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Updating age and growth parameters for South Pacific albacore (Project 106)

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Executive summary

Uncertainty in the accuracy of growth parameters for South Pacific albacore tuna led to uncertainty in the 2018 stock assessment. Inconsistencies were found between the otolith age-at-length estimates from Williams et al. (2012) and modes in the catch-at-size data for the New Zealand troll fishery.

Here we used a combination of daily and annual ageing methods to improve age estimates for South Pacific albacore, focusing on the New Zealand troll fishery, for input into the 2021 stock assessment. We estimated the daily age of 60 small fish from the New Zealand fishery to determine length-at-age and the relationship between otolith size and daily age. We also re-analysed otoliths from Farley et al. (2013) and applied a new age algorithm to obtain updated decimal age estimates for albacore.

The results of the growth analysis on the daily and annual age data show that:

1) Growth is similar between sexes up until 4-5 years, after which the length-at-age is greater on average for males than for females.
2) For both sexes, length-at-age is slightly greater for eastern longitudes versus western longitudes.
3) For fish in the west, growth is similar between north, central and southern latitudes.

In addition, the mean ages of albacore caught in the three smallest length modes (43-55, 56-64 and 65-74 cm FL) in the New Zealand troll fishery were 1.1, 1.9 and 2.9 years, which are consistent with the length modes being annual. Furthermore, growth analysis, specifically focused on the New Zealand region, predicted the length of albacore at age 1, 2 and 3 years to be 50.3, 61.9 and 72.4 cm FL respectively, which is consistent with the modes observed in the New Zealand length data. These results appear to resolve the inconsistency found between the otolith age-at-length estimates in the 2018 stock assessment and the length modes observed in the New Zealand troll fishery, supporting the use of the new age algorithm to estimate decimal age of South Pacific albacore.

Background

The South Pacific albacore stock assessment is being conducted in 2021. One area of uncertainty in previous assessments was the age of albacore, particularly understanding differences found in age-at-length estimates when compared to modes in the catch-at-size data for the troll fishery (Tremblay-Boyer et al. 2018). The smallest three length modes in the troll fishery are separated by ~10 cm, while the logistic growth curve for all South Pacific albacore combined indicates ~20 cm growth per year in the youngest age classes (Williams et al. 2012). The difference is less when restricting the data to fish caught in southern latitudes, however, there were still inconsistencies that needed to be examined before the next stock assessment.

The aim of this project was to determine if the age and growth information for albacore caught in New Zealand could be improved by applying a new method to estimate decimal age from annual increment counts. Farley et al. (2020) recently developed an improved method to convert increment counts into annual decimal age for western Pacific bigeye and yellowfin tuna using a combination of opaque zone counts, daily ageing of young of the year (YOY) samples and otolith measurements. This method negates the use of a single assumed birth date for all fish and a uniform increment formation period and may provide a more accurate conversion of zone counts to age estimates.

Objectives

To further improve age estimates for South Pacific albacore, focusing on the New Zealand troll fishery, for input into the 2021 stock assessment.

1) Prepare and read available albacore otoliths marked with oxytetracycline (OTC) to determine if increments formed annually (frontal sections, max 4 otoliths).
2) Prepare frontal sections of 60 otoliths collected from the New Zealand troll fishery and estimate daily age. Analysis was restricted to a maximum fish size (60 cm) that we recommend that daily age can be reliably obtained.
3) Determine the relationship between otolith size and daily age in young fish.
4) Mark and measure the (annual) opaque zones in up to 600 transversely sectioned otoliths to determine the mean width of each annulus.
5) Use the new age algorithm from Farley et al. (2020) to estimate decimal age of all the albacore examined.
6) Compare the new decimal age of albacore in the NZ troll fishery with the modes in the length frequency to determine if any inconsistency remains.

Results against objectives

OTC marked otoliths

Three OTC marked otoliths were analysed by Farley et al. (2013). The results supported the hypothesis of annual formation of opaque zones in albacore between 61 and 82 cm FL. One additional OTC marked otolith was obtained after the above analysis was complete. The fish was released on 18 March 2009 and recaptured on 6 August 2014, so at liberty for 1980 days, or 5 years and 5 months. The amount of growth after the OTC injection (Figure 1) is also consistent with the expected otoliths growth if the opaque zones form annually. No additional OTC-marked otoliths have been recaptured.

