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Age and growth of skipjack tuna (*Katsuwonus pelamis*) in the western equatorial Atlantic based on dorsal spines analysis

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ABSTRACT

The skipjack tuna (*Katsuwonus pelamis*) is a migratory pelagic fish occurring in all tropical and subtropical oceans of the world. Due to its economic importance and the unbridled increase in fishing efforts, stocks may collapse if this resource is not managed properly. The present study aimed to estimate growth parameters from different growth models based on annual rings from the dorsal spines of skipjack tuna caught in the western equatorial Atlantic. The first dorsal spine of each individual was extracted to produce cross-sections with 0.6 to 0.8 mm in thickness. We used a multi-model approach to select the best growth model based on the Akaike information criterion (AIC). Two hundred seventy individuals were analyzed, with an average length of 49.58 ± 7.72 cm. The von Bertalanffy growth model had the best fit to the data, but the Gompertz and Logistic models also had essential support. Average asymptotic length ($\overline{L_\infty}$) was estimated to be 114.05 and 102.63 cm for observed and back-calculated data, respectively. The dorsal spines are indeed efficient tools for estimating growth parameters and multi-model inference is a novel approach for adjusting discrepancies that likely result from a single-model approach.

Keywords: growth equation; growth model; growth parameter; multi-model inference; pelagic fish.

Idade e crescimento do bonito-listrado (*Katsuwonus pelamis*) no Atlântico Oeste Equatorial com base na análise dos espinhos dorsais

RESUMO

O bonito-listrado (*Katsuwonus pelamis*) é um peixe pelágico migratório que ocorre em todos os oceanos tropicais e subtropicais do mundo. Devido à sua importância econômica e ao aumento desenfreado do esforço de pesca, os estoques podem entrar em colapso se este recurso não for manejado adequadamente. O presente estudo teve como objetivo estimar parâmetros de crescimento para diferentes modelos baseados nos anéis etários formados nos espinhos dorsais do bonito-listrado capturado no Atlântico Oeste Equatorial. O primeiro espinho dorsal de cada indivíduo foi extraído para produzir cortes transversais com 0,6 a 0,8 mm de espessura. Utilizamos uma abordagem de múltiplos modelos para selecionar o melhor modelo de crescimento com base no critério de informação de Akaike (AIC). Foram analisados 277 indivíduos, com comprimento médio de 49,58 ± 7,72 cm. O modelo de crescimento de von Bertalanffy teve o melhor ajuste aos dados, mas os modelos de Gompertz e Logístico também tiveram um suporte essencial. O comprimento assintótico médio ($\overline{L_\infty}$) foi estimado em 114,05 e 102,63 cm para dados observados e retrocalculados, respectivamente. Os espinhos dorsais são de fato ferramentas eficientes para estimativa dos parâmetros de crescimento e a inferência de multi-modelos é uma nova abordagem para ajustar as discrepâncias que provavelmente resultam de uma abordagem com base em um único modelo.

Palavras-chave: equação de crescimento; modelo de crescimento; inferência multi-modelo; peixe pelágico.

INTRODUCTION

The skipjack tuna (*Katsuwonus pelamis* Linnaeus, 1758) is a migratory pelagic fish belonging to the Scombridae family, with a high natural mortality rate that travels great distances and can be found in all tropical and subtropical oceans of the world (Collette and Nauen, 1983). With the increase in landings involving this species and due to its commercial value, the skipjack tuna constitutes an economically important fishery resource and is the third most widely captured fish in the world, contributing with 3.2 million tonnes (FAO, 2020). Due to the high catch rates, studies on its current population are needed both for proper management of this fishery resource (Campos and Andrade, 1998).

For the Atlantic Ocean, the International Commission for the Conservation of Atlantic Tunas (ICCAT) works on the two-stocks hypothesis, divided into two distinct units in the West and East by the Meridian at 30ºW (ICCAT, 2016). The total catch for the Atlantic was estimated at 305,300 t, with a production by Brazilian fleets corresponding to almost 20,000 t (ICCAT, 2019). The skipjack tuna is caught along almost the entire coast of Brazil, mainly by the pole-and-line fleet in the surface portion of the water column in the southern and southeastern regions of the country (Campos and Andrade, 1998; Madureira and Monteiro-Neto, 2020). However, part of the small-scale fleet based in northeastern Brazil has recently engaged in the fisheries directed at tunas in the vicinity of data buoys in the western Atlantic, where the skipjack tuna is one of the target species, along with bigeye and yellowfin tunas (Silva et al., 2016). This technique is locally named as associated school fisheries, where the own boat act as a Fish Aggregating Device (Silva et al., 2018, 2019).

