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PILOT STUDY OF BLUEFIN TUNA AGE VALIDATION

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SUMMARY

A preliminary investigation of the utility of using deposition of bomb radiocarbon as a dated mark to validate inferences of ages of bluefin tuna was completed. Using archived samples obtained from St. Margaret's Bay, Nova Scotia in 1976, it is shown that the actual ages of the samples were likely considerably older than predicted by the age-length relationship currently in use by the SCRS. The implications of this possible over-estimation of the $L_{infinity}$ term of the growth equation on population productivity and resilience requires investigation.

RÉSUMÉ

Une recherche préliminaire portant sur l'utilité de l'utilisation de dépôt de carbone radioactif produit par les essais nucléaires comme marqueur de date a été menée pour valider les conclusions tirées sur l'âge du thon rouge. L'utilisation des échantillons archivés obtenus de St. Margaret's Bay, Nouvelle Ecosse, en 1976, a permis de montrer que les âges réels des échantillons étaient probablement plus avancés que ce qui avait été prévu d'après le rapport âge-taille actuellement utilisé par le SCRS. Les implications de cette possible surestimation du terme $L_{infinity}$ de l'équation de croissance sur la productivité et la résistance de la population nécessitent de nouvelles recherches dans ce sens.

RESUMEN

Se ha terminado una investigación preliminar sobre la utilidad de usar señales de las bombas de radiocarbono como marcador de datación para validar deducciones sobre edades de atún rojo. Utilizando muestras archivadas obtenidas en la Bahía de Santa Margarita, Nueva Escocia, en 1976, se muestra que las edades reales de las muestras eran probablemente mucho mayores que las predichas por la relación edad-talla que utiliza actualmente el SCRS. Las implicaciones de esta posible sobreestimación del término $L_{infinity}$ de la ecuación de crecimiento sobre la productividad y elasticidad de la población requieren más investigaciones.

KEYWORDS

Otoliths, age determination, growth curves, longevity, validation

1. Introduction

Bluefin tuna (*Thunnus thynnus*) ages in the western Atlantic stock are currently assigned by empirical length modal separation for ages 1-3, then through application of a length-age relationship (Anon. 2003). The growth model that informs the slicing is that of Turner and Restrepo (1994), who used mark and recapture information to provide a description of the relationship between length and age, following the von Bertalanffy growth equation.

Recent discussions within the SCRS have recognized that there is a need for additional investigations of the growth of bluefin tuna, given that the information upon the Turner and Restrepo investigation is now somewhat dated, and there is a possibility that growth patterns observed in the past may no longer reflect the contemporary

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situation. As a precursor to detailed investigations of age and growth of bluefin tuna using direct ageing approaches, it was considered important to develop an approach to validate inferences of growth obtained from examination of hard parts.

Among techniques for age validation for long-lived marine fish, the use of bomb radiocarbon as a dated marker is considered among the most accurate approaches available (Campana 1999). The premise of the approach is that atmospheric testing of nuclear weapons during the period 1958 to 1965 resulted in rapid increases in the concentration of ^{14}C in the world's oceans. The general trend observed in the literature has been that hard parts of living organisms began to accumulate radiocarbon at similar rates during this period (Kalish 1993; Campana 1997). Comparison of radiocarbon concentrations near the core of otoliths can then be compared to reference material of known age or date of formation as a means of validation. This approach has been used as part of the validation of ages from otoliths of the congener *Thunnus macoyii*, and has contributed to a realization that the longevity and age at maturity was considerably older than previously thought (N. Clear, CSIRO, pers. comm.).

A prerequisite to a study of this nature is that otoliths from fish thought to be born in the years during or close to the period of atmospheric testing be available. Canada is in the position of holding extensive collections of archived otoliths collected from the 1970s to the 1980s, thus having the necessary biological samples. Recognizing that the analytical costs are expensive (about $1000.00/sample), we elected to undertake a pilot study to establish the technical feasibility of the approach. The results of the preliminary study are reported here.

2. Methods

Bluefin tuna sagittal otoliths were collected from archived material stored at the St. Andrews Biological Station. Material selected for the pilot study was collected in 1976 from St. Margaret's Bay, Nova Scotia **(Table 1)**. The material was stored dry in coin envelopes, and details of the sampling operations were available from an electronic database.