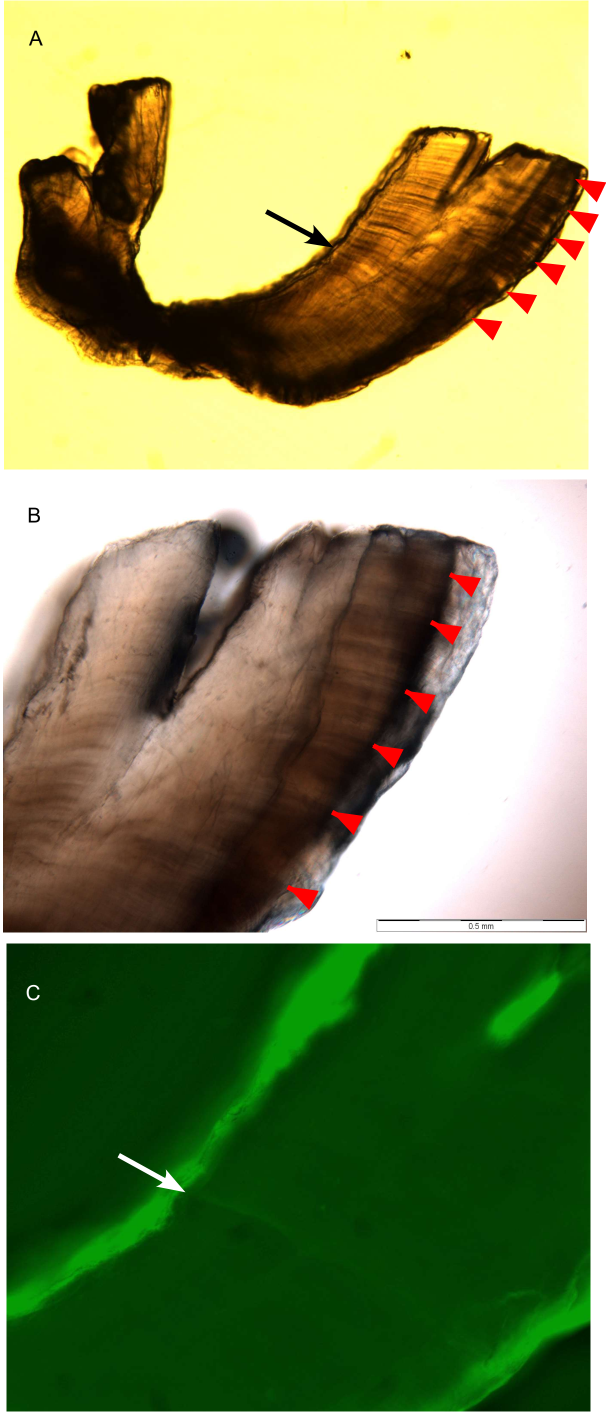


Figure 1. Transverse sections of albacore otoliths injected with oxytetracycline (OTC) showing the location of the distal edges of the opaque zones in A and B (red arrows). The OTC mark is visible under ultraviolet light (C) and is located adjacent to the first marked opaque zone (black arrow in A). Five subsequent opaque zone are indicated before the fish was captured.

Daily ageing

Otoliths from 60 albacore were selected for daily ageing. All fish were from the New Zealand troll fishery and they ranged from 43 to 57 cm fork length (FL) (age ~1). All otoliths were sent to Fish Ageing Services (FAS) for sectioning and reading. The otoliths were weighed to the nearest 0.1 mg if undamaged and longitudinal sections were prepared following the methods outlined in Williams et al. (2012). The number of visible microincrements were counted from the primordium to the terminal edge of the section under high magnification on a compound microscope. Two outliers were removed based on their unusual otolith weight to length relationship. Age estimates ranged from 235 days (43 cm FL) to 451 days (54 cm FL) (Figure 2). The daily age data was included in the growth analysis (section 4.5.2).

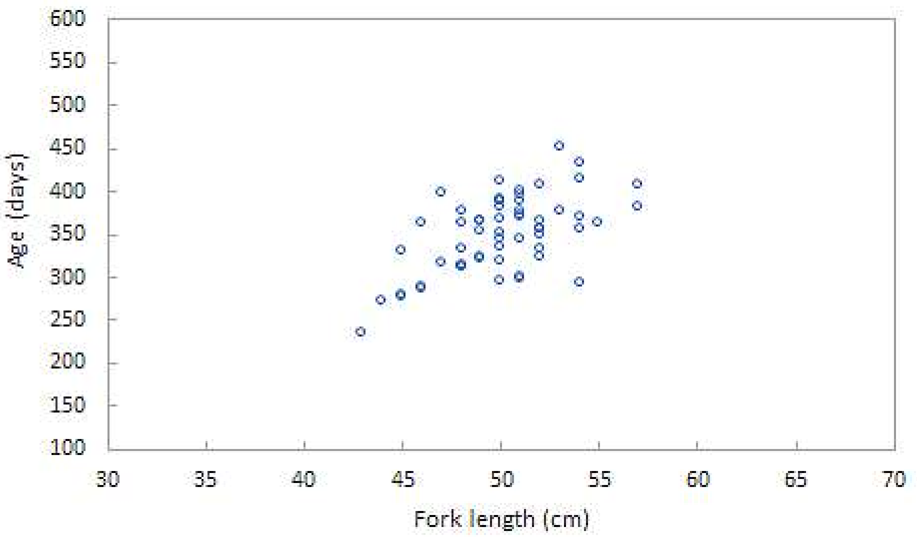


Figure 2. Relationship between fish length (cm) and counts of assumed daily increments from longitudinally sectioned otoliths.

Relationship between otolith size and daily age

The sister otolith was available for 43 of the 60 otoliths prepared for daily ageing (above). Transverse sections were prepared following the methods outlined in Williams et al. (2012) and the distance from the primordium to the edge in the "inner" side (sulcus acusticus) of the otolith was made. Using this measurement, and the corresponding daily age estimated above, we plotted the relationship between otolith size and daily age (Figure 3). Unfortunately, there are no data available for fish <235 days old as very few albacore <45 cm FL are caught in New Zealand or elsewhere. Therefore, we were unable to obtain a power curve of the form y = a*x^b, where y = daily age and x = otolith size, based solely on the albacore data for use in the age algorithm. Instead, we used the power parameter, *b*, from the relationship between otolith size and daily age for yellowfin tuna (*b* =1.87; see Farley et al. 2020) and estimated the remaining parameter to be *a* = 347 (Figure 3). The power curve estimated for albacore was used in the age algorithm to estimate decimal ages from annual counts (see section 4.5).

