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Age estimates for black oreo and smooth oreo

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

AGE ESTIMATES FOR BLACK OREO AND SMOOTH OREO

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1. EXECUTIVE SUMMARY

Smooth oreo (*Pseudocyttus maculatus*) and black oreo (*Allocyttus niger*) appear to be slow growing species, like orange roughy. Unvalidated age estimates were made by counting zones (assumed to be annual) in otolith thin sections. Maximum otolith zone counts were 86 for smooth oreo (51.3 cm total length (TL) fish) and 153 for black oreo (45.5 cm TL fish).

Smooth oreo age estimates were similar to those reported for Australian fish by Smith & Stewart (1994). However, our black oreo age estimates were higher than those made for Australian black oreo by Smith & Stewart (1994) and this discrepancy needs to be resolved. Estimated age at maturity was 30 years for female smooth oreo and 42 years for female black oreo.

2. INTRODUCTION

2.1 Overview

This FARD presents the results of oreo age estimation at MAF Fisheries (now NIWA). Estimates of age are fundamental to stock assessment. We estimated the growth parameters of smooth oreo which were used in the 1995 stock assessment of smooth oreo for area OEO 3A (Annala 1995, Doonan *et al.* 1995). Black oreo age estimates have not yet been used in a stock assessment. Age validation for black oreo and smooth oreo has not proved possible so far but is a key goal. We have been unable to sample small oreos so the partial validation techniques used by Mace *et al.* (1990) cannot be applied. Radiometric techniques have been considered, but are expensive. Australian radiometric work should provide comparative age estimates for Australian black oreo and smooth oreo.

2.2 Literature review

Mel'nikov (1982) examined whole fresh otoliths of warty oreo (*Allocyttus verrucosus*) with a binocular microscope using transmitted light, and reported a maximum age of 15 years (unvalidated), claiming also that scales observed under polarised light showed annual zones. Stewart *et al.* (1995) compared age estimates from otolith thin sections with estimates from radiometric methods for warty oreo, reported a range of 7–130 years (15.2–36.5 cm TL fish), and concluded that the similarity of the results strongly supported the age estimates. Davies *et al.* (1988) examined black oreo and smooth oreo otolith preparations including "cross sections" and were unable to establish age estimation. Preliminary (unvalidated) age estimation for black oreo and smooth oreo was given by McMillan & Hart (1991) and age estimates from otolith thin sections for these species from Australian waters was reported by Smith & Stewart (1994).

3. METHODS

3.1 Otolith samples

Smooth oreo and black oreo sagittal otoliths were selected from research samples collected from the south Chatham Rise, New Zealand. Fish were measured to the nearest 0.1 cm below actual size and weighed to the nearest 0.01 kg. Samples were taken from the two oreo management areas (OEO 3A and OEO 4) and from "hills" at the eastern end of the south Chatham Rise. Otoliths from OEO 3A came from the research surveys COR8802 and COR9004, and those from OEO 4 were from TAN9210, TAN9309, and TAN9406. A random subsample of stations was chosen and all otoliths collected at those stations were used (Table 1).

Table 1: Numbers of otoliths from the south Chatham Rise that were sectioned and used for estimating age

	Smooth oreo			Black oreo		
	OEO 3A	OEO 4	Total	OEO 3A	OEO 4	Total
Number of otoliths sectioned	335	100	435	177	108	285
Number of readable† otoliths	265	81	346	149	78	227

† Readable otoliths were given a grade of 1–4, unreadable otoliths 5 (*see* "Reading criteria" below).

In addition, a sample of 175 smooth oreo otoliths from fish less than 25 cm TL were sectioned for measurement of the distance (radius) of the first six zones from the centre of the otolith (primordium). These otoliths were sampled from a series of *James Cook* trawl surveys (JCO8404, JCO8407, JCO8410, JCO8414, and JCO8417) of the southwestern end of Chatham Rise.

3.2 Otolith preparation

Otoliths were stored in 50% isopropyl alcohol or 70% ethanol. They were removed from storage, cleaned of any saccular membrane, then air dried for about 24 h or oven dried (at 30–40 °C) for about 6 h, before being weighed to 0.1 mg. They were marked along the dorso-ventral axis with a pencil and imbedded in an Araldite block. The otolith was sawn in half along the marked axis, the sawn face was polished and glued to a glass slide, and the protruding Araldite block containing the half otolith was polished down to a thickness of about 0.2 mm on the slide. Some sections were cut directly from the otolith imbedded in the Araldite block using a double saw set to 0.6 mm. These sections were polished on one side, glued to a slide, and ground to about 0.2 mm thick. Some otoliths from fish less than 15 cm (smooth oreo) and 23 cm (black oreo) TL were viewed whole using transmitted light or were prepared for micro-increment examination (assumed "daily" zones) by mounting directly onto a slide.

3.3 Zone measurement

Otoliths for zone measurement were prepared as thin sections as above and were viewed with transmitted light under a compound microscope. The radius of each of the first six distinct opaque (dark, transmitted light) zones along the ventral/inner axis was measured using an ocular micrometer. Two readers examined these otoliths and the radii were plotted to determine if zone size was consistent in the otoliths examined.

3.4 Otolith reading

3.4.1 Protocol set

There were three readers, but reader 3 read fewer otoliths than the others. Initially, reader 1 and reader 3 conducted comparative readings for a number of otoliths. Subsequently a set of 21 (19 readable) smooth oreo otoliths (7 otoliths each from the size ranges 15–29, 30–44, and 45–60 cm TL) and 21 (16 readable) black oreo otoliths (11 from 16–27 and 10 from 28–39 cm TL size groups) were selected and a set of agreed interpretations was established between reader 1 and reader 2. These sets were re-read to re-establish reading interpretation after interruptions of more than a few days.

3.4.2 Reading criteria

The sections were viewed with transmitted light using a compound microscope at 63 or 100 times magnification. The surface of the ground otolith was moistened with a little immersion oil before reading. The opaque zones (dark) were counted from the primordium to the edge of the otolith. The first six to seven (smooth oreo) and four to five (black oreo) zones were much wider than the rest and are possibly formed during the pelagic early life of these fish. The first zone was often difficult to establish because of what was considered a "false" zone in some preparations. Each reading was assigned a subjective readability value (1 = clear and unambiguous, 2 = clear but one to a few zones are ambiguous, 3 = readable but difficult, 4 = counts made with great difficulty, 5 = unreadable). The ventral (usually) or the dorsal axis of the otolith was read depending on which showed the clearer zones. A readability of 2 was assigned when both axes could be counted and gave similar values. Readers 1 and 2 read all the smooth oreo and the black oreo otolith sets. Reader 3 read part of the smooth oreo set. A minimum of two independent readings was made by each reader for each otolith. The second reading from each reader was compared and otoliths were re-read where between reader variation was greater than five years.

3.5 Analysis

The second or third otolith readings were taken as the "final" readings for each reader. Any count where the readability of the otolith was 4 or less for all readers was used, e.g., for two readers, zone counts were not used if one reader had a 5 but the other reader a readability of 1–4 for the same otolith. The data from reader 3 were used only in the analysis of reader consistency.

"Mean age" used in the analyses below depended on context. For between-reader comparisons, it is defined as the mean of the final readings from the two or three readers for each fish otolith. For within-reader work, it is the mean of the first and final readings of the same reader.

3.5.1 Reading error calculations

The reading error coefficient of variation (*c.v.*) for each fish was estimated from s_i / a_i where a_i is the mean age for the *i*th fish and

$$s_i^2 = \sum_j \frac{(a_{ij}-a_i)^2}{n_i-1}$$

For between-reader errors, a_{ij} is the age of fish i by the jth reader. For within-reader error, a_{ij} is the jth age estimate of fish i by the same reader.

3.5.2 Fitting a general equation for growth

Data from each sex were treated separately for both oreos species because females grow to a larger size than males.

Smooth oreo
Fish aged at less than 15 years were combined as an unsexed group and were used for the analysis of age estimates for each sex. The von Bertalanffy growth curve was used to describe growth. The parameters were estimated by minimising:

$$\sum_i (l_i - f(age_i))^2$$

where l_i is the length of fish i, age_i is its age, and $f(x)$ the von Bertalanffy curve,

$$L_\infty(1-e^{-K(x-t_0)}) \quad .$$

The minimisation is with respect to the parameters L_∞, K, and t_0.

