DIRECT AGEING FOR CONSTRUCTING AGE-LENGTH KEYS AND RE-ESTIMATING THE GROWTH CURVE FOR EAST ATLANTIC AND MEDITERRANEAN BLUEFIN TUNA

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SUMMARY

This paper analyzes the available direct ageing information for Atlantic bluefin tuna caught in the eastern management area. Historical fin spine readings were incorporated into the biological database, after having established that the age estimation was equivalent to that performed following the standardized methodology. This allows having a database of aged structures (otoliths and spines) from 1984 to 2013, which can be used for generating catch at age estimates. An integrated analysis of tag-recapture and age-length data was carried out in an attempt to update growth parameter estimates for the eastern stock. Neither the von Bertalanffy nor the Richards parameterization was able to adequately describe growth. The reason for the misfit was largely due to the lack of individuals older than14 years in the dataset as well as possible differences in selectivity pattern between young and old fish.

RÉSUMÉ

Le présent document analyse les informations disponibles sur la détermination directe de l'âge du thon rouge de l'Atlantique capturé dans la zone de gestion orientale. Les lectures historiques des épines des nageoires ont été incorporées à la base de données biologiques, une fois qu'il a été constaté que l'estimation de l'âge était équivalente à celle réalisée en suivant la méthodologie standardisée. Cela permet d'avoir une base de données de structures dont l'âge a été déterminé (otolithes et épines) de 1984 à 2013, ce qui peut être utilisé pour générer les estimations de prise par âge. Une analyse intégrée des données de marquage-récupération de marques et d'âge-longueur a été réalisée dans le but de mettre à jour les estimations des paramètres de croissance pour le stock oriental. Ni le paramétrage de von Bertalanffy ni celui de Richards n'ont pu décrire adéquatement la croissance. La raison de l'inadéquation est en grande partie due à l'absence de spécimens de plus de 14 ans dans le jeu de données ainsi qu'à de possibles différences dans le schéma de sélectivité entre les poissons jeunes et âgés.

RESUMEN

Este documento analiza la información disponible sobre la determinación directa de la edad del atún rojo Atlántico capturado en el área oriental de ordenación. Se incorporaron en la base de datos biológica las lecturas históricas de espinas de aleta dorsal, después de haber comprobado que la estimación de la edad era equivalente a la realizada siguiendo la metodología estandarizada. Esto permite tener una base de datos de estructuras calcificadas leídas (otolitos y espinas) de 1984 a 2013, que puede ser utilizada para generar capturas por edad. Se realizó un análisis integrado de datos de marcado-recaptura y de talla-edad para actualizar la estimación de los parámetros de crecimiento para el stock oriental. Ni la parametrización de von Bertalanffy ni la de Richards fueron capaces de describir adecuadamente el crecimiento. La razón se debió en gran medida a la escasez de individuos mayores de 14 años en el conjunto de datos, así como a las posibles diferencias en el patrón de selectividad entre los peces jóvenes y viejos.

KEYWORDS

Age determination, direct aging, growth, otoliths, spines, Thunnus thynnus

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1. Introduction

At the 2017 Atlantic bluefin tuna (*Thunnus thynnus*) data preparatory meeting (Anon, 2017), the Group requested that gaps in the eastern biological database be completed with historical records to make data available to construct age-length keys (ALKs) and re-estimate the growth curve. Direct ageing information from the last decade for Atlantic bluefin tuna (ABFT) caught in the eastern management area was made available in the 2016 intersessional meeting (Quelle *et al*., 2017). This information includes ageing from otoliths and dorsal fin radii (spines), which have been aged using standardized reading protocols (Luque et al., 2014; Busawon *et al*., 2015; Rodriguez-Marin *et al*., 2016a).

The preparation methodology and the criterion for reading the spines have undergone, over time, some minor modifications regarding sectioning location, the reference table used for estimating the number of missing annuli that lie within the vascularized nucleus and age adjusting related to date of capture and section edge type (Luque et al., 2014). All samples aged after 2000 (regardless of the year in which they were sampled) were estimated following the standardized protocol (Luque et al., 2014), but it has not been verified whether the methodology used for reading samples prior to 2000 (Cort, 1990) is equivalent to the one currently used (Luque et al, 2014). To test whether the two methodologies can be treated as being equivalent, we will apply both methodologies to the same set of samples and compare results. Once the comparison is made and if the results are equivalent, we will analyze all the age information available from 1984 to present, incorporate historical readings from spines prior to 2005, and use this data to re-estimate the eastern growth curve.

