Validated age and growth of ribaldo (*Mora moro*)

C. P. Sutton[1]
D. M. Tracey[2]
A. H. Andrews[3]
A. C. Hart[2]
D. J. MacGibbon[2]

[1]NIWA
PO Box 893
Nelson 7040

[2]NIWA
Private Bag 14901
Wellington 6241

[3]NOAA Fisheries - Pacific Islands Fisheries Science Center
Life History Program – Age and Longevity Research
99-193 Aiea Heights Drive 417
Aiea, HI 96701, USA

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EXECUTIVE SUMMARY

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This report addresses Objectives 1 and 2 of Project RIB2007-02, Ribaldo age and growth. The aim of Objective 1 was to validate the use of otolith zone counts as a method of estimating the age of ribaldo. Objective 2 sought to age a sample of ribaldo otoliths, and estimate biological parameters required for fish stock management.

Biological data, including fish length, weight, sex, and gonad maturity were collected from ribaldo during random-stratified trawl surveys undertaken on the Chatham Rise. A subsample of 300 sagittal otoliths was selected using a length/sex stratified design. The resulting data were used to investigate validated age and growth characteristics of ribaldo.

Regression equations for defining length-weight relationships were calculated and are presented for male and female fish separately, and for both sexes, combined.

Counts of growth zones in thin-sectioned otoliths were used to determine ages, von Bertalanffy growth parameters, and natural mortality. Fish growth is rapid for about the first 10 years, slows between 10 and 20 years, and is negligible after about 25 years. Females reached a significantly greater maximum length than males, but differences in growth rate were not significant at the 95% level of confidence. Maximum ages of 37 years and 39 years were obtained for female and male fish, respectively.

Ageing error was considered to be minimal, as both within-reader and between-reader ageing variability showed no significant systematic difference (bias).

Natural mortality was estimated using Hoenig's regression equation to produce *M* values of 0.11 for females and 0.10 for males. It is suggested that these values are appropriate estimates at this stage.

The ageing methodology used above was validated using lead-radium dating. This method uses the known properties of radioactive decay for radium-226 (^{226}Ra) and lead-210 (^{210}Pb), and has previously been useful as a natural chronometer in otoliths.

1. INTRODUCTION

Ribaldo (*Mora moro*, Risso 1810) (Figure 1) is a species of morid cod reported from the northeast Atlantic Ocean, Mediterranean Sea, off western Africa, Indian Ocean, Pacific Ocean (off Chile) and around Australia and New Zealand. It has a demersal habit and occurs most frequently at depths between 450 and 2500 m (Cohen et al. 1990).

In New Zealand waters, ribaldo is caught generally by bottom longlines and as a bycatch of bottom trawling in depths of 200–800 m. It is considered to be widespread but not abundant (Paul 2000, Ministry of Fisheries 2009) (Figure 2).

Ribaldo landings increased steadily from 108 tonnes in 1989–90 to a peak of 1824 t in 1996–97 (Ministry of Fisheries, 2009). Since this time they have fluctuated around 1000–1300 t. Most of the commercial catch is taken from the Chatham Rise, east coast South Island, and west coast South Island.

Very little is known about the biology of ribaldo. In the Mediterranean Sea, fish mature at 32–34 cm total length (TL), spawning is believed to take place in winter and early spring, and eggs and larvae are pelagic (Cohen 1986, Rotllant et al. 2002). Adults feed on a variety of fishes, crustaceans, molluscs, and other invertebrates (Cohen et al. 1990). Limited ageing work has been carried out by the Central Ageing Facility (Queenscliff, Australia) on fish from the northeastern Atlantic (Talman et al. 2002). Age estimates ranged from 3 to 34 years for fish between 29 and 65 cm fork length (FL). There were limitations with this work as it was acknowledged that the morphology of sectioned ribaldo otoliths was very complex and that the central zones were difficult to interpret. The ageing methodology was not validated.

Similarly, little previous research has been undertaken on ribaldo from New Zealand waters. Clark & King (1989) investigated length-at-maturity of fish sampled from off the North Island and reported finding mature male and female fish at 34 cm and 29 cm, respectively. McMillan & Hart (1998) describes the fishery which was updated by Dunn (2006). No ageing studies have been undertaken on New Zealand ribaldo.

The purpose of the current study was to age a sample of ribaldo otoliths and estimate biological parameters which are required for stock management. A second aim was to validate the applied ageing methodology. Validation is an important component of robust ageing studies, as while zone counts are often found to be equivalent to age, this is not always the case (Campana & Thorrold 2001). The results of subsequent population modelling can be misleading if input parameters for growth are incorrect.

It was considered that radiochemical dating may be a suitable validation technique for ribaldo, as this method is most appropriate for estimating ages ranging from 10 to 50 years (Campana & Thorrold 2001). Talman et al. (2002) had previously indicated that ribaldo ages typically fall within this range. The species has otoliths with a large core size, which means it is likely that fewer otoliths would need to be pooled to provide sufficient material for analysis. Furthermore, the method has been applied successfully to other New Zealand species, including middle depth fishes (Paul et al. 2002), black and smooth oreos (Andrews & Tracey 2003), lookdown dory (Tracey et al. 2007), orange roughy (Andrews at al. 2009), and black cardinalfish (Andrews & Tracey 2007). The technique involved measuring the extent of radioactive decay of ^{226}Ra and ^{210}Pb, which are incorporated into otoliths during growth. Decay levels of ^{226}Ra into ^{210}Pb are known and fixed and therefore can be used to estimate the elapsed time since they were incorporated into the otolith.

This research establishes a validated ageing protocol for ribaldo. It presents age and growth estimates for a principal fishery on the Chatham Rise. This will assist in providing more robust biological parameters for stock management.

2. METHODS

2.1 Data collection

Ribaldo otoliths were sampled randomly during summer trawl surveys of the Chatham Rise undertaken from 2001 to 2005. This area is an important region to obtain growth data from as it supports a high TACC. During this period about 770 sagittal otoliths were collected, cleaned, and stored dry in paper envelopes for further analysis. Biological data (including total length, weight, sex, and gonad maturity) were recorded for each specimen.

A subsample of 300 otoliths (149 male, 151 female) was selected (using a length/sex stratified design) for the current age and growth study.

2.2 Length-at-weight

All 1199 ribaldo sampled during Chatham Rise trawl surveys undertaken from 2001 to 2005 were used to estimate the length-at-weight relationship for male and female fish separately, and for both sexes combined.

The length-at-weight relationships were calculated using the equation

$$W = \alpha L^{\beta} \tag{1}$$

where W = weight (g) and L = total length (cm).

2.3 Age and growth

2.3.1 Otolith preparation

Initial investigations indicated that the most appropriate technique for preparing ribaldo otoliths was the longitudinal thin-sectioning method used previously for orange roughy (Tracey & Horn 1999) (Figure 3). However, after further examination it was concluded that the modified transverse thin-sectioning method used for icefish (Sutton et al. 2008) was more appropriate as it produced consistently clearer preparations.