The abundance of tuna and their economic importance make them widely studied worldwide and the estimation of age and growth parameters is an important tool for fisheries management. Unfortunately, however, the number of growth studies for the skipjack tuna has decreased despite the increase in catches in all oceans (Murua et al., 2017). Different techniques and structures have been used to develop age and growth studies on the skipjack tuna, such as tagging and recapture (Hallier and Gaertner, 2006; Gaertner et al., 2008), size frequencies (Garbin and Castello, 2014; Soares et al., 2019), dorsal spines (Vilela and Castello, 1991; Andrade et al., 2004), and otoliths (Adams and Kerstetter, 2014).

The aim of the present work was to estimate growth parameters of the skipjack tuna captured in the western equatorial Atlantic based on analysis of annual rings from dorsal spine and compare with those parameters estimated in the previous studies, as well to furnish information that can contribute to effective stock assessments and the management of this fishery resource.

MATERIAL AND METHODS

Study area and sampling

The skipjack tuna was caught by pole-and-line and handline in the vicinity of the Pilot Moored Array in the Tropical Atlantic (PIRATA) data buoy, which is anchored at coordinates 00ºN and 035ºW at a depth of 4,500 m 323 nautical miles from the fishing pier in the municipality of Areia Branca (state of Rio Grande do Norte [RN], northeastern Brazil), where the fleet is based (Figure 1).

The specimens were purchased in the period from May 2015 to November 2017 during landings at the local market in Areia Branca, RN They were transported to the Laboratory of Fishing Technology and Oceanography, where fork length was measured using 1.5-meter calipers with an accuracy of 1 cm. The first dorsal spine was removed, stored in a duly labeled plastic bag and kept refrigerated.

Dorsal spine processing

The spines were air dried for 24 to 48 h for further processing using the protocols adopted by Sun et al. (2001), Lessa and Duarte-Neto (2004) and Duarte-Neto et al. (2012). Slices were extracted from the range between 5 and 30% of the spine length from the base of the condyle and were embedded in polyester resin solution to obtain 0.6 to 0.8 mm cross-sections using a low-speed saw (Buheler Isomet®) equipped with a diamond disc. The slices affixed to glass slides using Entellan® resin.

A stereoscopic microscope was used to obtain images of the sections (Figure 2). Measurements of spine diameter (defined as the horizontal distance between the outer margins above the sulcus) and diameter of the age rings, defined as the horizontal distances between the translucent bands and the opposite margin were obtained using the open-source Image Process and Analysis in JAVA-ImageJ (Abramoff et al., 2004). To test the proportionality between spine diameter (SD) and fork length (FL), the data were adjusted to a linear regression (SD = a + b x FL, in which a is intercept and b is slope), using the linear model function (*lm*) of the R software version 3.4.3 (R Core Team, 2017).

Reading and interpretation of age structures

Under transmitted light in a stereoscopic microscope, three independent readings were taken by readers who had no knowledge of fish size or previous readings. The coefficient of variation (CV) (Equation 1) proposed by Chang (1982) was used to determine the reliability of the readings. This equation estimates the accuracy of the reading for each spine.

$$\text{Equation 1: } CV_j = 100\% \text{ x } \frac{\sqrt{\sum_{i=1}^{R} \frac{(X_{ij} - X_j)^2}{R-1}}}{X_j};$$

in which CVj is the estimated accuracy of reading the j^{th} fish, Xij is the i^{th} reading of the j^{th} fish, Xj is the average reading of the j^{th} fish and R is the number of readings.

To determine periodicity in growth increment formation in the dorsal spines, a database was organized with one complete year of collections between April 2015 and March 2016. With these data, marginal increment ratio (MIR) analysis was performed (Equation 2) to estimate the months in which band deposition occurred.

$$\text{Equation 2: } \mathrm{MIR} = \frac{(\mathrm{SD} - \mathrm{Dn})}{(\mathrm{Dn} - \mathrm{Dn\text{-}1})};$$

in which SD is spine diameter, Dn is the diameter for the last full band and Dn-1 is the diameter for the second to last full band.

To validate the marginal increment analysis, analysis of variance (ANOVA) was performed to determine whether significant differences occurred in the formation of growth bands in different months of the year. Tukey's test was then performed to determine which months differed from the others.