2. Material and methods

Historical spine readings with non-standard methodology include 4 172 records from tunas caught in the Bay of Biscay from 1984 to 1996. These tunas have a size range of 51 to 204 cm straight fork length (SFL). Dorsal fin radii (spines) from these specimens were prepared and interpreted for ageing following Cort (1991). A total of 661 samples were selected in proportion to their abundance by size range to be re-read with the standardized reading methodology (Luque *et al.*, 2014) (**Table 1**). Diagnosis of paired age agreement was evaluated by precision indices through Average Percent Error (APE) and Coefficient of Variation (CV), tests of symmetry (chi-squared test) and age-bias plots (Hoenig *et al*., 1995; Campana *et al*., 1995).

Available length at age data include aged spines with non standardized methodology from 1984 to 1996 (previously mentioned) and spines and otoliths aged with standardized methodology from 1984, 1990 and 1997 to 2013. This data base includes spines and otoliths readings coming from the IEO (Instituto Español de Oceanografía, Spain) with 86% of the records and from GBYP (ICCAT) with 14%. A summary of available data was prepared and mean length and standard deviation at age was estimated for different periods of time and type of calcified structure.

An integrated analysis of tag-recapture and age-length data (otoliths and spines) was carried out in an attempt to update growth parameter estimates for the eastern stock. The same methodology that had been successfully applied to the western stock (Ailloud et al. 2017) was applied to the eastern data. Available data included 10,034 otolith and spine records (age samples from the dataset presented here plus specimens captured in the West with probabilities of East origin >70%) and 295 conventional tagging records obtained from the ICCAT tagging database (tested for quality control following guidelines outlined in Ailloud et al. 2014). Two growth models were considered to describe the functional relationship between fish length and age: the Richards model and the von Bertalanffy model. Both models can be expressed as special cases of the Schnute (1981) model where the model takes on the shape of a von Bertalanffy curve if the shape parameter equals 1 and a sigmoidal form like the Richards curve if the shape parameter is less than 1.

3. Results and Discussion

The age range of the samples read with the pre-standardized methodology was 1 to 8 years old, with ages 1 to 4 representing nearly 90% of the sample. The comparison of both reading methodologies for paired samples (n = 661) shows a CV of 2.03 and an APE of 91.8%. The hypothesis of symmetry was rejected ($X^2 = 31$, df = 7) and bias-plot showed significant differences for readings at ages 3 and 5 (**Figure 1**). When fall months were excluded from the comparison, precision improved (CV = 0.33; APE = 96.7), readings were symmetric ($X^2 = 4.5$, df = 4, $p < 0.001$) and bias plot did not present differences (**Figure 1**).

Analyzing fall samples, it appears that edge type interpretation in relation to date of capture is not responsible for the differences between readings. It seems that differences were a result of inconsistent sectioning location (not clearly stated) and the use of a slightly different reference tables for estimating the number of missing annuli (rings lost by the vascularization of the nucleus) (**Figure 2**), both being important factors for replacing missing annuli since the appearance and size of annuli varies between sectioning levels (Kopf et al., 2010; Luque et al., 2014). Although there was a significant disparity for ages 3 and 5, that disparity represented less than a quarter of a year. It was therefore deemed acceptable to use historical records.

Direct ageing data from ABFT caught in the eastern Atlantic management unit and available for the construction of ALKs and growth parameters estimation is presented in **Table 2**. This information includes spines and otoliths readings. Spines represent most of the structures aged, 90% of the total, with samples from 1984 to 2013 (spines aged older than 13 years were excluded, Rodriguez-Marin *et al*., 2016b), and otoliths representing the remaining 10%, with records from 2010 to 2013. Only 2011 and 2012 (GBYP samples) included samples for most of the length range, while other years had limited length range coverage and uneven geographic representativeness. There are few aged fish after 2012.

Mean length and standard deviation by age was estimated from spine samples for two year periods: prior to and after the year 2000, to account for reading methodology (**Figure 3**); and prior to and after the year 2007, to account for changes in management measures (including minimum size) (**Figure 4**). Time series comparisons showed no clear trends except for a higher average length at ages 4 to 6 years old for years prior to 2007. The standard deviation of length at age increased linearly with mean length. The mean lengths at age obtained with both calcified structures are similar and are included in the confidence interval (± 1 s.d.) of one structure with respect to the other, although there is a slight age overestimation of 2 to 6 year old individuals when using otoliths with respect to spines (**Figure 5**).

