Age, growth, and maturity of four New Zealand rattail species

D. Stevens
M. H. Smith
P. Grimes
J. Devine
C. Sutton*
D. MacGibbon
C. Ó Maolagáin

NIWA
Private Bag 14901
Wellington 6241

*NIWA
P O Box 893
Nelson 7040

New Zealand Aquatic Environment and Biodiversity Report No. 59
2010

Published by Ministry of Fisheries
Wellington
2010

ISSN 1176-9440

Stevens, D.; Smith, M.H.; Grimes, P.; Devine, J.; Sutton, C.;
MacGibbon, D.; Ó Maolagáin, C. (2010).
Age, growth, and maturity of four New Zealand rattail species.
New Zealand Aquatic Environment and Biodiversity Report No. 59.

This series continues the
Marine Biodiversity Biosecurity Report series
which ceased with No. 7 in February 2005.

EXECUTIVE SUMMARY

Stevens, D.; Smith, M.H.; Grimes, P.; Devine, J.; Sutton, C.; MacGibbon, D.; Ó Maolagáin, C. (2010). Age, growth, and maturity of four New Zealand rattail species.

New Zealand Aquatic Environment and Biodiversity Report No. 59.

Age, growth, maturity, and biomass trends of four rattail bycatch species, two saddle rattail, *Coelorinchus biclinozonalis*, Bollons's rattail, *C. bollonsi*, javelinfish, *Lepidorhynchus denticulatus*, and ridge-scaled rattail, *Macrourus carinatus*, were studied. Bollons's rattail and javelinfish are widespread in New Zealand in depths from about 250 m to 700 and 1200 m respectively. Two saddle rattails are found in the North and South Island and northwest Chatham Rise from 5 to about 500 m depths, and the ridge-scaled rattail is found from about North Cape south from 600 to 1200 m depths. All four species were difficult to age and both within-reader and between-reader agreement was generally low. Maximum observed age estimates were 15 years for two saddle rattail, 24 years for Bollons's rattail, 13 years for javelinfish, and 42 years for ridge-scaled rattail. Chapman-Robson estimates of total mortality were 0.54, 0.41, 0.51, and 0.15 respectively. Preliminary estimates of female length and age at first maturity were made from a limited set of gonad staging data. Length and age at first maturity based on weighted data are as follows: two saddle rattail matures at about 31 cm and 2 years of age; Bollons's rattail at about 34 cm and 3 years of age; javelinfish at about 35 cm and 3 years of age; and female ridge-scaled rattail at about 56 cm and 11 years of age.

Biomass trends from the 1992–2009 Chatham Rise hoki trawl surveys (*C. biclinozonalis*, *C. bollonsi*, *L. denticulatus*), 1991–2009 sub-Antarctic trawl surveys (*L. denticulatus*, *M. carinatus*) and the 2000–2009 west coast South Island inshore trawl surveys (*C. biclinozonalis*) were examined. Only javelinfish on the Chatham Rise time series showed a significant trend with an estimated instantaneous constant rate of increase of 6% of biomass per year.

1. INTRODUCTION

Studies on the biology of deepsea species often lag behind the development of commercial fisheries. There are many documented cases where a fishery has developed and declined before basic biological parameters, such as growth, maturation, or fecundity have been determined (Atkinson 1995, Merrett & Haedrich 1997, Koslow et al. 2000).

Populations of bycatch species caught incidentally in commercial fisheries may be threatened if a significant portion of their biomass is captured or if they have low productivity. Information on basic life history parameters for these species is required to help assess the risk of population decline.

Rattails or grenadiers (Family Macrouridae) are a large and diverse family of fishes with about 400 species found throughout the world's oceans (Iwamoto 2008). The New Zealand Exclusive Economic Zone (EEZ) is well represented with about 60 rattail species, some of which are a substantial bycatch in deepwater fisheries. Several species are caught as a bycatch during target fishing for hoki (*Macruronus novaezelandiae*) and other species (Ballara et al. 2010). Small quantities may be landed but most bycatch probably ends up as fishmeal or is discarded. No rattail species are currently managed in the New Zealand Quota Management System. Little is known of their size at maturity, age, growth, or longevity. Preliminary studies have found that some species, such as the white rattail (*Trachyrincus aphyodes*), may be long-lived (about 80 years), which could make them vulnerable to overexploitation (D. Stevens, unpublished data).

Rattails generally have a continental slope distribution (200–1200 m), although some species extend onto the continental shelf (less than 200 m). Some species are a major component of the demersal fish assemblages in the New Zealand EEZ (Francis et al. 2002). The environmental principles of the Fisheries Act provide for an ecosystem-based approach to fisheries management, including the sustainability of dependent species, aquatic biodiversity, and habitats (www.fish.govt.nz). Data on length at maturity, age, and growth (including longevity) will provide important information about the likely vulnerability of these species to fishing exploitation.

Four rattail species were selected by the Ministry of Fisheries for study based on their abundance, suspected longevity, or commercial potential. These include: two saddle rattail, *Coelorinchus biclinozonalis*; Bollons's rattail, *C. bollonsi*; javelinfish, *Lepidorhynchus denticulatus*; and ridge-scaled rattail, *Macrourus carinatus.*

Relative abundance estimates are available for these species from the Chatham Rise summer hoki trawl surveys (*C. biclinozonalis*, *C. bollonsi*, *L. denticulatus*, 1992–2009), the sub-Antarctic summer and autumn hoki trawl surveys (*L. denticulatus*, *M. carinatus*, 1991–2009), and the west coast South Island inshore trawl surveys (*C. biclinozonalis*, 2000–2009).

