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EXECUTIVE SUMMARY

Tracey, D.M., George, K., & Gilbert, D.J. 2000: Estimation of age, growth, and mortality parameters of black cardinalfish (*Epigonus telescopus*) in QMA2 (east coast North Island). ***New Zealand Fisheries Assessment Report 2000/27.*** **21 p.**

This report addresses Objective 2 of Project CDL9801 – "To determine age and growth and estimate natural mortality rate of black cardinalfish in QMA 2."

Biological samples were collected randomly from the established black cardinalfish fishery in QMA 2. Otolith structures formed the basis for a detailed investigation into the age structure and growth characteristics of black cardinalfish. An ageing methodology was developed but has not been validated. Counts of growth zones from sectioned otoliths were used to determine ages. Growth parameters and natural mortality were estimated from these data.

Maximum age over 100 years, a slow growth rate, and apparent high ages at recruitment and maturity show black cardinalfish to be a long-lived species with low productivity. A von Bertalanffy growth curve was fitted to length at age data for 722 fish. The calculated von Bertalanffy growth parameters were $L_\infty = 70.8$ cm, growth coefficient $k = 0.035$, $t_0 = -6.32$ y.

From the proportion at age data, full recruit age of black cardinalfish appeared to be about 45 years. Using the Chapman-Robson technique with recruited age of 45 y, natural mortality (M) was estimated to be 0.034.

For adult black cardinalfish, we were unable to validate the ageing technique using marginal increment analysis of otoliths. Even at high magnification marginal increments were not discernible in adult fish. Marginal increments on juvenile otoliths, however, provided some evidence of annual periodicity. As with other long-lived deepwater species, validation remains a high priority.

1. INTRODUCTION

Several species of cardinalfish (Family Apogonidae) are found in New Zealand waters, but only the black cardinalfish (*Epigonus telescopus*) is fished commercially. It is widespread throughout the EEZ at depths of 300–1100 m (Anderson *et al.* 1998). Cardinalfish have a global distribution, with *E. telescopus* also fished in small quantities in the North Atlantic Ocean and off South Africa. The fishery in New Zealand is one of the largest and most established. The preferred depth range of schools of black cardinalfish fished by commercial vessels is 600–1000 m (Field *et al.* 1997).

Commercial fisheries for black cardinalfish in New Zealand developed in the early 1980s in association with trawl fisheries for orange roughy (*Hoplostethus atlanticus*), alfonsino (*Beryx splendens*), and bluenose (*Hyperoglyphe antarctica*). The main fishing grounds are in QMA 2 between Cape Kidnappers and East Cape, in QMA 1 in the Bay of Plenty, and outside the Exclusive Economic Zone (EEZ) on the northwest Challenger Plateau. A smaller fishery operates off the southeast coast of the South Island (Figure 1).

Total commercial catches of black cardinalfish increased dramatically from a few hundred tonnes (t) in the early 1980s to 1800 t in 1986–87. This increase was in association with the development of the orange roughy fisheries on Ritchie Banks and Tolaga Hill in QMA 2. Reported catches from these areas peaked at 4300 t in 1990–91 and have fluctuated between 1100 and 2600 t since then.

There was a steady decline in standardised catch per unit effort (CPUE) indices in QMA 2 between 1989 and 1993. In 1994 black cardinalfish CPUE dropped to 16% of its 1989 value, and since then has fluctuated between 10 and 23 % (Field & Clark unpublished results).

Black cardinalfish was introduced into the Quota Management System on 1 October 1998 and the TACC set for QMA 2 was 2223 t (Annala *et al.* 1999). Before the work presented in this report, there had been no formal stock assessment. The overall objective of the present study was to carry out a stock assessment of black cardinalfish, including estimating biomass and sustainable yield.

This document reports on a market sampling programme carried out to obtain biological data and otoliths to estimate age and growth parameters and rate of natural mortality (Objective 2 of MFish Project CDL9801).

2. BACKGROUND BIOLOGICAL INFORMATION

There has been little research on black cardinalfish in New Zealand. A summary of biological information was complied by Field *et al.* (1997) who showed the average size landed by the commercial fishery is 50–60 cm fork length (FL) and that black cardinalfish reach a maximum length of about 75 cm FL.

Reproductive biology is not well known. Indications from research surveys and the Ministry of Fisheries Observer Programme data (Field *et al.* 1997) are that spawning may occur in May-June, with fish becoming sexually mature at 40–50 cm length. Pshenichny *et al.* 1986 (in Vinnichenko 1997) presented some biological information on *Epigonus telescopus* in the Corner Rising Seamount area in the Russian EEZ. These fish ranged from 32 to 85 cm, with most specimens being 38–47 cm in length. Spawning was said to take place in spring-summer.

Prey items evidenced from research surveys in New Zealand waters include mesopelagic fish, natant decapod prawns, and octopus. Pshenichny *et al.* 1986 (in Vinnichenko 1997), investigated deepwater species over seamounts in the eastern area of the Saragasso Sea: *E. telescopus* in this area had a similar diet to the New Zealand specimens.

Tracey (1993) reported mean mercury levels of 1.47 $mg.kg^{-1}$ in flesh samples of black cardinalfish from the Bay of Plenty. Flesh samples from the Challenger Plateau had mean levels of 1.02 $mg.kg^{-1}$ (Field *et al.* 1997). These levels are well above the maximum permissible level of 0.5 $mg.kg^{-1}$ set by the New Zealand Department of Health.

3. PREVIOUS WORK ON AGE AND GROWTH

Fish age is customarily determined by counting zones in the banding patterns seen in bony structures, especially otoliths and scales. Validation studies have shown that the variation in the zones reflect variations in growth rate. Otoliths are considered more reliable than scales for age estimation (Haedrich 1997). Assumed annual dark and light zones are counted microscopically for estimating age.

Several samples of black cardinalfish otoliths had been collected from various areas in the New Zealand EEZ before this study, but no detailed age and growth studies had been carried out. In the early 1990s a small sample of black cardinalfish otoliths were collected from the Bay of Plenty as part of a study of mercury levels in black cardinalfish (Tracey 1993). These otoliths were transversely sectioned and baked, and age estimated using counts of dark and light zones. The age data indicated that fish of 45–72 cm FL were 15 to 42 years (Tracey 1993). Pshenichny *et al.* (in Abramov 1991) examined whole otoliths and considered that *Epigonus telescopus* on the North Atlantic Ridge attained a length of about 70 cm at only 10 years. Pshenichny *et al.* in Vinnichenko (1997) stated that *Epigonus telescopus* become sexually mature at age 7.