Producing annual forward age length-keys has been challenging for this species as there remain gaps in data (not all fish sizes neither geographical areas are sampled each year). Nonetheless, this database has proven useful for generating catch at age estimates using the Hoenig *et al*. (2002) method (a combination of forward ALKs and inverse ALKs), which was recommended by the ABFT Group for assigning ages to the catch during the 2017 data preparatory meeting (Anon. 2017).

Neither the von Bertalanffy nor the Richards parameterization was able to adequately describe growth for eastern bluefin tuna given the available data. The shape parameter of the Schnute model was estimated to be around 1, thus both Richards and von Bertalanffy model fits were nearly identical (**Figure 6**). Fit was poor, particularly for ages 12 and beyond, and $L\infty$ was estimated at 394cm SFL. The reason for the misfit was largely due to the lack of older individuals in the dataset as well as possible differences in selectivity pattern between young and old fish. The data were heavily skewed towards young fish (105:1 in the age length data) and there was a noticeable lack of very old fish. Since $L\infty$ is known to be poorly estimated when data are heavily skewed towards younger ages, a quick exercise was carried out to see if the estimate of $L\infty$ would change if the sample were more balanced. The ratio of young to old fish was gradually decreased by replicating the records of old fish. As expected, the estimate of $L\infty$ gradually decreased as the ratio of young to old fish was lowered (**Figure 7**). The $L\infty$ appeared to stabilize around 260-280cm SFL across both von Bertalanffy and Richards model fits (**Figure 7**). However, when the estimate of $L\infty$ appeared reasonable, the remainder of the curve did not fit the data properly (**Figure 8**). Other, more flexible, models will need to be explored to obtain reliable growth parameters for eastern Atlantic bluefin tuna.

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Table 1. Number of samples by length range. Pre-standardized series with all available “historical” samples (1984-1996) and standardized series with paired samples re-read.

	Reading methodology	
Length (cm, SFL)	Pre-standardized	Standardized
50-59	188	30
60-69	584	66
70-79	479	119
80-89	649	138
90-99	488	98
100-109	459	48
110-119	349	42
120-129	289	24
130-139	182	35
140-149	197	22
150-159	147	7
160-169	78	9
170-179	46	13
180-189	31	6
190-199	4	2
200-209	2	2
Total	4172	661

Table 2. Length at age data by year and length range (cm, SFL) for east Atlantic bluefin tuna.

Length	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
20-30																										1	1	10			12
30-40																				28		25				17	29	10			109
40-50																				3	1	3		3				6	14		30
50-60		38	14	14	47	17	5	2	11	11		8	24	9	44	6	2		2	28	7	8	1	20			3	18	7		346
60-70		31	101	80	79	45	31	50	29	34	17	33	55	91	19	2	64	2	28	10	77	45	30	22	20	2		17	13		1027
70-80		104	46	63	50	48	38	38	21	13	21	10	28	43	51	27	42	38	23	23	39	44	6	16	54	2	2	40	19		949
80-90		108	56	62	72	18	47	54	45	47	37	51	53	37	79	27	25	48	33	6	29	16		25	51	25	43	78	17		1189
90-100		74	57	16	44	11	31	30	47	28	51	74	25	57	69	12	18	13	33	10	3	41	3	1	36	23	29	27	17		880
100-110		64	54	22	53	20	34	38	31	26	13	25	79	58	51	2	17	6	11	7	1	32	2	9	11	25	10	75	26		802
110-120		63	53	33	26	11	13	32	25	25	18	18	31	8	35	19	7	7	2	6	13	20	6	9	28	19	6	154	22		709
120-130		32	65	22	30	19	17	28	11	25	10	6	24	27	7	16	5	10		3	14	3	1	5	29	16	4	64	33		526
130-140	2	15	20	16	32	3	18	7	10	18	28	3	14	31	2	37	2	5		5	7	4	1	1	11	13	1	58	40		404
140-150	2	23	32	36	29	11	25	8	7	12	7	2	5	13	8	4	6	1	5	8	3	7	3	1	1	9	6	56	28		358
150-160	6	21	23	23	19	15	12	14	7	4	1	1	2	2	8	2	5	4	1	5	6	3	20	1	1	9	6	39	30		290
160-170	13	4	14	6	19	6	3	8		3			2	1	2	3	3	7	1	2	8	2	9	9	17	8	27	22	24	1	224
170-180	19		5	6	3	3	3	5	1	1	2		5			4	1	6		3	2	6	5	20	10	4	23	19	18	4	178
180-190	19		2	2	4	2	6	1	2	2	1		2			1		3	4	1	1	9	3	15	15	8	15	47	15	3	183
190-200	14					2	16			1								7	11		3	10	2	11	30	12	18	40	26		203
200-210	19						7	1		1								4	9	1	4	16		2	22	4	29	51	55	2	227
210-220	27						13											4	4		3	35	1	4	20		26	63	47	7	254
220-230	33						7					1						1	2	3	9	47		3	11	3	11	47	26	1	205
230-240	24						13											2		1	4	51		2	12	2	5	48	17	7	189
240-250	12						6											1			3	17			6	1	3	16	14	4	83
250-260	5						2											1	1	1	2	7			1		4	10	4		38
260-270	3																					1						5	4		13
270-280																						1						1	1	1	4
280-290	1																											1	1		3
Total	199	577	542	401	507	231	347	316	247	251	206	232	349	377	375	162	197	170	170	154	239	453	93	179	386	203	301	1022	518	30	9435