Black oreo
Black oreo less than about 23 cm TL are rarely caught by bottom trawl (because they probably live pelagically), but data for eight fish caught in bottom trawls are available. When these are included in the data to estimate growth they caused a poor fit between the data and the estimated von Bertalanffy curve. Therefore, only growth for fish that were greater than or equal to 23 cm TL was estimated. Only growth of fish that have recruited to the fishery, i.e., greater than 27 cm, is of interest for stock assessment. The log-likelihood was altered to allow for length-at-age distributions which are truncated at lengths below 23 cm, i.e.,

$$-0.5\ n \log \sigma^2 \ -0.5 \sum_i (l_i - f\ (age_i))^2/\sigma^2 - \sum_i \log\{1 - F\ [(23 - f\ (age_i)/\sigma]\}$$

where σ^2 is the variance of length at age, n is the sample size, and $F[x]$ is the cumulative standard normal function. The last term is needed to normalise the truncated normal distribution. To evaluate $F[x]$, which cannot be expressed in an analytic form, the approximation,

$$H(x) = 0.5(G(x) + G(-x))$$

was used, where

$$G(x) = 1 - [1 + (0.644693 + 0.161984\ x)^{4.874}]^{-6.158}$$

(Johnson & Kotz 1970). This approximation has a maximum error of 0.00046.

3.5.3 Estimation of age at maturity (A_m)

Mean length at maturity for female black oreo and smooth oreo was calculated using a probit analysis (Pearson & Hartley 1976; Chris Francis, NIWA, Wellington, pers. comm.). This analysis used length and macroscopic gonad stage data collected from six south Chatham Rise trawl surveys, i.e., ARR8603, AEX8702, COR9004, TAN9104, TAN9210, and TAN9309. All these surveys took place at or just before the spawning season for oreos, i.e., October-November. Fish with gonad stages of 3–7 were classed as mature (spawned or likely to spawn that year) and those with gonad stages of 1–2 were classed as immature (very unlikely to spawn that year). Pankhurst *et al.* (1987) defined macroscopic gonad staging for oreos. The data used in the analysis were: the mean length of fish in each 1 cm length class, the number of mature fish in that length class, and the total number of fish in that length class. The mean age at maturity was calculated from the mean length at maturity using an age-length key resulting from the age estimation results from this study listed below.

4. RESULTS

4.1 Smooth oreo

The maximum mean age was 86 years for a 51.3 cm TL female fish.

The variability of the first and final readings of the otoliths made by two readers was examined (Figures 1–2). [To avoid clutter in Figures 1–3 and 13–15 the mean *c.v.* for each age is plotted, rather than the *c.v.* for all estimated ages. However, the smoothed curve is based on the *c.v.*s for all estimated ages.] There were some slight differences between readers: reader 1 had a constant *c.v.* of about 9%, but reader 2 had a declining *c.v.* with age, from about 12–15 % for ages under 15 down to 5–7% for those over 30. The variability of the final readings of the same otolith between readers 1 and 2 (Figure 3) shows a similar trend and magnitude to the within-reader variability, indicating that otolith interpretation was roughly consistent between readers.

Comparison of final readings from the three readers (Figures 4–6) showed that otolith reading was similar between the readers.

A plot of otolith weight against mean age (Figure 7) indicates a linear relationship. The distributions of the radii of each zone show that they are separate for the first two or three zones (Figure 8). The mean of the radii increase smoothly but at a decreasing rate as the zone number (age) increases. This pattern is observed in other species whose ageing has been proved accurate, although we do not claim that this observation validates our age estimates for smooth oreo.

Growth curves are shown in Figure 9 (males) and Figure 10 (females) and life history parameters for each sex are given in Table 2. Residuals of length from the von Bertalanffy curves (Figures 11 and 12) show no trend for most of the data. There are indications of bias where there are few data, e.g., females greater than 40 years. Inadvertently, a 64.2 cm TL, mean age 73 years, specimen from the "Arrow Plateau" on the north Chatham Rise was included in the otolith samples and shows up as an outlier in the residuals. This and our preliminary readings of smooth oreo otoliths from the Puysegur area indicate that fish from different areas should be analysed separately to determine if they have different growth rates.

Table 2: Life history parameters for oreos estimated in this paper unless otherwise noted. –, not estimated

Parameter	Symbol (unit)	Smooth oreo Female	Smooth oreo Male	Black oreo Female	Black oreo Male
Natural mortality	M (yr^{-1})	0.05	0.05	–	–
Age at recruitment	A_r (yr)	20	20	–	–
Age at maturity	A_m (yr)	30	30	42	–
von Bertalanffy parameters	L_∞ (cm, TL)	52	41	44.4	43.0
	k (yr^{-1})	0.046	0.080	0.019	0.017
	t_0 (yr)	-2.9	-1.0	-35.1†	-42.5†
Length–weight parameters*	a	0.029	0.032	0.008	0.016
	b	2.90	2.87	3.28	3.06
Recruitment steepness‡		0.75	0.75	0.75	0.75
Length at recruitment§	(cm)	34	–	27	–
Length at maturity	(cm)	40	–	34	–

† These parameters were estimated for the growth of post-settlement fish (≥ 23 cm TL) only
* Calculated from research survey data (TAN9104, TAN9210 & TAN9309)
‡ Assumed value, (*see* Francis 1990)
§ Calculated from observer collected length data, *see* p. 7 of McMillan & Hart (1994)

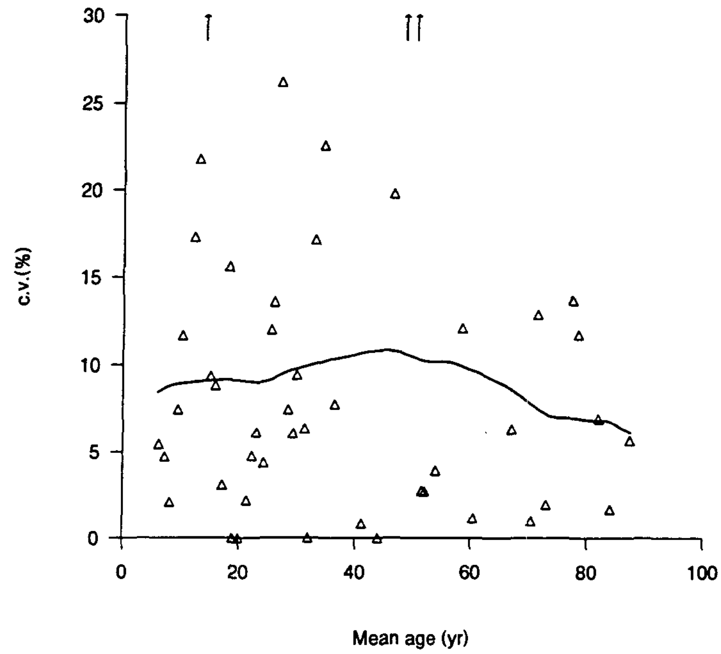

Figure 1: **Smooth oreo within-reader error (mean of the *c.v.*(%) for each fish, Δ) for reader 1, plotted for each mean age, where "mean age" is the mean of the first and second (or third) counts for each otolith. The solid line is a smoothed curve through the data. Arrows indicate positions of points off the plot.**

