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AGE AND GROWTH OF BIGEYE TUNA *THUNNUS OBESUS* CAPTURED IN THE MADEIRA ARCHIPELAGO

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SUMMARY

The age and growth of bigeye tuna have been investigated by several authors for different geographic areas, using growth marks on fin spines or length-based methods. In this work, the age and growth of bigeye tuna caught in the region of the Madeira archipelago was investigated. The precision of the ageing procedure was high. There were no significant differences in growth curves estimated for males and females. The growth curves estimated compare well with those estimated by previous authors.

RÉSUMÉ

L'âge et la croissance du thon obèse ont fait l'objet d'études par plusieurs auteurs pour différentes zones géographiques, en utilisant des marques de croissance des rayons de nageoires ou des méthodes fondées sur la taille. Dans ce document, on a étudié l'âge et la croissance du thon obèse pris dans la région de l'archipel de Madère. La procédure de détermination de l'âge était d'une haute précision. Il n'y a pas eu de différences significatives dans les courbes de croissance estimées pour les mâles et les femelles. Les courbes de croissance estimées coïncident bien avec celles qui avaient fait l'objet d'estimations par de précédents auteurs.

RESUMEN

La edad y crecimiento del patudo han sido investigados por numerosos autores para diferentes áreas geográficas, utilizando marcas de crecimiento de los radios de las aletas o métodos basados en la talla. En este trabajo se investigó la edad y crecimiento de patudo capturado en la región del archipiélago de Madeira. La precisión del procedimiento de determinación de la edad fue alta. No había diferencias significativas en las curvas de crecimiento estimadas para machos y hembras. Las curvas de crecimiento estimadas se corresponden bien con las curvas de crecimiento estimadas por autores anteriores.

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Introduction

In their feeding migrations through the Atlantic, bigeye tuna cross the archipelagos of Canaries, Madeira and Azores, Madeira region in the spring and summer (Gouveia, 1986; Pereira, 1995). Here, they are fished by a fleet of mostly small and medium boats using exclusively pole and line. This fishery targets mostly adults and sub-adults, and the landings include fish from about 45 cm to 180 cm fork length (Carvalho *et al.*,1983; Gouveia, 1986; Pereira, 1995).

Some studies of age and growth of bigeye tuna in the Atlantic have been carried out by several authors (e.g. Champagnat & Pianet, 1974; Marcille *et al.*, 1978; Gaikov *et al.*, 1980; Weber, 1980; Cayré & Diouf, 1984; Draganik & Pelczarski, 1984; Pereira, 1984; Delgado de Molina and Santana, 1986), but none has yet been carried out for the bigeye tuna captured in the Madeira archipelago. Estimates of age and growth rates are an essential element for fish stock assessment. When estimating these, it is important that differences in average growth of different segments of the population are properly accounted for. The age and growth parameters of bigeye tuna have been earlier estimated for different areas by several authors, using both length-frequency analysis methods and reading of growth rings on fin spines. Some of these studies indicate the existence of a difference in growth patterns between sexes, while others could not prove such differences.

In this work, we used vertebrae from the caudal peduncle of bigeye tuna captured in the region of the Madeira archipelago to obtain estimates of size-at-age and Bertalanffy growth parameters of bigeye tuna captured in this area. We also investigated whether there was evidence of a sexual difference in growth patterns of these fish.

Material and Methods

All the bigeye tuna sampled originated from the commercial pole and line fishery, landed at the port of Funchal, Madeira. Fish were sampled all through the fishing season, which lasted from April to August 1995. Sampling was spread throughout the fishing season, to ensure the greatest possible coverage of the whole range of lengths of tuna captured in this fishery. In each sampling occasion, a random sample of 30 fish, or the total catch, if it was less than 30 fish, was selected. Each of the selected fish was measured (Furcal length) to the nearest cm and the sex was recorded by visual inspection of the genital cord. The first spine of the dorsal fin was removed, using the procedure suggested by Cort (1990). Also the caudal peduncle (vertebrae 33 to 36) were removed, and stored frozen, after appropriate tagging.

A total of 877 fish were sampled. Among these, it was possible to determine the sex of 777, while 100 could not be sexed, due to partial or total removal of the gonads when handling the fish for the market.