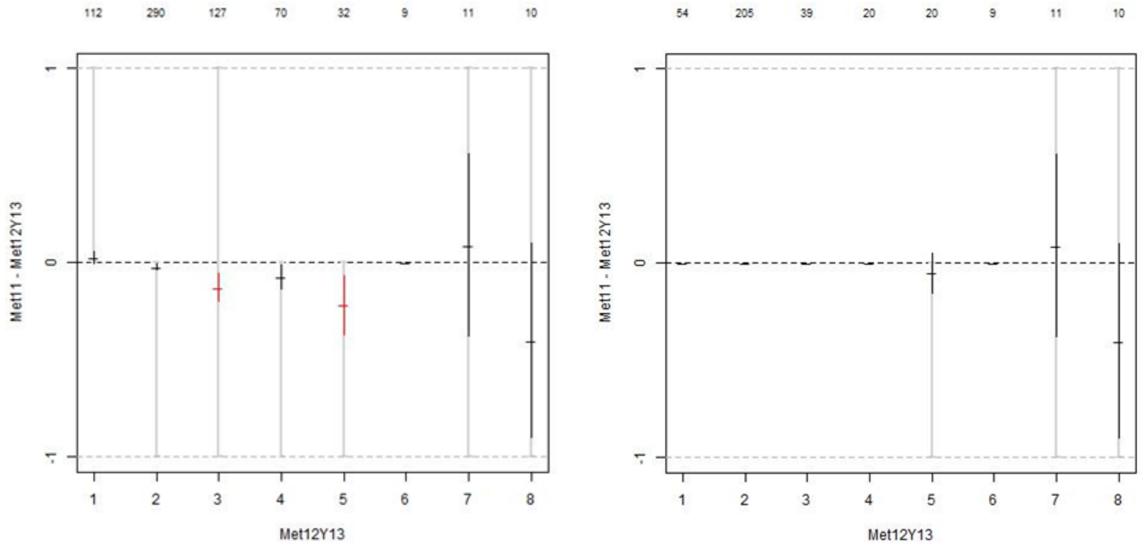

Figure 1. Difference in age estimates from previous and standardized methodology (y axis) by estimated age (x axis). Crosses indicate the average with black lines indicating the 95% confidence intervals and the grey lines indicating the age range. The 1:1 equivalence line (black dashed) and one year difference line (grey dashed) are also indicated. Numbers above the figure indicate number of samples by age. Left for all year samples (May to November, n=661) and right excluding the autumn samples (October and November excluded, n=368).