Otoliths to be aged were first embedded in a slow-drying hard epoxy (Araldite epoxy GY502 and hardener HY956 in a 5:1 weight ratio). Otolith cores for bomb radiocarbon age validation were isolated from three adjacent transverse sections of the sagittae: a 1.2-mm central section through the core intended for micro-milling and ~ 450 µm thick sections on either side for age determination. All sections were prepared with a single cut using multiple blades separated by spacers on an Isomet low-speed diamond-bladed saw. Sections were lightly polished to improve visibility of the growth sequence, and then digitally photographed at 1280 x 1024 pixel resolution while under a binocular microscope at 16-40X magnification using reflected light. Age interpretation was based on digitally enhanced images, and counts were made along the longer of the two arms of the sectioned sagittae **(Figure 1)**. The electronic images were also supplied to two experts familiar with age determination using otoliths of bluefin tuna at a recent workshop concerned with direct age determination techniques for this species held in Santander, April 3-7, 2006.

Otolith cores representing the first 2-3 years of life were isolated as solid pieces from one or both thick sections with a Merchantek computer-controlled micromilling machine using 300-µm diameter steel cutting bits and burrs. Cores from both sections were sometimes required to bring the sample weight up to the minimum of 3 mg necessary for radiocarbon assay. The date of sample formation was calculated as the year of fish collection minus one half the number of growth increments extracted in the core. After sonification in Super Q water and drying, the sample was weighed to the nearest 0.1 mg in preparation for ^{14}C assay with accelerator mass spectrometry (AMS). AMS assays also provided $\delta^{13}C$ ($^{0}/_{00}$) values, which were used to correct for isotopic fractionation effects and provide information on the source of the carbon. Radiocarbon values were subsequently reported as $\Delta^{14}C$, which is the per mil ($^{0}/_{00}$) deviation of the sample from the radiocarbon concentration of 19th-century wood, corrected for sample decay prior to 1950 according to methods outlined by Stuiver & Polach (1977). The mean standard deviation of the individual radiocarbon assays was about $5^{0}/_{00}$.

To assign dates of core deposition for the bluefin tuna otoliths, we compared the tuna $\Delta^{14}C$ data to a $\Delta^{14}C$ chronology based on known-age material (a reference chronology) for the northwest Atlantic derived from known-age fish otoliths formed between 1949-2000 (Campana et al. 2006). The $\Delta^{14}C$ chronology of fish otoliths in the NW Atlantic parallels that of North Atlantic corals and bivalves (Campana 1997) so it is a good proxy for the $\Delta^{14}C$ DIC history of the tuna environment.

3. Results and discussion

An example transverse section is shown in **Figure 1**, and demonstrates the periodic banding that we assumed to represent annuli. In our experience, these bands were relatively straightforward to identify and count for this species.

The results of the radiocarbon assays are shown in **Figure 2**, in comparison with the reference chronology for the Northwest Atlantic. All five otoliths cores have concentrations of radiocarbon that appear to be associated with the period before atmospheric testing of atomic weapons. This implies that the cores of the otoliths were formed before 1958. This observation is consistent with age estimates obtained from inspection of presumed annuli **(Table 1)**.

This study with a small sample size does not constitute a validation of the otolith approach for age determination of bluefin tuna, but the radiocarbon assays do indicate that the fish must have been at least 19-20 years old at the time of their collection in 1976, consistent with our estimates of age from inspection of presumed annuli presented in **Table 1**. By comparison, the predicted ages from the age-length relationship ranged from 15-17 years old for the fish in our sample **(Figure 3)**.

The results of our investigation, though limited by sample size, suggest that the growth model used by the SCRS may be overestimating the $L_{infinity}$ of the function describing growth of bluefin tuna **(Figure 3)**. If this conclusion is correct, further investigations are required to determine possible impacts on calculations of population productivity and resilience implied by this result. Finally, our next step is to increase the sample size used in this validation study, and to include the period of rapid increase in radiocarbon by including younger fish in the investigation.

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Table 1. Summary of samples used in the bomb radiocarbon pilot study, and the ages obtained by the three age readers.