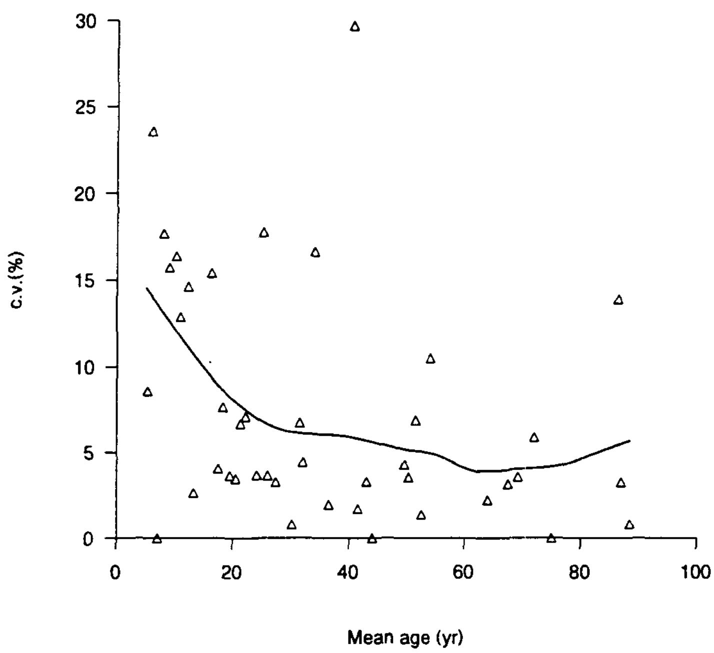

Figure 2: **Smooth oreo within-reader error (mean of the *c.v.*(%) for each fish, Δs) for reader 2, plotted for each mean age, where "mean age" is the mean of the first and second (or third) counts for each otolith. The solid line is a smoothed curve through the data.**

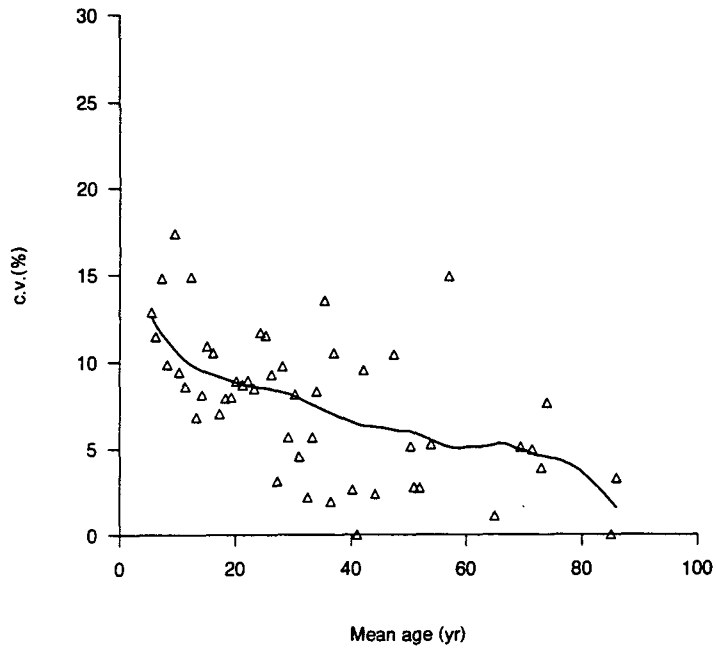

Figure 3: **Smooth oreo between-reader error (mean of the *c.v.*(%) for each fish, ∆s) for each mean age, where "mean age" is mean of the final readings for reader 1 and reader 2. Solid line is a smoothed curve through the data.**

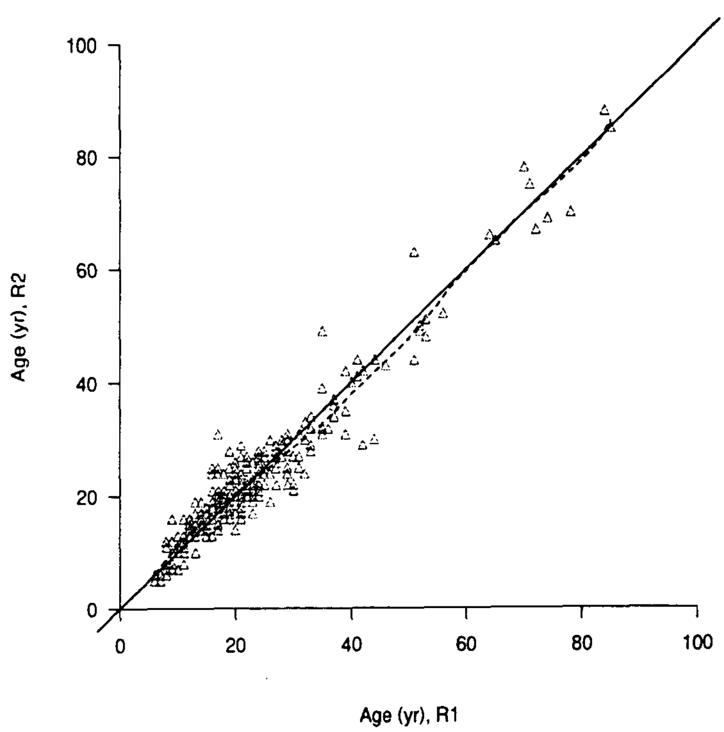

Figure 4: **The consistency of smooth oreo age readings between readers 1 (R1) and 2 (R2). The solid line is the 1:1 line and the dashed line is a smoothed curve through the data.**

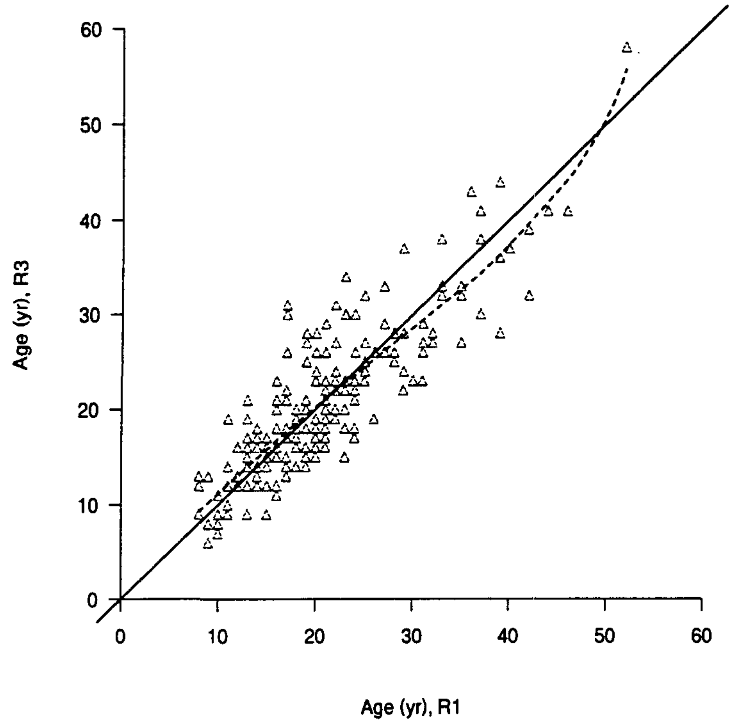

Figure 5: The consistency of smooth oreo age readings between readers 1 (R1) and 3 (R3). The solid line is the 1:1 line and the dashed line is a smoothed curve through the data.

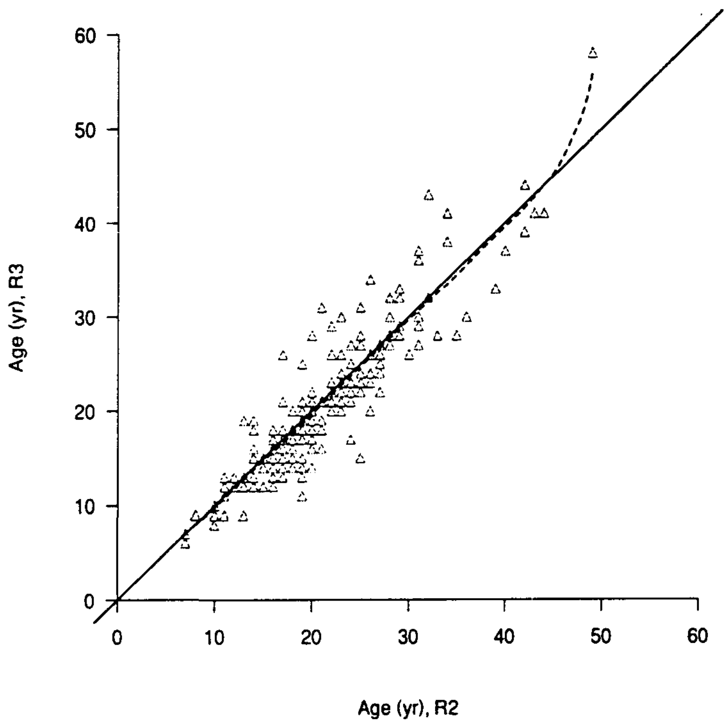

Figure 6: The consistency of smooth oreo age readings between readers 2 (R1) and 3 (R3). The solid line is the 1:1 line and the dashed line is a smoothed curve through the data.