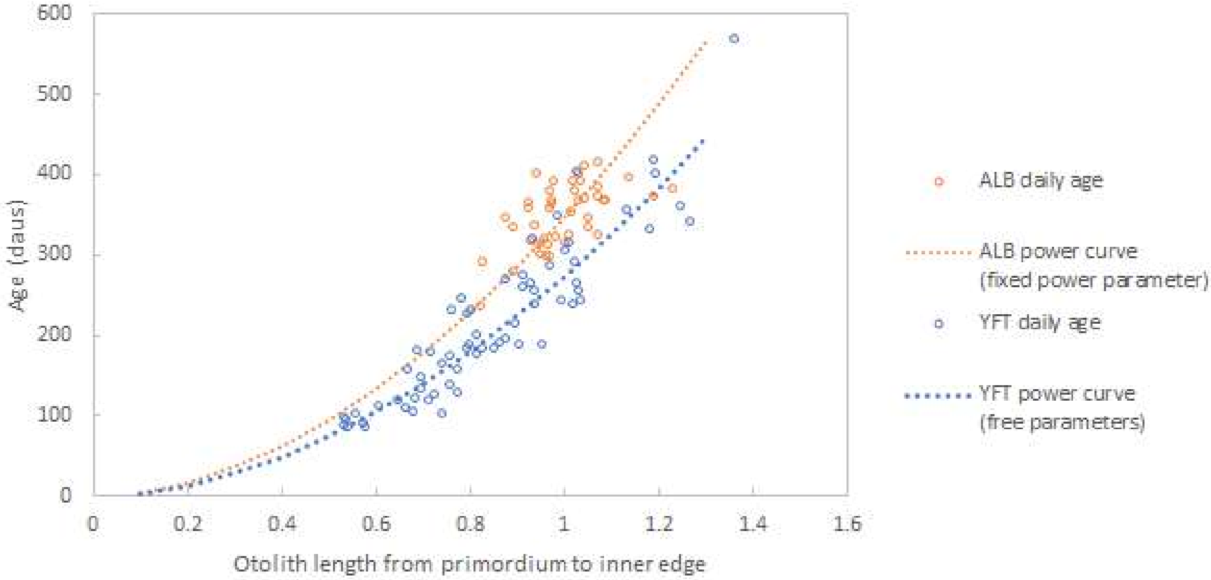


Figure 3. Relationship between daily age vs otolith size with fitted power curve for (i) yellowfin tuna from Farley et al. (2020) and (ii) albacore using a fixed power parameter from yellowfin tuna. Otolith size is the distance from the primordium to the edge in sectioned otoliths.

Annual ageing

A total of 600 sectioned otoliths were initially selected from Farley et al. (2013) for re-analysis. All otoliths from fish caught in New Zealand were selected (n = 132) and the remaining samples selected were those with a high (4 or 5) readability score from other regions. Two additional otoliths were read (by accident) during the reading process, and as the otoliths were classified as with a high readability, the readings were retained and included in the analysis. An additional four otoliths from large fish with clear increments were selected to increase the number of age estimates available for analysis. Fish ranged in size from 43 to 115 cm FL.

For calibration purposes, a reference set of annotated images of sectioned otoliths was prepared and discussed prior to the otoliths being read. The first 30 otoliths read by FAS were subsequently examined by CSIRO to ensure reading protocols were consistent. Each otolith was then read once by two experienced readers (FAS and CSIRO), apart from the additional four otoliths from large fish that were only ready by one reader (CSIRO). Opaque zones were counted along a transect that ran from the first inflection point on the otolith to the edge of the otolith. An opaque zone on the margin was only counted if it was fully formed (i.e. translucent otolith material could be observed between the last opaque zone and the otolith margin). The average percent error (Beamish and Fournier 1981) between readers was 5.01%, indicating a good level of precision. Percent agreement in counts was 64.8%, and when counts differed, 31.6% were only by +/- 1 (Figure 4). When counts differed, the FAS count was used for all fish except 6 where obvious error in the FAS counts were detected and the CSIRO count were used.

The distance between the first inflection point (apex) and the distal edge of each opaque zone, and to the edge of the otolith was measured on the ‘outer’ side of the otolith section (see Appendix Figure 1). In addition, the distance between the primordium to the distal edge of the first opaque zone was measured on the ‘inner’ side of the otolith (see Appendix Figure 1).

The mean distance on the otolith section from the primordium to the terminal edge of the first opaque zone (inner side measurement) was 0.85 mm, which is estimated at age of 256 days based on the otolith size to age relationship for albacore in Figure 3. The mean width of each annulus (annual increment; 1 year of otolith growth) is shown in Figure 5.

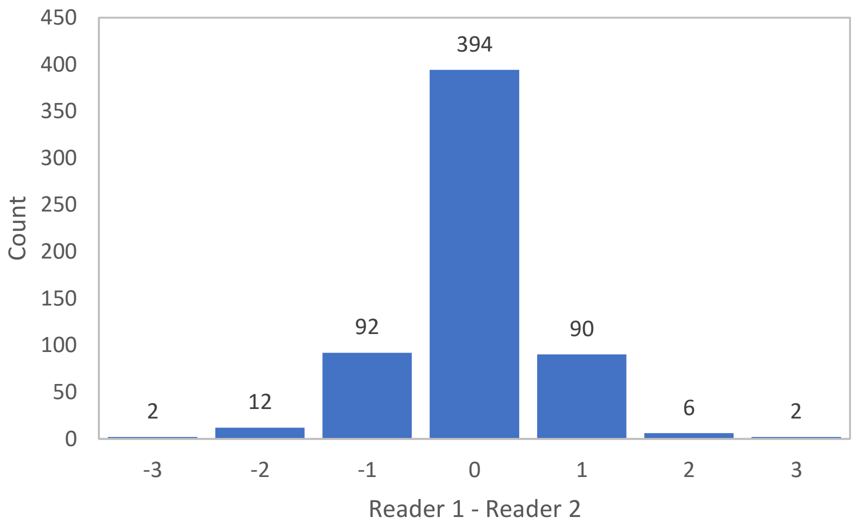


Figure 4. Age bias plot comparing counts by two experienced readers. Sample sizes are indicated.