Two of these species (javelinfish and Bollons's rattail) were included in a trophic study on the Chatham Rise (Dunn et al. 2009). Preliminary results suggest that there is clear resource partitioning between these species (Stevens & Dunn, 2010), and they provide an important trophic link between small benthic/epibenthic invertebrates and piscivorous opportunists, such as large ling (*Genypterus blacodes*), hoki, hake (*Merluccius australis*), and smooth skate (*Dipturus innominatus*).

Javelinfish are one of the most abundant fishes caught in New Zealand middle depth fisheries, forming up to 15% of the total biomass, with widespread occurrence during the Chatham Rise summer hoki trawl surveys and the Southland and Sub-Antarctic summer and autumn hoki surveys (O'Driscoll & Bagley 2001, Livingston et al. 2002). They are also a common bycatch species in hoki, scampi, and middle depth trawl fisheries, and are likely to be an important component of fishmeal in some of these fisheries. Javelinfish were considered for introduction into the QMS in 2004, although they have not yet been incorporated. The relative abundance of javelinfish has varied considerably over the time series and there appears to have been significant recruitment in the late 1990s

(Livingston et al. 2002). They are a small and abundant species, but there are no available data on longevity, growth, or maturation. They may be vulnerable to fishing pressure as bycatch.

Bollons's rattail are widespread in central and northern New Zealand and are abundant on the Chatham Rise, forming up to 7% of the total biomass of the summer hoki trawl series (1992–2009). Bollons's rattail were considered by the Ministry of Fisheries as possible candidates for introduction into the QMS. They are a relatively large rattail species, but there are no available data on longevity, growth, or maturation. They may be vulnerable to fishing pressure.

The two saddle rattail is widespread around the North and South Island, and on the Mernoo and Reserve Banks on the Chatham Rise. Although similar in appearance and size to Bollons's rattail, they tend to occur at shallower depths (Anderson et al. 1998). They are a relatively large rattail species, but there are no available data on longevity, growth, or maturation. They may be vulnerable to fishing pressure.

The ridge-scaled rattail is one of New Zealand's largest rattail species and there is the potential for a localised commercial fishery in the sub-Antarctic. They are also taken as bycatch in the orange roughy fishery on the Chatham Rise, but it is unclear if they are landed. Little information is available for ridge-scaled rattail. However, the genus *Macrourus* contains several large, closely related species that are commercially important overseas and long lived (e.g., *M. holotrachys* at South Georgia (Morley et al. 2004), *M. whitsoni* in the Ross Sea (Marriott et al. 2003), and *M. berglax* in the northern hemisphere (Swan & Gordon 2001, Murua 2003)).

There is little age and growth information on New Zealand rattails. This is not surprising given most species are small and although some species are likely to be important in the production of fishmeal, they are unlikely to be landed whole. The only age and growth studies relate to species that have a more extensive distribution: *Coelorinchus fasciatus* (Laptikhovsky et al. 2008), *Coryphaenoides armatus* (Swan & Gordon 2001), and *Macrourus carinatus* (van Wijk et al. 2003, Laptikhovsky et al. 2008). There are no known publications on age or growth for the endemic *C. bollonsi* and *C. biclinozonalis* or the more widespread *L. denticulatus*; however, van Wijk et al. (2003) studied age, growth, and sexual maturity of *M. carinatus* from the Heard and MacDonald Islands, and Laptikhovsky et al. (2008) studied age and growth of the same species from the Falkland Islands.

There is also little published maturity data on New Zealand rattails, with the exception of *Macrourus carinatus.* Alekseyeva et al. (1993) gave a detailed account of the female maturation cycle and total length at maturity of *Macrourus carinatus* from the Patagonian Shelf and the Falkland Islands. Laptikhovsky et al. (2008) estimated pre-anal length at maturity together with age data from the Falkland Islands. Van Wijk et al. (2003) estimated total length and age at maturity from Heard and MacDonald Islands. Cousseau (1993) estimated total length at maturity from the South Atlantic Ocean.

1.1. Objectives

Overall objective

1. To determine the productivity and trends in rattails commonly taken as bycatch.

Specific objectives

1. To estimate growth, longevity, rate of natural mortality, and length at maturity of four key rattail bycatch species in New Zealand trawl fisheries.

2. To examine data from trawl surveys and other data sources for trends in catch rates or indices of relative abundance for species in Objective 1.

2. METHODS

2.1 Age and growth

2.1.1 Otolith sample collection

Bollons's rattail, javelinfish, and two saddle rattail were sampled from the 2009 Chatham Rise hoki and middle depths species trawl survey using RV *Tangaroa*, voyage code TAN0901 (Stevens et al. 2009). Ridge-scaled rattail were sampled from the 2006 Southland and sub-Antarctic middle depth species trawl survey, TAN0617 (O'Driscoll & Bagley 2008). Each rattail was measured (total length, TL, and pre-anal length, PAL, to the nearest millimetre), weighed (to the nearest 5 g), sexed, and its sagittae (hereafter otoliths) extracted. When measuring rattails, if a small portion of the end of the tail was missing, the TL was estimated by matching the tail with a similar sized individual. If a significant portion of the tail was missing, then the specimen was not sampled. Pre-anal length was measured using digital calipers. Otoliths were removed from 526 Bollons's rattail, 544 javelinfish, 241 two saddle rattail, and 255 ridge-scaled rattail for ageing. All otolith pairs from two saddle and ridge-scaled rattail otoliths were prepared and aged. Bollons's rattail and javelinfish were subsampled to provide 200 javelinfish and 250 Bollons's rattail. Sample details are provided in Table 1.