Since the amount of biological material was obviously too large for being analysed with the resources available, a subsampling was undertaken. The fish were first grouped into 5 cm length-classes. A random sample of 10 fish was then selected from each length-class. If in a given length-class there were fewer than 10 fish, all the fish in that length-class were selected. The sample used for the ageing work included 241 individuals.

For the purposes of this work, only the vertebrae were used.

In the laboratory, caudal peduncles were thawed, and then boiled for a short period. The flesh was trimmed from around the vertebrae. The 35^{th} vertebra was separated from the others using a knife. The connective tissue and the cone jelly were removed, taking care not to damage the surface of the vertebrae. The vertebrae were then carefully washed in running water, and air-dried before being stored in plastic bags.

Each vertebra was clamped in a vise by the keel, and sawed in half by the saggital (dorso-ventral) plane. The left lateral section was normally used for staining unless it had been damaged by cutting.

Sections were stained using the silver nitrate technique of Stevens (1975). Sections were soaked for 3-10 minutes in a 1% silver nitrate ($AgNO_3$) solution under UV light. The soaking process was carefully monitored, to avoid an excessive darkening of the vertebral sections. The sections were then washed in distilled water, and the staining was fixed by immersing the sections in a 5% solution of sodium tiosulfate for 3 minutes. Finally, the sections were again washed in distilled water, and slightly brushed with xylol, to enhance the contrast between the impregnated calcified rings and the less calcified zones.

Stained vertebrae examined under reflected light in a binocular microscope displayed distinct alternating light and dark rings. Each set of one dark and one light ring was considered to be a distinct growth ring. The vertebral ring count was given by the number of complete growth rings observed. When age-reading, no information on the fish length or sampling date was available to the reader, to avoid biases. After reading, the vertebrae were again stored in the plastic bags. Each vertebra was age-read independently for at least 3 times, giving an interval of at least 2 weeks between consecutive readings, so as to minimise possible remembering. Vertebrae were rejected whenever the three readings provided different ages, or when one of the readings differed from the other two by more than one ring. When two of the readings agreed, and the third differed by one ring only, the vertebral ring-count for that vertebra was taken as the ring-count of the two similar readings.

Ageing was carried out under the assumption that ring counts indicate total relative age (in complete years). To evaluate the reliability of each ageing, the number of readings with the same assigned age for each fish was computed. The precision of the age-reading procedure was evaluated using the percentage of total agreement among readings (percentage of vertebrae for which all three readings provided the same estimated age), the Variation coefficient (CV) (Chang, 1982 and the Index of Average Percent Error APE (Beamish and Fournier, 1981).

The Bertalanffy growth curve was fitted to the length-at-age data by direct non-linear least squares estimation. For estimating the parameters, it was assumed that the fish were captured in the middle of growth marks formation. The relative ages assigned corresponded thus to the ring-count plus 0.5 years.

The null hypothesis that there was no difference between males and females in the estimated Bertalanffy growth curves was tested using the extra-sum-of-squares principle (Draper and Smith 1981, Bates and Watts 1988).

Results

The fork length of the bigeye sampled ranged from 44 to 179 cm, reflecting fully the size range of the bigeye caught in the pole and line fishery of Madeira and Azores archipelagos (Gouveia, 1986; Pereira, 1995). The length range in the sample was approximately the same for both sexes.

Of the 241 vertebrae examined, 5 (2.1%) were rejected, as the readings did not agree.

The precision of the ageing procedure was relatively high (Table I).

As a general trend, and with the exception of age 0, precision decreased with the ring count, although there were some fluctuations for ring counts above 5.

Up to 8 full rings, assumed to be annuli, were visible in the vertebrae sampled. Sample sizes for all relative age classes were greater than 20, except for age 0 and the oldest ages. Excluding relative age-classes 0 and 8, however, all sample sizes were above 10 fish.

The progression of lengths with age-classes was very clear. The overlap in lenghts between consecutive age-classes increased with the age-classes, as expected. Fish following a growth pattern conforming to an asymptotic growth curve, like the Bertalanffy curve, should exhibit a relative growth increment decreasing with age (Ricker, 1975). The pattern observed for bigeye tuna in this study agrees with these theoretical expectations, except for the relatively small increment from age 0 to 1, and the large increment from age 7 to 8. Since ages 0 and 8 were represented by only 6 and 3 fish respectively, however, these calculated increments are clearly unreliable as a representation of the pattern in the population.