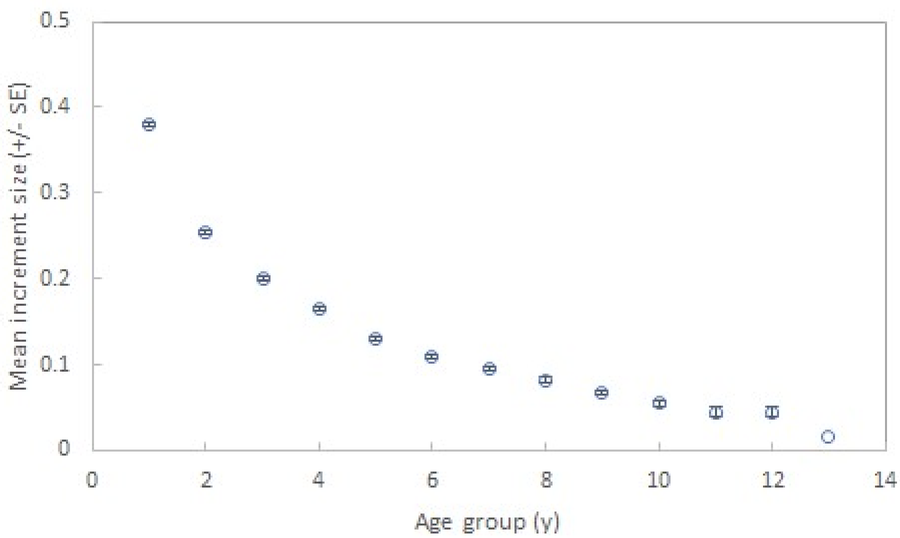


Figure 5. Mean (+/- SE) annual increment width in millimetres by age class for albacore tuna.

Decimal age calculation

Decimal age was calculated for each fish using three steps following Farley et al. (2020):

Step 1: Use the relationship between daily age and otolith size for albacore from section 4.3 (Figure 3) to estimate the age of each fish when the first opaque zone was completed in the transverse section.

Step 2: Calculate the number of complete annual increments in the otolith. A complete annual increment is one opaque zone + one translucent zone, which represents one year of growth, and is calculated as the total count of opaque zones minus 1.

Step 3: Estimate the time elapsed after the last counted opaque zone was deposited and when the fish was caught. This was calculated using the size of the marginal increment as a proportion of the mean size of the complete annulus for that age group (from Figure 5).

Total age was estimated by adding together the age components estimated in each step. Appendix Figure 2 illustrates the steps involved using an otolith with four completed opaque zones as an example. A decimal age was obtained for 602 of the 606 otoliths read. The other four considered unreadable/too difficult to read with confidence. Four fish had both daily and annual ages available; the daily age was included in the growth analysis.

Growth analysis

Figure 6 shows the sampling locations of albacore with an age estimate included in the growth analysis (decimal annual ages and daily ages). Logistic, von Bertalanffy (VB) and Richards growth models were fit to the age and length data for males and females separately, noting that fish <55 cm FL (assumed to be immature) were included in the models for both sexes. The models were fit using maximum likelihood assuming a Normal(0, σ^2) error distribution According to AIC, the logistic curve, L(a)=Linf*(1+exp(-k(a-a0)))^(-1), gave the best fit to both sexes (Figure 7). Note that the a0 parameter in the logistic curve is age of inflection in growth, not theoretical age at length 0 as in the VB curve.

East-west differences in growth were investigated by fitting separate (sex-specific) models to the data from three longitudinal bands (<170°E plus New Zealand, 170-210°E, >210°E) (Figure 8). In fitting the logistic growth model to these longitudinal bands, we fixed the a0 parameter for the central and eastern bands at the value estimated for the western band since only the western band has data for young fish.

North-south differences in growth within the western Pacific (<170°E plus New Zealand) were investigated by fitting separate models to the (combined sex) data from three latitudinal bands (10-25°S, 25-35°S, 35-45°S) (Figure 9). The growth curve for the 'southern' region is essentially the same as a New Zealand-only growth curve, as only 17 additional points were available in the south from around Australia. It was necessary to fix the a0 parameter for the north and central latitudinal bands at the value estimated for the southern band since only the southern band has data for young fish.

The results of the growth analysis indicate that:

1) Growth is similar between sexes up until 4-5 years, after which the length-at-age is greater on average for males than for females.
2) For both sexes, length-at-age is slightly greater for eastern longitudes versus western longitudes.
3) For fish in the west, growth is similar between north, central and southern latitudes.

These results are consistent with those of Williams et al. (2012), although the growth parameters differ slightly.