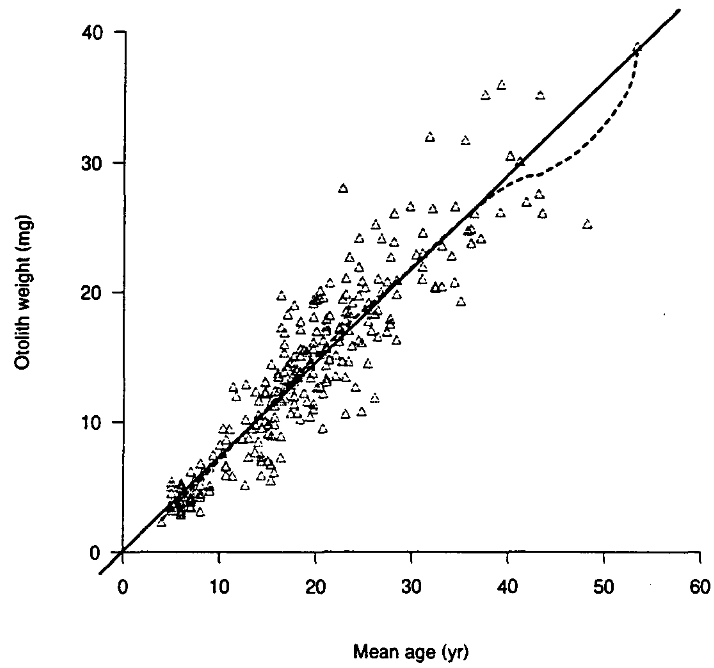

Figure 7: **Smooth oreo otolith weight versus mean age, where "mean age" is the mean of the final readings of reader 1 and 2. The solid line is a regression line, and the dashed line is a smoothed curve through the data.**

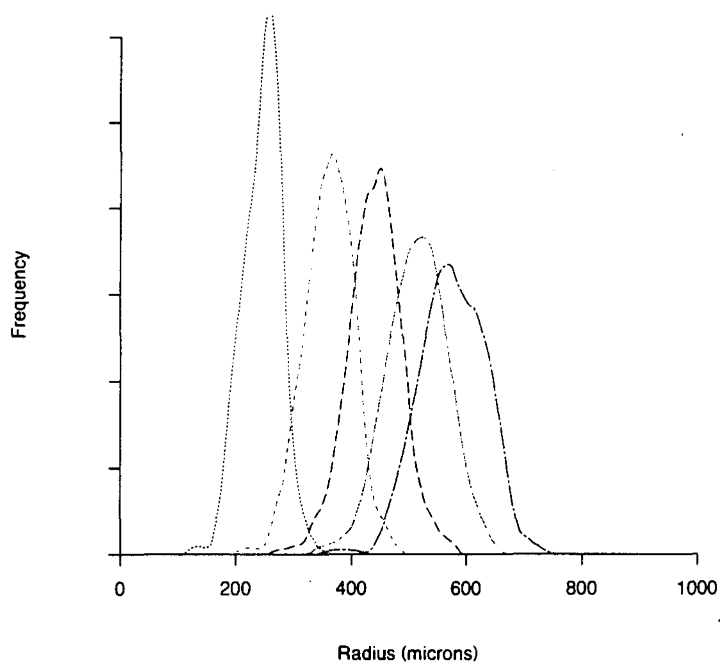

Figure 8: **The distributions of the radii of the inner 5 zones in smooth oreo otolith sections. Each line type is for a different zone. "Frequency" on the Y axis is a relative measure of the proportion at each radius.**

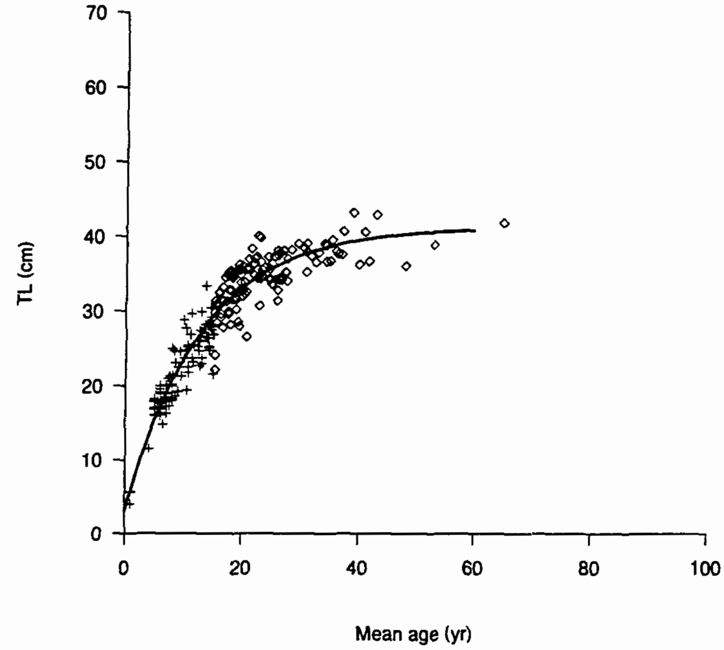

Figure 9: Growth of male smooth oreo. Mean age, i.e., the mean of final counts from the same otolith by readers 1 and 2 are plotted as ◇ for means > 15 years or as + for means ≤ 15. A von Bertalanffy curve is fitted to the data.

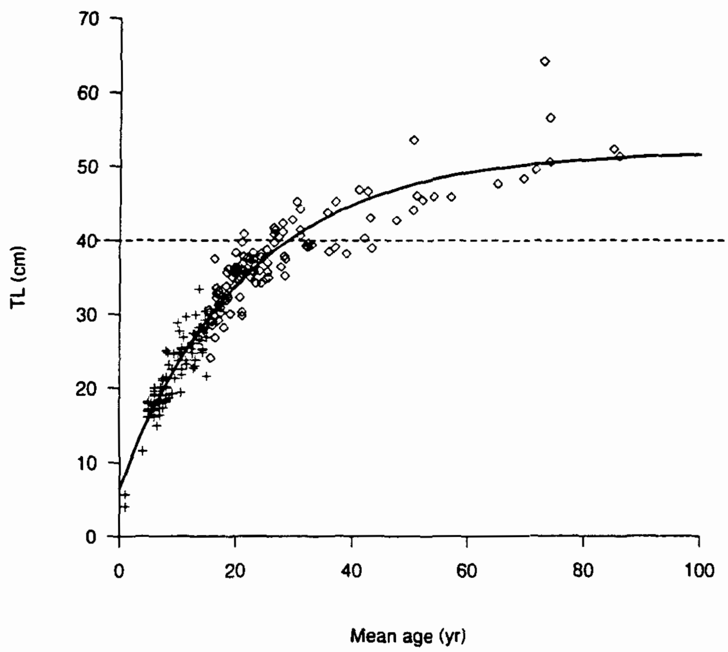

Figure 10: Growth of female smooth oreo. Mean age, i.e., the mean of final counts from the same otolith by readers 1 and 2 are plotted as ◇ for means > 15 years or as + for means ≤ 15. A von Bertalanffy curve is fitted to the data. The horizontal line is the length at maturity.

