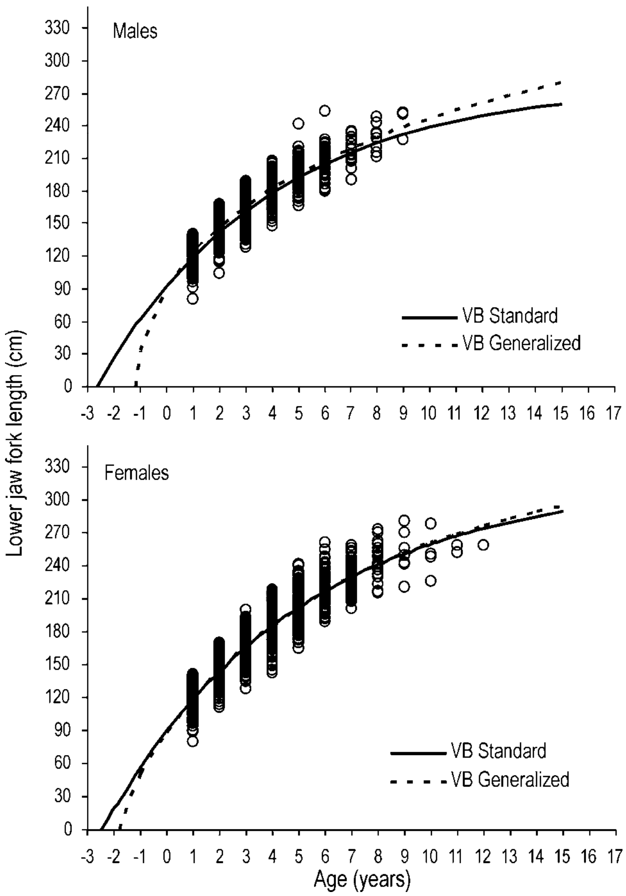

Figure 7. Standard and generalized Von Bertalanffy (VB) growth curves for swordfish from the southeastern Pacific off Chile.

Figura 7. Curvas de crecimiento de Von Bertalanffy en su forma estándar y generalizada para el pez espada en el Pacífico suroriental frente a Chile.

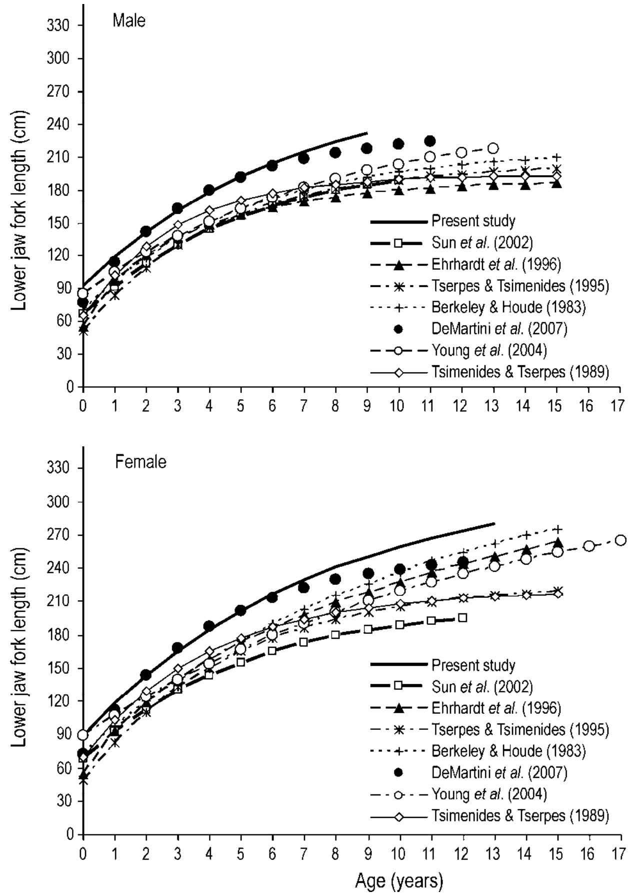

Figure 8. Sumary of Von Bertalanffy growth curves of swordfish estimated by different studies.