Table 1: Rattails used for age determination. Mean, range, and s.d. are the mean, range, and standard deviation of the total lengths (cm) of fish aged.

Species	Code	Survey	Sex	n	Mean	Range	SD.
Two saddle rattail, *Coelorinchus biclinozonalis*	CBI	Chatham Rise	M	78	33.9	24.2–44.1	4.6
			F	163	41.7	26.2–71.3	7.8
Bollons's rattail, *C. bollonsi*	CBO	Chatham Rise	M	120	40.9	25.3–53.3	7.2
			F	130	46.2	25.1–64.0	7.9
Javelinfish, *Lepidorhynchus denticulatus*	JAV	Chatham Rise	M	83	35.2	22.8–51.3	5.7
			F	117	42.3	18.4–60.7	9.2
Ridge-scaled rattail, *Macrourus carinatus*	MCA	Sub-Antarctic	M	69	57.1	24.8–75.8	11.5
			F	186	71.1	29.7–95.6	12.9

2.1.2 Otolith preparation

Each otolith was marked transversely along the sectioning plane with a fine pen, embedded in slow curing epoxy resin (Araldite K142), and sectioned with a low speed saw. Each section was then mounted on a microscope slide, and a coverslip was fixed on top with slow curing epoxy resin. A section thickness of about 530 μm (range 480–560 μm) provided the best increment resolution.

2. 1.3 Otolith-reading protocol

Thin sections were read with transmitted light under a binocular microscope (x20 and x25). Polarised-light filters were used to enhance zone clarity. A pattern of light (translucent) and dark (opaque) zones was visible. Opaque zones were counted in the regions either side of the sulcus, although increment resolution was generally clearer on the ventral side of the sulcus. Each otolith count was given a readability score from 1 to 5, where 1 was considered 100% reliable and 5 was considered unreadable. All grade 5 readings were omitted from further consideration. Details of the numbers of otoliths which were assigned final ages are given in Table 2.

To assess within-reader and between-reader variability, each otolith thin section was read twice by the first reader (Reader A) three months apart, and once by a second reader (Reader B). The final age assigned to each fish was derived from the similarity of the three age estimates. If two or more readings were the same, then this age estimate was used as the agreed age. If all three readings differed, then the first reader re-read the otolith and assigned a final age.

Table 2: Numbers of rattail otoliths assigned final ages by species code and sex. Species names are given in Table 1.

			Numbers of otoliths aged		
Species	Trip	Year	Males	Females	Total
CBI	TAN0901	2009	78	163	241
CBO	TAN0901	2009	117	125	242
JAV	TAN0901	2009	82	115	197
MCA	TAN0617	2006	68	185	253

2.1.4 Ageing bias and precision

Imprecision in ageing was determined by averaging the coefficients of variation of age estimates over all fish, while bias was determined from age bias plots (Campana et al. 1995). Age bias plots have been shown to be better at detecting bias, and estimating imprecision in the presence of bias, than other frequently used techniques (e.g., average percentage error) (Campana et al. 1995), and have been used effectively in recent age and growth studies (Francis & Mulligan 1998, Francis et al. 1999, Francis & Ó Maolagáin 2000, Stevens et al. 2005).

Following Campana (2001), two measures of ageing imprecision were calculated: the mean ageing coefficient of variation (c.v.), and the mean ageing c.v. of the within-reader variation for Reader A. The index of average percent error (IAPE) was also calculated for comparison purposes as this measure has often been used in past analyses.

2.1.5 Growth and longevity

The von Bertalanffy growth model was fitted to the length-at-age data for both males and females of each species. The curve expresses the mean length (ℓ) as the function of age (a) with three parameters L_∞, k, and t_0 given by

$$\mathrm{E}(l) = L_\infty\left(1-\exp\left(-k\left(a-t_0\right)\right)\right).$$

The ageing sample selected from a survey may not represent the population of fish in the area covered by the survey because larger, older fish may be under- or over-represented and smaller, younger fish may be under-represented. To account for this, the procedure for fitting the von Bertalanffy growth curves for each sex used weights, which adjusted for the differences between the length proportions of the fish in the ageing sample and the scaled length proportions for the survey. The procedure assumed a normal error model for lengths with a constant c.v. That is, it is assumed that the standard deviation of lengths at age a is proportional to the mean length at age a.

A common issue associated with data used for fitting growth curves (and relevant to the survey data used in this analysis) is the lack of data for very young fish resulting from low gear selectivity for small fish. This often leads to a biased underestimate of the age intercept t_0, which in turn leads to biased estimates of k and L_∞. Therefore, any comparisons of the growth curve parameters between the sexes are likely to be unreliable.