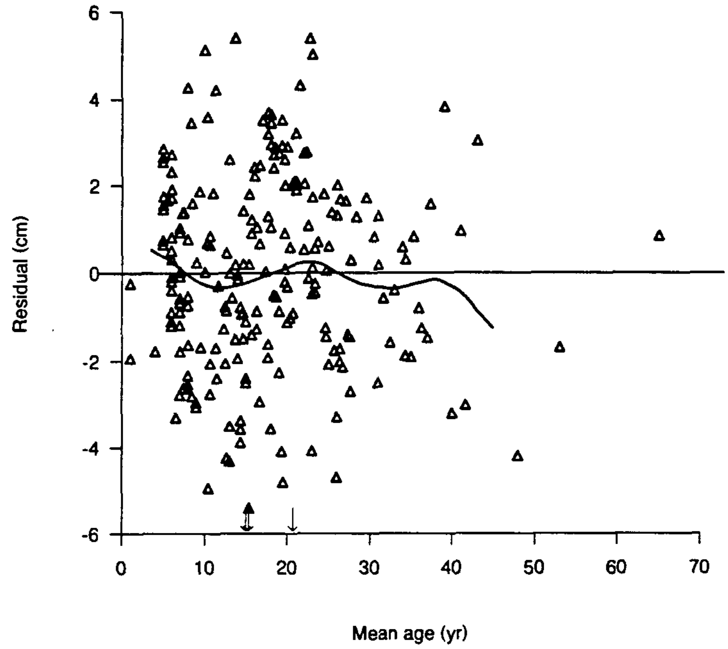

Figure 11: **Growth of male smooth oreo. Residuals (cm) from the von Bertalanffy curve. A smooth curve through the data has been plotted. Arrows indicate positions of points off the plot.**

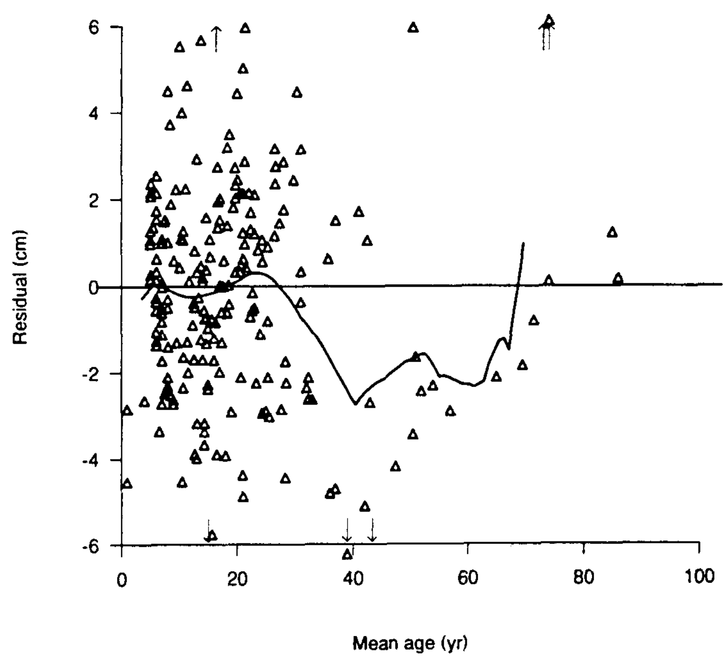

Figure 12: **Growth of female smooth oreo. Residuals (cm) from the von Bertalanffy curve. A smooth curve through the data has been plotted. Arrows indicate positions of points off the plot.**

4.2 Black oreo

The maximum mean age was 153 years for a 45.5 cm TL female fish.

The variability of the first and final otolith readings made by two readers was higher for black oreo than for smooth oreo, reflecting anecdotal observation that the otoliths are "harder to read" than those of smooth oreo. The two readers had slightly different error patterns, i.e., reader 1 had a higher *c.v.* (about 13%) for fish less than 20 years which declined to about 8% for fish of about 80 years; reader 2 had a lower *c.v.* for younger fish (about 9%) which declined to about 7% at 80 years (Figures 13 and 14). The between reader variability was high for fish less than 20 years old, but declined to about 7% for fish of about 80 years (Figure 15). This shows a similar trend and magnitude to the within-reader variability, indicating that otolith interpretation was more or less consistent between readers.

Comparison of final readings from the two readers (Figures 16) also showed that otolith reading was consistent between readers. A plot of otolith weight against mean age indicates a linear relationship, although the regression line does not pass through the origin (Figure 17).

Growth curves are shown in Figures 18 (males) and 19 (females) and growth parameters for each sex are given in Table 2. Residuals of the length for males and females from the von Bertalanffy curves for fish greater than or equal to 23 cm TL (Figures 20 and 21) show a slight bias for both sexes for fish less than about 30 years old. This is due to the absence of fish less than 23 cm TL from the samples, resulting in the observed mean length being greater than the theoretical (expected) length. There is no trend for the rest of the residuals except where there are only a few data points.

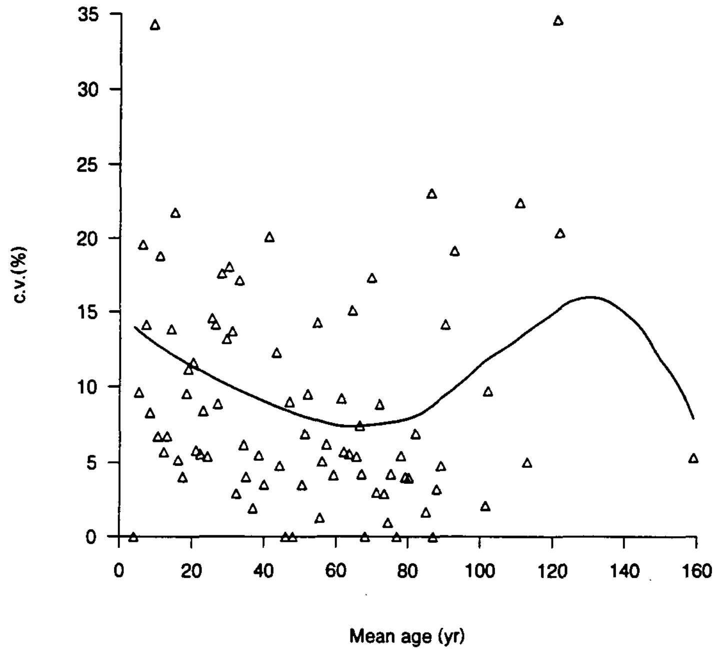

Figure 13: Black oreo within-reader error (mean of the *c.v.*(%) for each fish, ▵) for reader 1 plotted for each mean age, where "mean age" is the mean of the first and second (or third) counts for each otolith. The solid line is a smoothed curve through the data.

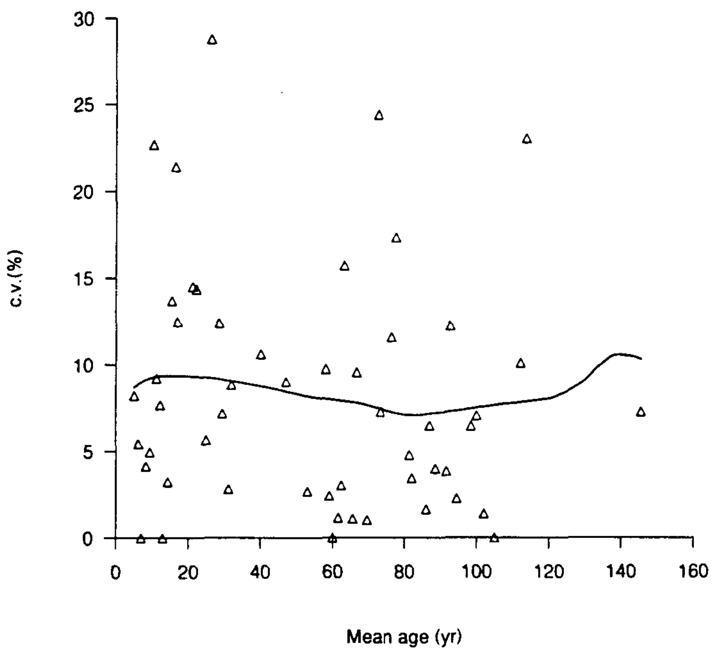

Figure 14: Black oreo within-reader error (mean of the *c.v.*(%) for each fish, ▵) for reader 2 plotted for each mean age, where "mean age" is the mean of the first and second (or third) counts for each otolith. The solid line is a smoothed curve through the data.