Figura 8. Resumen de curvas de crecimiento de Von Bertalanffy estimadas por diferentes estudios.

that different populations could exist in the northwestern (Japan, Taiwan), southwestern (Australia), and southeastern Pacific (Chile, Peru, Mexico) (Reed *et al.*, 2000), no genetic similarity has been established between the southeastern and central North Pacific. Chow *et al.* (1997) stated that the degree of differentiation between the swordfish population units in the Pacific is very low due to the short divergence time. In this context, the life history information for different regions, e.g. the variations in growth rates (Sun *et al.*, 2002; Young *et al.*, 2004; De Martini *et al.*, 2007, this study), spawning season and area (De Martini, *et al.*, 2000; Donoso *et al.*, 2003b), and stock structure with an environmental mark (Humphreys *et al.*, 2005) are important for stock assessment and identification because these differences in life history may result from different adaptive responses, such as those observed among the Atlantic, Mediterranean, and Pacific populations.

CONCLUSIONS

The standard Von Bertalanffy growth equation seems to be more appropriate for modeling swordfish growth in the southeastern Pacific off Chile. This fit of growth revealed the existence of significant differences between males and females.

The southeastern Pacific swordfish stock off Chile has different growth rates than those of the Atlantic Ocean, Mediterranean Sea, northwestern Pacific (Taiwan), and southwestern Pacific (Australia). These regions show lower rates than those estimated for Chile, coinciding with the grade of differentiation between the population units of different oceans. On the other hand, the rate of growth in the central North-Pacific should be more similar to Chile's estimate (De Martini *et al.*, 2007).

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REFERENCES

Akaike, H. 1973. Information theory as an extension of the maximum likelihood principle. In: B.N. Petrov & F. Csaki (eds.). Second international symposium on information theory. Akademiai Kiado, Budapest, Hungary, pp. 267-281.

Barbieri, M.A., C. Canales, V. Correa, M. Donoso, A. González, B. Leiva, A. Montiel & E. Yáñez. 1998. Development and present state of the swordfish, *Xiphias gladius*, fishery in Chile. US Dep. Commer., NOAA Tech. Rep. NMFS, 142: 1-10.

Beamish, R.J. & E.A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci., 38: 982-983.

Bernard, D. 1981. Multivariate analysis as mean of comparing growth in fish. Can. J. Fish. Aquat. Sci., 38: 233-236.

Berkeley, S.A. & E.D. Houde. 1983. Age determination of broadbill swordfish, *Xiphias gladius*, from the strait of Florida, using anal fin spine sections. US Dep. Commer., NOAA Tech. Rep. NMFS, 8: 137-147.

Campana, S.E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. J. Fish Biol., 59: 197-242.

Cerrato, R.M. 1990. Interpretable statistical test for growth comparison using parameters in the Von Bertalanffy equation. Can. J. Fish. Aquat. Sci., 47: 1416-1426.

Chow, S. 1998. Genetic comparison of Pacific and Mediterranean swordfish, *Xiphias gladius*, by FRLP analysis of the mitochondrial D-loop region. US Dep. Commer., NOAA Tech. Rep. NMFS, 142: 239-244.

Chow, S., H. Okamoto, Y. Uozumi, Y. Takeuchi & H. Takeyama. 1997. Genetic stock structure of the swordfish (*Xiphias gladius*) inferred by PCR-RFLP analysis of the mitochondrial DNA control region. Mar. Biol., 127: 359-367.

De Martini, E.E., J.H. Uchiyama & H.A. Williams. 2000. Sexual maturity, sex ratio, and size composition of swordfish, *Xiphias gladius*, caught by the Hawaii-based pelagic longline fishery. US Fish. Bull., 98: 489-506.

De Martini, E., J. Uchiyama, R. Humphreys Jr., J. Sampaga & H. Williams. 2007. Age and growth of swordfish (*Xiphias gladius*), caught by the Hawaii-based pelagic longline fishery. US Fish. Bull., 105: 356-367.

Donoso, M. & J. Chong. 1992. Determinación de edad y estimación de crecimiento en albacora (*Xiphias gladius*, L.). Etapa I. Determinación de la factibilidad de utilizar el método de lecturas de marcas, bandas o annuli que se forman en estructuras duras, para determinación de edad. Informe Técnico IFOP-SUBPESCA, 32 pp.