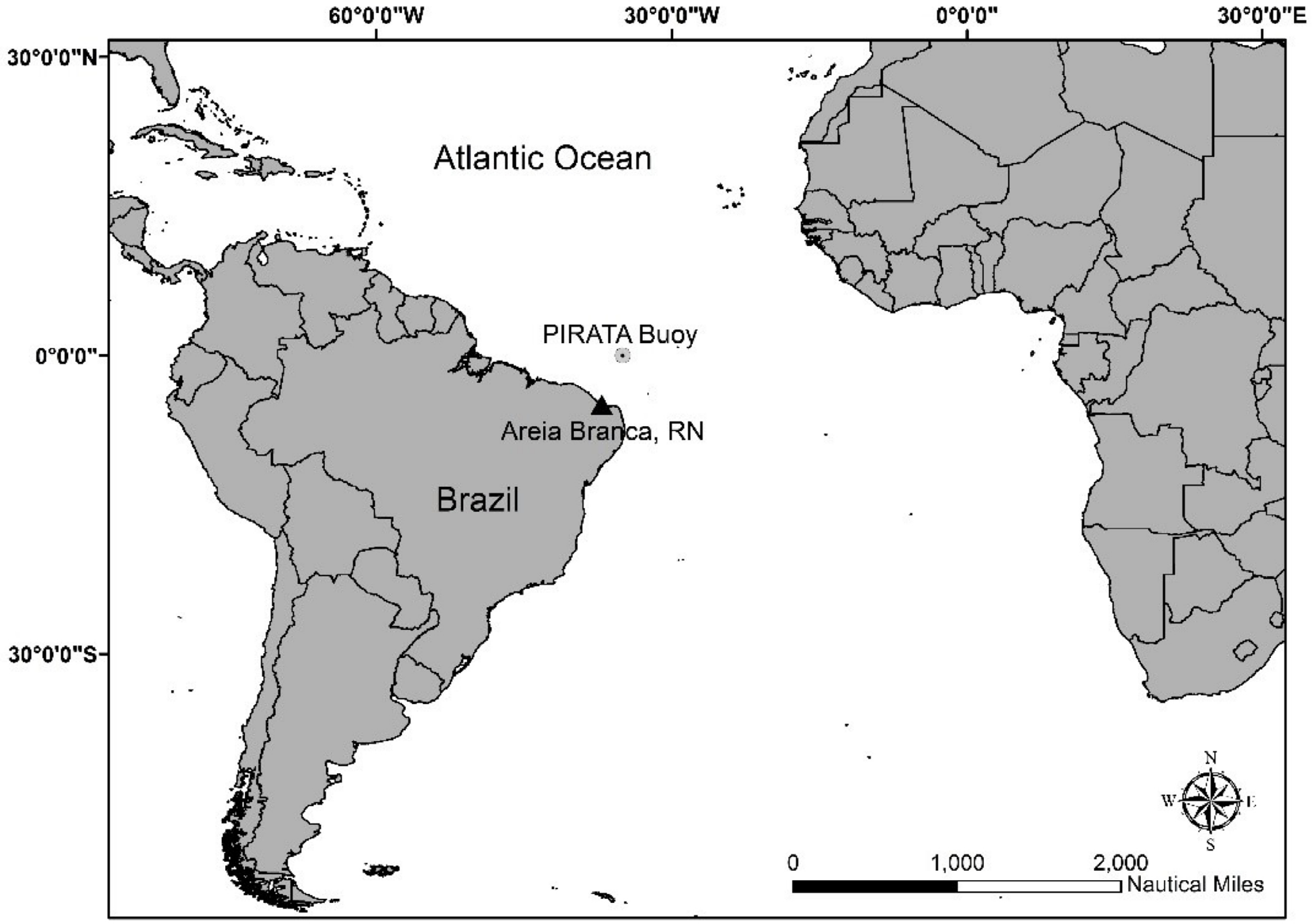

Figure 1. Map with location of the PIRATA data buoy in the western equatorial Atlantic and fishing pier in municipality of Areia Branca, RN, Brazil.

Estimates of lengths at earlier ages were obtained using the back-calculation technique with the relationship between fish length and spine increments proposed by the Fraser-Lee equation (Francis, 1990) (Equation 3).

Equation 3: $Lt = \left(\frac{Dn}{SD}\right) \text{ x } (Lc - a) + a$;

in which Lt is the length of the fish corresponding to ring deposition at age t, Dn is the distance between the ring and margin of the spine, SD is spine diameter, Lc is length at the time of capture and a is a parameter representing the regression intercept between spine diameter and fish length.

Growth models

Pairs of length and age data were adjusted to the following models: von Bertalanffy (von Bertalanffy, 1938) (Equation 4); Gompertz (Gompertz, 1825) (Equation 5) and Logistic (Ricker, 1975) (Equation 6), using the nonlinear regression function (*nls*) in the R software version 3.4.3 (R Core Team, 2017), which is adjusted by the least-squares method and uses the Gauss-Newton algorithm as default.

Equation 4: von Bertalanffy: $Lt = L_\infty\{1 - e^{-K_1.(t-t_1)}\}$;

Equation 5: Gompertz: $Lt = L_\infty e^{-e^{-K_2.(t-t_2)}}$;

Equation 6: Logístic: $Lt = L_\infty\{1 + e^{-K_3.(t-t_3)}\}^{-1}$;

in which L_t is estimated length at age t, L_∞ is maximum theoretical length, $K_{1,\,2 \text{ and } 3}$ are the growth coefficients for each model, t_1 is age when theoretical length is zero and t_2 and t_3 are parameters related to the inflection point relative to each model.