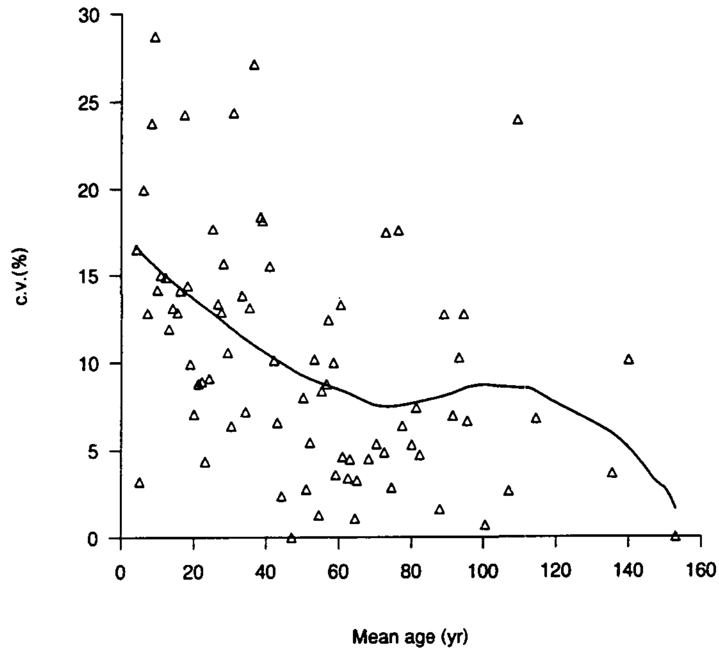

Figure 15: **Black oreo between-reader error (mean of the *c.v.*(%) for each fish, △) for each mean age, where "mean age" is mean of the final readings for reader 1 and reader 2. The solid line is a smoothed curve through the data.**

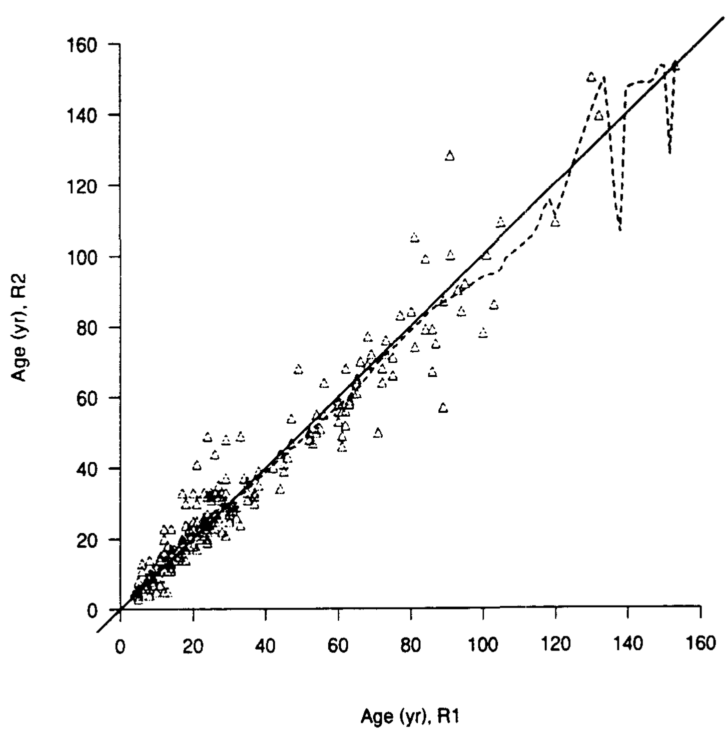

Figure 16: **The consistency of black oreo age readings between readers 1 (R1) and 2 (R2). The solid line is the 1:1 line and the dashed line is a smoothed curve through the data.**

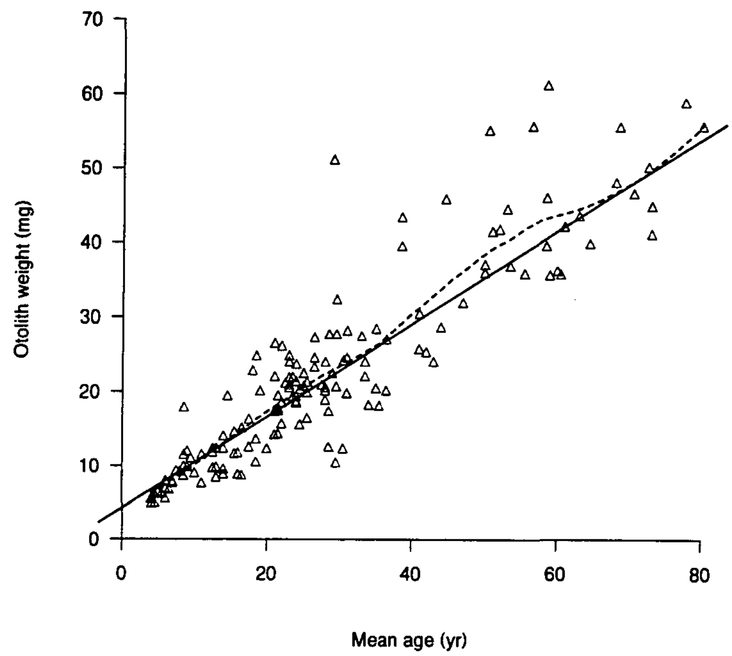

Figure 17: **Black oreo otolith weight versus mean age, where "mean age" is the mean of the final readings of reader 1 and 2. The solid line is a regression line, and the dashed line is a smoothed curve through the data.**

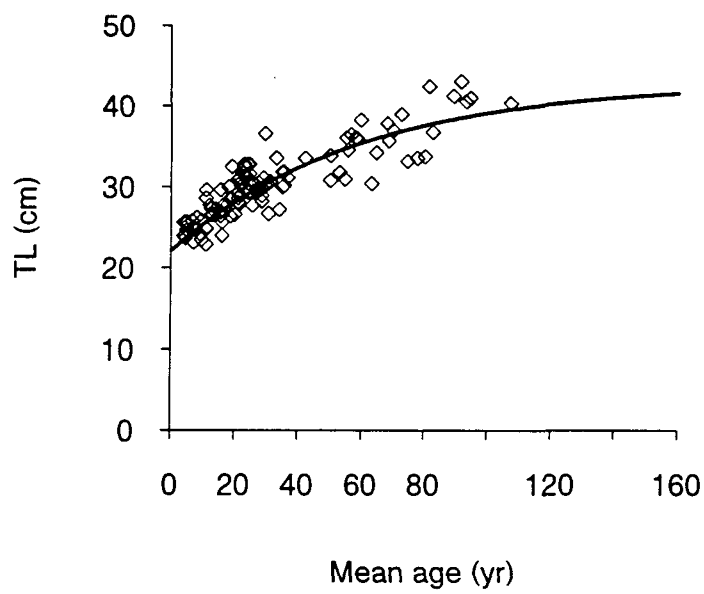

Figure 18: **Growth of male black oreo. Mean age, i.e., the mean of final counts from the same otolith by readers 1 and 2. Only fish 23 cm TL or over are plotted and a von Bertalanffy curve (solid line) is fitted to the data.**

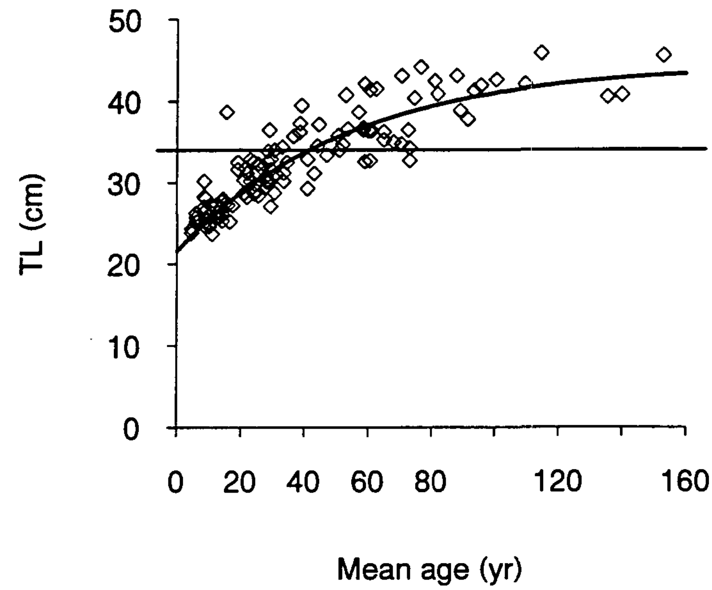

Figure 19: **Growth of female black oreo. Mean age, i.e., the mean of final counts from the same otolith by readers 1 and 2. Only fish 23 cm TL or over are plotted and a von Bertalanffy curve (solid line) is fitted to the data. The horizontal line is the length at maturity.**