4. METHODS

4.1 Samples from commercial catch

Samples of black cardinalfish were obtained as part of a market sampling programme from commercial landings in QMA 2. The weight of each landing was recorded and when possible specific information on the location of the landing and the number of tows that contributed to it was noted. To help determine the sampling regime, the black cardinalfish QMA 2 commercial catch data from the previous 3 years provided by the Ministry of Fisheries were examined for seasonal patterns in the fishery. Monthly samples of otoliths were required for an age validation study involving an examination of the state of the otolith margin throughout the year. An effort was made to ensure samples were collected during less intense fishing periods so that adequate samples were available for the age validation study. Data were also examined to plan the sampling regime for the mortality estimate. More from the main period of fishing were required for the mortality estimate to ensure that the population structure was sampled adequately.

About 200 fish were selected randomly from 15 landings and measured to the nearest centimetre below the fork length (FL). Sex and reproductive state (reference) were recorded, and a random subsample of otoliths collected and stored dry in coded paper envelopes.

A minimum of 30 otoliths was extracted at regular intervals throughout the year to satisfy the age validation objective. To ensure the subsample size of otoliths from each tow was approximately proportional to the catch size for the estimation of natural mortality objective, catch percentiles from previous commercial data in QMA 2 were obtained (Table 1). This determined the numbers of otoliths per catch that were to be collected. Based on the upper and lower quartiles of these catch data, the weighted sampling of otoliths per catch was planned as follows: 100 otoliths taken for landings over 8 t, 50 otoliths for landings between 500 kg and 8 t, and 10 otoliths for landings under 500 kg.

Table 1: Percentile estimated catches of black cardinalfish from previous TCEPR data in QMA 2

Percentile	Catch (kg)
10	10
20	30
30	80
40	200
50	520
60	1 500
70	3 780
80	8 290
90	20 000
100	147 000

During the market sampling programme details of the catch were obtained to ensure there was no mixing of small and large samples or mixing of samples from geographically separate areas. Because black cardinalfish form aggregations, the samples for the estimation of mortality were frequently taken from one large bag from one hill feature or from two hills close to each other. Hence the assumption was made that all fish from one landing were taken in one large catch.

4.2 Samples from research voyages

A few juvenile black cardinalfish (Figure 2) were opportunistically collected on two research voyages in September 1999 (TAN9911) and January 2000 (TAN0001). The sampling areas were west coast South Island and northeast Chatham Rise respectively (*see* Figure 1). The juveniles were caught between depths of 450 and 620 m, well within the depth range of adults.

4.3 Otolith preparation and ageing

To determine the otolith preparation technique, a small sample of otoliths collected in earlier years and held in storage by NIWA were prepared using two methods: 1. baking, embedding, and transverse sectioning through the nucleus (Horn & Sullivan 1996, Walsh *et al.* 1999), and 2. embedding and longitudinal thin sectioning method (Stevens & Kalish 1998, Tracey & Horn 1999). For both methods, reasonably clear patterns of dark and light zones were visible on the sections. The more efficient preparation technique, baking and embedding, was applied to obtain ages from the market sampling otoliths.

For all otolith samples, one of the paired otoliths was marked through the centre of the primordium (nucleus) and baked whole in an oven at 285 ^{0}C for about 5 min until amber coloured. Otoliths were then embedded in ordered rows in epoxy resin blocks. Each block was cut along each row, providing transverse sections through the primordium of up to 60 otoliths per block. To improve clarity of the zones for reading, the sectioned surfaces were polished, coated in paraffin oil to increase the visibility of the zones, and then examined using reflected light under a binocular microscope at x30 and x100.

Two readers were involved in this study. From the sample of 788 otoliths that were read, a sub-sample of 170 otoliths was read twice by readers 1(DT) and 2 (KG).

Each otolith was assigned a readability value according to the following scale: 1, excellent; 2, good; 3, acceptable – some doubt about grouping bands; 4 poor, edge counts unclear; 5, not readable. In addition to the unreadable otoliths, those otoliths with a readability of 4 where total age estimates were probably underestimated were removed from the dataset for the growth estimates. The otoliths excluded from the dataset tended to be from older fish, but we believe any bias to the growth estimate caused by removing these samples would be low due to (under 5%) the small sample size.

Juvenile black cardinalfish samples were thawed in the laboratory and length data and otoliths collected. Whole untreated otoliths were immersed in high refraction oil and examined distally for growth zones and marginal characteristics. Measurements were made horizontally from the primordium to the first, second, and third zones to aid identification of the first few zones on the adult sections.

4.4 Validation

The market sampling otoliths were used in attempts to validate the ages from the marginal state of the otolith sections. It was very difficult to discern the presence or otherwise of a marginal increment. The margins were too narrow, or the borders between the dark and light zones were indiscernible, to allow measurement of the width of the last incomplete zone.

The potential to validate the ages using juveniles collected from trawl surveys in September (n = 17) and January (n = 22) was investigated. Otoliths from juveniles from both sample sites were examined to see if marginal deposition varied between seasons.

4.5 Ageing precision and growth

Otolith zone counts were assessed for ageing bias and precision. The between-reader coefficient of variation (*c.v.*) error for each fish for each mean age was estimated following the method described by Doonan *et al.* (1995). The final age estimate for each black cardinalfish was taken as the mean of the reader 1 (R_1) and reader 2 (R_2) age counts. A growth curve was fitted to the length-at-age data from 722 samples using the von Bertalanffy growth model:

$$L_t = L_\infty\left(1 - e^{-K[t-t_0]}\right)$$

where L_t is the expected length at age t years, L_∞ is the asymptotic maximum length, k is the von Bertalanffy growth constant, and t_0 is the theoretical age at zero length. Von Bertalanffy growth parameters were calculated overall and separately by sex.

The age data from the Chatham Rise juveniles were included in the von Bertalanffy analyses. The assumption was made that similar ages would be found if samples of juveniles from QMA 2 were aged.

4.6 Estimating natural mortality

The proportions at age were obtained from the random sample of otoliths from each landing. A length-weight relationship ($W = 0.0269L^{2.87}$) from the unpublished NIWA data from research survey TAN9807 used by Doonan *et al.* (1999), was used here to obtain an estimated mean fish weight for landing, k, $\overline{w}_k$. Hence the landing weight, W_k, was used to obtain an estimate of the numbers of fish in a landing,

$$W_k / \overline{w}_k$$

The overall proportion at age was estimated from

$$\hat{p}_j = \frac{\sum_k (W_k / \overline{w}_k) \hat{p}_{jk}}{\sum_k (W_k / \overline{w}_k)}$$

where $\hat{p}_{jk}$ is the estimated proportion at age in landing k (*see* Davies & Walsh 1995).

An estimate of $\hat{c}_j$, the *c.v.* of $\hat{p}_j$, was obtained by 1000 bootstraps in which the landings were resampled with replacement.