The three models analyzed were classified according to relative importance based on the lowest value of Akaike's Criterion Information (AIC) (Equation 7) (Akaike, 1973; Burnham and

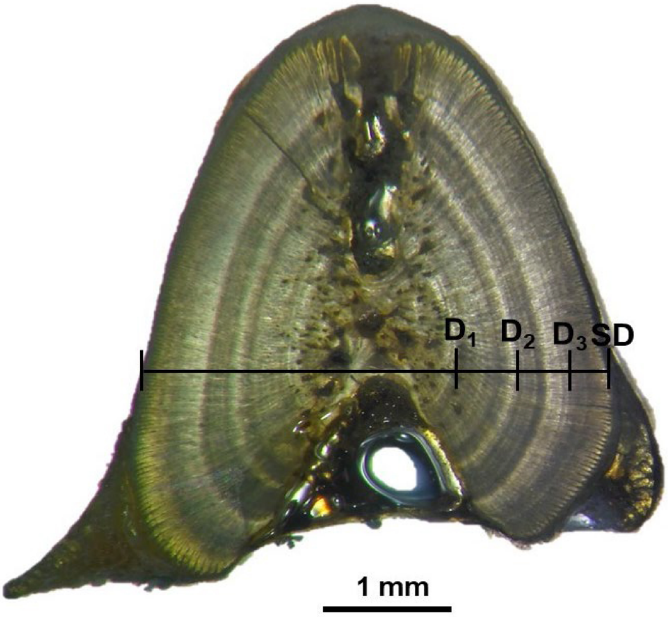

Figure 2. Cross-section of dorsal spine from skipjack tuna measuring 53 cm FL, showing main measurements: SD - spine diameter; D_1 - diameter for first band; D_2 - diameter for second band; D_3 - diameter for third band).

Anderson, 2002) adjusted by the method of least squares. This technique was proposed by Katsanevakis (2006) and has been used to compare growth models for *Thunnus obesus* in the southwestern Atlantic (Duarte-Neto et al., 2012) and *T. alalunga* in the Pacific (Farley et al., 2013).

Equation 7: $AIC = \text{n}.\log\left(\frac{\text{SQR}}{\text{n}}\right) + 2k$;

in which n is the number of observations, SQR is the sum of squares of residues and k is the number of parameters including σ^2, which is calculated by the equation: $\sigma^2 = \text{SQR} / \text{n}$.

The model with the lowest AIC value has the best fit to the data and the acceptability of the remaining models is determined by the difference (Δ_i) (Equation 8) between their respective AIC values (AIC_i) and the value of the best model (AIC_{min}). Models with $\Delta_i > 10$ are omitted because they do not have any essential support. Models with $\Delta_i < 2$ are considered essential and models with $4 < \Delta_i < 7$ have considerable support (Burnham and Anderson, 2002).

Equation 8: $\Delta_i = AIC_i - AIC_{min}$;

in which Δ_i is the difference between AIC_i and AIC_{min} values, AIC_i is the AIC value found in the adjusted model and AIC_{min} is the value of the model with the best fit.

Akaike (Wi) weight (Equation 9) was used to quantify the reliability of each model and establish an average value of asymptotic length ($\overline{L_\infty}$) (Equation 10) from the respective weight of each selected model.

Equation 9: $W_i = \frac{e^{-0,5\Delta}}{\sum_{j=1}^{m} e^{-0,5\Delta j}}$;

in which W_i is the Akaike weight and Δ is difference between AIC_i and AIC_{min} values.

Equation 10: $\overline{L_\infty} = \sum_{j=1}^{m} Wi.L_\infty$;

in which W_i is the Akaike weight and ($\overline{L_\infty}$) is average asymptotic length.

Growth Performance Index

We used the growth performance index (ϕ ') (Equation 11) suggested by Munro and Pauly (1983) to compare L_∞ and K parameters of the von Bertalanffy model estimated in this study to others previously estimated for the Atlantic Ocean. This index can be used to determine relativity between growth parameters, enabling the evaluation of the reliability of fitting the growth equation.

Equation 11: $\phi' = \text{Log } K + 2 \times \text{Log } L_\infty$;

in which ϕ' is the growth performance index, K is the growth coefficient and L_∞ is maximum theoretical asymptotic length.

RESULTS

The present work was initially performed with a sample of 276 skipjack tuna, six of which were discarded due to problems with the reading. Size ranged from 25 to 74 cm by fork length (mean ± standard deviation: 49.58 ± 7.72 cm). Most were concentrated in size classes from 40 to 55 cm FL (Figure 3).

The linear relationship between FL and SD is represented by the equation (FL = 20.11 + 9.08 x SD), with a significant coefficient of determination ($R^2 = 0.84$). Residuals were normally distributed and evenly dispersed, validating the fit to the linear model between FL and SD (Figure 4).

The variation in the marginal increment was significant at the 5% level (F = 3.93; P-value = 4.62 x 10-5), with the highest value found for November. Tukey's test revealed significant differences for the months of December 2015 and January 2016 compared to the other months (Figure 5).