Estimates of longevity based on age estimates from “large” rattails are likely to be incorrect, given that the survey areas have been fished for a number of years and are likely to be lower than those derived from an unexploited population. Where study areas have been fished for a number of years, Cailliet et al. (1992) suggested that theoretical longevity can be estimated as the age at which 99% of the von Bertalanffy mean maximum length parameter L_∞, is reached. This estimate of longevity is given in terms of the von Bertalanffy parameters k and t_0 and is

$$\frac{1}{k}\log(100)+t_0 .$$

Nevertheless, calculation of reliable longevity estimates by this method requires an accurate estimate of the von Bertalanffy growth parameter k and to a lesser extent, an accurate estimate of the intercept parameter t_0.

2.1.6. Total mortality

The Chapman-Robson method was used to estimate the instantaneous total mortality, Z (Chapman & Robson 1960). Dunn et al. (2001) compared the Chapman-Robson method with a number of regression methods for estimating Z from age-frequency data and found that this method provided the lowest root mean square error and smallest bias in most of the scenarios explored.

For this method, catch at age frequency plots for each species and sex were obtained from the survey scaled length frequencies by applying age keys derived from the aged otoliths. Total mortality was then estimated by fitting an exponential decay curve to the catch at age frequencies to the right of a threshold age determined by the maximum frequency.

2.1.7 Length-weight relationships

The usual form of the relationship between length ℓ (cm) and weight w (g) applied to fish is

$$w = a\ell^{b} .$$

These parameters were estimated by fitting log(w) to log(ℓ) assuming a straight line with a normal error model for log(w) given log(ℓ) and constant variance (equivalent to w having a lognormal error model with constant c.v.). The intercept of the fitted model is the estimate of log(a) and the slope is the estimate of b.

In the literature, rattails are often measured by pre-anal length as their tails are often broken or regenerated, making total length an imprecise measure of fish size. For ease of comparison, the ratios of pre-anal length to total length were estimated from measurements made of both sexes for each rattail species. The ratio was estimated from the difference between log(pre-anal length) and log(length) assuming a normal distribution with constant variance.

2.2 Maturity

Macroscopic maturity stage was determined and recorded at sea by visual gonad examination using a generic seven-point gonad scale (Table 3). Additional data were obtained from the Ministry of Fisheries *trawl* database to help deduce the timing and duration of spawning.

Length at 50% maturity (L50) was estimated by fitting a logistic growth function to the proportion of mature individuals at length. A second set of curves was produced weighted by the number of samples in each length bin.
Only female fish were staged and used to estimate maturity as they tend to mature at a larger size, grow larger than males, often have a longer lifespan (Tomkiewicz et al. 2003), and are therefore more vulnerable to overexploitation.

Table 3: Generic middle depth species gonad development scale used for females.

Gonad Stage	Females
1 Immature	Ovaries small and translucent. No developing oocytes.
2 Resting/maturing virgin	Ovaries are developed, but no developing eggs are visible.
3 Ripening	Ovaries contain visible developing eggs, but no hyaline eggs present.
4 Ripe	Some or all eggs are hyaline, but eggs are not extruded when body is squeezed.
5 Running-ripe	Eggs flow freely from the ovary when it is cut or the body is pressed.
6 Partially spent	Ovary partially deflated, often bloodshot. Some hyaline and ovulated eggs present and flowing from a cut ovary or when the body is squeezed.
7 Spent	Ovary bloodshot; ovary wall may appear thick and white. Some residual ovulated eggs may still remain but will not flow when body is squeezed.

Table 4: Comparison 7 point scale used with Kock & Kellerman (1991) female 5 point scale.

Gonad Stages used	Kock & Kellerman (1991)
1 Immature	1 Immature
2 Resting/maturing virgin	2 Maturing Virgin or Resting
3 Ripening	3 Developing
4 Ripe	4 Gravid
5 Running-ripe	
6 Partially spent	
7 Spent	5 Spent

We were guided by the methodology of Kock & Kellerman (1991) in attempting to use the proportion of fish in stages 2–7 to estimate length at sexual maturity ($L50_{2\text{-}7}$ or L_{50}), and the proportion of fish in stages 3–7 to estimate length at first spawning ($L50_{3\text{-}7}$ or Lm_{50}).

However, there were differences between the seven point scale used in this study (Table 3) and the five point scale used by Kock & Kellerman (Table 4). A gonad stage of 2 represents females in the early stages of development before the vitellogenic yolk is clearly visible to the naked eye. A fish is assumed to be mature once the cortical aveoli stage is reached. This is roughly equivalent to macroscopic stage 2 in Table 4. The two gonad scales are in practical terms the same for stages 1 to 3 which are the critical stages in assessing maturity. However, the description of stage 2 does differ in the use of the words “visible eggs”, but not we believe in intent. The middle depths scale states “stage 2 has no developing eggs visible”, whereas Kock & Kellerman state “eggs visible giving the ovary a grainy appearance”. The point at which a developing egg becomes visible is subjective and will vary depending on a number of factors such as species, lighting conditions, and if the ovary is removed from the fish. For this reason, in our application of the middle depths scale, we classified an ovary with merely “a grainy appearance” as stage 2, i.e., no eggs visible. It is not till yolky eggs are clearly visible that an ovary was staged as a 3. There was no scope for histological validation of macroscopic stages as a part of this project. There are comparisons of macroscopic and microscopic stages for *M. carinatus* (Alekseyeva et al. 1993). They used histology and large numbers of macroscopic stages to elucidate the maturation cycle for *M. carinatus*.