Of the 236 fish for which there was age data, 175 were sexed. The von Bertalanffy model was fitted to the data of the fish for which sex was known, separately for each sex and for the sexes combined. (Table III).

The extra-sum-of-squares analysis (Table IV) indicates that our data provide no evidence of a significant difference in growth patterns between sexes. The null hypothesis of no difference in growth patterns between sexes is thus not rejected.

A single growth curve was thus fitted to data on all fish between ages 1 and 7, including the immature and undetermined sex fish (Figure 1).

The Bertalanffy growth parameters estimated are presented in Table V.

Discussion

In this study, the precision of the ageing procedure was relatively high. The percentage of concordance was 67%, with a Coefficient of variation and an average percent error of 5.9% and 4.5%, respectively. Powers (1983), in a Monte Carlo simulation study, concluded that the acceptable limit for error in age estimation of large pelagic fish was 10%. The precision of the ageing in this study was well below this limit, meaning precision can be considered quite good. We could not find other studies of bigeye ageing and growth which used vertebrae for age determination. However, Prince *et al* (1985) obtained an APE of 0.3%-6.3% and a CV of 0.4-7.2%, when reading vertebrae of *Thunnus thynnus*, while Foreman (1996) calculated an average CV of 6.3% in reading the vertebrae of the same species.

The size range of the bigeye tuna used in this work was among the widest of other bigeye tuna growth studies published. This makes its results more reliable than otherwise.

The growth curves estimated from this work agree well with the growth curves estimated earlier by other authors for bigeye tuna (Figure 2).

In our study, no differences in average growth were detected between male and female bigeye tuna. Delgado de Molina and Santana (1986) did not detect significant differences in growth of males and females. Shomura and Keala (1963) and Kume and Joseph (1966), however, refer that pacific bigeye tuna males grow faster than females, after 3 years and 150 cm FL respectively. This discrepancy may be the result of differences in the behaviour of different sub-stocks, which are likely to be enhanced in small samples, or a sampling effect.

The ageing procedure used in this study was not strictly validated (Beamish and McFarlane, 1983). The length-at-age and the growth parameters estimated must thus be treated with some caution. However, the growth curves estimated are very similar to the same curves estimated for Atlantic bigeye tuna by other authors, using other hard parts and even length-frequency analyses (Fig. 2). This correspondence gives at least a semi-quantitative appreciation that the method used is reliable, and reinforces the confidence on our findings. They also indicate that it is possible to obtain reasonably reliable estimates of growth curves for bigeye tuna using vertebrae. The difficulty associated with these studies, however, is the collection of the hard parts. In the case of this study, it was possible to collect the caudal peduncle as the fish were prepared for sale. In many cases, however, removal of the caudal peduncle may well reduce the market value of the fish, and this may well be impracticable. It may thus be of interest to evaluate the possibility of achieving equally good results using other structures (e.g. spines) whose removal will not affect the market value of the fish, and which may thus be routinely colleted.

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Table I. Precision of the ageing procedure, by classes of ring-counts. APE – Average percent Error; CV –Coefficient of Variation

Ring count	Sample Size	% Concordance	APE	CV
0	6	66.667	44.44	57.74
1	35	100.00	0.00	0.00
2	54	94.44	1.48	1.92
3	42	78.57	3.41	4.43
4	28	71.43	3.46	4.50
5	40	22.50	7.32	9.51
6	15	46.67	4.66	6.06
7	13	15.38	5.64	7.33
8	3	0.00	7.91	10.27
Total	236	68.22	4.44	5.76

Table II. Summary statistics on the size-distributions of bigeye tuna aged from vertebral ring-counts.