In preparation for reading, each otolith was embedded in clear epoxy resin (Araldite K142) and left to cure at 50 °C for 24 hours. Once cured, the blocks were transversely cut along the nuclear plane using a diamond-edged saw. One half of the sectioned block was mounted (otolith section down) onto a microscope slide using clear epoxy resin. Preparations were left to cure at 50 °C for 24 hours. A 1200 μm diamond-coated disc was used to grind the upper surface of each mounted, sectioned block to a thickness of about 300 μm.

Prepared sections were examined under a stereo microscope (x25) illuminated by transmitted light. A pattern of translucent and opaque zones was evident with the number of complete opaque zones interpreted as annuli. A five-point "readability" score was recorded for each otolith reading (Table 1).

2.3.2 Mean length-at-age

Von Bertalanffy growth curves were fitted to the age-length data from male and female fish. Three unsexed fish were not included in the analysis. Separate equations (with 95% confidence intervals) were calculated for each sex using a likelihood ratio procedure (Kimura 1980).

2.3.3 Ageing error

Otolith zone counts were assessed for ageing bias and precision. To assess the within-reader variability of the results, 144 otoliths were read twice by the primary author (CPS). First and second readings were made 3 weeks apart. To assess the level of between-reader variation, 128 otoliths (representing a range of lengths and both sexes) were also read by a second experienced otolith reader (DMT). Any readings that differed between readers were re-examined and a final agreed age was determined.

Ageing bias was determined from reader bias plots with error bars denoting 95% confidence intervals (Chang 1982).

2.3.4 Estimating natural mortality

An estimate of the natural mortality coefficient, M, was obtained using Hoenig's (1983) regression equation describing the relationship between mortality rate and life span:

$$\log_e M = 1.46 - 1.01[\log_e(t_{max})] \tag{2}$$

where t_{max} = the maximum age reached by 1% of an unexploited population (Sparre et al. 1989).

2.4 Radiochemical age validation

2.4.1 Otolith selection

A subsample of 'sister' otoliths (from the 300 fish chosen for ageing) was selected for micro-milling. To obtain sufficient mass for the radiochemical validation protocol (i.e., to produce measurable levels of ^{210}Pb and ^{226}Ra activity) it was necessary to pool otoliths from three relatively wide year-class groups: 3–6 yrs (young age), 9–14 yrs (mid-age), and 18–22 yrs (old age) (Table 4). However, it was possible to limit otolith samples to the 2001 and 2002 trawl surveys, thereby minimising variability which may result from sampling over a longer time period. In addition, material sampled during the 2001 trawl survey from 9 year old fish was considered to be the same as material sampled during the 2002 survey from 10 year old fish. This approach enabled the number of otolith cores in each category to be increased without increasing the number of year-class groups.

2.4.2 Sample coring

Otoliths were initially prepared in a manner consistent with the methodology outlined above (Section 2.3.1). The only variation to this technique was that thicker (1 mm) sections were cut and these were attached to microscope slides using double-sided adhesive tape. Otolith material outside the first three “annual” zones was then removed using NIWA’s Merchantek New-Wave micromill. This left intact cores (about 0.018 grams per otolith) which were pooled and collected in three vials. This enabled the accumulation of sufficient material to produce theoretically measurable levels of lead-210 and radium-226 activity, while keeping the age range within samples as low as possible.

2.4.3 Radiochemical analyses

The three vials containing the otolith cores were sent to Moss Landing Marine Laboratories for analysis. This involved using alpha spectrometry and inductively coupled plasma mass spectrometry (ICPMS) to determine the levels of ^{210}Pb and ^{226}Ra, respectively (Andrews et al. 1999, Lundstrom, pers.comm.).

Initially, samples 1, 2, and 3 (representing young age, mid-age, and old age fish) had to be tested to determine if levels of lead-210 and radium-226 were in a range that provided measurable activity. If activity is too low, radiochemical age validation is not possible.

Sample 1 (young age fish comprising 3–6 year olds) which represents the early growth phase of ribaldo was considered extremely important as it potentially provides a baseline measurement for establishing whether exogenous lead-210 is a factor that will need consideration in subsequent analysis.

3. RESULTS

3.1 Length-at-weight

The raw data and calculated length-at-weight equations are shown in Figure 4. The relationship between length and weight produced similar α estimates of 0.005 for males and 0.004 for females, respectively. β estimates were also similar between sexes with 3.18 for males and 3.27 for females, respectively. The relationship between length and weight was positively correlated with high R^2 values of 0.94 for males and 0.97 for females.

3.2 Age and growth

3.2.1 Otolith interpretation

A whole ribaldo sagittal otolith with the sectioning plane marked is shown in Figure 5. Transverse sections of otoliths from young and old fish are shown in Figures 6 and 7.

The nuclear region of sectioned otoliths comprises a large regular core. Interpretation of up to the first five zones was often difficult due to a lack of clarity. However, zones became clearer and more regular after this period. Talman et al. (2002) found that initial otolith growth is confined to the distal surface and that at about 8 years of age growth is restricted in this region with the main deposition occurring on the proximal surface, particularly within the ventral side. This interpretation is consistent with the present study and is shown by dashed red lines in Figure 7.

3.2.2 Mean length-at-age

Data from 297 otoliths were used to calculate von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals for the estimates) for both males and females (Table 2).

The raw age-length data and calculated von Bertalanffy growth curves for ribaldo are plotted in Figure 8.

The graphs show that both male and female fish grew rapidly for about the first 10 years, before slowing in growth between 10 and 20 years. Growth rates are negligible after about 25 years. This trend is consistent between the sexes. Females were consistently larger than males at corresponding ages and reached a greater maximum length, but the difference in L_∞ is not significant at the 95% level of confidence (Table 2). In contrast, the difference in k values is statistically significant (at the 95% level) with females growing more rapidly than males. The t_0 value for male fish is strongly negative, which is indicative of there being insufficient data to accurately define initial growth. Increasing the number of young male fish (under 5 years) would result in the growth curve intersecting the x-axis closer to the origin, which would increase the k parameter for males.

There was considerable overlap in the length-at-age data for both sexes: Table 3 shows mean lengths-at-age (with standard deviation and sample size) for all fish aged. The calculated von Bertalanffy curves in Figure 8 fit these data reasonably well given that there is some spread in the data points.

3.2.3 Ageing error

Both readers found ribaldo otoliths difficult to interpret, particularly in the core region where the first five zones were formed. Despite this, there was a high level of agreement in the within-reader comparison test with 59% of the first and second age estimates in agreement. Eighty-two percent were within 1 year and 95% were within 2 years. The agreement level for the between-reader comparison test was not as high, but still showed reasonable consistency with 39% of the first and second age estimates in agreement. Seventy-two percent were within 1 year and 86% were within 2 years. These findings are further supported by the high level of consistency shown in the age bias plots for both the within-reader and between-reader comparison tests (Figures 9 and 10). These plots showed that no systematic bias was detected in the results, and ageing error appeared to be negligible over the aggregated age range. In general, the error bars are absent or small indicating close agreement between all readings. The exceptions to this (for ages 23, 26, and 35 years) are a consequence of small sample sizes.

One notable difference is evident in the between-reader comparison test (Figure 10). Reader 1 obtained an age estimate of 39 years, whereas Reader 2 estimated 26 years. Both readers re-examined this otolith and estimates of 39 years and 37 years were obtained by readers 1 and 2, respectively. It was therefore considered appropriate to retain the primary readers' estimate of 39 years.

