

## UPDATE ON GROWTH ESTIMATES FOR SWORDFISH, *Xiphias gladius*, IN THE NORTHWESTERN ATLANTIC

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### SUMMARY

A total of 3623 anal fins from swordfish were collected in April-December 1990 and from January 1996 through December 1999 for age and growth studies. Only 2512 of newly cut spine sections provided readable growth bands. Updated parameter estimates were calculated using all aged spines from 1990 through 1999. The standard von Bertalanffy growth function and two versions of the generalized model (Richard's and Chapman's) were used to fit length-at-age data of 2392 female and 1817 male cut spine sections for the period analyzed. All models fitted the data appropriately, but some differences were evident. Model selection was based on the Akaike information criterion, Bayesian information criterion and likelihood ratio tests. Selection criterion indicated that Chapman's generalized model was the most appropriate model to express the growth of female and male swordfish in the northwestern Atlantic.

### RÉSUMÉ

Un total de 3.623 nageoires anales d'espadon ont été prélevées entre avril et décembre 1990 et de janvier 1996 à décembre 1999 aux fins d'études sur l'âge et la croissance. Seuls 2.512 segments épineux récemment découpés ont fourni des anneaux de croissance lisibles. Des estimations de paramètres actualisés ont été calculées en utilisant tous les rayons épineux dont l'âge avait été déterminé entre 1990 et 1999. La fonction de croissance standard de von Bertalanffy et deux versions du modèle généralisé (celle de Richard et celle de Chapman) ont été utilisées pour ajuster les données de longueur à l'âge de 2.392 segments épineux femelles et de 1.817 segments épineux mâles pour la période analysée. Tous les modèles se sont adéquatement ajustés aux données, même si certaines différences étaient évidentes. La sélection du modèle s'est fondée sur le critère d'information Akaike, sur le critère d'information bayésien et sur des tests du rapport des vraisemblances. Le critère de sélection a indiqué que le modèle généralisé de Chapman constituait le modèle le plus approprié pour exprimer la croissance de l'espadon femelle et mâle dans l'Atlantique nord-ouest.

### RESUMEN

Se recogieron un total de 3.623 aletas anales de pez espada en abril-diciembre de 1990 y desde enero de 1996 hasta diciembre de 1999 para realizar estudios de edad y crecimiento. Sólo 2.512 secciones de espina recientemente cortadas proporcionaron bandas de crecimiento legibles. Las estimaciones actualizadas de los parámetros se calcularon utilizando todas las espinas para las que se había determinado la edad desde 1990 hasta 1999. Se utilizaron la función de crecimiento estándar de von Bertalanffy y dos versiones del modelo generalizado (la de Richard y la de Chapman) para ajustar los datos de talla por edad de las secciones de espina cortadas a 2.392 hembras y 1.817 machos para el período analizado. Todos los modelos se ajustaron adecuadamente a los datos, pero se evidenciaron algunas diferencias. La selección del modelo se basó en el criterio de información Akaike, el criterio de información bayesiano y las pruebas de ratio de verosimilitud. El criterio de selección indicaba que el modelo generalizado de Chapman era el más apropiado para expresar el crecimiento de hembras y machos de pez espada en el Atlántico noroeste.

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## KEY WORDS

*Swordfish, age, growth estimates, North Atlantic*

## 1. INTRODUCTION

Swordfish, *Xiphias gladius*, has been subjected to intensive exploitation in the North Atlantic where the catches have been in decline since 1987 (ICCAT-SCRS, 2000). Conservation measures were recommended by ICCAT to slow down and stop the decline in the catches, and in 1999 a 10-year rebuilding program was adopted by the Commission to restore the stock to sustainable biomass levels (ICCAT, 2000). The Commission also recommended follow up stock assessments every three years (starting in 2002) to evaluate the stock status and recommend possible changes in annual total allowable catch (TAC).

North Atlantic swordfish stock assessments were based on age-structured algorithms for combined sexes, until recently when the stock assessment was conducted using sex-specific information on size and age (ICCAT-SCRS, 2000). During the last assessment, catches were aged using the sex-specific growth equations developed by Ehrhardt *et al.* (1996) from aged spines collected in 1991-1994 by scientific observers on board U.S. and Venezuelan fishing vessels. Although, the estimated sex-specific growth equations appear to reflect the true growth trend during the first year of life, it does not appear to represent realistic asymptotic length, particularly for males. Concerned with these results, efforts were continued by the U.S. and Venezuelan pelagic longline observer programs to collect biostatistical data to generate new sex-specific growth equations.

The objective of this study is to develop new growth estimates combining aged spine data from 1991 to 1994 with biostatistical data and aged anal spines collected on a monthly basis in 1990 and from 1996 to 1999.

## 2. MATERIALS AND METHODS

A total of 3623 anal fin rays were sectioned from sampled anal fins collected on a monthly basis from April to December 1990, and between January 1996 and December 1999. Only spine sections showing clear, unequivocal growth marks that could be used for aging were utilized. Date, location of capture, length of fish (LJFL in cm), and sex was recorded for each anal fin collected by scientific observers on board U.S. and Venezuelan longline fishing vessels in the northwestern Atlantic as described by Lee (1991). Anal spines were sectioned using the same protocol described in Ehrhardt *et al.* (1996), which consisted in cutting a 0.45 mm spine section above the condyle base. Cuts were made using a Buehler Isomet low speed saw (at 6-7 rpm) with a high concentration diamond wafering blade. Cut sections were dehydrated in alcohol for several minutes, and then were air dried over night. Dried cut spine sections were placed in labeled minigrip plastic bags, cataloged and maintained refrigerated.

For age determination, all cut spine sections were digitized at different magnifications (6X, 9X, 12X or 25X, depending on the size of the section) with a video analysing system linked to a dissecting microscope, using reflected light and a translucent background. A sub sample of 300 spine sections were read from the digitized images by three readers and identical counts were obtained in >90% of the cases; unresolved discrepancies in the readings resulted in the elimination of the spine section from the analysis. One reader read the rest of the digitized spines section images. One count or annulus was considered to be a broad dark band followed by a narrow light band, and age classes were assigned on the basis of the total number annuli (**Figure 1**). In cases where multiple light bands were observed, only the clearest band that extended around the entire circumference of the spine in the outermost limit was considered as a true growth ring. In cases when interpretation was impossible, spines were rejected.