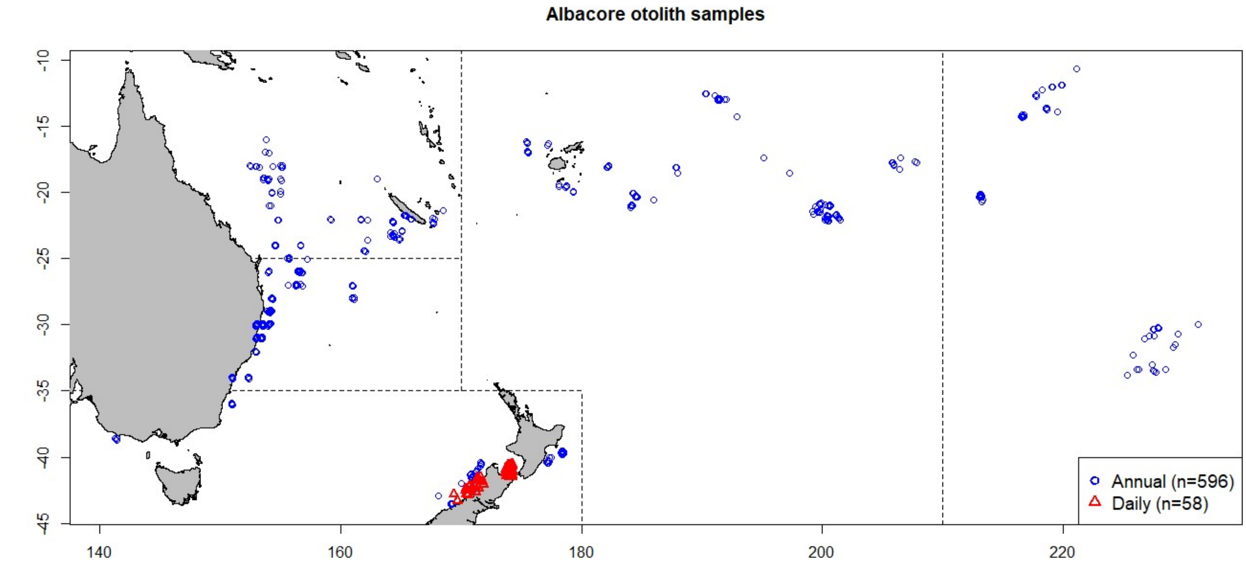


Figure 6. Map showing sample locations of fish used in the growth models. Points have been jittered slightly to give a better indication of sample size since many were collected at the same location.

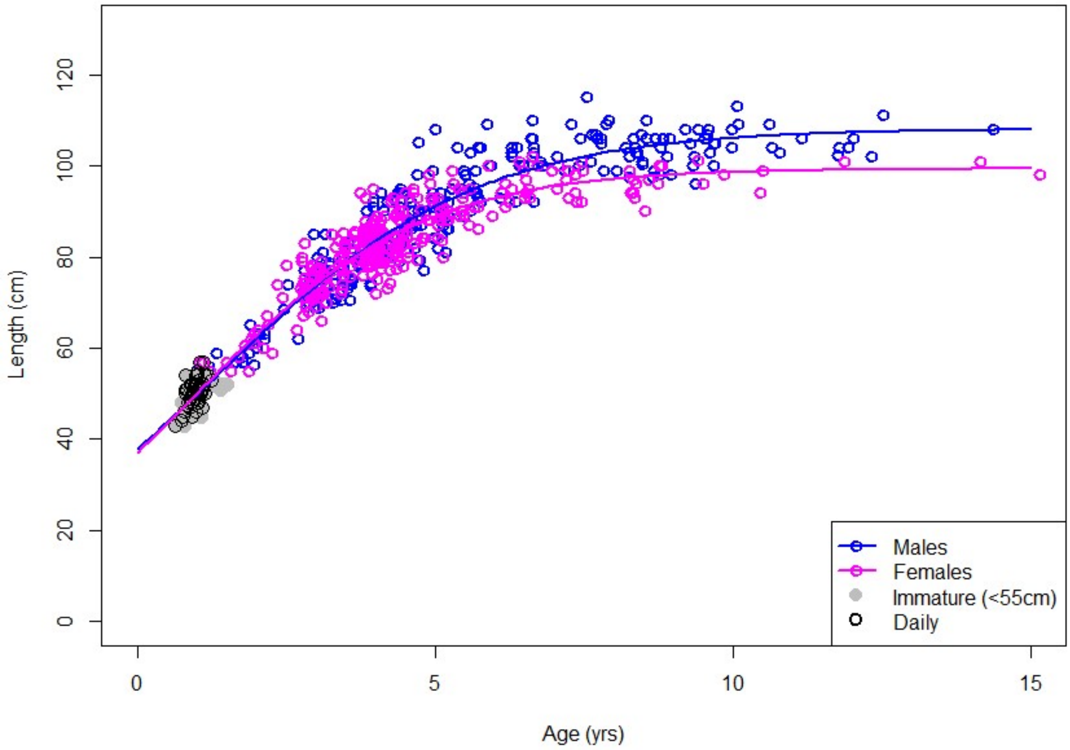
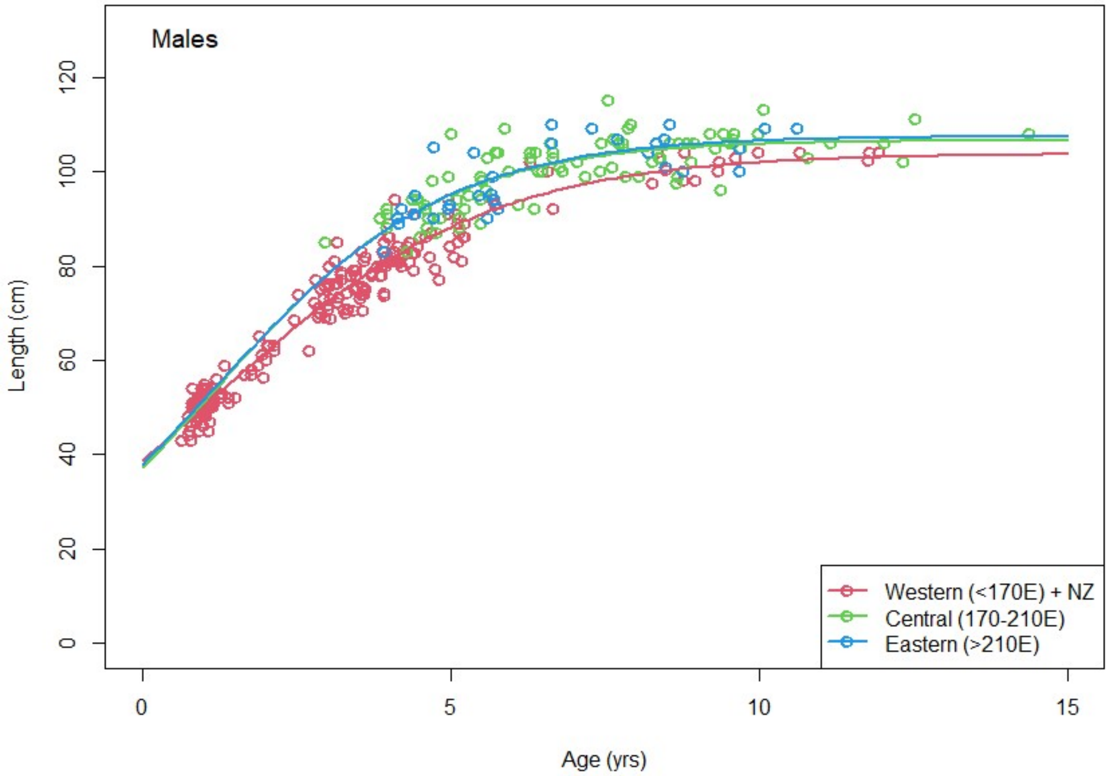