Estimates of the total mortality, Z, were then obtained from the proportions at age using the estimator developed by Chapman & Robson (1960).

$$\hat{Z} = \log_e \left(\frac{1 + \overline{a} - 1/n}{\overline{a}} \right)$$

where $\overline{a}$ is the mean number of years above the "recruitment" age, A_r,

$$\overline{a} = \frac{\sum_{j=A_r}^{a_{max}} j\hat{p}_j}{\sum_{j=A_r}^{a_{max}} \hat{p}_j} - A_r$$

Various values of A_r were applied. We obtained an "effective" simple random sample size, n, by equating theoretical with observed mean weighted coefficient of variation,

$$\sum_j \hat{p}_j \hat{c}_j = \sum_j \sqrt{\frac{\hat{p}_j (1 - \hat{p}_j)}{n}}$$

$$\therefore \; n = \left(\frac{\sum_j \sqrt{\hat{p}_j (1 - \hat{p}_j)}}{\sum_j \hat{p}_j \hat{c}_j} \right)^2$$

Dunn *et al.* (1999) showed that the Chapman-Robson estimator, which is derived for a simple random sample, performs fairly well under a range of assumptions,

5. RESULTS

5.1 Sampling from the commercial fishery

Length, sex, reproductive state, and otoliths were obtained from *E. telescopus* from QMA 2. Sampling sites extended from the Palliser region and Wairarapa Hills in the south to Ritchie Banks and Tuahine High in the north (*see* Figure 1). Market sampling began in November 1998 and continued until December 1999 (Table 2).

Table 2: The east coast North Island (QMA 2) landing dates and numbers of black cardinalfish measured (length frequencies) and otolith samples. (*, samples used for natural mortality estimate)

Landing date	Number of fish measured	Number of otoliths	
09 Nov 1998	207	54	*
17 Nov	201	33	*
06 Feb 1999	205	33	*
22 Feb	211	35	*
12 Mar	206	33	*
07 Apr	200	33	*
18 May	205	33	*
28 May	204	101	*
01 Jun	240	100	*
20 Sep	211	100	*
27 Oct	206	50	
15 Nov	210	100	
20 Nov	204	100	*
08 Dec	204	100	*
12 Dec	224	100	*

A random sample of 1232 males and 1906 females were measured, sexed, and staged, with more than 200 fish measured from each commercial landing. Length frequency data from the catch samples are shown in Figure 3. The length range of the commercial landings in QMA 2 was 28 to 76 cm FL. The length frequency distribution for the otolith sample had a similar size structure to the total length frequency distribution of the QMA 2 market samples and to the size structure presented by Field *et al.* (1997).

Otoliths were collected from sub-samples of the measured fish: the length frequency of these fish is shown in Figure 4. For the age validation study, samples were planned for each month, but due to the commercial fishing patterns samples were not collected during December 1998 and January, July and August 1999. Collection of the natural mortality samples took place throughout the year, with the most intensive sampling carried out during the main fishing period in the latter part of 1999.

Otoliths were collected from 1005 fish in QMA 2. The sample sizes of otoliths for estimation of natural mortality were based on the distribution of catches of black cardinalfish and were relative to the median catch to ensure the population was fully represented. Hence optimal otolith sampling occurred with the subsample size from each landing proportional to the catch. About 100 otoliths were taken for landings over 8 t and 50 otoliths from landings between 500 kg and 8 t (*see* Table 2). There were no landings under 500 kg. Some otoliths sampled for age validation were included in our natural mortality estimates.

Reproductive state from the market sampling programme is summarised in Table 3.

Table 3: Percentages of black cardinalfish at each reproductive stage in samples from QMA 2

	Stage				
	1	2	3	4	5
Females	40.9	49.8	8.3	0.7	0.3
Males	47.5	36.7	12.3	0.3	3.1

Most fish were in an immature or resting reproductive state. A few (n = 12) ripe fish (stage 4) were recorded from the June samples and 54 spent fish from the October-November samples, possibly confirming the winter spawning period assumed by Field *et al.* (1997).

5.2 Otoliths

Alternating dark and light zones were clearly visible in the whole juvenile otoliths up to about 12 years (30 cm fish) and it appears that the zones are annual (Figures 5a and b). Juvenile samples from the two *Tangaroa* surveys provided valuable information to interpret the zones, such as information on marginal increment deposition over time and between zone measurements. The maximum radius of the first four zones is about 2.68 mm (Figures 5a and b). The same measured distance on the sectioned adult otoliths (Figure 6) occurs at zone 4, which gives confidence in our interpretation of these zones.

For fish over 12 cm it was necessary to section and bake the otolith to clarify the zones. In adult otolith sections the clarity of the zonation pattern was reasonably good with 86% of the otolith sample having a readability value of 1, 2, or 3. Blocks were polished to clarify the zones. The region inside the first dark zone comprised the primordium and the opaque zone for the first year's growth (Figure 6). The first few zones after the primordium were widely spaced and relatively easy to define. Measurements made on the whole juvenile otoliths (Figures 5a and b) were used as a guide for the position of the first few zones on the larger fish. Within the first few years of growth, dark zones were counted and any multi-banding patterns or split zones were ignored (*see* Figure 6). The patterns of the zones past these first five or so assumed years were generally fine and regular. Counts of these fine dark and light zones were made adjacent to the sulcal groove (*see* Figure 6). Little micro-banding occurred within individual growth zones and the fine zones were assumed to be annual. Otoliths with very clear banding supported our grouping of the micro-bands. Toward the edge of the otolith, higher magnification was required to count the closely spaced fine zone pattern (Figure 7): counting was difficult in this region.

5.3 Validation

Samples of black cardinalfish otoliths were collected at regular intervals between October 1998 and December 1999 for a marginal increment analysis to validate the otolith ages. We were unable to validate the ages from the commercial catch otolith samples due to the state of the otolith margin. The outer growth zones for fish over 12 cm FL are regular but very fine and narrow, and it was not possible to measure the width of the last incomplete zone. For most otoliths, it was difficult to determine whether the otolith margin was dark or light.

Otoliths from juveniles provided more promising results of margin information. Although too few data were available to carry out this investigation in full, a brief examination of the state of the otolith margin on otoliths for the juvenile fish showed that there appeared to be a relatively broad light margin present in whole otoliths from the September sample and a narrow dark margin forming on the January 2000 samples.

5.4 Age and growth

All age and growth length data derived for black cardinalfish in this study are shown in Figure 8. Fish ranged in age from 3 to 104 years (from 14 years for the QMA 2 samples).

Black cardinalfish were aged from whole otoliths up to 12 years and radial measurements made on a sub-sample of the juvenile otoliths. From the primordium to zones on the transverse ventral edge of the otolith (*see* Figures 5a and b), we obtained measurements of 1.40–1.90 mm to the first zone and 2.33–2.68 mm to the fourth zone. Estimated age at length at 3–4 years (about 15–18 cm), 6 years (26 cm), and 11 years (32 cm) indicates slow growth. Zone counts up to 12 years could be determined relatively easily, but the cut-off age to classify marginal increments is lower (about 4–5 years).