Growth estimates were obtained by fitting length-at-age data to the standard von Bertalanffy growth function (1) and two versions of the generalized von Bertalanffy growth function, the Richards' version (Richards, 1959) (2), and the Chapman's version (Chapman, 1961) (3):

$$l_t = L_{\infty} \left( 1 - e^{-k(t-t_0)} \right) + e \quad (1)$$

$$l_t = L_{\infty} \left( 1 - e^{-k(1-m)(t-t_0)} \right)^{\frac{1}{1-m}} + e \quad (2)$$

$$l_t = \left[ L_{\infty}^{(1-d)} - \left( L_{\infty}^{(1-d)} - l_0^{(1-d)} \right) e^{-k(1-d)t} \right]^{\frac{1}{(1-d)}} + e \quad (3)$$

Where,  $l_t$  is length (LJFL) at age  $t$ ,  $L_{\infty}$  is asymptotic length,  $k$  is the growth coefficient,  $t_0$  is theoretical age at zero length,  $l_0$  is length at zero age, and  $m$  and  $d$  is a fitted fourth function parameter. Growth parameters were estimated for females and males using non-linear least square and normal likelihood procedures assuming a normal error distribution, using length-at-age data obtained in this study, and combined with length-at-age data from the study of Ehrhardt *et al.* (1996). Selection of the most appropriate model was based on analysis of residuals of fitted growth models, likelihood ratio tests, Akaike information criterion and Bayesian information criterion (Quinn and Deriso, 1999).

### 3. RESULTS AND DISCUSSION

A total of 2512 sectioned spines were aged successfully (1364 females and 1148 males). In 291 of the 1111 unreadable spines, no annuli could be identified because no growth zone could be identified. In about 700 of the sectioned spines, information on length or sex was missing. The remaining 120 spines were considered unreadable due to the existence of multiple bands, which made the identification of growth zones impossible. Of the readable spine sections used for age determination, the lengths of fish ranged from 74 to 284 cm LJFL in females and in males, from 62 to 246 cm LJFL (**Figure 2**). The progression of length of fish as a function of age appear to increase faster in females than in males, as observed in the box-plots, and the high variability of length-at-age is evident across all ages with sample size  $>5$  for both sexes (**Figure 2**). Although, the variability of length-at-age in males appears to be less than in the females, there are several outliers at younger ages.

Combined data (Ehrhardt *et al.*, 1996 and this study) of length-at-age for the period of 1990-1999 increased the sample size to 2392 females and 1817 males, with similar size range as in the present study (**Figure 3**). The progression of length of fish as a function of age for the combined data, observed in the box-plots, show the same trend as the new data, but the variability of length-at-age increased as well as the numbers of outliers in both sexes for the combined data. The variability of length-at-age could be attributed to reading experience and different readers between the study of Ehrhardt *et al.* (*op.cit.*) and the present one. It can also be attributed to natural variability in growth between years, as we combined data for a period of 10 years from specimens that had been collected from different areas of the northwestern Atlantic and where spawned at different time of year (Arocha, 1997), all of which may affect the growth rate. We are inclined to believe that the variability observed of length-at-age in the combined data is more related to natural variability than differences in reader experience, as the same protocol for assigning ages in the study of Ehrhardt *et al.* (*op.cit.*) was followed in the present study.

Assigned ages for the combined data based on counts of growth zones in spine sections of 2392 females and 1817 males, ranged from 1-16 years in females and from 1-12 years in males (**Table 1**); where more than 65% of females and males were between ages 1-4 and ages 1-3, respectively. Difference in mean size between successive ages revealed different pattern of growth between sexes (**Table 1**), in which females tend to grow more rapidly than in males at ages 1-4, following the theory that absolute growth is expected to be rapid in young ages and to decrease progressively at older ages. Also, the difference in mean size-at-age between sexes confirms the dimorphic growth swordfish

displays throughout his life history (Berkeley and Houde, 1983; Tserpes and Tsimenides, 1995; Vanpouille *et al.*, 2001).

Parameters of the standard von Bertalanffy (VB) growth function and the two versions of the generalized model estimated for female and male swordfish using least square (LS) and likelihood (LL) procedures revealed differences in parameter estimates (**Table 2**). Results in Chapman's generalized model, showed larger asymptotic length estimates when LS estimation was used. In contrast to the VB model where the situation is reversed when LS is used. Although, the difference is not as marked as in Chapman's model. In case of the Richards' model, asymptotic length does not vary between the two estimation procedures in the case of females, but in males LS estimate was exceedingly higher. The error distribution plots of residuals vs model estimates (**Figures 4 and 5**) do not show any visible pattern of the residuals that would indicate a lack of fit in any of the estimation procedures, as all models followed the null pattern. We chose to use parameter estimates based on normal likelihood procedure as they are assumed to converge to the correct value and attain the smallest variance (Kimura, 1980).

Predicted length-at-age using normal likelihood procedure in the 3 fitted models show the effect of the difference in model parameter estimates (**Table 3**). Despite the difference in parameter estimates, predicted length-at-age in the standard VB and the Richards' generalized models are almost identical for both sexes in all ages, and very similar with Chapman's model estimates for males. These similarities prompted the use of several criteria for selection of the best model.

The Akaike information criterion (AIC) and the Bayesian information criteria (BIC) revealed that Chapman's generalized model for females is the most parsimonious, while for males, the AIC favors Chapman's model and the BIC favors the standard VB (**Table 4**). Likelihood ratio tests indicated that the addition of an extra parameter is statistically significant in both sexes when the standard VB and Chapman's model are compared, but non significant in both sexes when the standard VB and Richards' model are compared. The results of the test suggests that the additional parameter in the Chapman's model results in a significantly improved fit over the standard VB model, while the added parameter in the Richards' model does not improve the fit. On this basis, Chapman's generalized model was adopted as the most appropriate model to express the growth of female and male swordfish in the northwestern Atlantic (**Figure 6**).