2.3 Biomass trends

Biomass series were obtained for the four rattail species from survey series appropriate to the distribution of each species. For each species and survey series, a straight line function of time was fitted to the log-transformed biomass, with the assumption of a normal error distribution, and weighted by the inverse of the c.v. This is equivalent to assuming that the error model for the biomass series is lognormal with the c.v. equal to the biomass c.v. To test for a significant trend in the biomass, a t-test was used to determine whether the slope of the fitted line was significantly different from zero.

3. RESULTS

3.1 Age and growth

3.1.1 Two saddle rattail (CBI)

Representative otolith thin sections of male and female two saddle rattail are shown in Figure 1. Of the 238 two saddle rattail thin sections that were read by both readers, 44.1% of readings were identical between readers A and B, 81.1% were within one year, and 92.0% were within two years of each other. Of the 240 thin sections (2 thin sections were unable to be read by reader B) that were read twice by Reader A, 63.8% of readings were identical, 89.2% were within one year, and 97.0% were within two years of each other. There was reasonable within- and between-reader agreement for two saddle rattail. Readability was likely enhanced because of its apparent short life span, and the otolith sections were easier to interpret than those of the longer-lived species (Figure 2). There was little evidence of bias between readers, although reader B tended to give slightly older ages than Reader A (in both his readings) for the younger range of ages. The bias for ages 9 years or greater are uncertain as few larger fish were aged.

The mean ageing c.v. for two saddle rattail was 14% (Table 5).

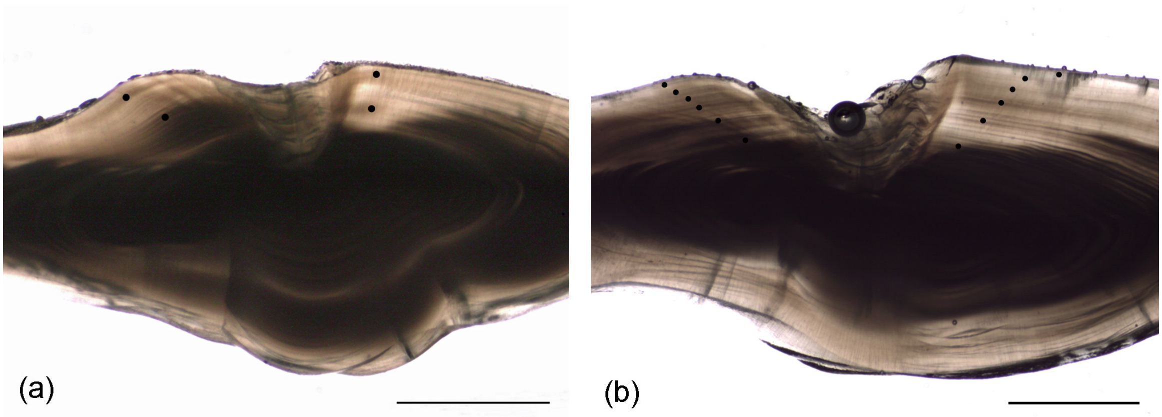

Figure 1: Thin transverse otolith sections of (a) a 309 mm TL female *Coelorinchus biclinozonalis* aged 2+ years, and (b) a 383 mm TL male aged 6+ years. Circles denote opaque zones. Scale bar = 1 mm.

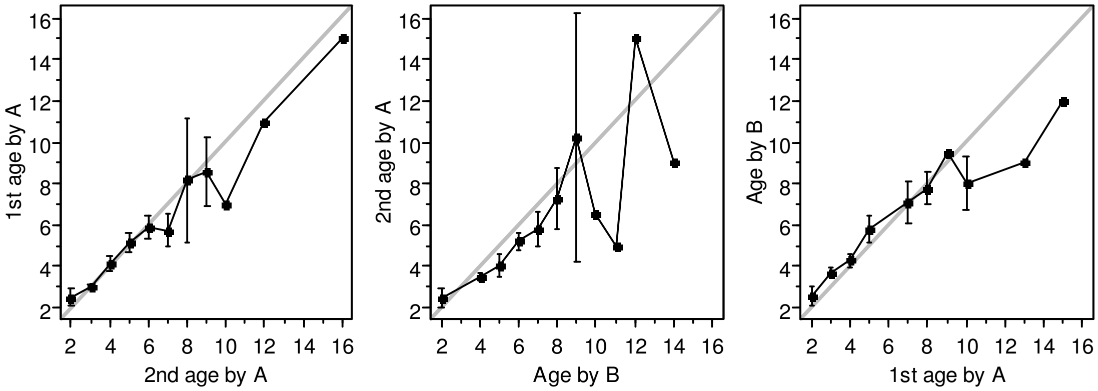

Figure 2: Bias plots for the two saddle rattail (CBI). Error bars are 1 standard error of the vertical age and are drawn only when there is more than one fish with the x-axis age.

Von Bertalanffy growth curves were fitted for each sex using the age length data, weighted so that the sample ageing represented the scaled length distribution. The curve parameters and the population c.v.'s for males and females are given in Table 6. For the two saddle rattail, the lack of aged older fish contributed to the very different parameter estimates between males and females because the data for the males did not enable L_∞ , k, or t_0 to be estimated accurately (all had very large SE's compared with those for females). The plot of the length at age points and curves also illustrates the problem (Figure 3).

Table 5: Imprecision measures of ageing for the four rattail species. Values are percentages. Species names are given in Table 1.