From a sample size of 1005 otoliths, 855 were prepared, 788 were read (or attempted), and 722 (including the 30 aged juveniles) used in the growth analyses. The mean age of the sample (including the 30 juveniles) was 41 years: 552 age estimates were based on readings from either R_1 or R_2 , and 170 ages from mean readings from both readers.

5.5 Ageing precision

Between-reader error (mean of the *c.v.* (%) for each fish) was estimated for each mean age where "mean age" is the mean of the final readings for readers 1 and 2. The correlation coefficient of between-reader variability was obtained from a sample of 170 otolith readings. There was very little bias between reader (Figure 9, slope is 1.02 and a slope = 1 is unbiased). Otolith readings by the two readers were positively correlated. The between-reader variability had a measured *c.v.* of 16.7% indicating moderate precision. The horizontal regression line in Figure 10 shows that there is little change in the *c.v.* of readings with age and so 16.7% is an appropriate *c.v.* for between-reader variability for all ages.

Von Bertalanffy growth curves were estimated for both sexes individually as well as combined. The relationships between length and age (all fish combined) and the von Bertalanffy curve fitted to the data are shown in Figure 8. The combined estimated von Bertalanffy growth parameters are given in Table 4.

5.6 Natural mortality

We estimated natural mortality (M) from randomly collected samples of 722 black cardinalfish.

The gradual increase in the left hand limb of the distribution of proportion at age (Figure 11) suggests that fish may not be fully recruited until 35–50 y. We have chosen A_r = 45 y as our preferred estimate of age at full recruitment, and this gives an estimate of total mortality of $Z = 0.034\ y^{-1}$.

The slope of the decline in frequency with age determines the estimate of Z. This slope will not be changed by fishing mortality for those fish that were fully "recruited" (age A_r or over) before the fishery began (assuming flat selectivity with age). The fishery could have affected only the few age classes that have recruited since the fishery began to take large catches. Therefore we have assumed that $M = Z = 0.034\ y^{-1}$. The estimated Z generally increases as A_r increases (Figure 12). This suggests that natural mortality may increase with age. We have not investigated this further. Further sampling would help determine A_r and M more reliably. The spikiness of Figure 11 could be reduced by additional samples.

Table 4: Life history parameters for black cardinalfish estimated from this study

Parameter	Symbol	All	Female	Male
Natural mortality	M	0.034	–	–
Age at recruitment	A_r	45		
Von Bertalanffy parameters	L_∞	70.8	70.9	67.84
	k	0.034	0.038	0.034
	t_0	-6.32	-4.62	-8.39
Length weight parameters*	a	0.027		
	b	2.87		

* calculated from research data (TAN9807)

6. DISCUSSION

Estimation of age and growth of fish is central to stock assessment. This study develops an ageing technique for black cardinalfish, and applies it to a sample of fish from QMA 2 to estimate growth rate and natural mortality.

Black cardinalfish appear to be a long-lived species, but there is uncertainty in the estimates of M because our ages are unvalidated. It is likely, however, that the clear zones visible in both the whole juvenile otolith samples and in the sectioned otoliths represent some constant time interval. The zone pattern is very similar to that observed in otoliths from other species known to be long-lived and is assumed to reflect an annual growth cycle. In addition the information on zone deposition, zone size, marginal increments, and counts obtained from the juvenile samples provided confidence in the interpretation of the zone patterns and subsequent ages.

It is well known that the length of exposure to mercury in the environment is positively related to the levels of mercury in fish flesh and species may accumulate mercury with age (Working Group on Mercury in Fish 1980). The elevated mercury levels found in black cardinalfish are consistent with a long-lived slow growing species (Tracey 1993).

The reading precision is lower than those found for other deepwater species. A reading *c.v.* of 9% was found for smooth oreo (Doonan *et al.* 1995) and of 10% for orange roughy Doonan & Tracey (1997). Doonan *et al.* (1995) examined reading precision in detail and found that the variability of the final readings of the same otolith between two readers showed a similar trend and magnitude to the within-reader variability, indicating that otolith interpretation was roughly consistent between two readers. The thin otolith section technique is used for ageing deepwater species and choosing this technique may have improved reader precision. However, at the start of the study, the readers found that the readability of the zones was not very different with either the thin section or baking and embedding techniques. Future work should address improving the reader precision.

Ages in this study were similar to earlier findings by Kalish & Lister (unpub. data cited by Tracey 1993). Pshenichny *et al.* (1986) reported that *Epigonus telescopus* become sexually mature at age 7 (determined from scales and otoliths). These age estimates are well below our assumed estimates of age at full recruitment and maximum ages. However Pshenichny *et al.* (1986) also reported lengths at maturity as 40–50 cm, similar to our estimate of full age at recruitment of 45 years.

Age estimates and the fitted von Bertalanffy growth curve suggest that growth of black cardinal fish is very slow. The Chapman-Robson estimate of Z (0.034) was also very low, and because the QMA 2 black cardinalfish stock has been exploited for more than 7 years, M is possibly lower than our estimate of Z.

We suggest that together with orange roughy (Doonan 1993, Horn *et al.* 1998, Tracey & Horn 1999), the oreo species (Doonan *et al.* 1997, McMillan *et al.* 1997) and rubyfish (Paul *et al.* 2000), black cardinalfish are among the longest-lived commercially fished species in New Zealand waters.

Von Bertalanffy growth parameters and estimates of maturity for these species are:

Species	$M(Z)$	L_∞	K	t_0	A_r	A_m^f	Max. age
Orange roughy (F)	0.045	38.0	0.061	-0.6	29	29	130
Orange roughy (M)	0.045	36.4	0.070	-0.4	29	29	
Black oreo (F)	0.044	39.9	0.043	-17.6	–	27	153
Black oreo (M)	0.044	37.2	0.056	-16.4		–	–
Smooth oreo (F)	0.063	50.8	0.047	-2.9	21	31	86
Smooth oreo (M)	0.063	43.6	0.067	-1.6	21	–	
Rubyfish (F)	0.035	49.1	0.043	-18.48	7–12*	–	88
Rubyfish (M)	0.035	48.6	0.043	-17.15		–	–
Black cardinalfish (F)	0.034	70.9	0.038	-4.62	45	36.4	104
Black cardinalfish (M)	0.034	67.8	0.034	-8.39	45	34.5	

A_m^f = Age at maturity, included for comparative purposes.
* A low age at recruitment was assumed for rubyfish due to early growth being rapid (Paul *et al* 2000).

Our attempts to validate the otolith ageing technique using marginal increment analysis failed because of our inability to classify the marginal composition on adult otoliths. Validation therefore remains a high priority for this species. The improved radiometric method developed by Andrews *et al.* (1999) should be investigated.