Sample	*Fish #*	*Sample Location*	*Year collected*	*Fork Length (cm)*	*Round Wt. (kgs)*	*Sex*	*Age (SC)*	*Age (NC)*	*Age (PM)*
13872	301	St. Margaret's Bay	1976	284	405	M	33	23	24
13873	353	St. Margaret's Bay	1976	273	492	M	32	25	26
13871	359	St. Margaret's Bay	1976	271	446	M	28	23	23
13874	404	St. Margaret's Bay	1976	271	428	M	25	26	29
13875	439	St. Margaret's Bay	1976	270	404	M	29	27	29

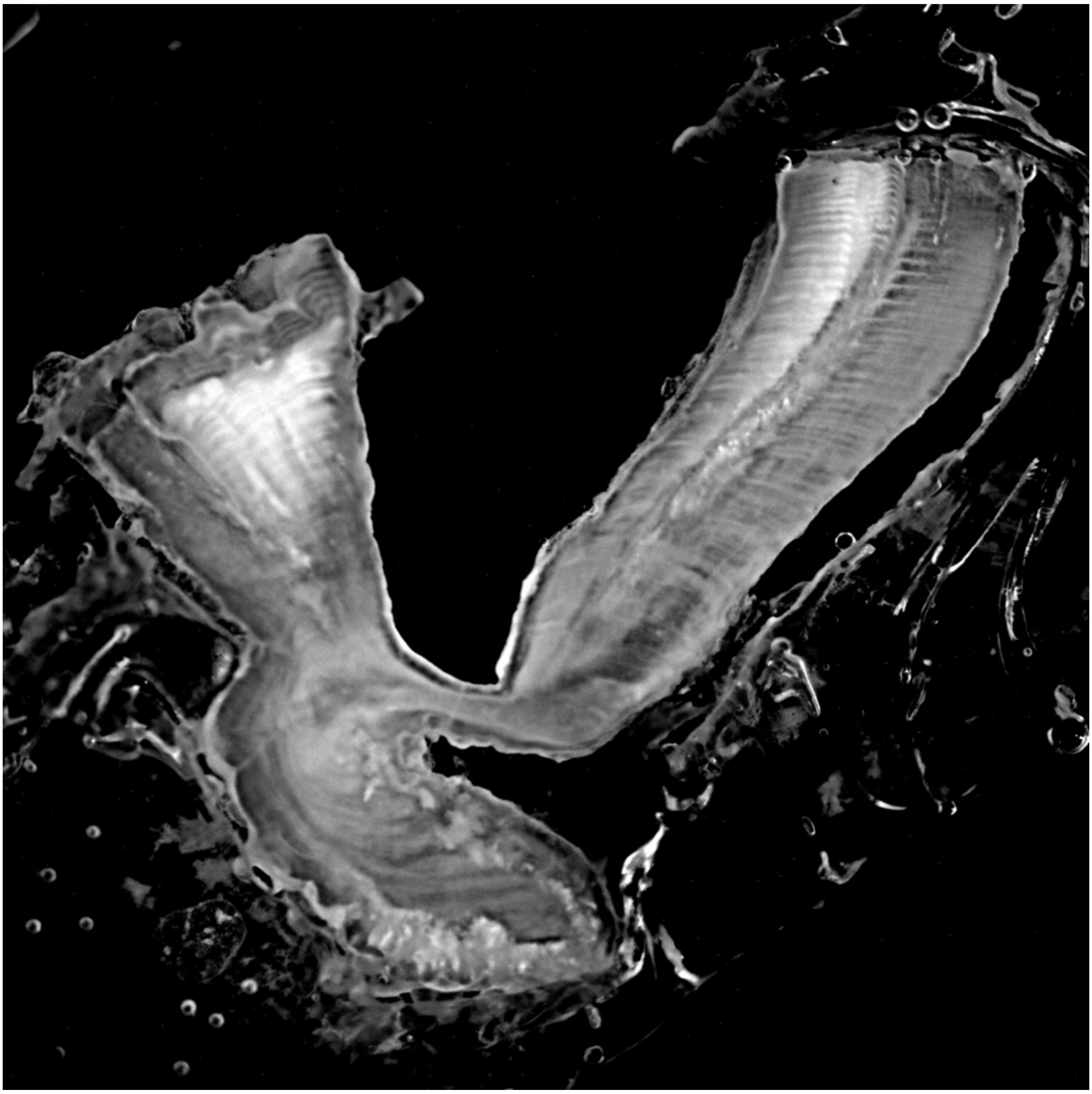

Figure 1. Polished cross section sagittal otolith of sample #439, aged as 29 years old. The specimen was photographed using reflected light, and the digital image was modified to enhance contrast.