	CBI	CBO	JAV	MCA
Mean CV	14.1	11.3	11.4	12.5
Mean CV for Reader A	7.8	6.5	8.5	10.8
IAPE	10.6	8.4	8.5	9.2

Chapman-Robson estimates of total mortality, Z, for male and female two saddle rattail (together with their sampling c.v.'s in parentheses) are 0.54 (11.5%) and 0.67 (8.0%), respectively (Table 7). The threshold ages for both males and females were 3 years, and were chosen from the survey catch at age proportions (Figure 4).

Table 6: Parameter estimates from fitting the von Bertalanffy curves to the length age data for males and females for the four rattail species. Standard errors (SE) and population coefficients of variation (Popln c.v.) of the sampling distributions of the estimates are also given. Species names are given in Table 1.

		Males			Females		
Species	Parameter	Estimate	SE	CV(%)	Estimate	SE	CV(%)
CBI	L_∞	53.82	18.7	35	54.83	2.52	4.6
	k	0.1180	0.118	100	0.3400	0.0766	23
	t_0	-4.471	3.343		-0.490	0.515	
	Popln. CV (%)	8.6		16	9.8		11
CBO	L_∞	44.81	0.66	1.5	49.76	0.72	1.4
	k	0.2422	0.037	15	0.3231	0.0361	11
	t_0	-2.142	0.708		-0.446	0.310	
	Popln. CV (%)	8.0		13	8.5		13
JAV	L_∞	47.19	4.79	10	55.22	4.32	7.8
	k	0.2439	0.097	40	0.1882	0.054	29
	t_0	-1.300	0.967		-1.935	0.808	
	Popln. CV (%)	8.7		16	8.7		13
MCA	L_∞	76.46	6.22	8.1	105.33	14.4	14
	k	0.0694	0.017	25	0.0426	0.015	36
	t_0	-1.147	1.755		-6.847	2.946	
	Popln. CV (%)	12.3		18	15.1		11

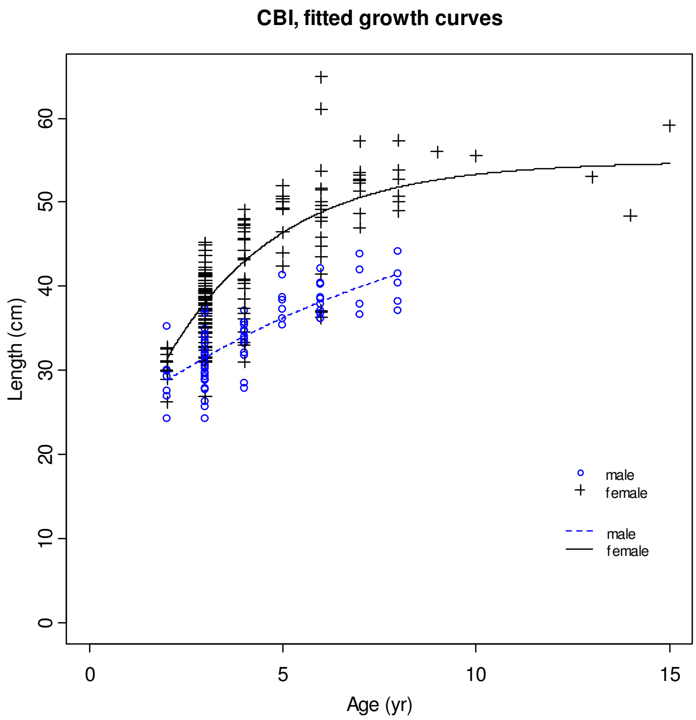

Figure 3: Length at age points with the fitted von Bertalanffy curves for male and female two saddle rattail (CBI).

Table 7: Chapman-Robson estimates of instantaneous total mortality (Z), together with sampling c.v.'s for males and females from the four rattail species. Threshold ages (yr) used to calculate the estimates are also given. Species names are given in Table 1.

	Males			Females		
Species	Threshold	Z (yr^{-1})	CV (%)	Threshold	Z (yr^{-1})	CV (%)
CBI	3	0.54	11.5	3	0.67	8.0
CBO	17	0.41	9.3	15	0.35	9.1
JAV	3	0.51	11.2	3	0.29	9.4
MCA	15	0.15	12.3	17	0.17	7.4