7. ACKNOWLEDGMENTS

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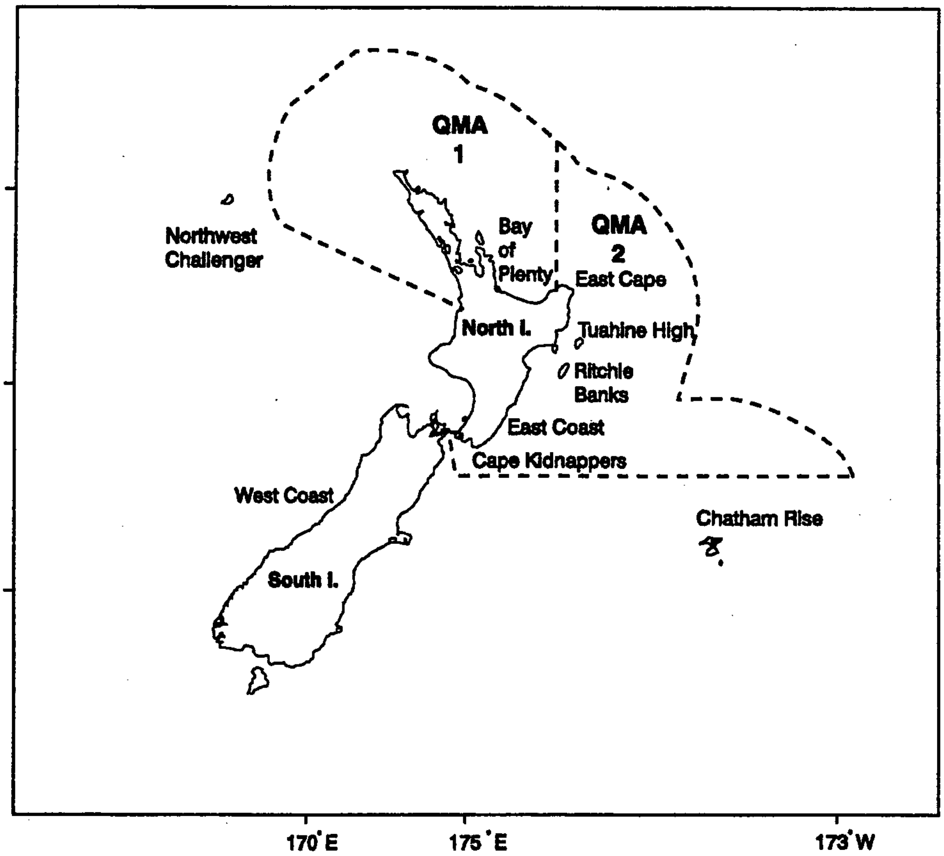

Figure 1: Sampling area.

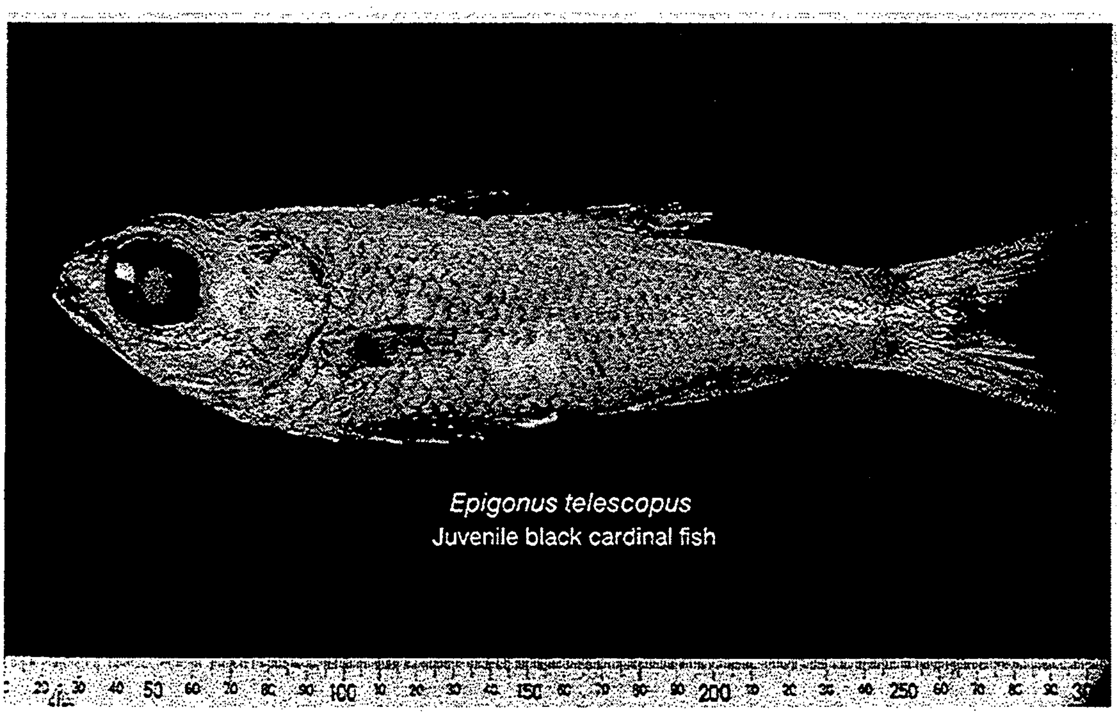

Figure 2: Juvenile black cardinalfish.

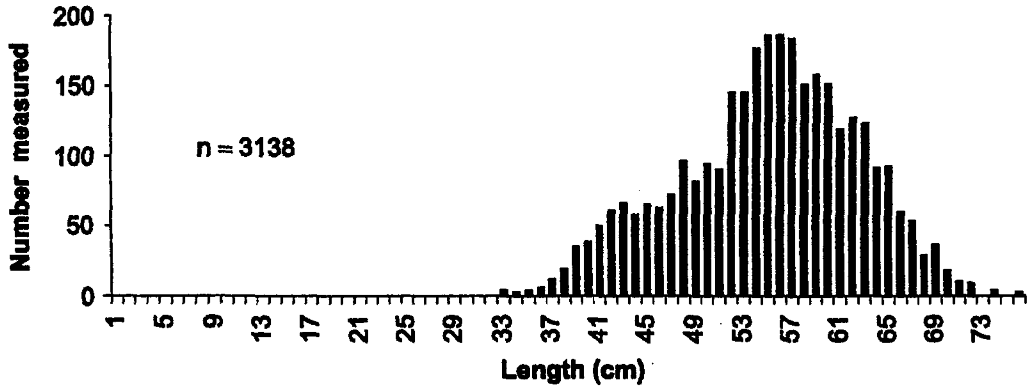

Figure 3: Length frequency distribution of market samples from QMA 2.