3.2.4 Estimating natural mortality

The samples aged suggest a t_{max} of about 37 years for female and 39 years for male ribaldo, giving estimates for M of 0.11 and 0.10, respectively. However, only about 14% of males and 8% of females reached an age greater than 25 years.

3.3 Radiochemical age validation

A summary of age, length, sex ratio, and mean capture date data, for each of the three year-class groups used in the radiometric analysis, is shown in Table 4.

The radiometric results are presented in Table 5. The three year-class groups comprised 27, 30, and 45 otolith cores, which had sample weights ranging from 0.46 g to 0.72 g. Mean core weight was consistent between groups. The lead-210 activity increased from the youngest to the oldest age group and ranged from 0.00765 ± 12.8% to 0.01503 ± 9.7% dpm·g^{-1}. Radium-226 levels were low, although adequate to enable activity to be quantified. The data provided in Table 5 show that radium-226 levels were relatively consistent (about 0.025 dpm·g^{-1}), although the margin of error increased with decreasing sample mass. The activity ratios also increased from the youngest to the oldest age group and ranged from 0.2609 to 0.6793. These values were greater than would be expected directly from estimated age (determined from otolith growth zone counts) due to the additional time involved since capture date (about 8 years).

Radiometric age is compared with mean estimated age (determined from otolith growth zone counts) in Table 6. The mean estimated age needed to be corrected for time elapsed between capture date and radiometric analysis. This was achieved by adding about 8 years to each of the three samples, thereby obtaining a “corrected” sample age. Agreement between the two age estimation techniques was reasonably good based on the observed trend relative to the lead-radium ingrowth curve (Figure 11). This result is further supported by the finding that the margins of error intersect the ingrowth curve for each of the three samples. A relatively high margin of error was calculated for the oldest age group, which can be attributed to the relatively low sample mass. This corresponded with low precision for the radium-226 determination.

4. DISCUSSION

This is the first validated age and growth study of ribaldo in New Zealand waters.

We have developed a consistent and reproducible method to age the species by counting growth zones in sectioned otoliths.

Von Bertalanffy growth parameters indicated that growth is initially rapid for about the first 10 years, before slowing and becoming negligible after about 25 years. This trend is consistent between the sexes, but, on average, females grew more rapidly and to a larger size than males. Although no statistically significant between-sex differences in growth parameters were found here, the comparison of the estimated parameters is not sound. This is because the male t_0 growth parameter is -5.24 and, therefore, does not accurately describe growth for juvenile male fish. In contrast, the t_0 value for female fish is much closer to zero. Including more data from juvenile males would shift the male t_0 value towards zero. Because all three von Bertalanffy parameters are strongly correlated, this will reduce L_∞ and increase the k value, resulting in parameters that are more likely to identify a significant difference in growth rate between sexes.

Maximum age was estimated to be 37 and 39 years for female and male fish, respectively. These values give estimates for *M* of 0.11 and 0.10, respectively. It is important to remember that the t_{max} values obtained in this study represent the maximum ages from an exploited fishery, rather than those attained by 1% of the population. It is therefore likely that *M* has been overestimated.

There is little published information on the age and growth of ribaldo. Talman et al. (2002) presented a brief report on 66 ribaldo sampled from the eastern north Atlantic. Their findings are largely consistent with those presented here, with fish ranging in length from 29 to 65cm (TL) and having ages of 3–34 years. Growth parameters or mortality estimates were not provided.

It was initially uncertain whether it would be feasible to apply the lead-radium dating technique to ribaldo otolith material. This is because success using this method is highly dependent on the levels of radium-226 uptake. For the application to be successful on small quantities of otolith material (as was the case in this study), radium-226 levels need to be relatively high. This fact was demonstrated in two age and growth papers on bocaccio rockfish (*Sebastes paucispinis*; Andrews et al. (2005)) and Atlantic tarpon (*Megalops atlanticus*; Andrews et al. (2001)). The bocaccio rockfish study exemplified the limits of detection using this technique by providing only rough estimates of age; the levels for radium-226 (consequently lead-210) were too low to provide a low margin of error associated with the calculated radiometric age. Contrary to these findings, the Atlantic tarpon study exemplified use of low sample size for meaningful lead-radium dating because radium-226 levels were higher than had previously been reported in otoliths from the literature.

In this study lead-210 activity in ribaldo otoliths increased from the youngest to the oldest age group and radium-226 levels were low, although adequate to enable activity to be quantified. There was general agreement between estimated age and radiometric age. This supports the use of otolith growth zone counts to derive age estimates for ribaldo. Despite the wide range of radiometric age for the oldest age group, it is reasonable to conclude that the lifespan of ribaldo exceeds 16.5 years.

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Table 1: Five-point otolith readability scores used in readings.

Readability	Description
1	Otolith very easy to read; excellent contrast between successive opaque and translucent zones
2	Otolith easy to read; good contrast between successive opaque and translucent zones, but not as marked as in 1; potential error ± 1 opaque zone
3	Otolith readable; less contrast between successive opaque and translucent zones than in 2, but alternating zones still apparent; potential error ± 2 opaque zones
4	Otolith readable with difficulty; poor contrast between successive opaque and translucent zones; potential error ± 3 opaque zones
5	Otolith unreadable

Table 2: Von Bertalanffy growth parameters (with 95% confidence intervals) for ribaldo sampled from Chatham Rise, New Zealand.

	male	female
L_∞	61.44 (58.51–66.95)	67.52 (65.25–70.18)
k	0.07 (0.05–0.09)	0.13 (0.11–0.16)
t_0	-5.24 (-8.81 to -2.99)	0.22 (-0.51 to 0.95)
Age range	3–39	3–37
n	146	151

Table 3: Mean lengths at age (cm, with standard deviation, S.D., and sample size, *n*) for fish sampled from Chatham Rise, New Zealand.

	Male			Female		
Age	Mean	S.D.	N	Mean	S.D.	N
1	-	-	-	-	-	-
2	-	-	-	-	-	-
3	21.1	-	1	23.7	1.6	2
4	26.5	-	1	25.1	-	1
5	31.8	4.6	3	31.1	2.5	5
6	35.0	4.3	8	38.0	4.7	9
7	37.5	4.3	6	39.6	5.5	10
8	39.5	2.5	8	43.8	6.5	8
9	39.4	2.8	9	48.4	5.7	10
10	34.8	4.0	9	44.9	5.4	5
11	43.0	4.4	10	49.2	5.6	12
12	42.3	7.3	4	53.4	5.8	10
13	45.4	8.2	4	57.3	7.7	16
14	56.3	5.5	2	61.9	5.2	5
15	44.8	4.5	5	49.0	1.4	3
16	48.4	2.7	3	56.9	4.7	4
17	49.4	4.3	2	62.3	4.0	5
18	51.8	3.0	6	65.4	4.7	7
19	48.2	3.8	6	63.3	4.7	8
20	47.4	2.2	5	58.7	8.0	4
21	50.2	1.5	8	71.5	-	1
22	51.5	4.7	12	63.3	5.7	7
23	57.6	6.2	6	-	-	-
24	58.0	5.0	6	67.1	3.5	4
25	54.6	1.6	2	66.2	4.7	4
26	54.3	-	1	59.0	-	1
27	54.2	4.3	2	71.9	-	1
28	58.1	-	1	65.9	7.8	3
29	52.6	-	1	56.3	-	1
30	57.7	2.6	4	70.4	-	1
31	-	-	-	-	-	-
32	-	-	-	64.4	6.0	3
33	58.9	0.8	2	-	-	-
34	-	-	-	-	-	-
35	57.8	4.4	3	-	-	-
36	55.3	6.1	3	-	-	-
37	-	-	-	57.6	-	1
38	60.9	0.2	2	-	-	-
39	59.0	-	1	-	-	-

Table 4: Summary of age, length, and sex ratio characteristics for each of the three year-class groups. Median capture date (standardised to the 2001 survey year) is also provided.