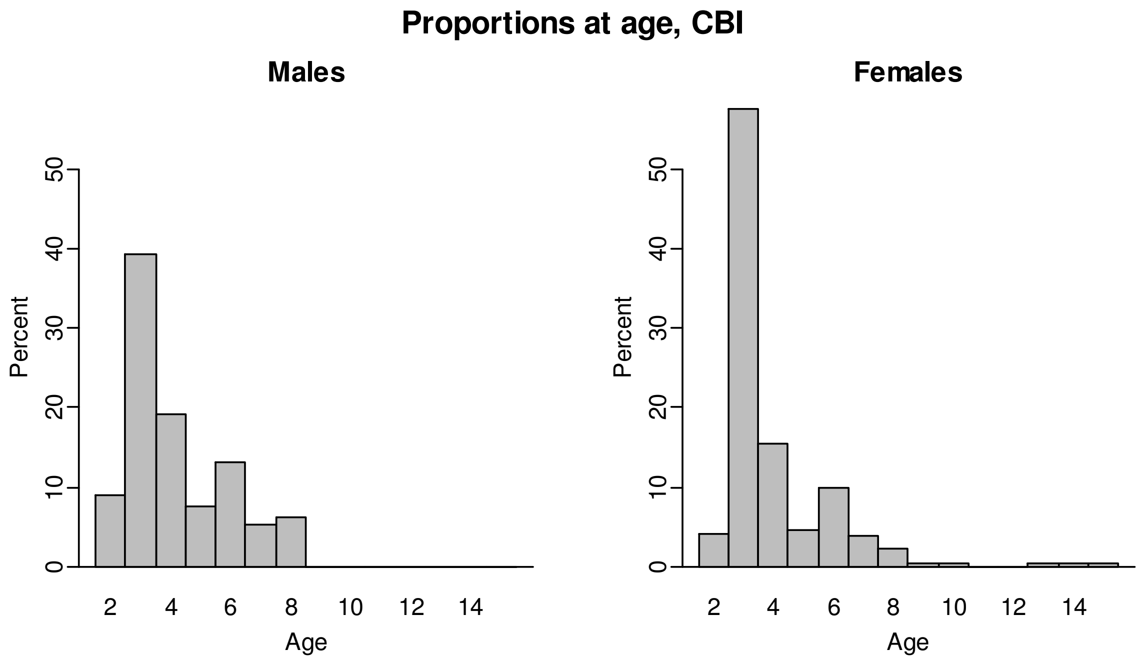

Figure 4: Catch at age proportions for two saddle rattail (CBI) from the 2009 Chatham Rise survey.

The oldest male two saddle rattail was estimated as 8 years old (Figure 4). The oldest female was aged as 15 years old and 6.7% (11 fish) of female fish were aged as 8 years or older. Estimates of longevity using the Cailliet method are 35 years for male two saddle rattails and 13 years for females.

The longevity estimate for females was less than the oldest age reading and the estimate for males seems unreasonably large, as it is more than four times the age of the oldest male in this study. Both longevity estimates reflect inaccuracies in the von Bertalanffy parameter estimates. Because a large negative t_0 was estimated for male CBI rattails (see Table 6), the estimate of k is likely to be biased low which in turn gives a higher estimate for longevity.

Length-weight parameters for male and female two saddle rattail are given in Table 8. Plots of weights against length show good fits for both sexes (Figure 5).

Table 8: Parameter estimates for the length-weight relationships for both sexes and all four rattail species (lengths in cm and weights in g). Species names are given in Table 1.

		Males		Females	
Species	Parameter	Estimate	CV(%)	Est.	CV(%)
CBI	*a* (g)	0.00137	41	0.00149	19
	b	3.336	3.4	3.299	1.6
CBO	*a* (g)	0.00337	17	0.00133	15
	b	3.124	1.5	3.379	1.2
JAV	*a* (g)	0.00150	24	0.00125	12
	b	3.101	2.2	3.166	1.0
MCA	*a* (g)	0.01059	27	0.00511	18
	b	2.808	2.4	3.008	1.4

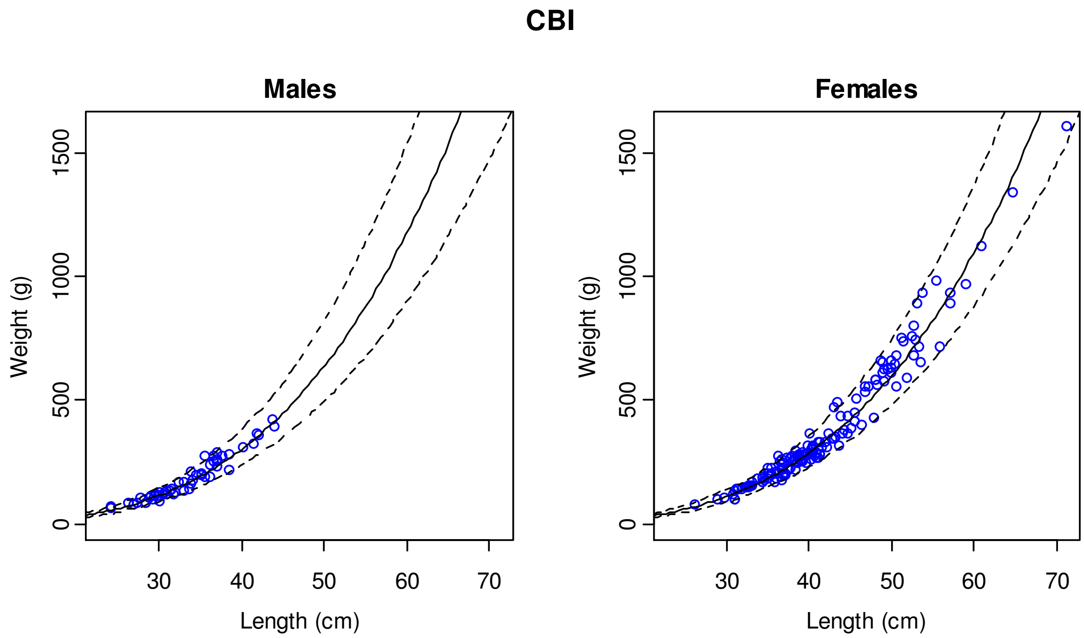

Figure 5: Plots of weight (g) against length (cm) for male and female two saddle rattail (CBI), with the fitted line (solid line) and 95% predicted interval bounds (dashed lines).

The ratios of pre-anal length to total length were similar within each of the four species but the ratios for females were always slightly larger (Table 9). The ratios for the two saddle rattail for males and females were 33.0% and 33.2%, respectively.