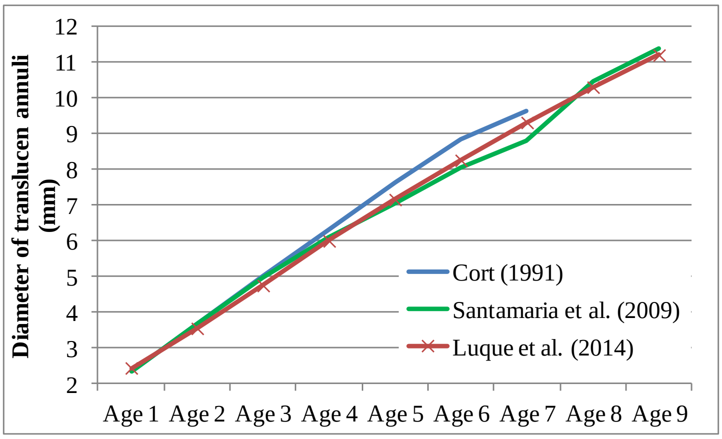

Figure 2. Spine annuli measurements available in the literature. The reference table from Cort (1991) was used for estimating historical samples age, and standardized methodology applies Luque et al. (2014).

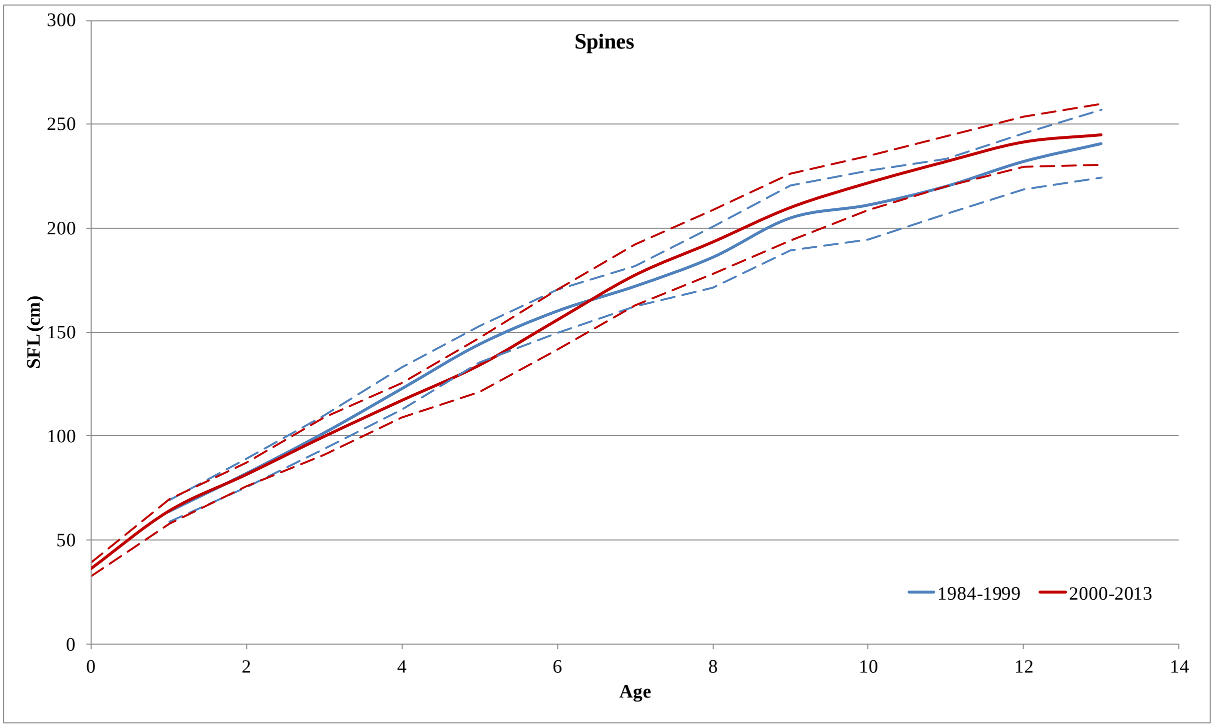

Figure 3. Spines mean length at age (solid line) and ± standard deviation (dashed line) for time periods prior to and after the year 2000.