Sample ID	No. of fish	Age range (yr)	Mean age (yr)	Length range (SD)	Mean length (cm)	Sex ratio (n_f/n_m)	Median capture date[1]
1 (young age)	23	3–6	4.9	22.5–42.6 (6.1)	33.9	1.14 (16/14)	29 March 2001
2 (mid-age)	30	9–14	11.8	38.5–71.5 (8.2)	53.3	2.75 (33/12)	26 June 2001
3 (old age)	20	18–22	20.1	42.3–69.8 (7.8)	57.4	0.93 (14/15)	5 August 2001

[1] Based on the assumption that each core contributed equally for two collection periods: 1 = 28 December 2000 to 25 January 2001 and 2 = 28 December 2001 to 26 January 2002.

Table 5: Radiometric results for each of the three year-class groups. The total number of otolith cores, sample weight, and average core weight are shown for each age-group. Measured ^{210}Pb and ^{226}Ra activity are also presented for each sample (± 2 SE). Activities are expressed as disintegrations per minute per gram (dpm·g^{-1}). The activity ratios and the corresponding margin of error were used to calculate sample age, corrected for time since capture (Table 1) and age uncertainty (Table 3).

Sample ID	No. of cores milled	Sample weight (g)[1]	Mean core weight (g)[2]	^{210}Pb (dpm·g^{-1}) ± % error[3]	^{226}Ra (dpm·g^{-1}) ± % error[3]	^{210}Pb: ^{226}Ra (2 SE)
1 (young age)	30	0.5395	0.0184	0.00765 ± 12.8%	0.02931 ± 17.2%	0.2609 (0.0558)
2 (mid-age)	45	0.7218	0.0164	0.00917 ± 9.6%	0.02410 ± 14.1%	0.3806 (0.0649)
3 (old age)	27	0.4618	0.0178	0.01503 ± 9.7%	0.02213 ± 23.4%	0.6793 (0.1718)

[1] Cleaned and dried sample weight before processing (loss of a small percentage of the original material is a result of cleaning).
[2] Extracted otolith core weight before cleaning.
[3] Calculation based on propagation of 2SE using the delta method (Knoll 1989) and/or the ICPMS analysis routine (± 2 SE).

Table 6: Comparison between age derived from otolith growth zone counts and radiometric analysis. Mean estimated age and age distribution uncertainty (2 SE) are shown for each of the three year-class groups. Total sample age is given as the mean age plus time since capture. This enables direct comparison with radiometric age. Radiometric age was calculated from the measured ^{210}Pb:^{226}Ra activity ratios and age range was based on the analytical uncertainty and error propagation (2 SE). Corrected age for time since capture date was calculated for direct comparison with the mean estimated age.

Sample ID	Mean estimated age (yr) and (2 SE)	Time since capture (yr)	Total sample age (yr) [1] and (2 SE)	Radiometric age and range (yr)	Corrected age and range (yr)
1 (young age)	4.9 (0.5)	8.0	12.9 (0.5)	11.2 (8.9–13.7)	3.2 (0.8–5.7)
2 (mid-age)	11.8 (0.4)	7.8	19.6 (0.4)	16.9 (13.7–20.4)	9.1 (5.9–12.7)
3 (old age)	20.1 (0.6)	7.7	27.8 (0.6)	38.0 (24.3–62.7)	30.3 (16.5–55.0)

[1] Total sample age is estimated age plus time since capture; this allows for a direct comparison to the ingrowth curve.

Figure 1: Ribaldo (*Mora moro*) specimen caught on the Chatham Rise, New Zealand.

Figure 2: Distribution of ribaldo (*Mora moro*) caught during research trawls.

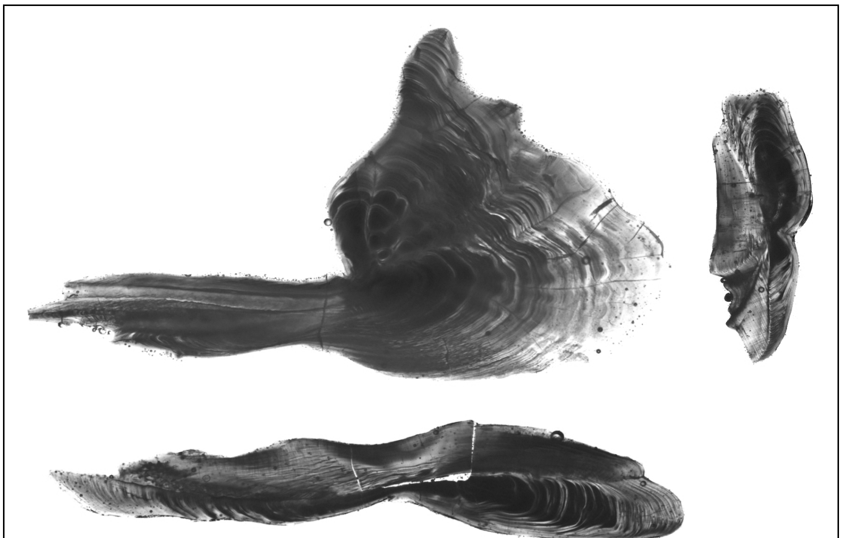

Figure 3: Ribaldo otolith thin sections: whole lateral (top left), transverse (top right), and longitudinal, the preferred sectioning technique (bottom left).