The coefficient of variation (CV) of the ring count exhibited an average variability of 2.8%. The mean back-calculated length at age (BCLA) and observed length at age (OLA) are presented in Table 1. Differences between BCLA and OLA were greater for the largest size classes.

The estimated parameters (L_∞, K and t_0) are presented in Table 2 for the growth models tested (von Bertalanffy, Gompertz and Logistic). Small differences in the standard error were found between observed and back-calculated values. The curves for each growth model did not differ significantly from each other for observed data. For back-calculated data, however, the von Bertalanffy model presented the highest asymptotic length among all models tested (Figure 6).

The von Bertalanffy growth model had the lowest AIC value for both observed and back-calculated data and was therefore considered the model with the best fit. Based on differences compared to the von Bertalanffy model, all the other models presented essential support (i.e., $\Delta_i < 2$; Table 3). According on the Akaike weight (Wi) of each model, mean asymptotic length ($\overline{L_\infty}$) was estimated to be 114.05 and 102.63 cm for the observed and back-calculated data, respectively (Table 3).

The growth performance index (ϕ') was determined from the parameters found with the von Bertalanffy model and studies conducted on the 1st dorsal fin spine. Based on this index, a bibliographic survey was performed. Results similar to those reported in previous studies, with the exception of the work by Cayré et al. (1986), who found a much higher value compared to all other studies conducted around the world (Table 4).

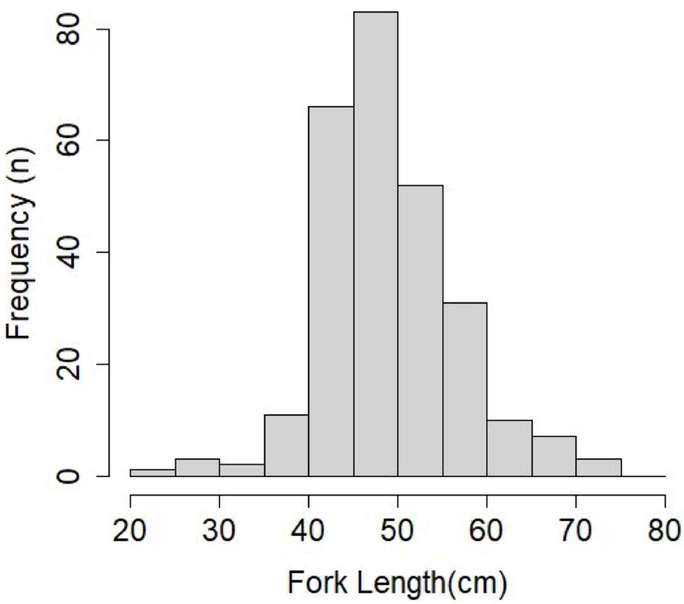

Figure 3. Size distribution of skipjack tuna caught in associated schools in western equatorial Atlantic.

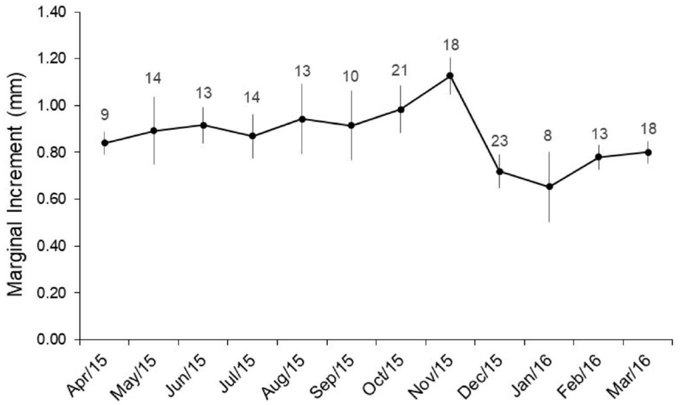

Figure 5. Variation in marginal increment index of 1st dorsal spine of skipjack tuna caught in associated schools in western equatorial Atlantic.