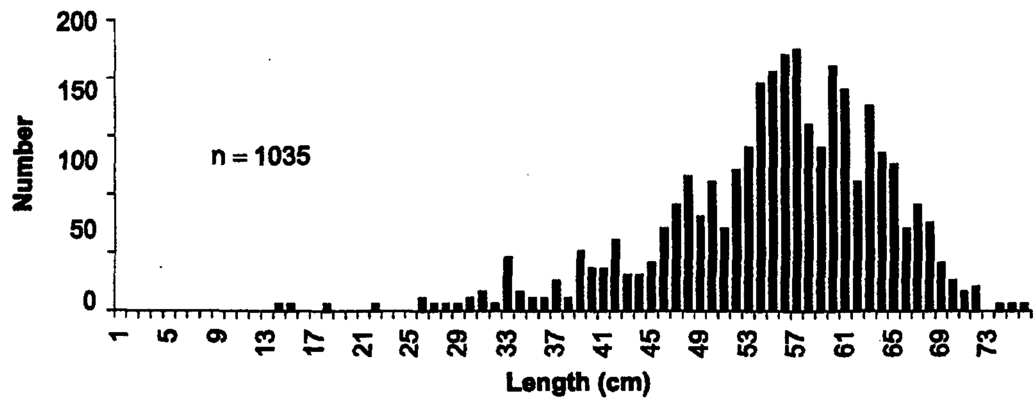

Figure 4: Length frequency distribution of otolith samples (includes the juvenile samples from research surveys.

(a)

Ventral

Posterior

Anterior

Dorsal

(b)

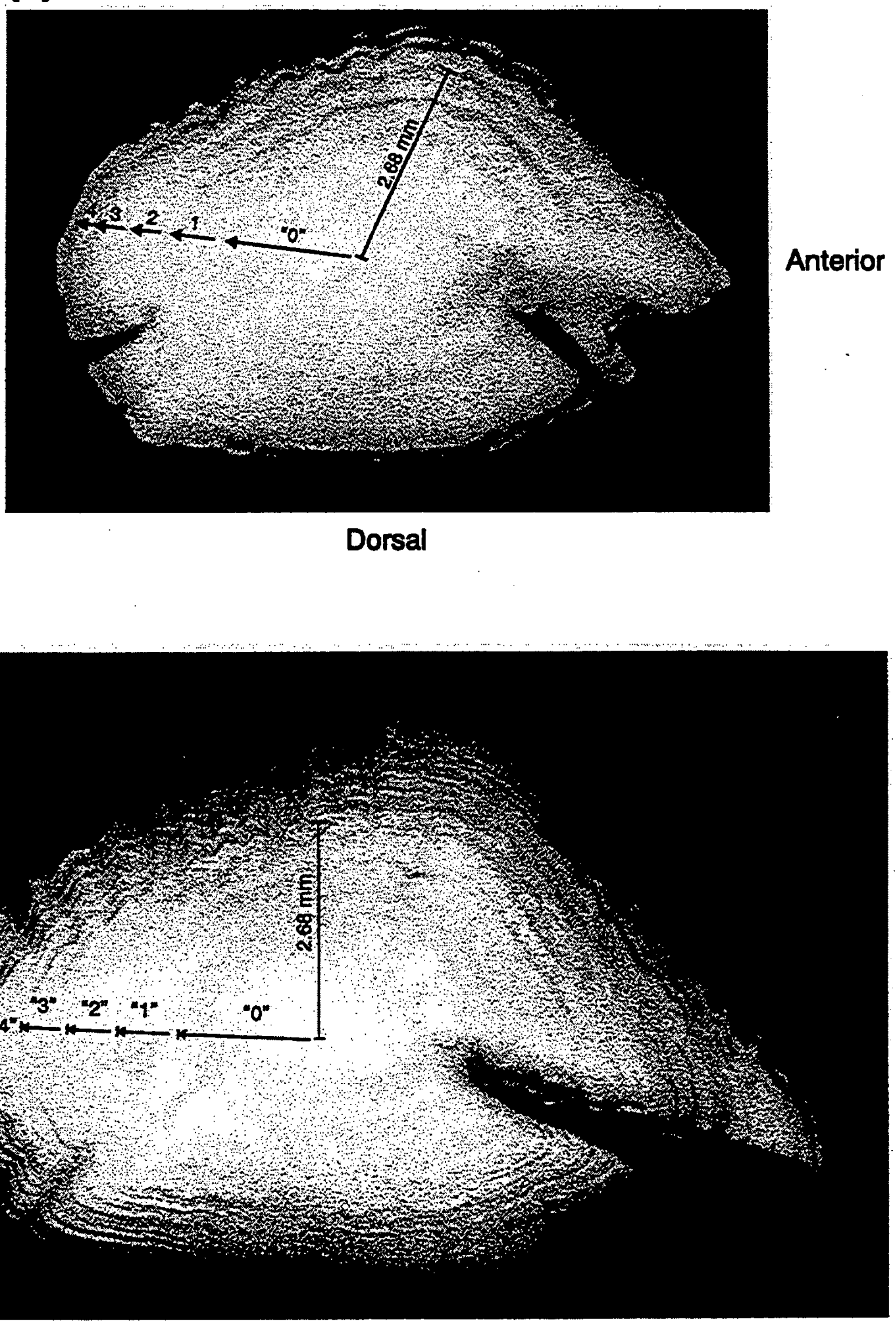

Figure 5: Whole otoliths immersed in high refraction oil and photographed with reflected light showing (a) 5 annuli, dark growth zones plus an inner ('0') zone, and (b) 9 annuli.