Previous growth parameter estimates of Atlantic (and Mediterranean) swordfish using anal-fin spines have differed substantially (**Table 5**). The previous estimates of  $L_{\infty}$  obtained are somewhat smaller than the estimates derived using Chapman's generalized model in the present study. This is possibly because previous studies had restricted data observations at older ages, also because of the large variability of length-at-age by using back-calculated data with different estimation procedures, and finally because all previous studies used LS procedures to estimate parameters. Based on the findings presented in this study, it is proposed that the growth parameters estimates by using Chapman's generalized model based on normal likelihood procedures be used to describe growth of female and male North Atlantic swordfish.

Following the recommendations of the 2002 swordfish species group meeting that a unisex growth curve be calculated using the new and updated information for length-at-age data; a new unisex growth curve was calculated using Chapman's generalized model based on normal likelihood procedures. Unisex growth parameters and estimated length-at-age are presented in **Table 6**. Results indicate that the growth of females is slightly underestimated, in contrast with the males where the combined sex estimates over-estimates markedly all ages after age 3 (**Figure 7**).

## REFERENCES

AROCHA, F. 1997. The reproductive dynamics of swordfish *Xiphias gladius* L. and management implications in the northwestern Atlantic. PhD Dissertation, University of Miami. University of Microfilms Inc. Ann Arbor, Mi. UMI #9805928. 383 pp.

- BERKELEY, S. and E. Houde. 1983. Age determination of broadbill swordfish, *Xiphias gladius* L., from the Straits of Florida. NOAA-NMFS Tech. Rep., 8:137-143.
- CHAPMAN, D.G. 1961. Statistical problems in dynamics of exploited fisheries populations. *Proceedings of the 4th Berkeley Symposium of Mathematics, Statistics and Probability*, 4:153-168. Univ. Calif. Press, Berkeley, CA-USA.
- EHRHARDT, N. 1992. Age and growth of swordfish, *Xiphias gladius*, in the northwestern Atlantic. *Bull. Mar. Sci.*, 50(2):292-301.
- EHRHARDT, N., R. Robbins and F. Arocha. 1996. Age validation and growth of swordfish, *Xiphias gladius*, in the northwestern Atlantic. *ICCAT, Coll.Vol.Sci.Pap.*, 45:358-367.
- ICCAT. 2000. Report of for Biennial Period 1998-1999. Part II (1999) Vol.1, 335 pp. Madrid.
- ICCAT-SCRS. 2000. 1999-Detailed Report – Swordfish. *ICCAT, Coll.Vol.Sci.Pap.*, 51:2-208.
- KIMURA, D.K. 1980. Likelihood methods for the von Bertalanffy growth curve. *Fish.Bull.*, 77(4):765-776.
- LEE, D.W. 1991. Tabulation of recent data on swordfish sex ratio at size collected from the U.S. fishery. *ICCAT, Coll.Vol.Sci.Pap.*, 35:405-414.
- QUINN, T. and R. Deriso. 1999. *Quantitative Fish Dynamics*. Oxford Univ. Press. 542 pp.
- RICHARDS, F.J. 1959. A flexible growth function for empirical use. *J. Exp. Bot.*, 10:290-300.
- TSERPES, G. and N. Tsimenides. 1995. Determination of growth of swordfish, *Xiphias gladius*, in the eastern Mediterranean using anal-fin spines. *Fish. Bull.*, 93(3):594-602.
- VANPOUILLE, K., F. Poisson, M. Taquet, A. Ogor and H. Troadec. 2001. Étude de la croissance de l'espadon (*Xiphias gladius*). Pp. 139-169. In : L'espadon : de la recherche à l'exploitation durable. F. Poisson and M. Taquet (Coords.). Programme Palangre Réunionnais, Rapport final.

**Table 1.** Descriptive statistics of female (top) and male (bottom) swordfish from the northwestern Atlantic used in the estimation of growth parameters from specimens collected in 1990-1999.

<i>Age ( ? )</i>	<i>No.of samples</i>	<i>LJFL range (cm)</i>	<i>Mean LJFL (cm)</i>	<i>Std. Error</i>
1	304	74 - 158	109.85	0.731
2	453	89 - 175	131.62	0.675
3	480	91 - 196	144.13	0.686
4	361	110 - 198	160.30	0.907
5	291	135 - 233	173.05	1.059
6	182	142 - 242	186.17	1.494
7	126	140 - 246	199.42	1.699
8	85	155 - 259	203.47	2.341
9	47	152 - 268	213.61	3.581
10	30	180 - 279	227.44	4.344
11	15	207 - 265	238.37	4.856
12	10	217 - 284	244.75	6.362
13	1	235	235	-
14	2	225 - 254	239.50	14.500
15	4	237 - 277	256.97	9.497
16	1	262	262	-

<i>Age ( ? )</i>	<i>No.of samples</i>	<i>LJFL range (cm)</i>	<i>Mean LJFL (cm)</i>	<i>Std. Error</i>
1	409	63 - 147	109.00	0.658
2	415	95 - 178	128.71	0.600
3	363	99 - 185	140.13	0.731
4	267	117 - 195	151.87	0.789
5	167	127 - 189	159.60	1.071
6	99	142 - 208	167.74	1.387
7	55	144 - 213	178.78	1.937
8	23	147 - 221	186.99	4.053
9	13	180 - 218	194.25	3.006
10	3	191 - 205	200.00	4.509
11	2	200 - 210	205.00	5.000
12	1	246	246	-

**Table 2.** Parameter estimates for the standard von Bertalanffy, and the two versions of the generalized model (Chapman, 1961; Richards, 1959) for female and male swordfish from the northwestern Atlantic using normal likelihood (top) and least square (bottom) estimation procedures.