Figure 7. Sex-specific growth curves for all areas combined using a logistic growth model.
Males: Linf=108.13, k=0.46, a0=1.34, sigma=4.39. Females: Linf=99.43, k=0.53, a0=0.97, sigma=3.89.



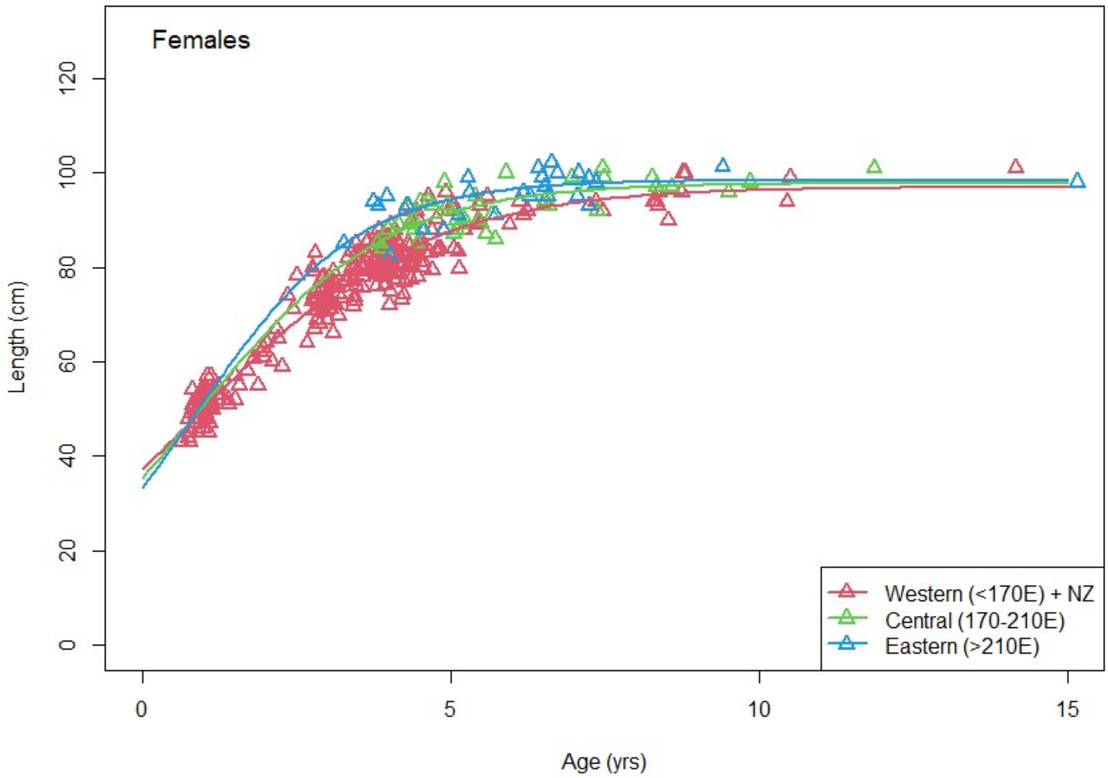


Figure 8. Sex-specific growth curves for western, central and eastern regions using a logistic growth model, and fixing the a0 parameter for the central and eastern regions at the value for the western region since they have no young fish. Males, Western: Linf=103.85, k=0.45, a0=1.15, sigma=3.34, Males, Central: Linf=106.68, k=0.55, a0=1.15, sigma=4.49; Males, Eastern: Linf=107.52, k=0.53, a0=1.15, sigma=4.57, Females, Western: Linf=96.98, k=0.54, a0=0.87, sigma=3.56, Females, Central: Linf=97.83, k=0.65, a0=0.87, sigma=3.29, Females, Eastern: Linf=98.43, k=0.76, a0=0.87, sigma=3.61