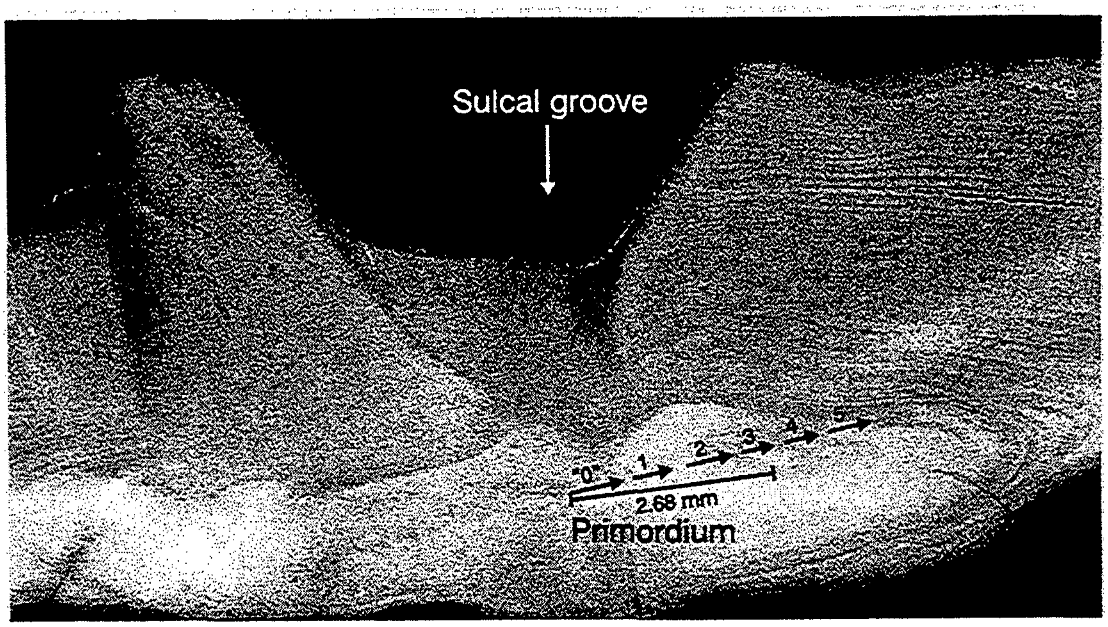

Figure 6: Section through an otolith of black cardinalfish photographed with reflected light and estimated to be 30 years. Note the wide inner dark zones followed at age 5 by the fine zone formation. Counts past the first five zones are made adjacent to sulcal groove.

(b)

(a)

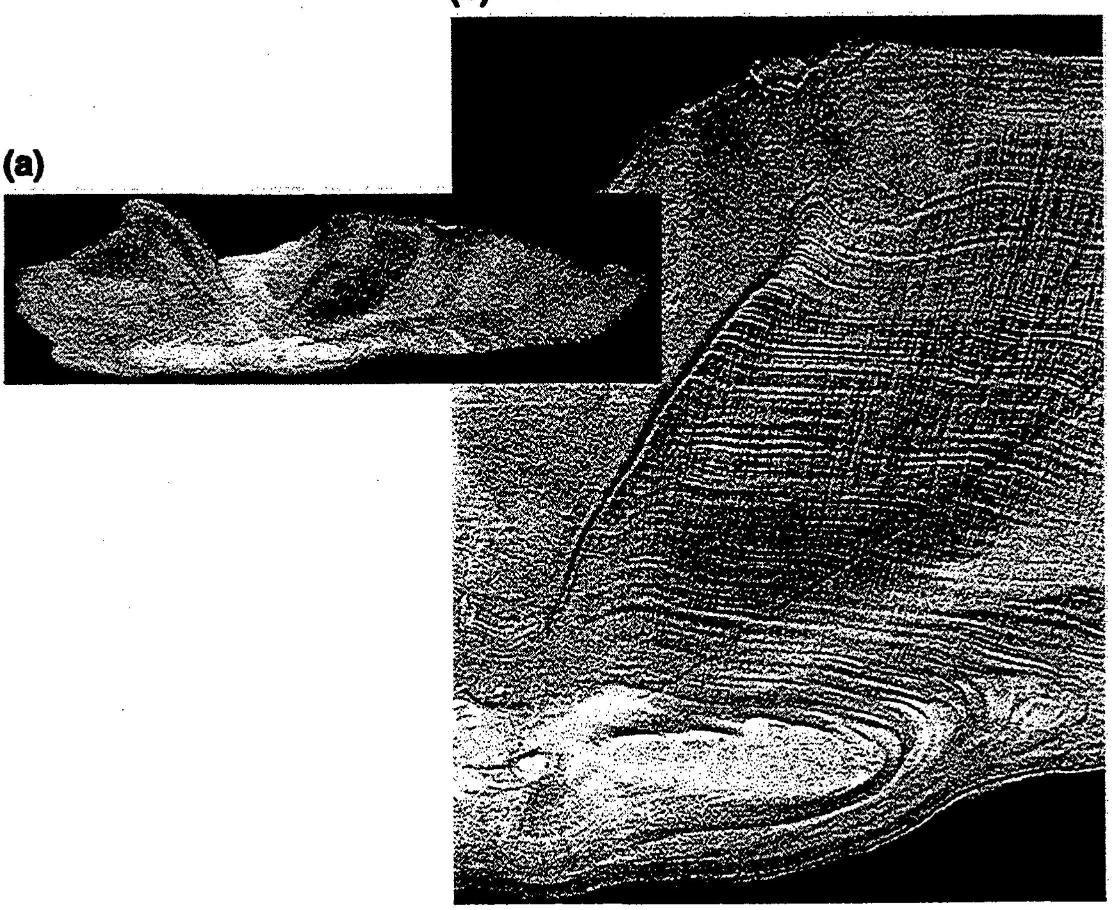

Figure 7: (a) Section through an otolith of black cardinalfish estimated to be about 90 years old. (b) Increased magnification of otolith edge required to count the fine regular outer zones.

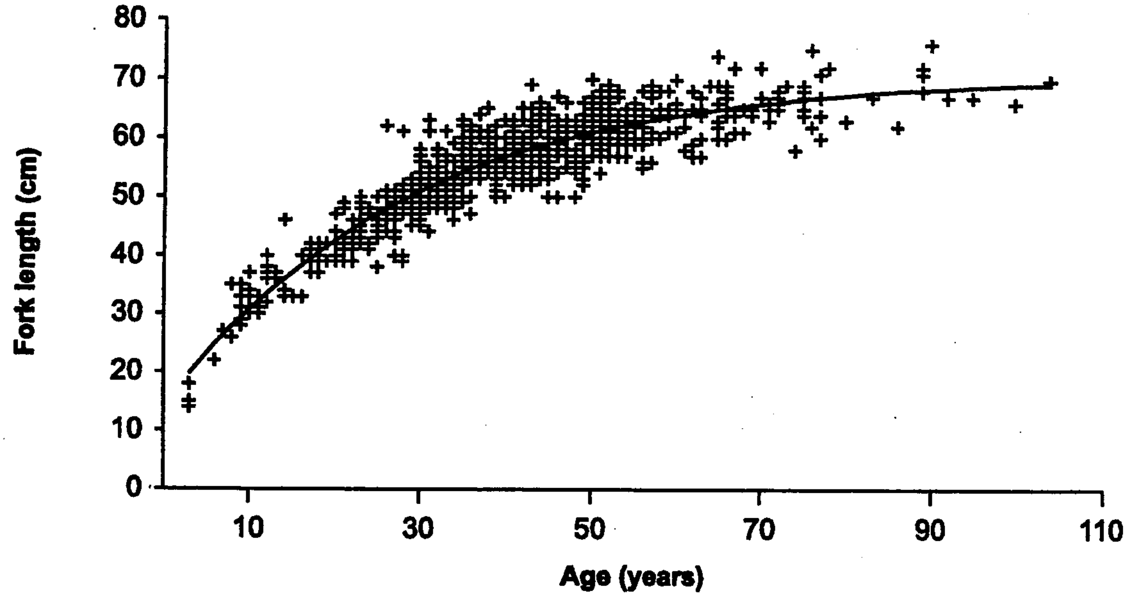

Figure 8: Relationship between black cardinalfish length and age for males and females combined and the von Bertalanffy curve fitted to the data.