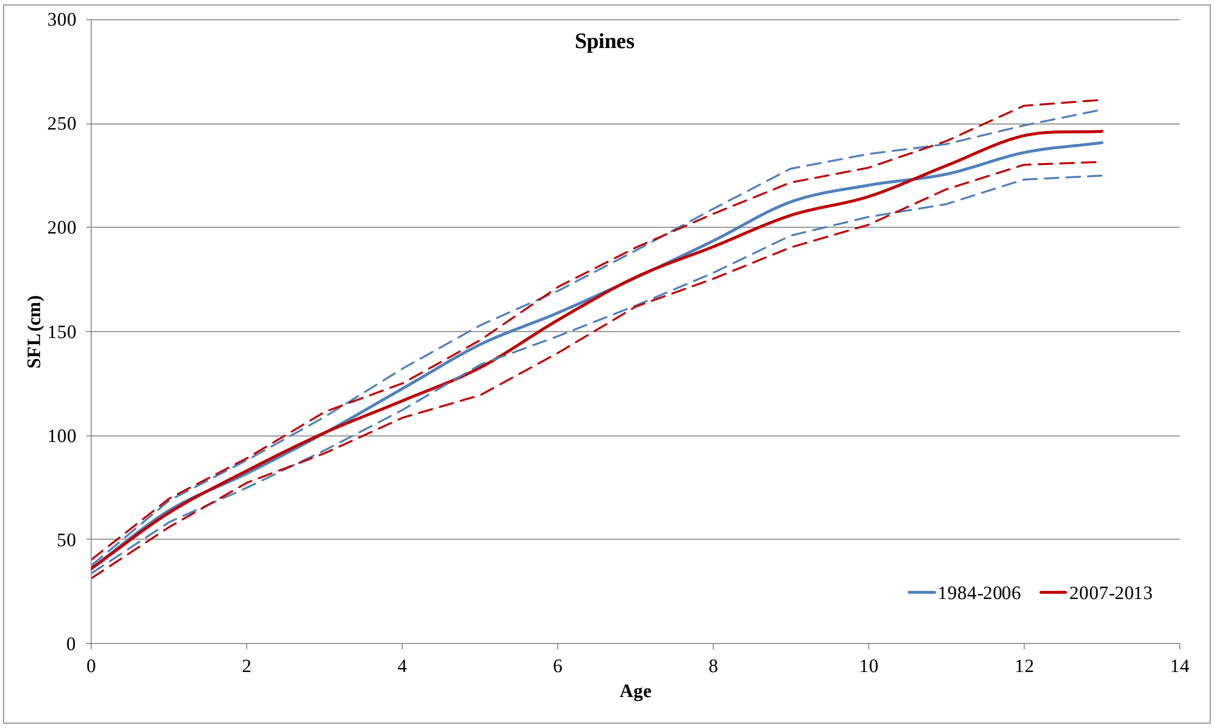

Figure 4. Spines mean length at age (solid line) and ± standard deviation (dashed line) for time periods prior to and after the year 2007.