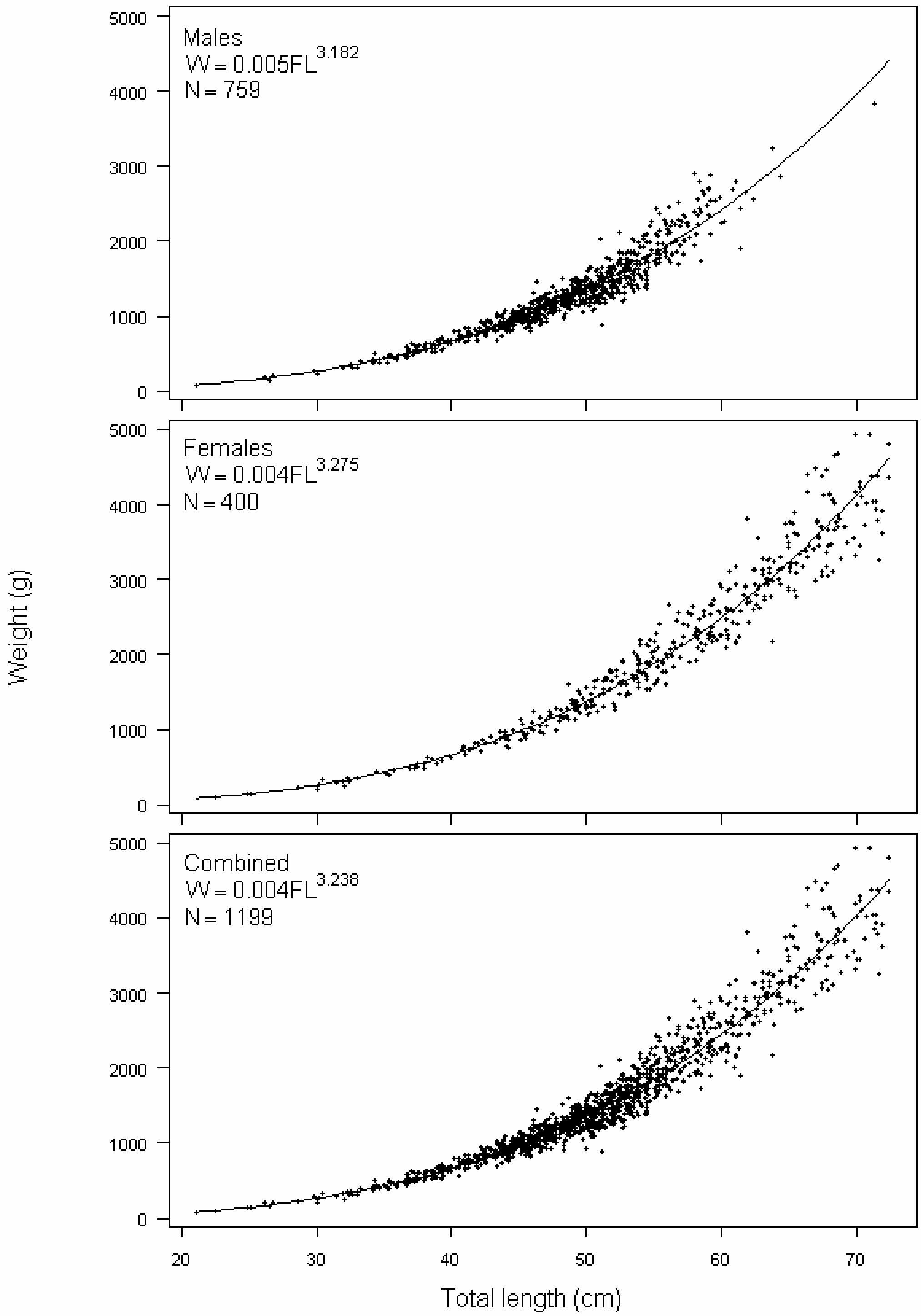

Figure 4: Length-weight relationship for male, female, and combined sex ribaldo from the Chatham Rise, New Zealand.

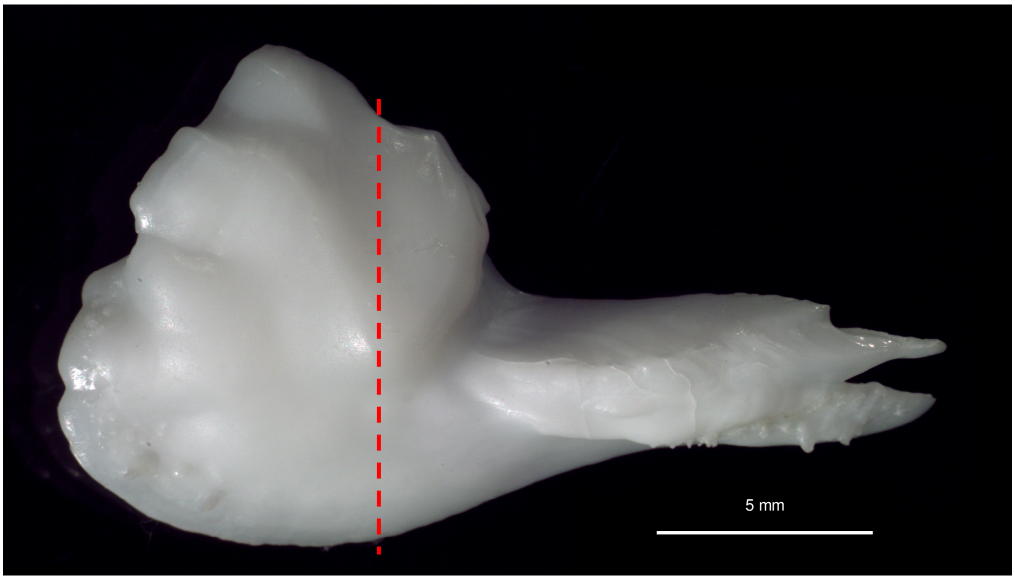

Figure 5: A whole ribaldo (*Mora moro*) sagittal otolith with the sectioning plane marked with a dashed line.

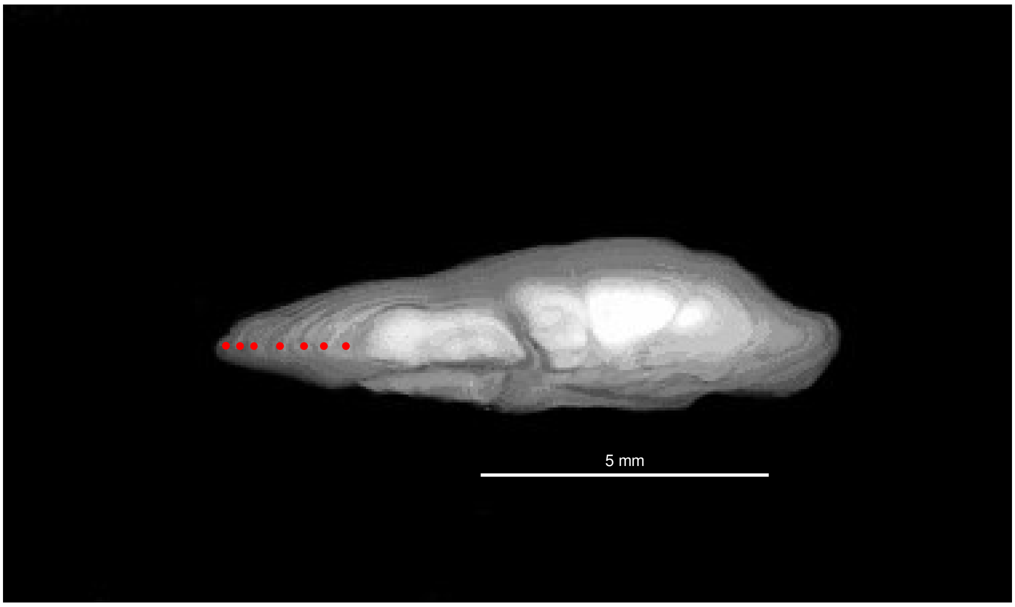

Figure 6: Transversely thin-sectioned ribaldo sagittal otolith from an age 7 fish. The circles indicate translucent zones interpreted as annuli.