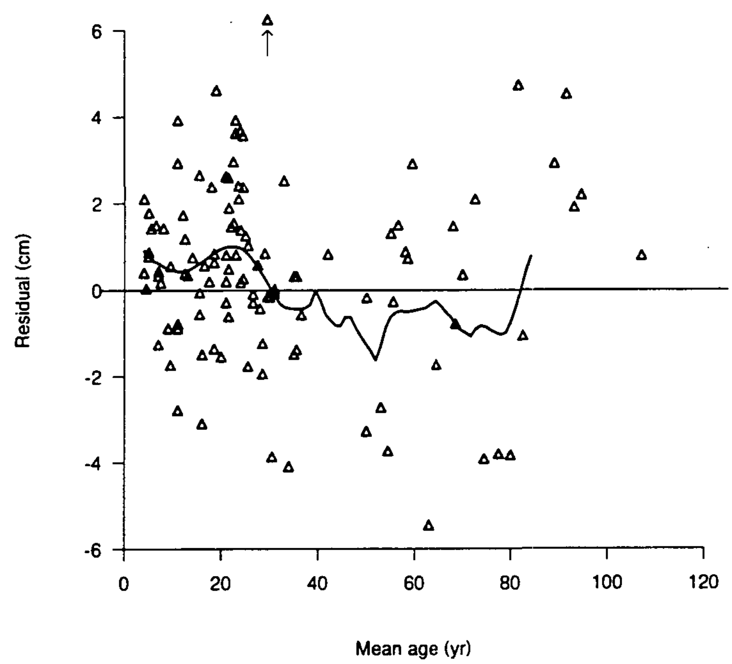

Figure 20: **Growth of male black oreo. Residuals from the von Bertalanffy curve for fish 23 cm TL or over. A smooth curve has been plotted. The arrow indicates a point off the plot.**

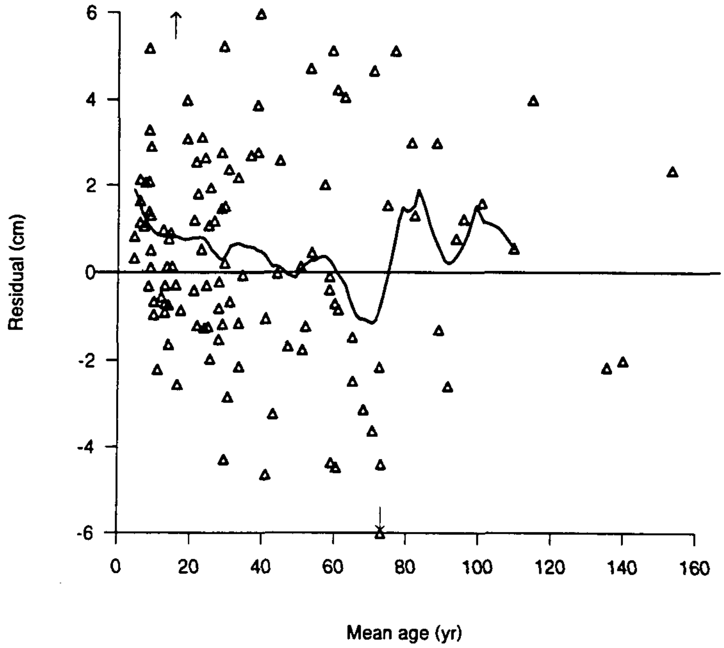

Figure 21: Growth of female black oreo. Residuals from the von Bertalanffy curve. A smooth curve for fish 23 cm TL or over has been plotted. The arrows indicate points off the plot.

4.3 Age at maturity (A_m)

Mean length at maturity results from the probit analysis for the six trawl surveys for black oreo and smooth oreo are presented in Tables 3 and 4. The values are similar for all years except for those from 1987 for both species. The mean values from all surveys (excluding the 1987 values), rounded to the nearest centimetre are 34 and 40 cm TL for black oreo and smooth oreo respectively. This corresponds to an age at maturity of 30 years for female smooth oreo and 42 years for black oreo.

Table 3: Mean length at maturity (cm TL) estimates for female smooth oreo, made from a series of research surveys on the south Chatham Rise, 1986–93

Year	Mean length	95% CI	No. of fish†	No. of mature fish‡
1986	39.3	38.9–39.7	1 288	301
1987	36.7	36.4–37.1	1 122	323
1990	40.6	40.0–41.3	1 090	153
1991	39.8	39.2–40.4	722	94
1992	39.6	39.3–39.8	3 284	892
1993	39.5	39.3–39.7	5 421	1 196

† All fish sampled for gonad stage during the survey (stages 1–7)
‡ Stages 3–7.

Table 4: Mean length at maturity (cm TL) estimates for female black oreo, made from a series of research surveys on the south Chatham Rise, 1986–93

Year	Mean length	95% CI	No. of fish†	No. of mature fish‡
1986	33.8	33.5–34.1	1 285	374
1987	32.7	32.5–32.9	1 278	384
1990	34.1	33.9–34.4	1 110	277
1991	33.8	33.5–34.1	717	215
1992	34.1	33.8–34.3	1 439	609
1993	34.6	34.4–34.8	2 161	687

† All fish sampled for gonad stage during the survey (stages 1–7)
‡ Stages 3–7.

4.4 Estimate of natural mortality for smooth oreo

Natural mortality (*M*) was estimated from

$$M = \frac{\ln 100}{A_{max}}$$

where A_{max} is the maximum reported age.

An estimate of *M* derived from the Australian data of Stewart & Smith (1993) was used in the stock assessment for smooth oreo in 1995. The revised data in Smith & Stewart (1994) were received after the assessment was complete. The Australian data were used because they were considered to be from a lightly exploited population, in contrast to New Zealand populations which have at least 10 years of fishing. Stewart & Smith (1993) reported a maximum age of 90 years, in contrast to a maximum age of 78 years in Smith & Stewart (1994). The former age gives an estimate of 0.051 for *M*. The maximum age from our reading was 86 years, giving an *M* of 0.054.

5. DISCUSSION

These age estimates for oreos are unvalidated, but it is highly likely that the clear zones visible in otolith sections (Figures 22 and 23) represent some constant time interval. There are indications that the otolith zone counting methods used by us and by the Australians (Smith & Stewart 1994) are consistent and are indexing periodicity. These include the linear relationship between otolith weight and age seen in our results. A linear relationship between otolith weight and age occurs in many other fish species (*see* Boehlert 1985), although estimated age only needs to be correlated with true age for this relationship to be seen. This relationship is not quite so good for black oreo because the regression line does not pass through the origin (*see* Section 5.2 below). The smoothly decreasing spacing of the first few zones (radii) of smooth oreo otoliths also implies periodicity.