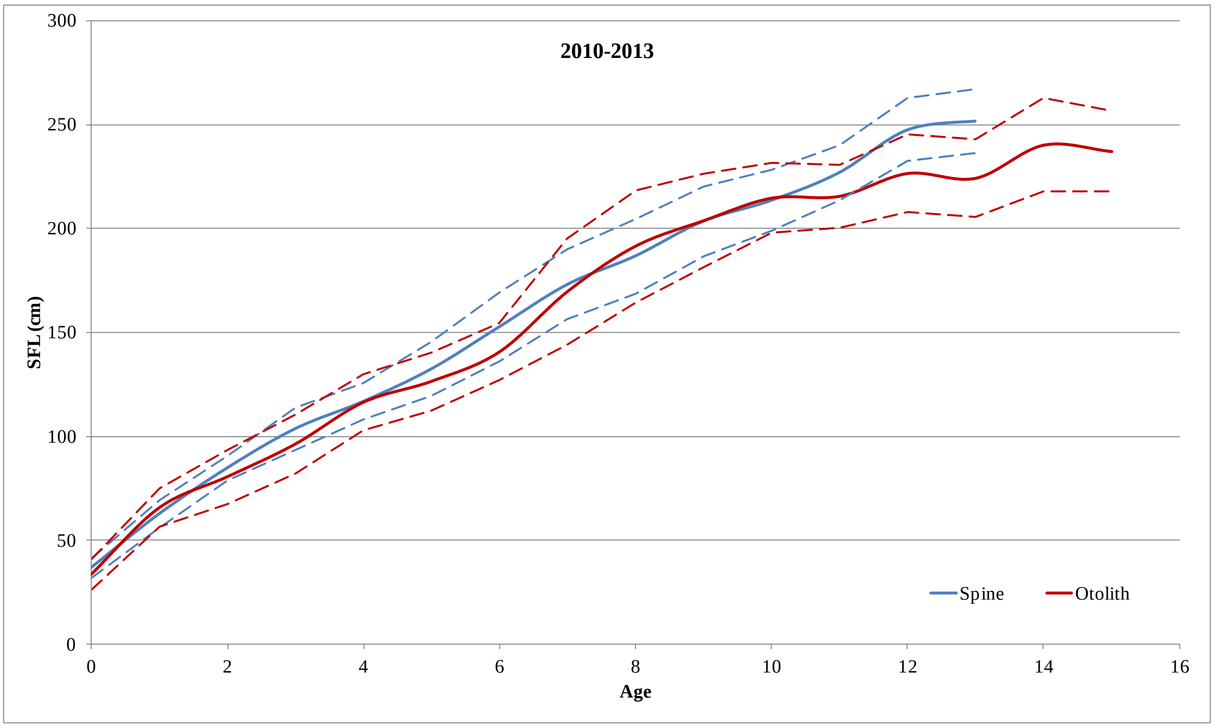

Figure 5. Mean lengths at age (solid line) and ± standard deviation (dashed line) obtained with aged spines and otoliths for years 2010 to 2013.

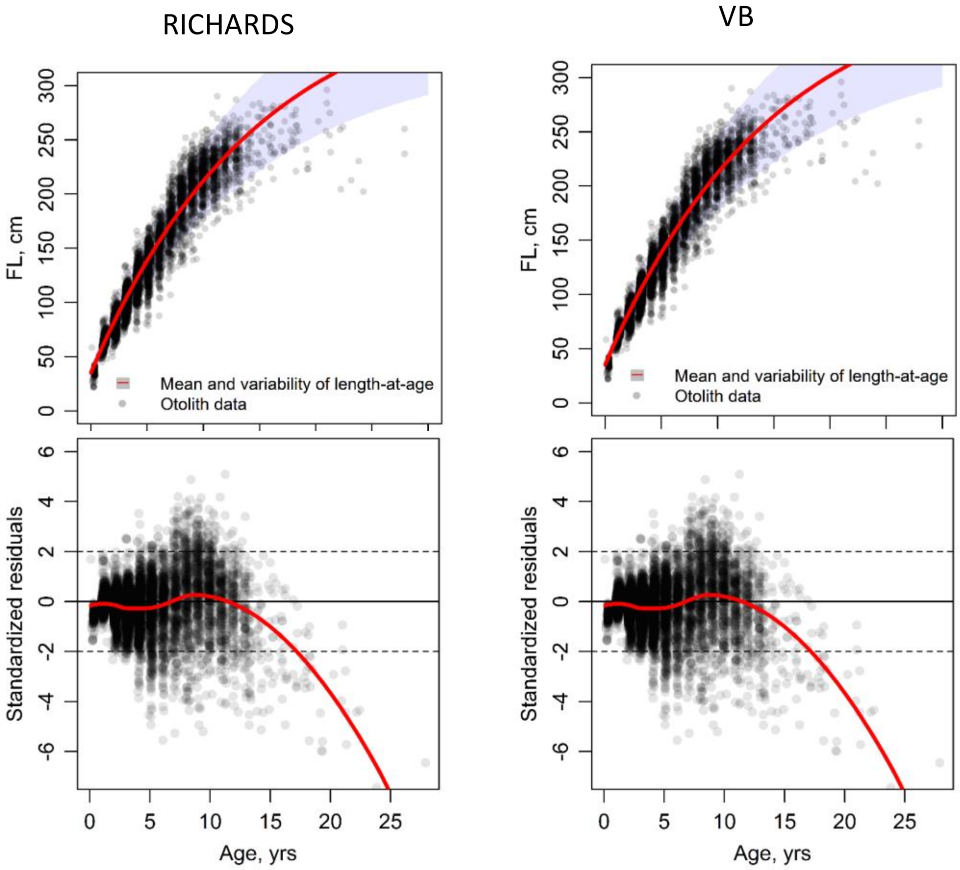

Figure 6. Richards and von Bertalanffy model fits (both are equivalent due to the Richards' model parameter p being estimated to equal 1). The top panel shows the fit to the age-length data and the bottom panel is a plot of the standardized residuals.