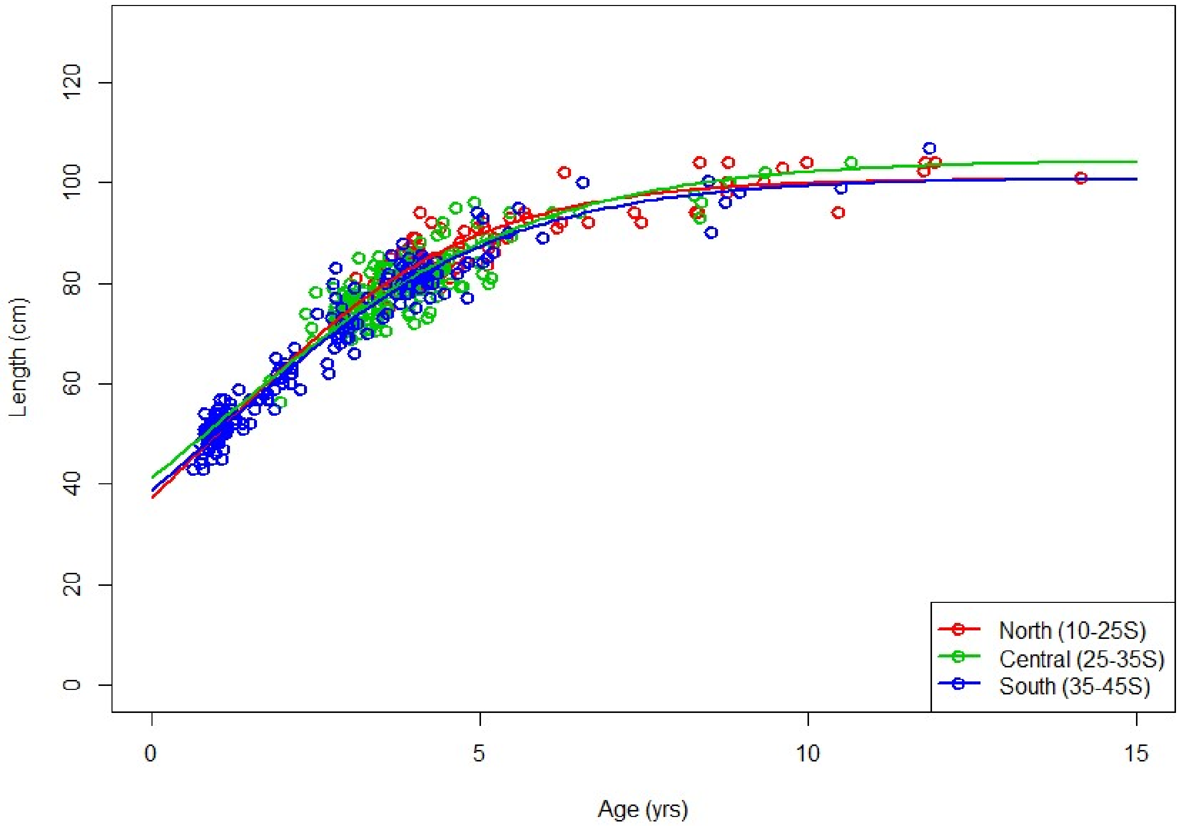


Figure 9. Combined-sex growth curves for the western Pacific (WP, <170°E plus New Zealand) for north, central and southern regions using a logistic growth model, and fixing the a0 parameter for the north and central regions at the value for the southern region since they have no young fish. WP, North: Linf=100.76, k=0.53, a0=1.01, sigma=3.62, WP, Central: Linf=104.43, k=0.42, a0=1.01, sigma=3.99, WP, South: Linf=100.85, k=0.47, a0=1.01, sigma=3.32.

Comparing decimal age with length modes in the New Zealand fishery

The mean age of fish in the three length modes from the New Zealand troll catch (e.g., Figure 10) is 1.1, 1.9 and 2.9 years (Table 1), which is consistent with the modes being annual. Growth analysis specifically focused on albacore in the 'southern' region (see Figure 9) predicted the length of albacore at age 1, 2 and 3 to be 50.3, 61.9 and 72.4 cm FL respectively, which is consistent with peaks in the New Zealand length data.

Table 1. Mean age of albacore by modal group in the New Zealand troll fishery.