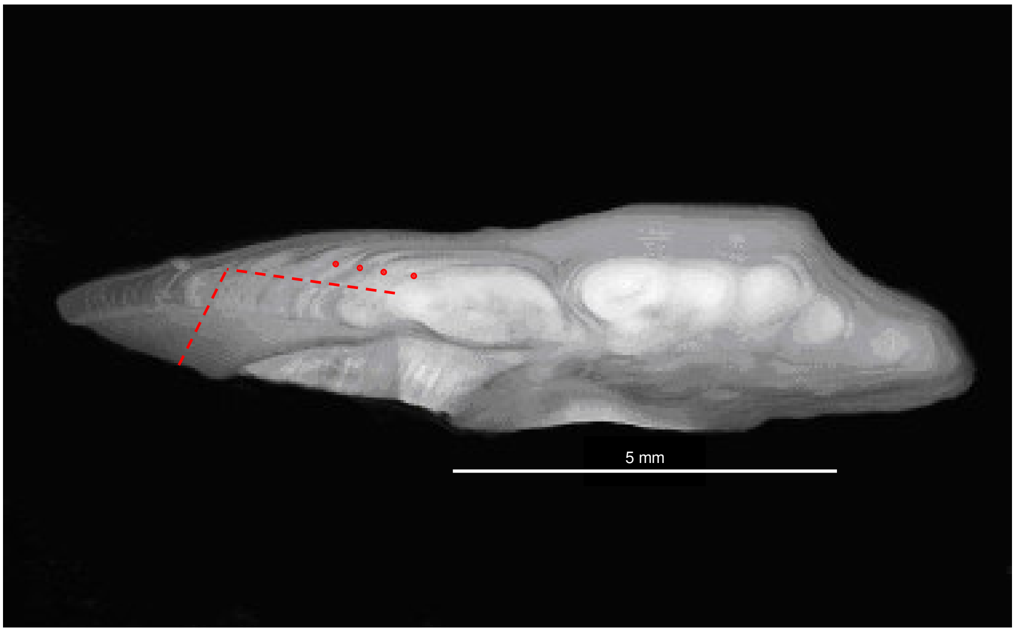

Figure 7: Transversely thin-sectioned ribaldo sagittal otolith from an age 22 fish. The circles indicate the first four translucent zones interpreted as annuli and the dashed lines indicate the reading axes.

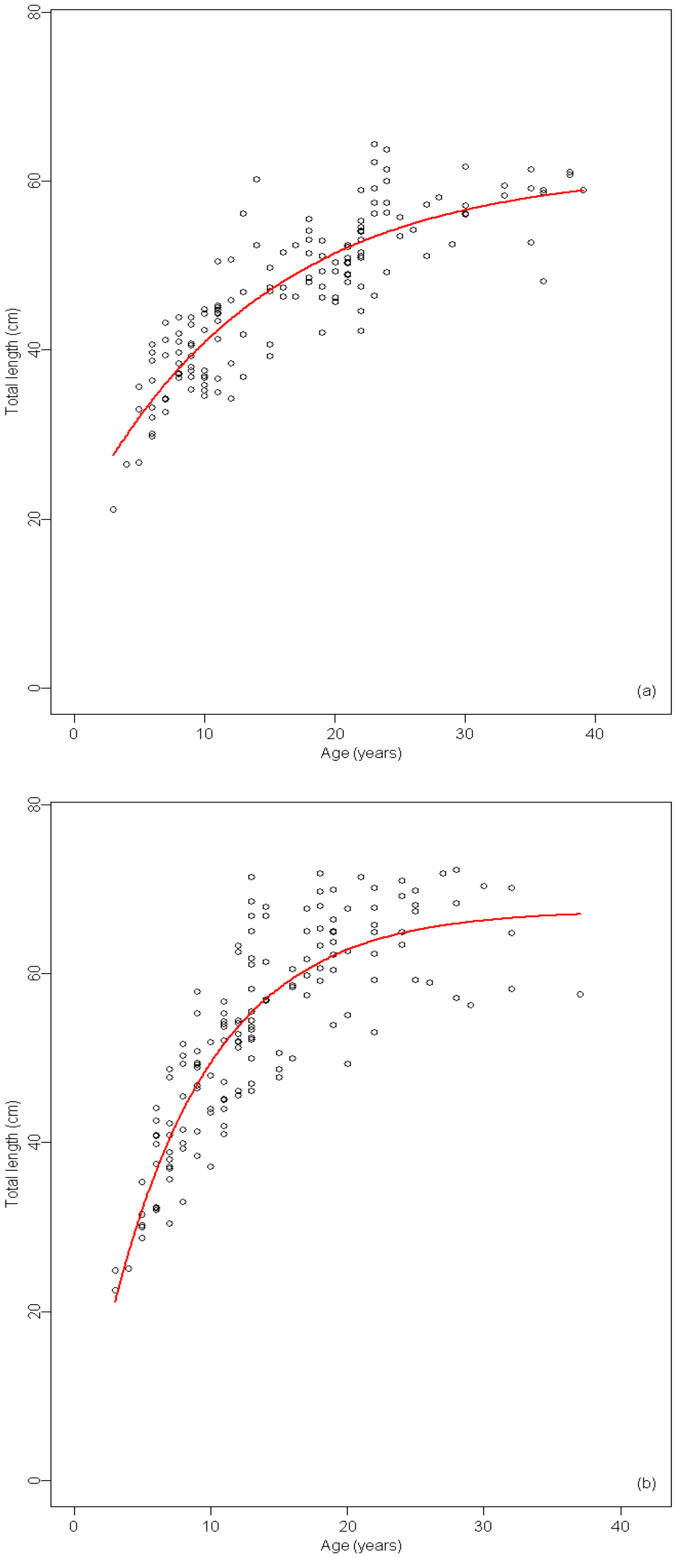

Figure 8: Raw length-at-age data and von Bertalanffy growth curves for (a) male and (b) female ribaldo sampled from Chatham Rise, New Zealand.

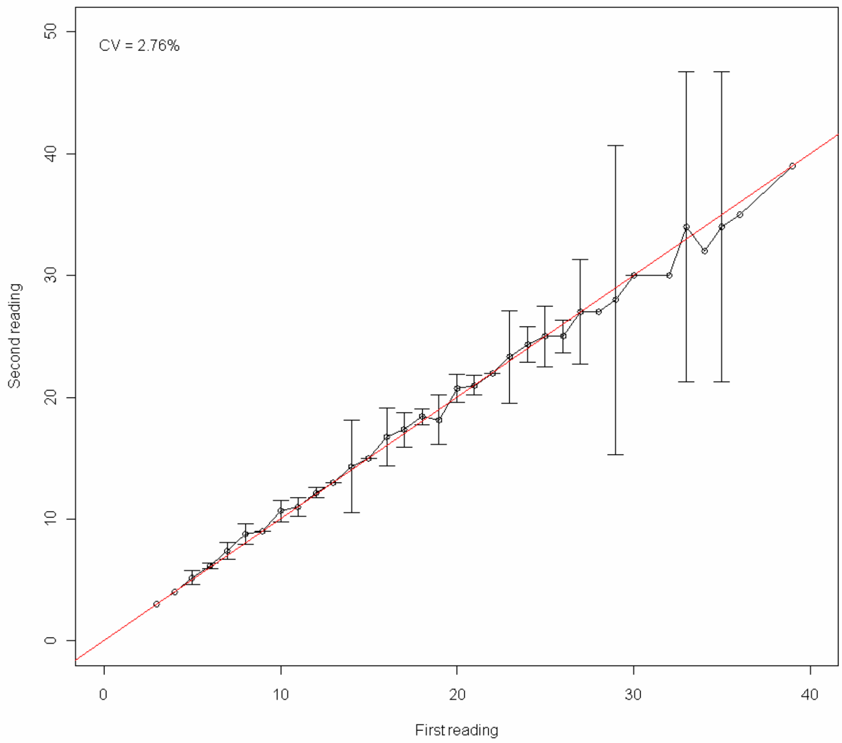

Figure 9: Within-reader comparison of 144 ribaldo otoliths.