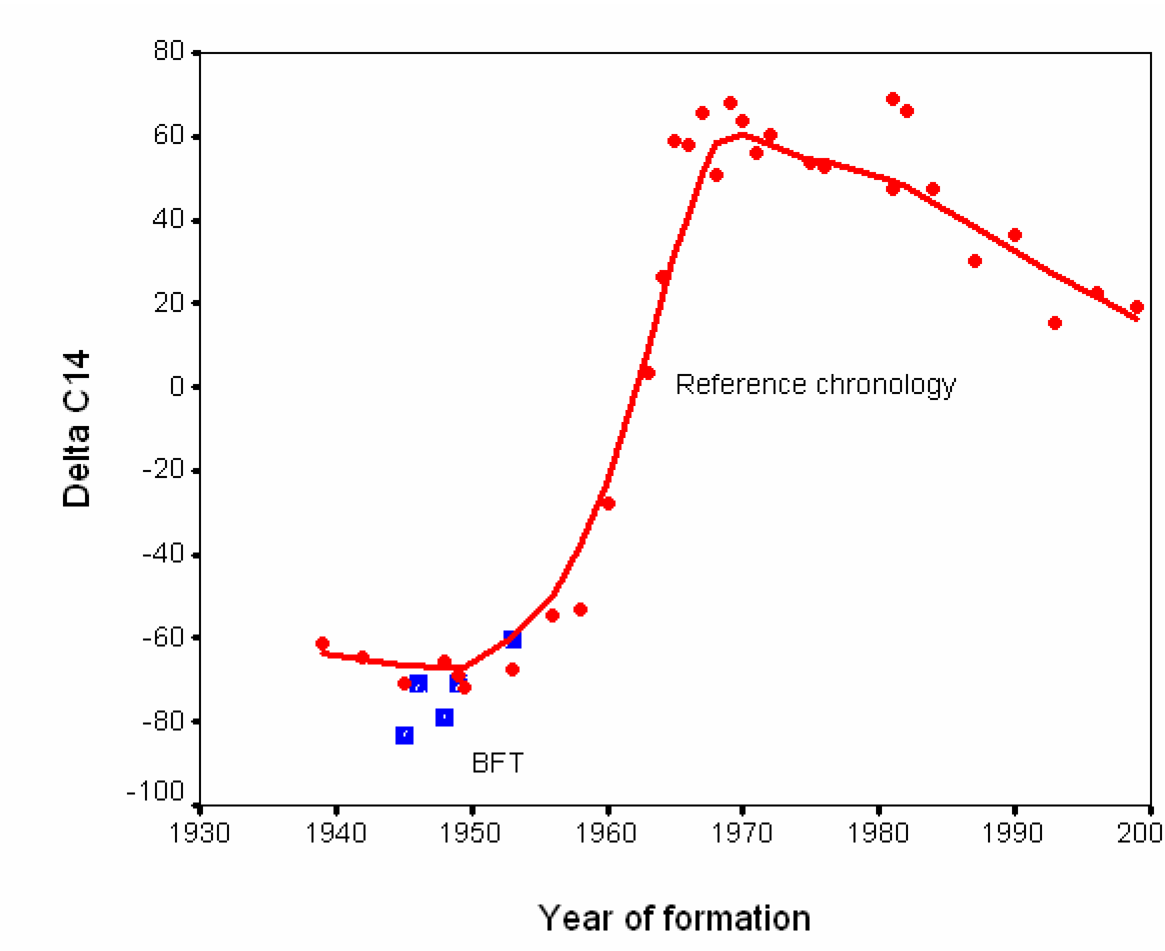

Figure 2. $\Delta^{14}C$ in otolith cores of bluefin tuna versus year of formation inferred from counts of the growth increments. The $\Delta^{14}C$ chronology of the cores (blue squares) was similar to that of a reference carbonate chronology (lines smoothed with a loess curve), with the crucial feature being the period of rapid increase.