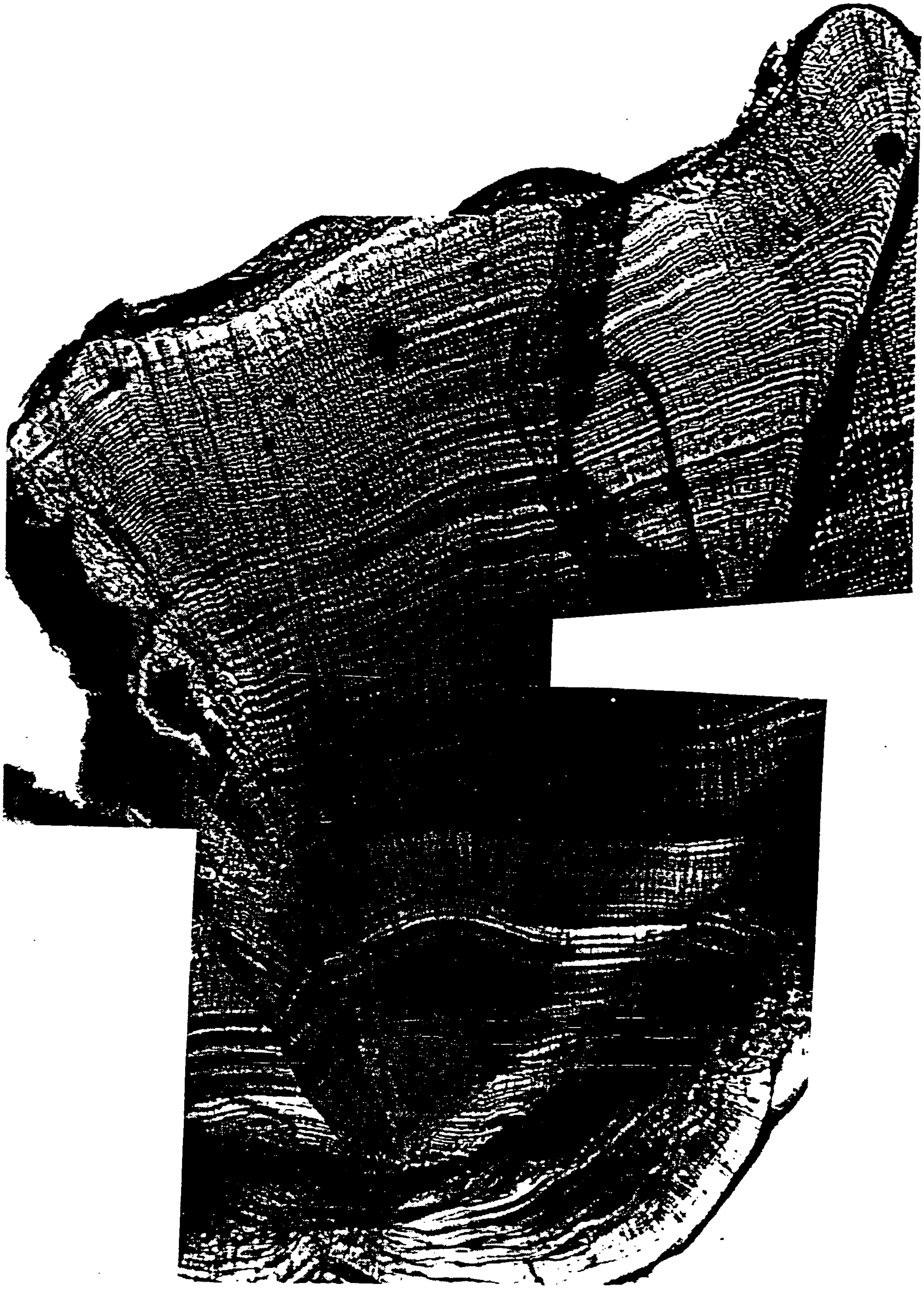

Figure 22: Smooth oreo otolith section from a female of 52.3 cm TL viewed by transmitted light. Mean zone count was 85.

Figure 23: Black oreo otolith section from a male of 41 cm TL viewed by transmitted light. Mean zone count was 95.

Age estimates made by other methods (e.g. radiometric analysis) should establish the periodicity of the visible zones. Validation may also be possible from measurements of radiocarbon resulting from nuclear bomb testing in the 1950s and 1960s. This work is being carried out by John Kalish (now at the Australian National University, Canberra). Radiometric age estimates for smooth oreo and black oreo are being carried out for Australian specimens by Australian workers (*see* Smith & Stewart 1994). Radiometric methods have been used to age orange roughy (Fenton *et al.* 1991) and warty oreo (Stewart *et al.* 1995). Smith & Stewart (1994) claimed that the partial validation of warty oreo age estimates by Stewart *et al.* (1995) supported their interpretation of the otoliths of spiky, black, and smooth oreos.

5.1 Smooth oreo

Age estimates similar to ours were reported by Smith & Stewart (1994) who read 131 sectioned Australian otoliths (Table 5). Their reported average percent reader error was lower than ours (Table 6). Smith and Stewart's sample contained fish that ranged in age from 7 to 78 years (18.1–54.0 cm TL), and their estimate of L_∞ = 51 cm for both sexes combined was close to our value for females (52), but more than our value for males (41 cm). They reported a length at maturity of 41 cm TL for females which corresponds to an age at maturity of about 35 years when read from their length-age plot (their figure 4.5a), though they reported about 25 years for females in the text. Their age at maturity estimate (35) is higher than ours (30 years).

Table 5: Life history parameters for oreos reported by Smith & Stewart (1994), plus revised A_m values

Parameter	Symbol (unit)	Smooth oreo Male & female	Black oreo Male & female
Age at maturity (in text)	A_m (yr)	20† & 25‡	20
Revised age at maturity*	A_m (yr)	35§	33§
Maximum age	A_{max} (yr)	78	100
von Bertalanffy parameters	L_∞ (cm, TL)	50.94	41.10
	k (yr^{-1})	0.051	0.052
	t_0 (yr)	-1.05	-10.30

* Read from the length-age plot (figure 4.5a) for a length at maturity of 41 cm TL
§ Females only
† Males
‡ Females

Table 6: Average percent errors for New Zealand (this study) and Australian otolith readings (Smith and Stewart, 1994), calculated using the method of Beamish and Fournier (1981)

	New Zealand			Australian	
	Between	Within		Between	Within
		Reader 1	Reader 2		
Smooth oreo	6.1	6.5	5.3	4.2	3.8
Black oreo	8.4	6.0	7.0	4.4	4.4

5.2 Black oreo

Smith & Stewart (1994) read 127 Australian black oreo otolith sections and their reported average reader error was lower than ours (Table 6). The Australian fish ranged in age from 8 to 100 years (28.1–43.5 cm TL) and their estimate of L_∞ = 41 cm for both sexes combined is slightly lower than our results (44 for females and 43 for males). They reported a length at maturity of 36 cm TL for females which corresponds to an age at maturity of 33 years when read off their length-age plot (their figure 5.5a), though they reported about 20 years in the text. Our age at maturity (42 years) is much higher than the Australian value.

When Smith and Stewart's growth curve (for both sexes) is plotted with our female growth curve it is clear that their ages are substantially lower than ours. The curves roughly coincide when our counts for fish with more than 10 zones were halved. Further work between the two laboratories is needed to resolve the discrepancy.

The relationship of otolith weight and mean age (*see* Figure 17) was examined by bootstrapping the linear regression of these two variables to determine if the *y*-intercept was significantly different from zero. The resulting 99% confidence interval for values of the *y*-intercept did not include the value 0, i.e., the regression line did not pass through the origin, but closer inspection of the data showed that the otolith weights from fish that were 10 years or younger were mostly below the "all data" regression line. A linear regression excluding data from fish older than 10 years produced a line that passed through the origin. This suggests a "broken-stick" relationship between otolith weight and mean age. A similar relationship was reported for *Sebastes diploproa* (Boehlert 1985).

The Australian samples did not contain any fish less than 28 cm TL so their growth curve is based only on larger fish. We had eight fish less than 23 cm TL, but when we attempted to fit the von Bertalanffy curve to these data as well, the resulting curve could not accommodate the data from the eight small fish. Two explanations are suggested. Firstly, that small fish have a much faster growth rate than that implied by the von Bertalanffy curve for the larger fish. Radically different growth rates may be due to different modes of life, i.e., pelagic early life and benthopelagic later life. Secondly, we have over-estimated the age of the larger fish. We plan to approach our Australian colleagues to compare readings of the same otoliths to test this possibility. We also await the results of their radiometric work on black oreo (and smooth oreo) which could provide a validation for age estimates from otolith sections.

5.3 Age at maturity (A_m)

Mean length at maturity and the consequent age at maturity (A_m) for females seem high, i.e., 30 years at 40 cm for smooth oreo and 42 years at 34 cm for black oreo. A similar value has been estimated for orange roughy, i.e., A_m for females of 34 years using assumed spawning marks observed in otolith sections (Doonan 1994).

A proportion of the females in both oreo populations may not spawn every year. These fish would be at gonad stage 2 and would cause the mean length at maturity in the research survey samples to be larger than expected. Analysis of the numbers of stage 2 female fish at a given total length showed that the proportion of stage 2 fish over 40 cm TL declined rapidly to almost zero, giving little support for a hypothesis that smooth oreo do not spawn every year.

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