<i>Normal-likelihood</i>						
<i>Parameter</i>	<i>Standard von Bertalanffy</i>		<i>Chapman's generalized VB</i>		<i>Richards' generalized VB</i>	
	<i>Female</i>	<i>Male</i>	<i>Female</i>	<i>Male</i>	<i>Female</i>	<i>Male</i>
L8	312.27	223.12	375.49	300.00	322.29	300.00
k	0.0926	0.1522	0.00734	0.00465	0.0897	0.1134
t <sub>0</sub>	-3.762	-3.4875	-	-	-3.764	-3.480
δ/m	-	-	-1.976	-2.921	-0.0315	-0.3458
l <sub>0</sub>	-	-	0.001	0.001	-	-

<i>Least Squares</i>						
<i>Parameter</i>	<i>Standard von Bertalanffy</i>		<i>Chapman's generalized VB</i>		<i>Richards' generalized VB</i>	
	<i>Female</i>	<i>Male</i>	<i>Female</i>	<i>Male</i>	<i>Female</i>	<i>Male</i>
L8	305.77	222.91	399.99	495.93	322.30	513.47
k	0.09679	0.15271	0.0058	0.00055	0.06260	0.00145
t <sub>0</sub>	-3.6742	-3.4810	-	-	-2.9201	-0.6470
δ/m	-	-	-2.003	-3.008	-0.250	-2.164
l <sub>0</sub>	-	-	0.0005	0.001	-	-

**Table 3.** Predicted lower-jaw-fork-lengths (LJFL cm) at age for female and male swordfish from the northwestern Atlantic based on parameter estimates using normal likelihood procedure.

<i>Age</i>	<i>Standard von Bertalanffy</i>		<i>Chapman's generalized VB</i>		<i>Richards' generalized VB</i>	
	<i>Female</i>	<i>Male</i>	<i>Female</i>	<i>Male</i>	<i>Female</i>	<i>Male</i>
1	111.43	110.47	103.53	107.83	111.43	110.46
2	129.20	126.38	130.20	128.38	129.20	126.39
3	145.41	140.05	148.66	142.04	145.40	140.06
4	160.17	151.79	163.16	152.50	160.17	151.79
5	173.64	161.86	175.23	161.06	173.63	161.86
6	185.91	170.52	185.63	168.34	185.91	170.51
7	197.09	177.95	194.80	174.69	197.09	177.93
8	207.29	184.33	203.01	180.33	207.29	184.30
9	216.58	189.81	210.46	185.41	216.59	189.77
10	225.05	194.52	217.27	190.03	225.06	194.46
11	232.77	198.56	223.55	194.26	232.79	198.49
12	239.81	202.03	229.38	198.18	239.83	201.95
13	246.22		234.80		246.25	
14	252.07		239.89		252.10	
15	257.39		244.66		257.43	
16	262.25		249.16		262.30	

**Table 4.** Test results for best model selection based on the Akaike Information Criterion, Bayesian Information Criterion, and Likelihood ratio tests.

<i>Model</i>	<i>No. of parameters</i>	<i>Parameters</i>	<i>Loglikelihood</i>	<i>L8</i>	<i>Akaike Information Criterion</i>	<i>Bayesian Information Criterion</i>
Standard VB (?)	3	$L8, k, t_0$	7296.63	223.12	-14587.27	<b>-14570.75*</b>
Standard VB (?)	3	$L8, k, t_0$	10138.10	312.27	-20270.21	-20252.87
Chapman's (?)	4	$L8, k, lo, \mathbf{d}$	7299.08	300.001	<b>-14590.17*</b>	-14568.15
Chapman's (?)	4	$L8, k, lo, \mathbf{d}$	10193.83	375.49	<b>-20379.66*</b>	<b>-20356.54*</b>
Richards' (?)	4	$L8, k, t_0, m$	7296.63	300.002	-14585.26	-14563.25
Richards' (?)	4	$L8, k, t_0, m$	10138.10	322.29	-20268.21	-20245.09

<b>Likelihood ratio tests</b>			
<i>Model comparisons</i>	$\chi^2$	<i>d.f.</i>	<i>Prob.</i>
Standard VB (?) vs Chapman's (?)	4.904266692	1	<b>0.026790*</b>
Standard VB (?) vs Richards' (?)	0.00073622	1	0.978353
Standard VB (?) vs Chapman's (?)	111.4480153	1	<b>4.72E-26*</b>
Standard VB (?) vs Richards' (?)	0.006221203	1	0.937132