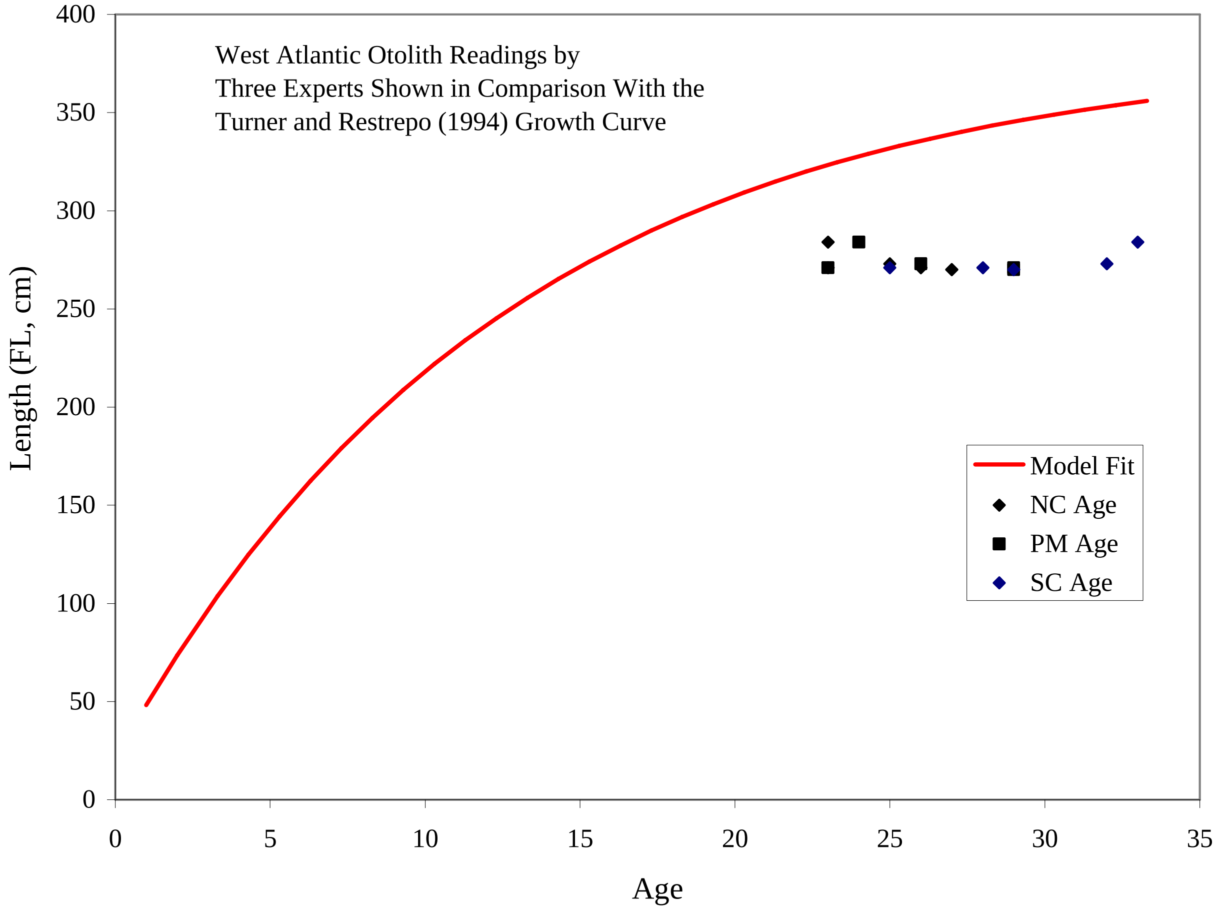

Figure 3. Predicted relationship between length and age, from Turner and Restrepo (1994). The parameters of the von Bertalanffy fit were L_{inf} = 382 cm, t_0= -0.707, and K = 0.079. The estimated ages from the five fish obtained by the three age readers are shown for comparison.