MODAL GROUP (CM)	MEAN AGE (Y)	N
43-55	1.1	32
56-64	1.9	22
65-74	2.9	22

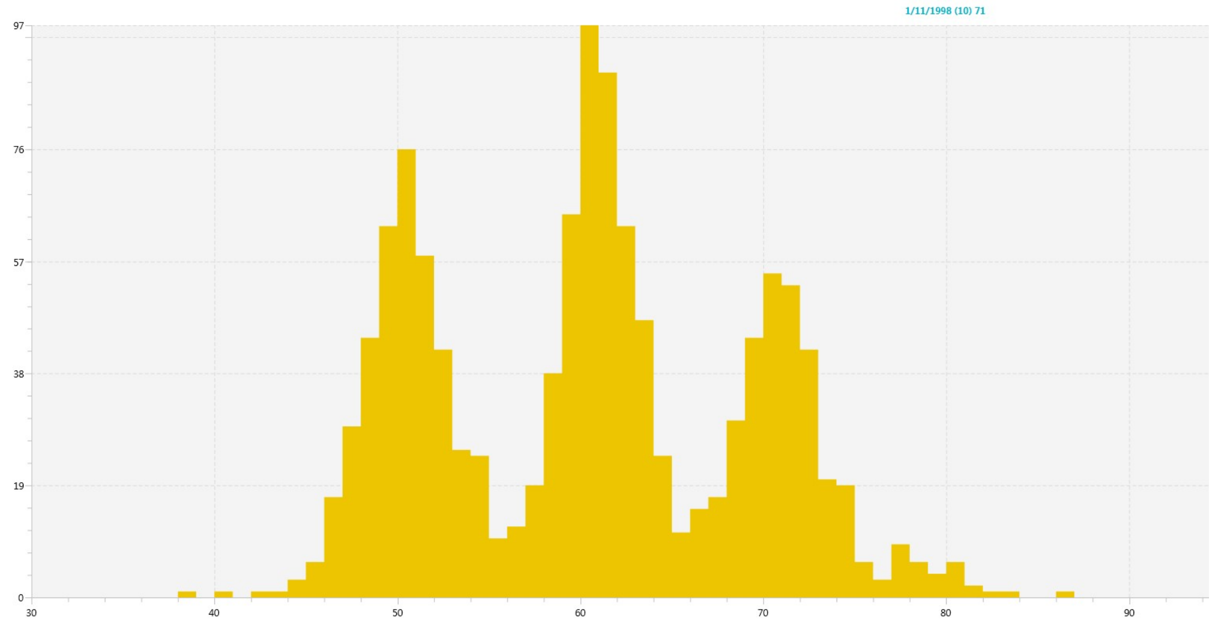


Figure 10. Length frequency distribution for albacore landed in the New Zealand troll fishery (Source: John Hampton).

Summary

The aim of this project was to improve age at length estimates for South Pacific albacore, focusing on the New Zealand troll fishery, for input into the 2021 stock assessment. The study applied recently developed methods to estimate a decimal age for 602 albacore tuna caught across the WCPO. The new approach did not rely on a single assumed birth date for all fish, otolith edge type, or increment formation period. The results of growth modelling were consistent with those of the earlier study of Williams et al. (2012), but the more refined age estimates appear to resolve the inconsistency found between the otolith length-at-age estimates and modes in the catch-at-size data for the New Zealand troll fishery, supporting the use of the new age algorithm to estimate decimal age of South Pacific albacore.

Acknowledgements

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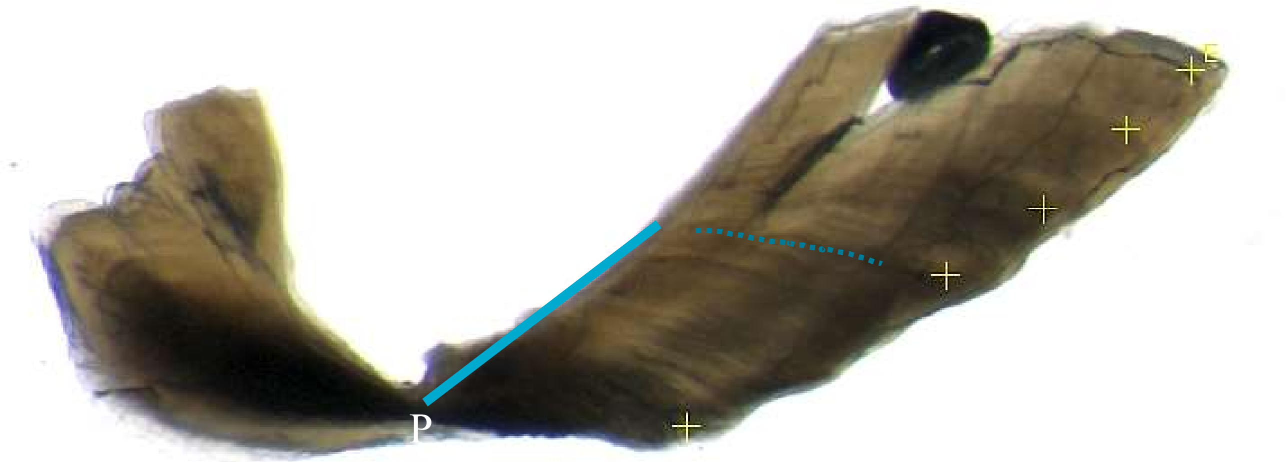
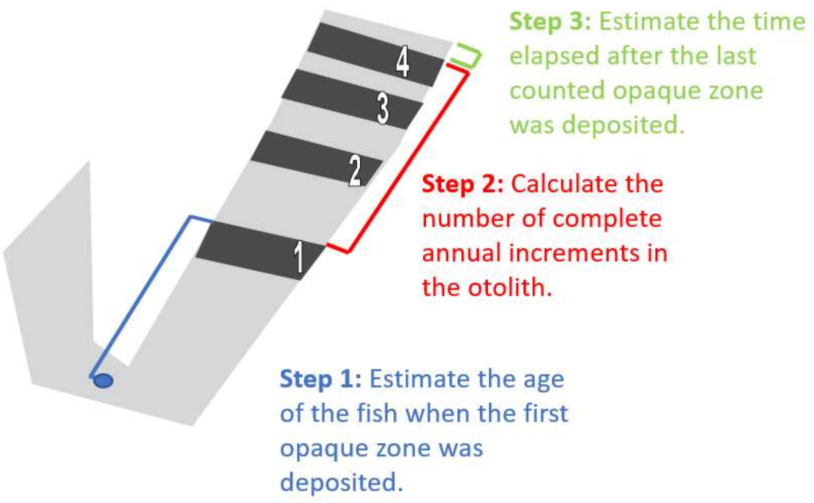
Appendix



Appendix Figure 1. Example image of albacore otolith prepared for annual ageing (ALB2379). The first inflection point (apex) and each opaque zone counted is marked with an + on the "outer" side of the otolith section. The otolith terminal edge is marked with an + E. The distance between the primordium (P) to the distal edge of the first opaque zone on the 'inner' side of the otolith is indicated by the aqua coloured bar.



Appendix Figure 2. Illustrative example of the steps used to estimate the decimal age for albacore tuna. Step 1 is estimated using the daily age-otolith size relationship using the distance measured from the primordium to end of the first opaque zone (inner side of the otolith section). Step 2 is the number of opaque zones counted minus 1. Step 3 is the marginal increment measurement as a proportion of the mean size of the complete annulus for the age group.