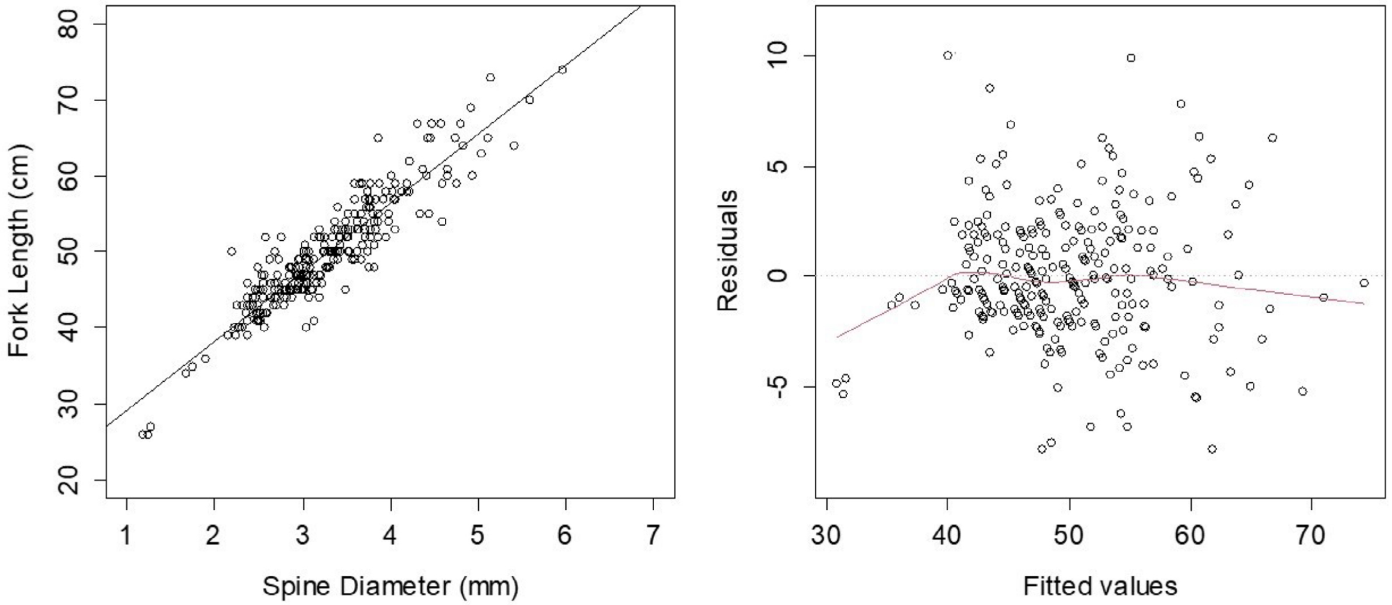

Figure 4. Linear regression and analysis of residuals for relationship between fork length and spine diameter of skipjack tuna caught in associated schools in western equatorial Atlantic.

Table 1. Mean back-calculated length at age (cm) and mean observed length at age (cm) with standard deviation. Hyphen represents loss of translucent zones. (Obs: observed; Back-Calc: back-calculated; FL: fork length).

Age (years)	**n**	**Age ring**				
		I	**II**	**III**	**IV**	**V**
1	13	32.2				
2	149	32.6	39.3			
3	88	32.9	38.9	44.7		
4	14	-	42.5	47.9	54.1	
5	6	-	-	49.3	54.2	64.3
Total Obs/Back-Calc.	270/633	250	251	106	20	6
Standard Deviation		5.83	3.43	3.95	2.96	2.01
Mean $FL_{Back\text{-}calculated}$ (cm)		32.56	40.23	47.30	54.15	64.30
Mean $FL_{observed}$ (cm)		33.46	46.18	54.15	63.78	71.00

Table 2. Estimated parameters for the growth models (VB: von Bertalanffy; GOMP: Gompertz; LOG: Logistic) applied for skipjack tuna in the western equatorial Atlantic, based on observed and back-calculated data with standard errors and confidence intervals (CI).

Data	**Parameter**	**Model**	**Parameter Value**	**Standard Error**	**2.5 % CI Lower**	**97.5 % CI Higher**
Observed	L_∞ (cm)	VB	122.50	32.12	59.25	185.72
		GOMP	96.73	12.59	71.95	121.51
		LOG	87.85	8.14	71.82	103.87
	K ($year^{-1}$)	VB	0.12	0.06	0.01	0.23
		GOMP	0.27	0.06	0.16	0.39
		LOG	0.42	0.06	0.3	0.55
	t_0 (year)	VB	-1.69	0.46	-2.61	-0.78
		GOMP	0.97	0.41	0.17	1.78
		LOG	1.82	0.42	0.98	2.66
Back-calculated	L_∞ (cm)	VB	118.05	29.73	59.64	176.45
		GOMP	83.43	8.03	67.65	99.2
		LOG	73.39	4.5	64.54	82.24
	K ($year^{-1}$)	VB	0.11	0.04	0.02	0.19
		GOMP	0.3	0.04	0.22	0.28
		LOG	0.5	0.04	0.41	0.58
	t_0 (year)	VB	-1.69	0.26	-2.21	-1.17
		GOMP	0.96	0.3	0.35	1.57
		LOG	1.62	0.25	1.11	2.12

DISCUSSION

The size distribution was sufficient to run the growth models. The main size classes in the landings were between 40 and 55 cm FL, which are quite similar to those described by Soares et al. (2019) for skipjack tuna caught by the Brazilian pole-and-line fleet in the southwestern Atlantic, in which the average size was 52 cm FL and most catches were concentrated in size classes between 47 and 52 cm FL. According to the aforementioned authors, the length at first maturity for the skipjack tuna in the southwest Atlantic is about 45 cm. Thus, part of the individuals caught were in the early maturity phase, which may lead to