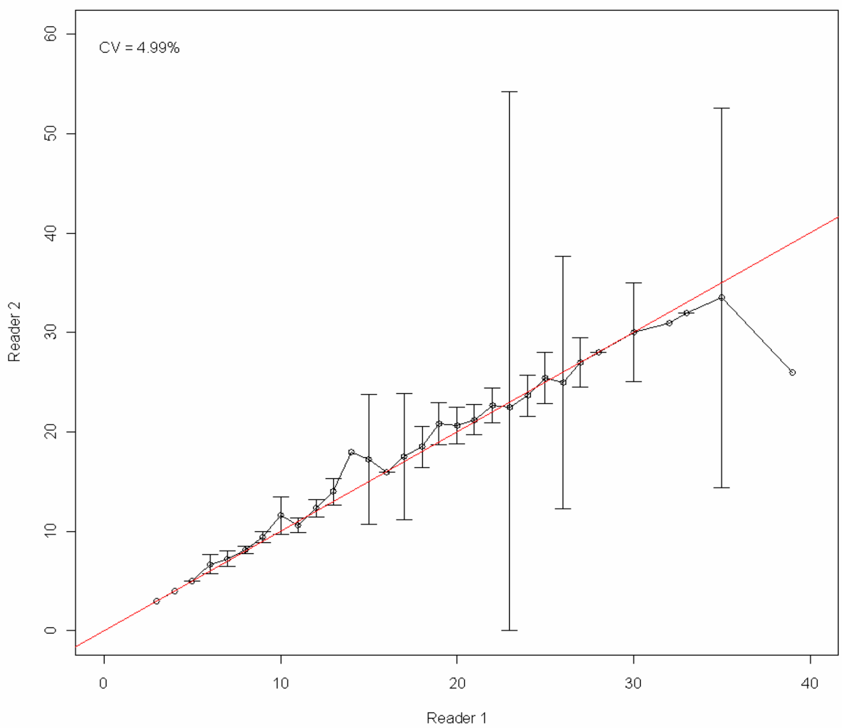

Figure 10: Between-reader comparison of 128 ribaldo otoliths.

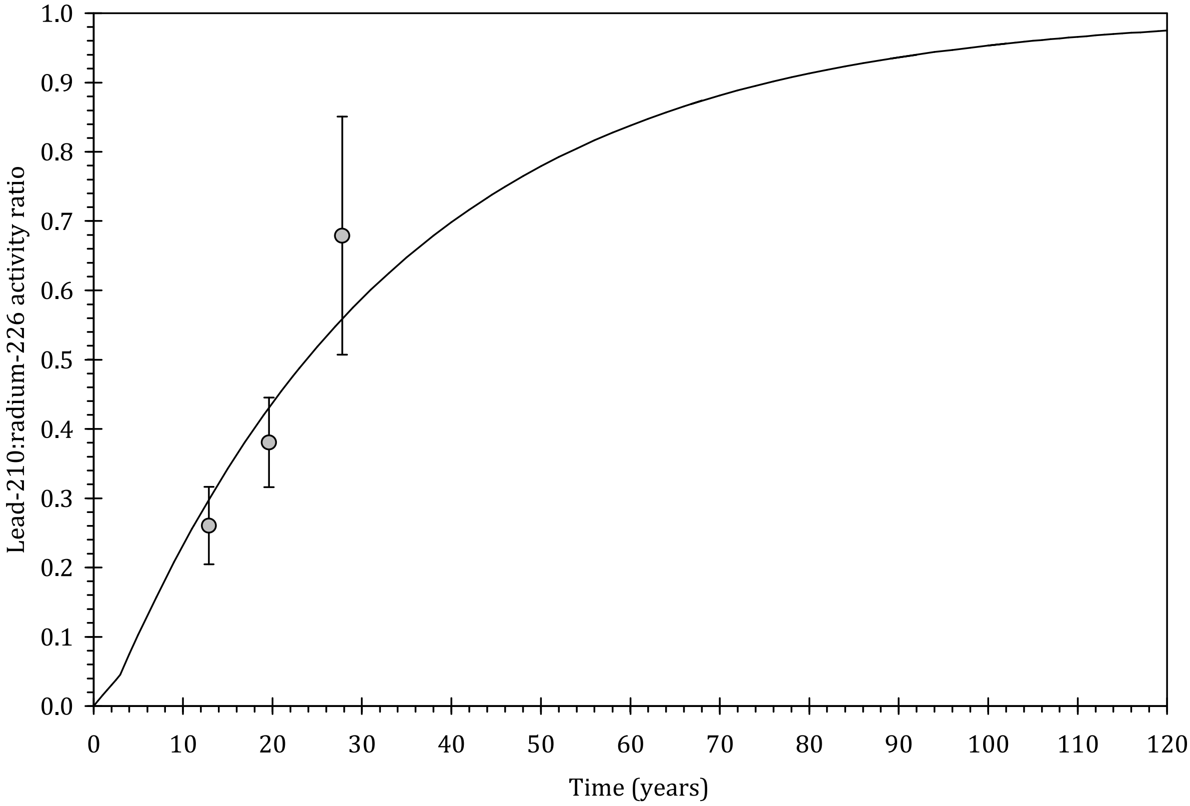

Figure 11: Total sample age (time since capture plus mean estimated age) plotted against measured lead-radium activity (for the three year-class groups sampled). Proximity of these data relative to the expected ingrowth curve can be used to gauge the accuracy of estimated age from growth zone counting. Vertical error bars represent 2 SE from the measured lead-radium ratios. Horizontal error bars are within the symbol and represent 2 SE of the estimated age range for the given age group (0.5–0.6 yr). The solid line represents ingrowth of lead-210 from radium-226 with a core compensated (3 years) near the origin.

Appendix 1: Data associated with the juvenile (3–6 year) age-group sample. Thirty otolith cores from 23 individual fish (which produced a total sample weight of 0.553 g before cleaning) were analysed.