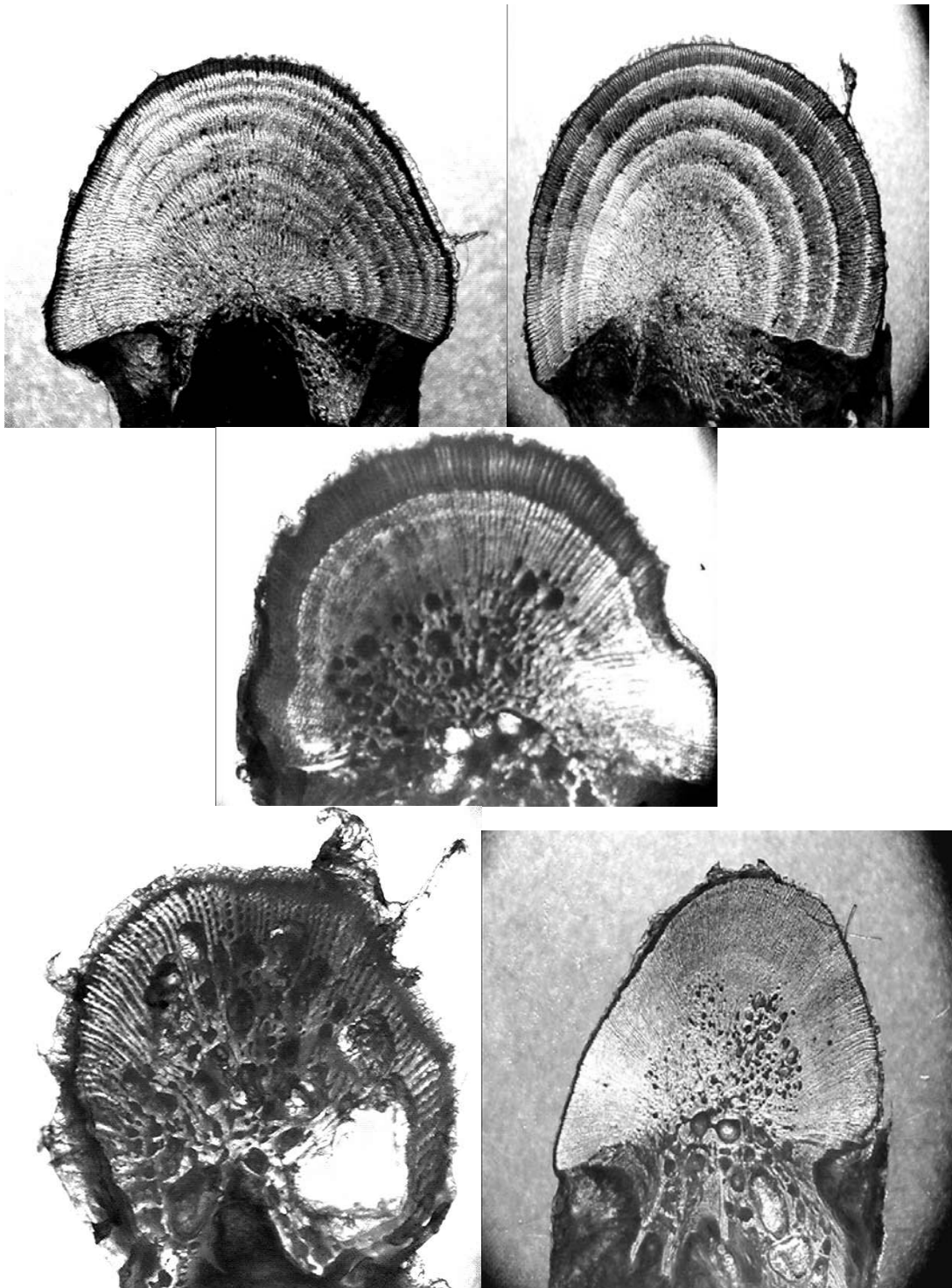
**Table 5.** Parameter models and estimates used in earlier studies to define growth of Atlantic and Mediterranean swordfish.

<i>Authors</i>	<i>Area</i>	<i>Model</i>	<i>Females</i>				<i>Males</i>			
			<i>L8</i>	<i>k</i>	<i>t<sub>0</sub>/lo</i>	<i>m/d</i>	<i>L8</i>	<i>k</i>	<i>t<sub>0</sub>/lo</i>	<i>m/d</i>
Berkely & Houde, 1983	US Florida coast	Standard VB	340	0.094	-2.59	-	217	0.19	-2.04	-
Ehrhardt, 1992	US Florida coast	Chapman's	326	0.036	2.04	-0.98	281	0.045	2.04	-1.02
Tserpes & Tsimenides, 1995	Mediterranean	Standard VB	227	0.210	-1.16	-	203	0.24	-1.20	-
Tserpes & Tsimenides, 1995	Mediterranean	Chapman's	275	0.037	0.00	-1.14	293	0.020	0.00	-1.43
Ehrhardt <i>et al.</i> , 1996	Northwestern Atlantic	Richards'	365	0.026	-0.55	-0.89	190	0.105	-0.41	-1.00