Donoso, M., F. Cerna, J. Campos & R. Vega. 2002. Seguimiento del estado de situación de las principales pesquerías nacionales. Investigación situación recursos altamente migratorios, 2001. Informe Final. IFOP-SUBPESCA, 96 pp.

Donoso, M., P. Barría, F. Cerna, J. Azócar & J. Campos. 2003a. Seguimiento del estado de situación de las principales pesquerías nacionales. Investigación situación recursos altamente migratorios, 2002. Informe Final IFOP-SUBPESCA, 71 pp.

Donoso, M., R. Vega, V. Catasti, G. Claramunt, G. Herrera, C. Oyarzún, M. Braun, H. Reyes & S. Letelier. 2003b. Biología reproductiva y área de desove del pez espada en el Pacífico Sur Oriental. Informe Final. FIP Nº 2000-11: 105 pp.

Ehrhardt, N. 1992. Age and growth of swordfish, *Xiphias gladius*, in the Northwestern Atlantic. Bull. Mar. Sci., 50(2): 292-301.

Ehrhardt, N., R.J. Robbins & F. Arocha. 1996. Age validation and age and growth of swordfish, *Xiphias gladius*, in the Northwestern Atlantic. ICCAT (International commission for the conservation of tunas) Coll. Vol. Sci. Pap., 45(2): 358-367.

Ehrhardt, N. 1999. Review of age and growth of swordfish, *Xiphias gladius*, using methods other than otolith sections. In: G.T. Dinardo (ed.). Proceedings of the Second International Pacific Swordfish Symposium. US Dep. Commer., NOAA Tech. Memo. NMFS, 263: 27-40.

Francis, R. 1990. Back-calculation of fish length: a critical review. J. Fish Biol., 36: 883-902.

Galleguillos, R., L. Troncoso & R. Montoya. 2001. Unidades poblacionales del pez espada (*Xiphias gladius* L.). Informe Final. FIP Nº 99-12: 15 pp.

Nakamura, I. 1985. FAO species catalogue. Billfish of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fish. Synop., 5(125): 1-65.

Reeb, C.A., L. Arcangeli & B.A. Block. 2000. Structure and migration corridors in Pacific populations of the swordfish, *Xiphias gladius*, as inferred through analyses of mitochondrial DNA. Mar. Biol., 136: 123-1131.

Richards, F.J. 1959. A flexible growth function for empirical use. J. Exp. Bot., 10: 290-300.

Rosel, P.E. & B.A. Block. 1996. Mitochondrial control region variability and global population structure in the swordfish, *Xiphias gladius*. Mar. Biol., 125: 11-22.

Sakamoto, Y., M. Ishiguro & G. Kitagawa 1986. Akaike information criterion statistics, Tokyo: KTK Scientific Publishers, 290 pp.

Sun, Ch-L., Sh-P. Wang & S-Z. Yeh. 2002. Age and growth of swordfish (*Xiphias gladius* L.) in the waters around Taiwan determined from anal-fin rays. US Fish. Bull., 100: 822-835.

Tserpes, G. & N. Tsimenides. 1995. Determination of age and growth of swordfish *Xiphias gladius* L., 1758 in the eastern Mediterranean using anal-fin spines. US Fish Bull., 93(3): 594-602.

Tsimenides, N. & G. Tserpes. 1989. Age determination and growth of swordfish *Xiphias gladius* L., 1758 in the Aegean sea. Fish. Res., 8: 159-168.

Ward, R.D., C.A. Reeb & B.A. Block. 2001. Population structure of Australian swordfish, *Xiphias gladius*. Final Report to the Australian Fisheries Management Authority, Canberra, 39 pp.

Wilson, C. & J. Dean. 1983. The potential use of sagittae for estimating age of Atlantic swordfish, *Xiphias gladius*. US Dep.Commer., NOAA Tech. Rep. NMFS, 8: 151-156.

Yabe, H., S. Ueyanagi, S. Kikawa & H. Watanabe. 1959. Study on the life-history of the swordfish, *Xiphias gladius* Linnaeus. Rep. Nankai Reg. Fish. Res. Lab., 10: 107-150.

Young, J., A. Drake & M. Langridge. 2004. Age and growth of broadbill swordfish, *Xiphias gladius*, in the domestic longline fishery off eastern Australia. FRDC Protect No 2001/014. CSIRO Marine Research. Tasmania, Australia, pp. 13-41.

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