Voyage	Prep. no.	Station no.	Fish no.	Length (cm)	Sex	Sample weight (g)	Estimated age (yr)
tan0101	y1	33	3009	29.8	1	0.0096	3
tan0101	y2	33	3010	28.7	2	0.0201	3
tan0101	y3	33	3011	26.7	1	0.0195	3
tan0101	y4	42	3003	32	2	0.0344	4
tan0101	y7	33	3008	32	1	0.0168	5
tan0101	y8	36	3002	40.9	2	0.0189	5
tan0101	y9	37	3005	31.5	2	0.0184	5
tan0101	y10	42	3004	33	2	0.0181	5
tan0101	y11	111	4002	35.4	2	0.0179	5
tan0201	y12	53	1004	22.5	2	0.0117	3
tan0201	y13	53	1002	25.1	2	0.0191	4
tan0201	y14	53	1003	24.9	2	0.0216	3
tan0101	y15	23	3002	32.3	2	0.0221	6
tan0101	y16	37	3004	36.4	1	0.0218	6
tan0101	y17	77	1001	40.9	2	0.0178	6
tan0101	y5	1	1007	38.8	1	0.0211	6
tan0101	y6	3	1006	40.7	1	0.0166	5
tan0101	y18	116	1003	42.6	2	0.0312	6
tan0101	y19	120	3013	39.7	1	0.0220	6
tan0101	y20	121	3006	39.8	2	0.0226	6
tan0101	y109	24	3007	33.2	1	0.0270	6
tan0201	y209	53	1006	26.5	1	0.0309	*
tan0201	y309	160	3002	26.2	1	0.0219	*
tan0201	y309a	160	3002	26.2	1	0.0193	*
tan0101	y5b	1	1007	38.8	1	0.0059	6
tan0101	y6b	3	1006	40.7	1	0.0185	5
tan0101	y8b	36	3002	40.9	2	0.0139	5
tan0101	y9b	37	3005	31.5	2	0.0013	5
tan0101	y19b	120	3013	39.7	1	0.0051	6
tan0101	y20b	121	3006	39.8	2	0.0075	6

*not aged as length indicates that fish must be in juvenile age group.

Appendix 2: Data associated with the mid (9–14 year) age-group sample. Forty five otolith cores from 30 individual fish (which produced a total sample weight of 0.740 g before cleaning) were analysed.

Voyage	Prep. no.	Station no.	Fish no.	Length (cm)	Sex	Sample weight (g)	Estimated age (yr)
tan0101	m1	35	1004	38.5	1	0.0246	10
tan0101	m2	113	1001	61.9	2	0.0318	13
tan0101	m3	113	1002	66.9	2	0.0203	11
tan0101	m4	116	1002	58.2	2	0.0179	11
tan0101	m5	9	4004	50.7	1	0.0157	12
tan0101	m6	11	3001	46.1	2	0.0190	12
tan0101	m7	14	3001	45.9	1	0.0188	12
tan0101	m8	24	3013	41.9	1	0.0167	13
tan0101	m9	116	1001	65.1	2	0.0251	12
tan0101	m10	11	3003	46.1	2	0.0229	13
tan0101	m11	40	3003	46.9	1	0.0263	13
tan0101	m12	111	4001	58.6	2	0.0285	13
tan0101	m13	111	4006	71.5	2	0.0174	13
tan0201	m14	2	3001	47.2	2	0.0228	10
tan0201	m15	122	4007	45.3	1	0.0260	10
tan0201	m16	139	3007	54.4	2	0.0146	10
tan0201	m17	122	4003	54.1	2	0.0271	11
tan0201	m18	138	3008	42	2	0.0273	11
tan0201	m19	121	4004	53.4	2	0.0193	12
tan0201	m20	121	4008	52	2	0.0108	12
tan0201	m21	122	4002	54.5	2	0.0222	12
tan0201	m22	127	1004	47	2	0.0128	12
tan0201	m23	139	3004	51.9	2	0.0150	12
tan0201	m24	121	4007	54.2	2	0.0199	13
tan0101	m109	24	3014	59.2	2	0.0171	14
tan0101	m209	38	3001	61.4	2	0.0156	14
tan0101	m309	134	1009	52.4	1	0.0194	14
tan0201	m409	27	4001	48	2	0.0148	9
tan0201	m509	123	3004	40.8	1	0.0184	9
tan0201	m609	127	1007	58.6	1	0.0221	9
tan0101	m2b	113	1001	61.9	2	0.0051	13
tan0101	m3b	113	1002	66.9	2	0.0102	11
tan0101	m4b	116	1002	58.2	2	0.0108	11
tan0101	m6b	11	3001	46.1	2	0.0067	12
tan0101	m8b	24	3013	41.9	1	0.0114	13
tan0101	m10b	11	3003	46.1	2	0.0112	13
tan0101	m13b	111	4006	71.5	2	0.0096	13
tan0201	m15b	122	4007	45.3	1	0.0050	10
tan0201	m17b	122	4003	54.1	2	0.0186	11
tan0201	m24b	121	4007	54.2	2	0.0150	13
tan0201	m21b	122	4002	54.5	2	0.0075	12
tan0101	m109a	24	3014	59.2	2	0.0022	14
tan0101	m109b	24	3014	59.2	2	0.0095	14
tan0201	m409a	27	4001	48	2	0.0038	9
tan0201	m609a	127	1007	58.6	1	0.0032	9

Appendix 3: Data associated with the old (18–22 year) age-group sample. Twenty seven otolith cores from 20 individual fish (which produced a total sample weight of 0.464 g before cleaning) were analysed.

Voyage	Prep. no.	Station no.	Fish no.	Length (cm)	Sex	Sample weight (g)	Estimated age (yr)
tan0101	o1	33	3002	42.3	1	0.0176	22
tan0101	o2	111	4003	69.8	2	0.0121	18
tan0101	o3	111	4004	67.7	2	0.0142	19
tan0101	o4	111	4008	59	1	0.0154	22
tan0101	o5	11	3004	46.3	1	0.0147	19
tan0101	o6	24	3009	49	1	0.0209	21
tan0101	o7	33	3001	51.2	1	0.0203	21
tan0101	o8	24	3012	65.8	2	0.0116	22
tan0101	o9	120	3007	58.2	2	0.0257	22
tan0201	o10	87	3002	62.3	2	0.0224	19
tan0201	o11	126	1005	49.3	1	0.0133	18
tan0201	o12	12	4004	65.1	2	0.0139	19
tan0201	o13	139	3002	54.2	1	0.0197	20
tan0201	o14	143	3002	62.7	2	0.0417	20
tan0201	o15	121	4005	52.5	1	0.0153	21
tan0201	o16	152	3004	50.9	1	0.0130	21
tan0201	o17	155	3001	64.9	2	0.0214	21
tan0201	o18	127	1005	56.3	2	0.0173	22
tan0201	o19	122	4005	53.1	1	0.0227	22
tan0101	o2b	111	4003	69.8	2	0.0274	18
tan0101	o3b	111	4004	67.7	2	0.0225	19
tan0101	o6b	24	3009	49	1	0.0163	21
tan0201	o10b	87	3002	62.3	2	0.0111	19
tan0201	o11b	126	1005	49.3	1	0.0121	18
tan0201	o13b	139	3002	54.2	1	0.0081	20
tan0201	o14b	143	3002	62.7	2	0.0170	20
tan0201	o309	127	1003	53.1	1	0.0138	18