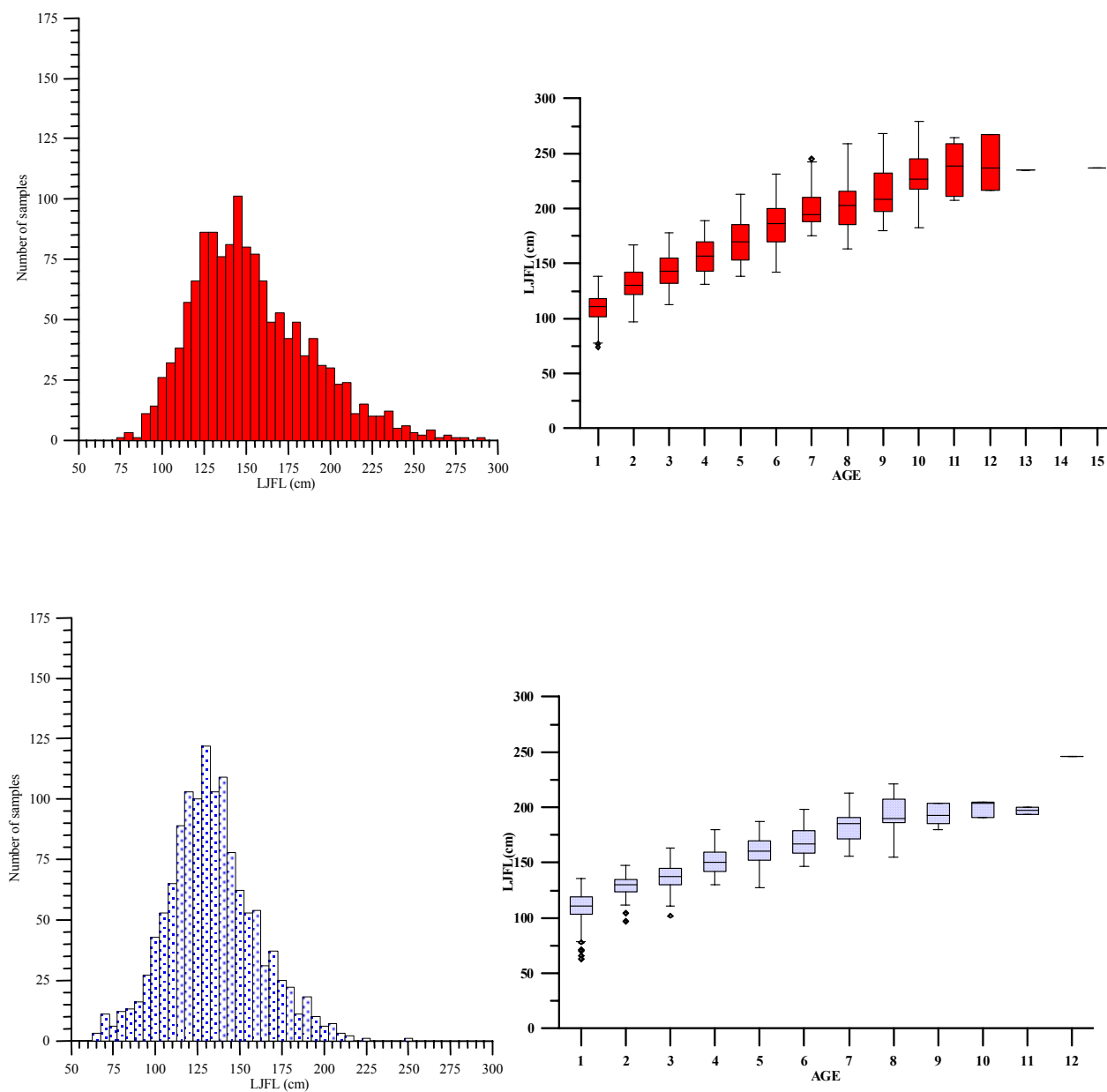


**Table 6.** Parameter estimates for Chapman's generalized model and predicted lower-jaw-fork-lengths (LJFL cm) at age for combined sex of swordfish from the northwestern Atlantic using normal likelihood estimation.

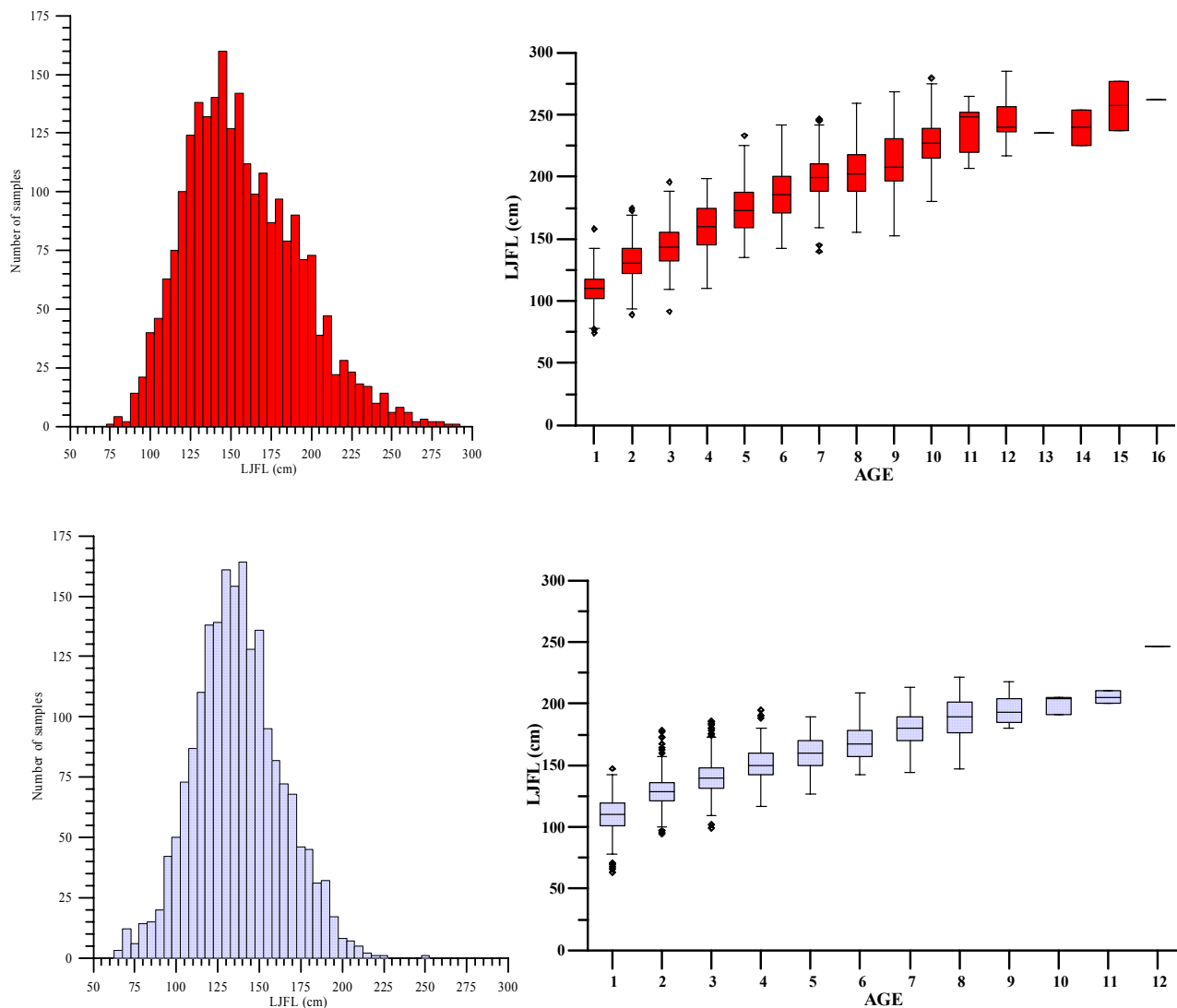
<i>Parameter</i>	<i>Combined sex</i>
L8	464.54
k	0.0023
$l_0$	0.0001
$\delta$	-2.2678
<i>Age</i>	<i>Predicted LJFL (cm)</i>
1	104.79
2	129.40
3	146.33
4	159.61
5	170.68
6	180.27
7	188.75
8	196.39
9	203.36
10	209.78
11	215.74
12	221.30
13	226.53
14	231.45
15	236.12
16	240.55