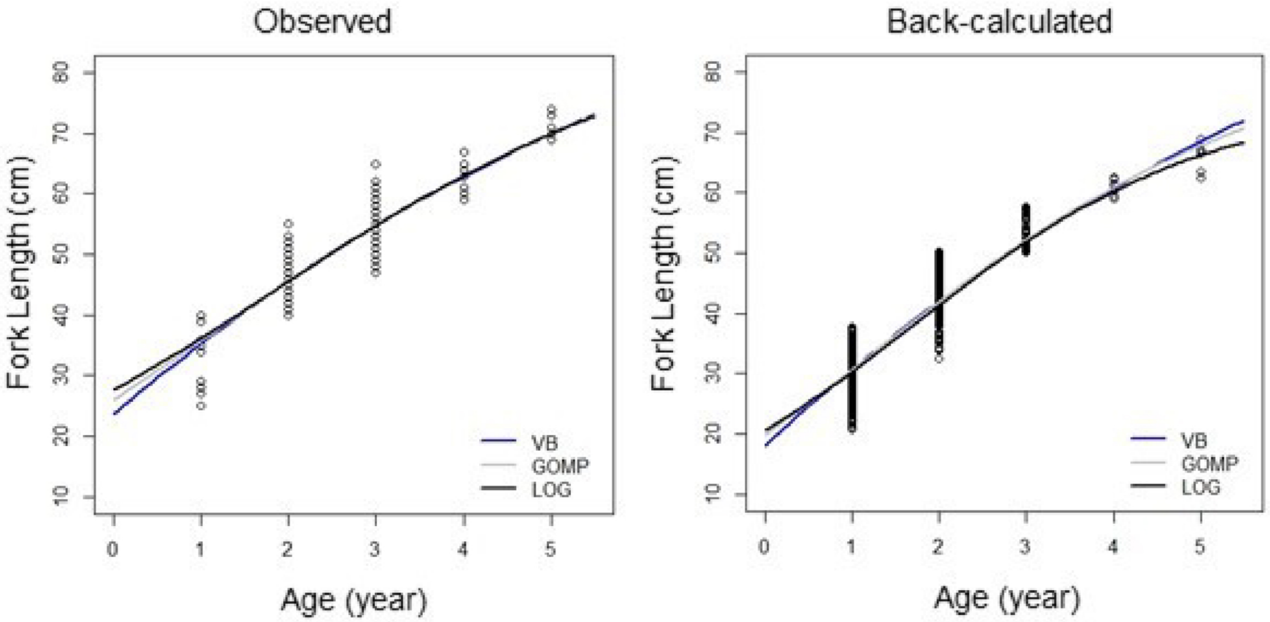

Figure 6. Growth curves (VB: von Bertalanffy; GOMP: Gompertz; LOG: Logistic) of skipjack tuna caught in associated schools in western equatorial Atlantic based on observed and back-calculated data from the 1st dorsal fin spine.

Table 3. AIC values, AIC differences (Δi) and AIC weight (Wi) for growth models based on data from dorsal spines of skipjack tuna in the western equatorial Atlantic (VB: von Bertalanffy; GOMP: Gompertz; LOG: Logistic).

Data	Model	AIC	Δi	Wi (%)
Observed	VB	1492.65	0	69.92
	GOMP	1494.94	2.29	22.25
	LOG	1497.03	4.38	7.83
Back-calculated	VB	3541.43	0	44.41
	GOMP	3541.96	0.53	34.07
	LOG	3542.88	1.45	21.51

Table 4. Growth parameters (L_∞ and K) and growth performance index (ϕ’) of skipjack tuna compared to major studies conducted previously in the Atlantic (WE: western equatorial; SW: southwestern; NW: northwestern).

Parameter		Locality	Method	Author (year)	ϕ’
L_∞	K				
122.5	0.12	WE Atlantic	Dorsal Spine	Present study	3.26
62	2.080	Eastern Atlantic	Tagging	Cayré et al. (1986)	6.90
80	0.601	Eastern Atlantic	Tagging	Bard and Antoine (1986)	3.59
87.12	0.219	SW Atlantic	Dorsal Spine	Vilela and Castello (1991)	3.22
97.9	0.14	SW Atlantic	Dorsal Spine	Andrade et al. (2004)	3.12
89.38	0.14	Eastern Atlantic	Tagging	Gaertner et al. (2008)	3.05
113	0.24	NW Atlantic	Otolith	Adams and Kerstetter (2014)	3.49
92.4	0.161	SW Atlantic	Dorsal Spine	Garbin and Castello (2014)	3,14
90.1	0.24	SW Atlantic	Length Freq	Soares et al. (2019)	3.29

recruitment overfishing in the future, hence the skipjack tuna is considered a target species in the associated school fisheries (Silva et al., 2016).