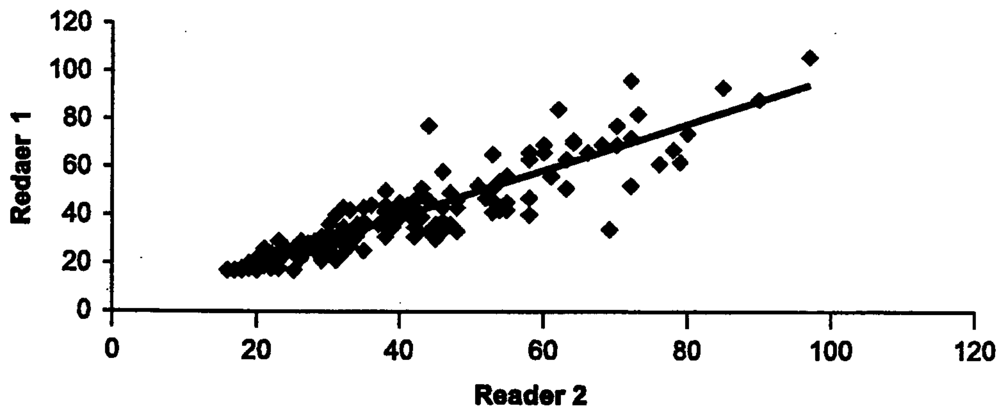

Figure 9: Comparison of black cardinalfish age estimates between readers 1 and 2 (n = 170). The solid line is the 1:1 regression line showing no bias between readers. Counts for juveniles not included.

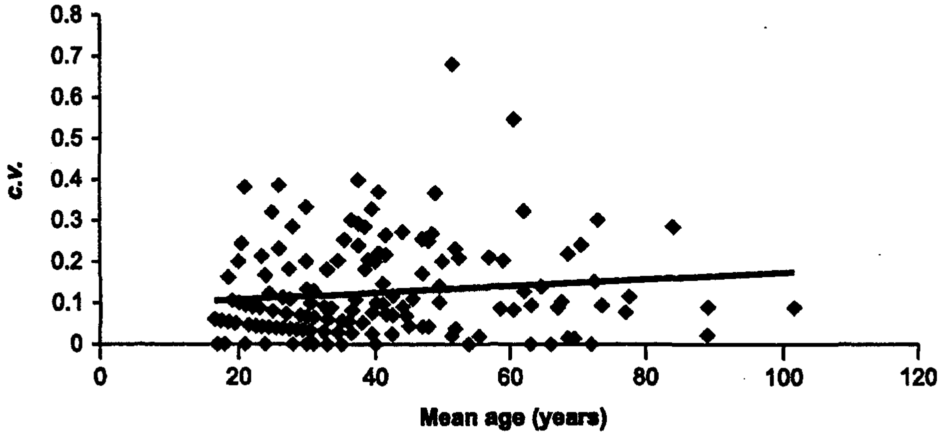

Figure 10: Individual coefficient of variation (*c.v.*) of readings.

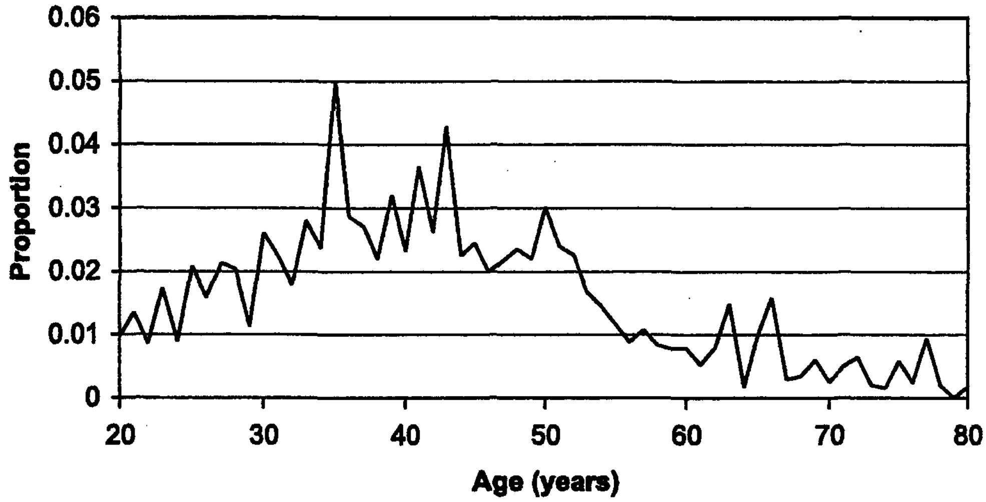

Figure 11: Proportion at age estimates for black cardinalfish in QMA 2 from 722 otolith readings.

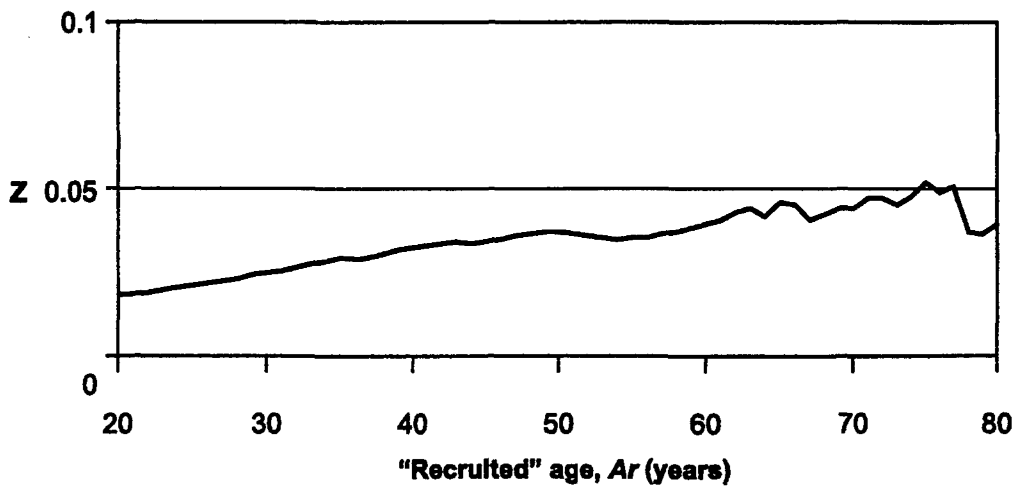

Figure 12: Chapman-Robson estimates of total mortality of black cardinalfish in QMA 2 for various "recruitment" ages.