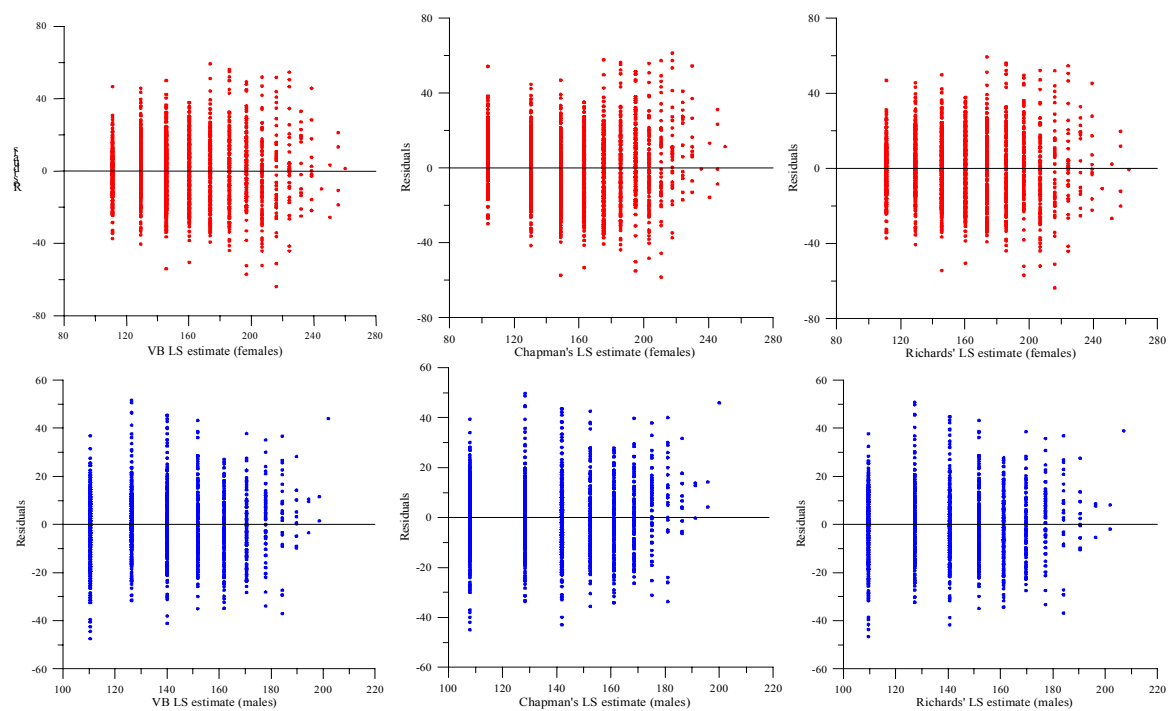
**Figure 1.** Examples of spine sections. Top: readable spines with 7 (left:200 cm LJFL) and 6 (right: 202 cm LJFL) growth zones. Middle: spine section with double-band (or false band) formation (145 cm LJFL). Bottom: unreadable spine sections (left:110 cm LJFL; right: 177 cm LJFL).



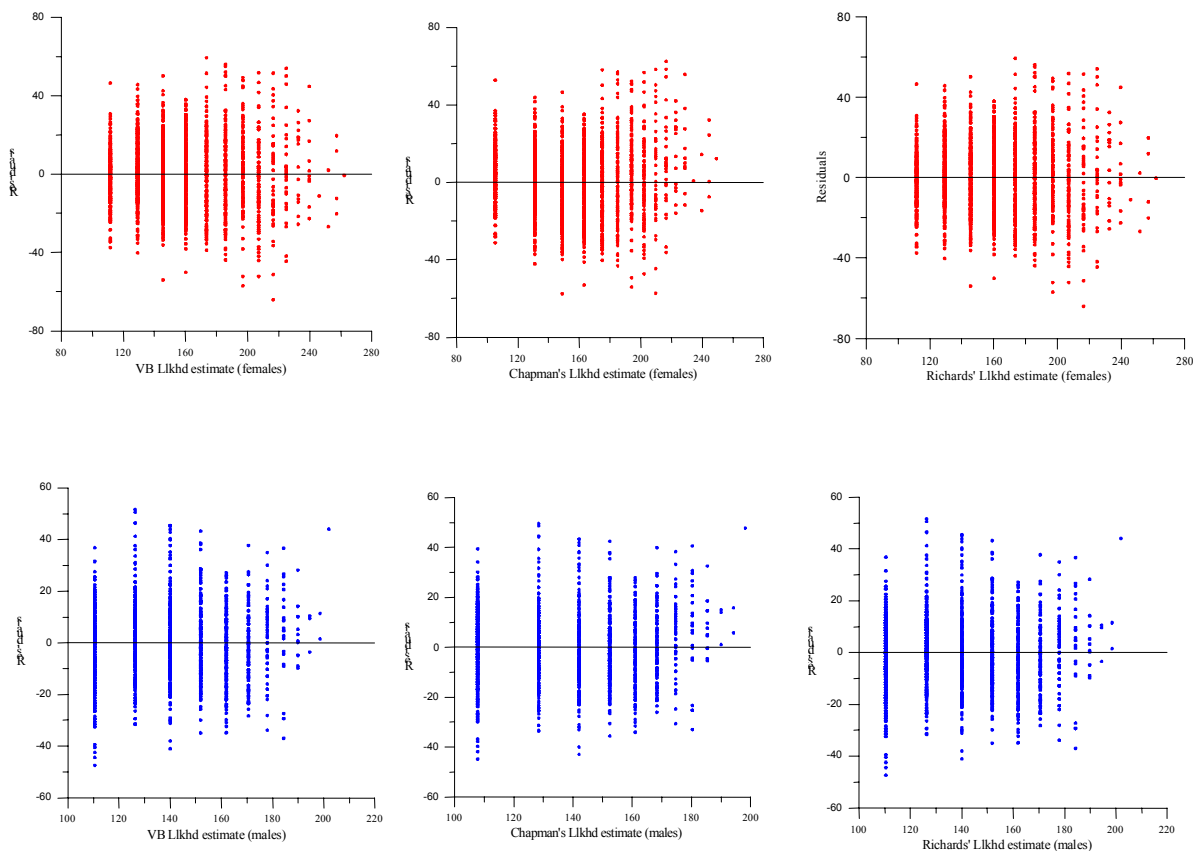
**Figure 2.** Length frequency distribution and box-plot of length-at-age of female (top, n=1364) and male (bottom, n=1148) swordfish from the northwestern Atlantic, indicating the number of specimens with readable spines (aged fish) and the progression of length as a function of observed growth zones from sampled specimens collected from 1990 and from 1996 through 1999.