Analyzing catches over a 30-year period of exploitation since the 1980s, Garbin and Castello (2014) found a significant reduction in median size and greater participation of smaller individuals (<40 cm FL) in catches by the Brazilian fleet operating in the southwestern Atlantic. The analyses made with skipjack tuna dorsal spines in the present study revealed individuals up to five years of age, with a concentration of the two-and-three-year-old groups in fishing activities carried out by the fleet from Areia Branca, RN, whereas Garbin and Castello (2014) found a greater occurrence of individuals aged two to five years based on the dorsal spines method and Uchiyama and Struhsaker (1981) found mostly fish between one and three years of age in the catches from Central Pacific, based on otolith daily increments.

A positive correlation is found between the formation of the age rings on the 1st dorsal fin spine and fork length of the skipjack tuna. Among the known techniques and aging structures, dorsal spines are relatively easy to obtain at low cost at commercial landings and the reading of this structure is quite easy, generating significant data for estimates of growth parameters (Lessa and Duarte-Neto, 2004; Duarte-Neto et al., 2012).

The marginal increment analysis revealed that the band formation pattern is different from that found in the work by Andrade et al. (2004) from southwestern Atlantic, in which the authors observed the formation of opaque and translucent bands in the periods from May to October and from December to May, respectively. In contrast, Vilela and Castelo (1991) reported the formation of two rings per year for the same region and this difference may occurred because they analyzed pooled data from different years (from 1983 to 1989). Environmental and biological factors, such as temperature, reproduction, migration, food availability or being associated with other schools, can interfere with the periodicity of the formation of annual rings on dorsal spines (Fowler, 1990; Lessa and Duarte-Neto, 2004; Nobrega and Lessa, 2009; Duarte-Neto et al., 2012).

The disadvantage of the dorsal spine as an aging structure is the possibility of a loss of the first growth rings in older individuals due to vascularization in the center of the spine (Andrade et al., 2004). Despite this phenomenon, the results of the present study indicate quite similar parameter values (L_∞ and K) compared to those reported in previous studies that used different techniques to estimate such parameters (Uchiyama and Struhsaker, 1981; Molony, 2008; Gaertner et al., 2008; Adams and Kerstetter, 2014).

Tunas are considered the fastest-growing species among fishes and the skipjack tuna has the highest growth coefficient in the group (Murua et al., 2017). The growth coefficient estimated ($K = 0.12$) in the present study is the lowest ever estimated for the Atlantic, although it is quite similar ($K = 0.14$) to those estimated previously by Andrade et al. (2004) and Gaertner et al. (2008), who respectively worked with dorsal spine and tagging data. Differences in growth rates depend on the year and zone of the survey, as fishes in equatorial zones grow slower than those in subtropical zones (ICCAT, 2016).

Comparing asymptotic length (L_∞) values estimated for the skipjack tuna using the von Bertalanffy growth model to those from previous studies conducted in the Atlantic Ocean, this is the highest ever estimated. However, the approach of estimating average asymptotic length ($\overline{L_\infty}$) proposed by Katsanevakis (2006) proved to be an important tool to solve this kind of problem. According to Collette and Nauen (1983), the largest size recorded was 108 cm FL in an individual weighing 34.5 kg. However, maximum size in catches does not normally exceed 80 cm (ICCAT, 2016).

The estimated growth performance index (ϕ') was quite similar to values reported by other authors (Bard and Antoine, 1986; Vilela and Castello, 1991; Andrade et al., 2004; Gaertner et al., 2008; Adams and Kerstetter, 2014; Soares et al., 2019), which confirms the fact that the dorsal spine provides satisfactory data to estimate skipjack tuna growth parameters, comparable to ϕ' values derived from otolith-based works, length frequency analysis, and tagging. The only difference was in the study by Cayré et al. (1986), who used the tagging approach but described a growth coefficient of 2.8 and asymptotic length of 62 cm, which may explain this difference.

Diverse growth modeling can produce differences in growth curve estimates (Murua et al., 2017). The von Bertalanffy growth model was indicated as the most suitable for the present study based on the AIC for both observed and back-calculated data. Apparently, this is the most widely used model in fish growth studies. However, a new trend is emerging, with the use of multi-models to estimate growth parameters based on the contribution by each model (Katsanevakis, 2006) and the present study is a pioneering work using this inference for the skipjack tuna.

CONCLUSIONS

Dorsal spines are indeed efficient tools for estimating growth parameters for skipjack tuna and the multi-model inference is a novel approach for adjusting discrepancies that likely result from a single-model.

Conflict of interests

Nothing to declare.

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Authors' Contributions

Cunha-Neto, M.A.: Conceptualization, Data curation, Methodology, Formal Analysis, Writing – original draft & Writing – review & editing. Hazin, H.G.: Conceptualization, Supervision

& Writing – review & editing. Silva, G.B.: Conceptualization, Data curation, Methodology, Formal Analysis, Supervision, Writing – original draft & Writing – review & editing.

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