Ring Count	Sample Size	Range (FL, cm)	Mean FL (cm)	SD (cm)	CV (%)	Mean FL Increment (cm)
0	6	44-54	51.8	3.87	7.46	----
1	35	53-69	60.6	4.47	7.38	8.8
2	54	68-	82.6	7.57	9.16	22.0
3	42	94-114	104.5	5.74	5.49	21.9
4	28	115-139	121.9	5.84	4.79	17.4
5	40	126-155	139.1	6.79	4.88	17.2
6	15	140-162	154.9	6.00	3.87	15.8
7	13	147-173	161.2	7.58	4.70	6.3
8	3	165-179	173.7	7.57	4.36	12.5

Table III – Parameters of the Bertalanffy growth equation estimated for each sex, and for the sexes together (only for the fish which could be sexed)

Sex	Sample size	L_8 (cm)	K	t_0
Females	62	245.08	0.13	-0.69
Males	113	267.32	0.12	-0.61
All	175	264.02	0.12	-0.68

Table IV. Extra-Sum-of-Squares Analysis Table comparing the fit of the model with a separate growth curve for each sex to the model of a single growth curve for both sexes.

Model	SS	df	MS	F	p
Extra	104.37	3	34.79	0.8201	>0.1
Full model (separate growth curves)	7169.30	169	42.42		
Single growth curve	7273.67	1·72			

Table V. Bertalanffy growth parameters estimated for the whole data-set of bigeye tuna aged 1 to 7 years.

Sample size	L_8 (cm)	K (y^{-1})	t_0 (y)
227	247.29	0.14	-0.54

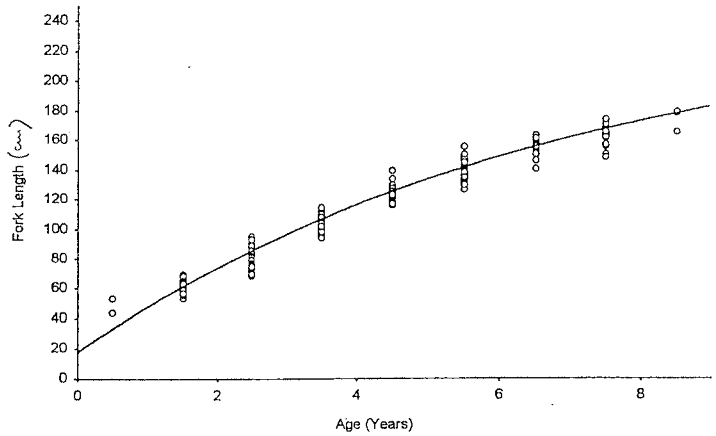

Figure 1. Observed bigeye tuna fork lengths (cm) versus relative age (years). The Bertalanffy curve fitted to the data on age-classes 1-7 is represented by the solid line.

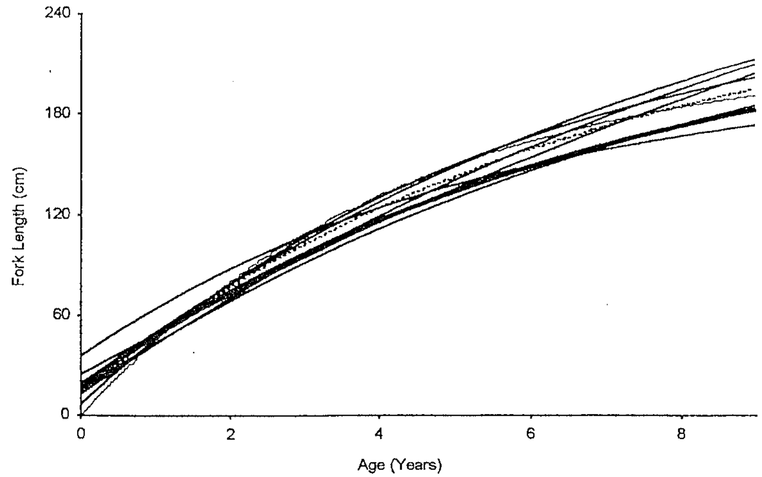

Figure 2. Comparison of the growth curve for bigeye tuna estimated in this work (heavy line) with the growth curves estimated by other authors. Studies included: Champagnat & Pianet 1974; Marcille *et al.* 1978; Weber (1980); Pereira (1984); Gaikov *et al.* 1980; Draganick & Pelczarski 1984; Cayré & Diouf 1984; Delgado de Molina & Santana 1986.