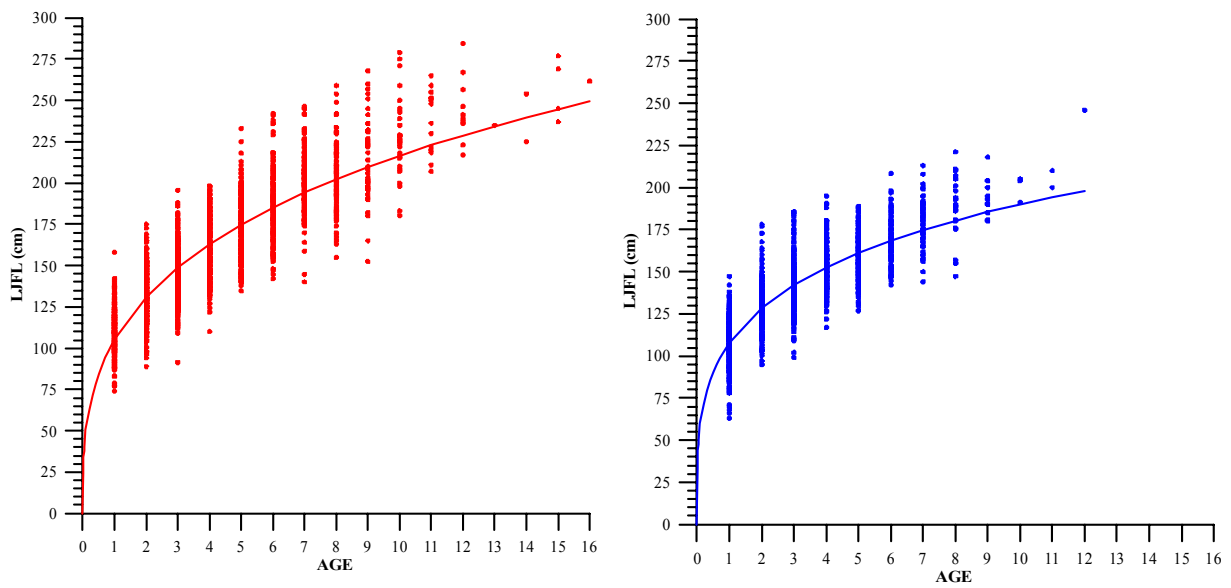
**Figure 3.** Length frequency distribution and box-plot of length-at-age of female (top, n=2392) and male (bottom, n=1817) swordfish from the northwestern Atlantic, indicating the number of specimens with readable spines (aged fish) and the progression of length as a function of observed growth zones from sampled specimens collected from 1990 through 1999.



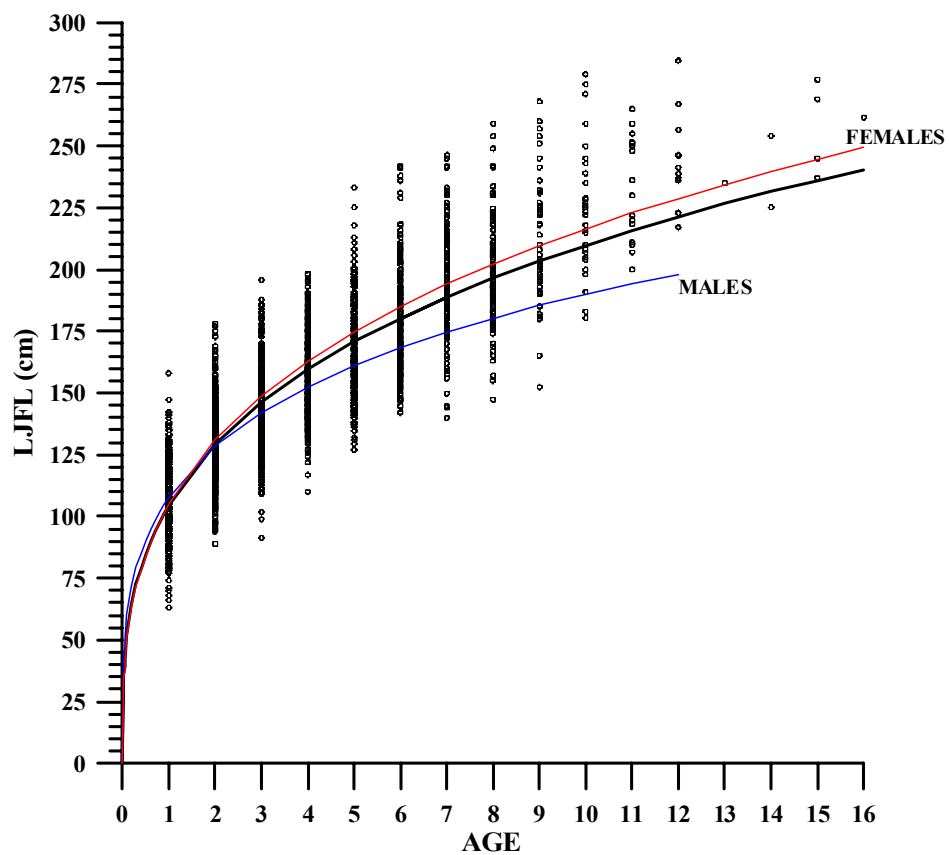
**Figure 4.** Error distribution plots of residuals vs model least squares estimates for the standard von Bertalanffy (VB), and the two versions of the generalized model (Chapman, 1961, and Richards, 1959) for female (top) and male (bottom) swordfish from the northwestern Atlantic.



**Figure 5.** Error distribution plots of residuals vs model likelihood estimates for the standard von Bertalanffy (VB), and the two versions of the generalized model (Chapman, 1961, and Richards, 1959) for female (top) and male (bottom) swordfish from the northwestern Atlantic.



**Figure 6.** Length-at-age and Chapman's generalized growth function for female (left) and male (right) swordfish from the northwestern Atlantic.



**Figure 7.** Sex combined length-at-age and Chapman's generalized unisex growth curve, with female (top) and male (bottom) estimated curves of swordfish from the northwestern Atlantic