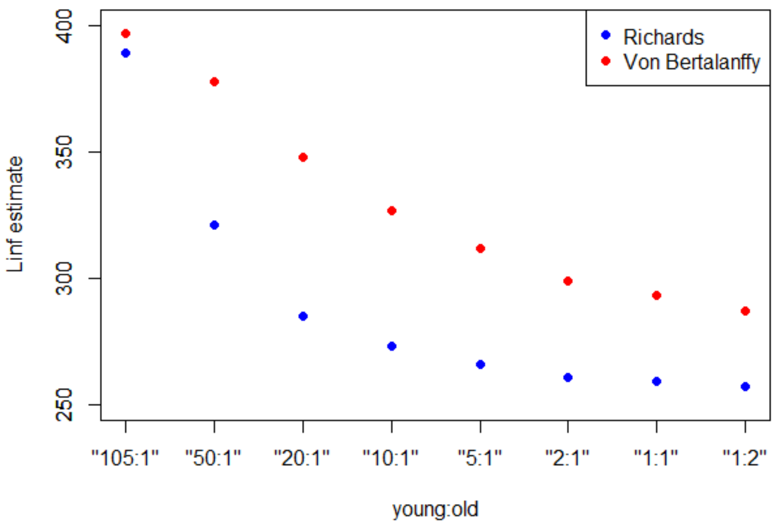

Figure 7. Estimates of L_∞ as a function of the ratio of young to old fish resulting from Richards and von Bertalanffy model fits.

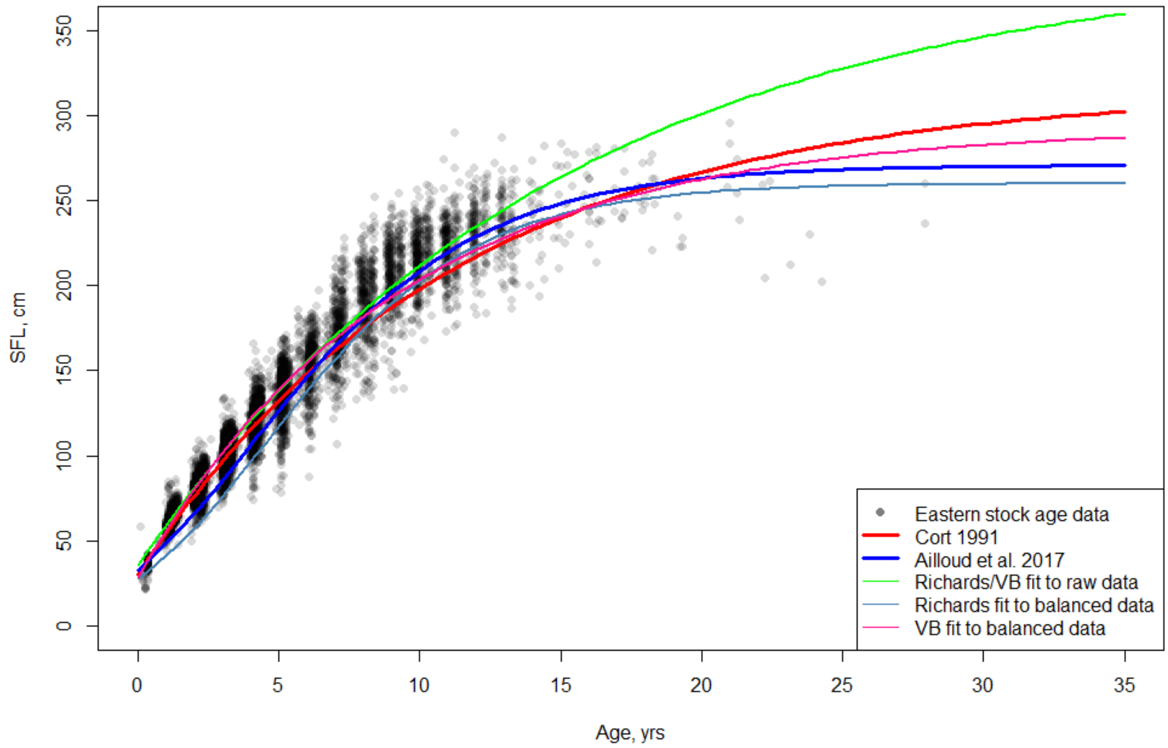

Figure 8. Three different model fits are shown: the Richards/von Bertalanffy fit to the raw data, and the Richards and von Bertalanffy fits to the balanced data (1:1 ratio of young to old fish). The Cort (1991) and Ailloud et al. (2017) curves are also plotted for comparison.