Table 9: Ratios of pre-anal length to total length (with c.v.'s) for male and female rattails for the four species. Species names are given in Table 1.

	Males		Females	
Species	Ratio (%)	CV (%)	Ratio (%)	CV (%)
CBI	33.0	4.9	33.2	5.2
CBO	33.3	7.8	33.5	7.8
JAV	23.0	7.1	24.4	7.1
MCA	36.6	5.4	37.2	4.6

3.1.2 Bollons's rattail (CBO)

Representative otolith thin sections of male and female Bollons's rattail are shown in Figure 6. Of the 242 Bollons's rattail thin sections that were read by both readers, 21.9% of readings were identical, 62.4% were within one year, and 82.2% were within two years of each other. Reader A generally aged Bollons's rattail older than Reader B (Figure 7).

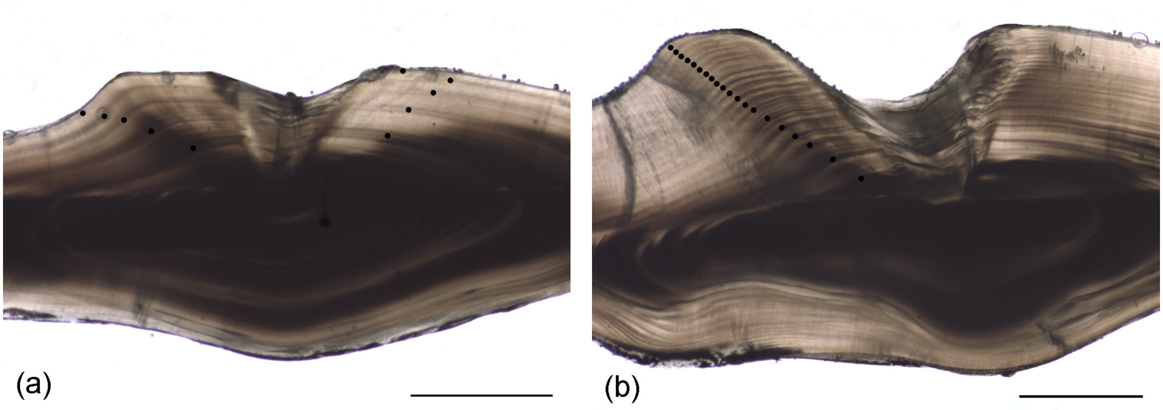

Figure 6: Thin transverse otolith sections of a (a) 382 mm TL female *Coelorinchus bollonsi* aged 5+ years, and (b) 503 mm TL male aged 20+ years. Circles denote opaque zones. Scale bar = 1 mm.

Of the 242 thin sections that were read twice by Reader A, 42.4% of readings were identical, 77.0% were within one year, and 87.7% were within two years of each other (Figure 7). The within-reader agreement for reader A was high (Figure 7, left panel). For fish aged about 17 years or younger, between-reader agreement was inconsistent with Reader B generally giving ages about 1 year less on average than for either reading by Reader A (Figure 7). This may reflect the difficulty in obtaining zone counts from this species. What appeared to be false increments derived from split opaque zones and areas of poor increment clarity were frequently observed. The bias for ages 17 or greater are uncertain because few older fish were aged. There is little evidence of reader bias for Bollons's rattail. The mean ageing c.v. for Bollons's rattail was 11% (see Table 5).

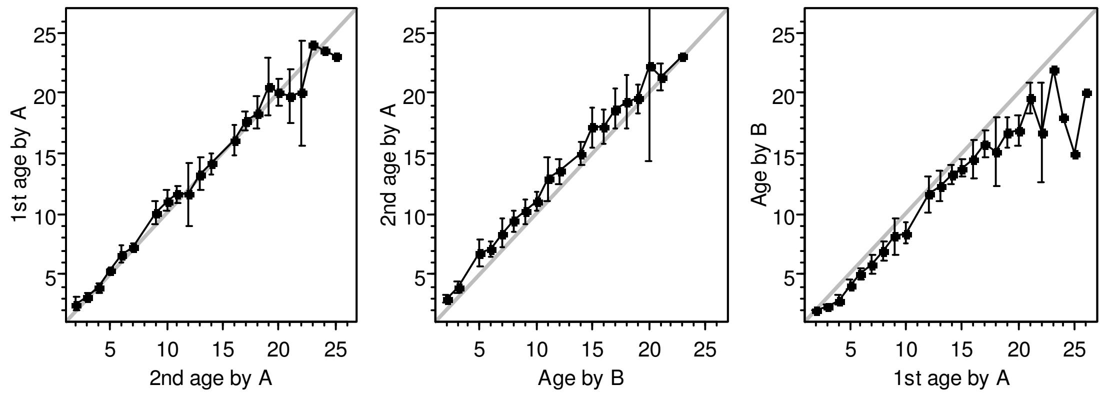

Figure 7: Bias plots for the Bollons's rattail (CBO). Error bars are one standard error of the vertical age and are drawn only when there is more than one fish with x-axis age.

The estimates of the parameters of the von Bertalanffy growth curves are much less uncertain than those for the two saddle rattail (see SEs in Table 6). The apparent slower growth rate, k, for males compared to females may be due to the strong correlation between k and t_0 and the relatively large negative value for t_0. Ages for both sexes spanned the range 2 to 24 years but the males were smaller on average at all ages greater than 3 years (Figure 8).

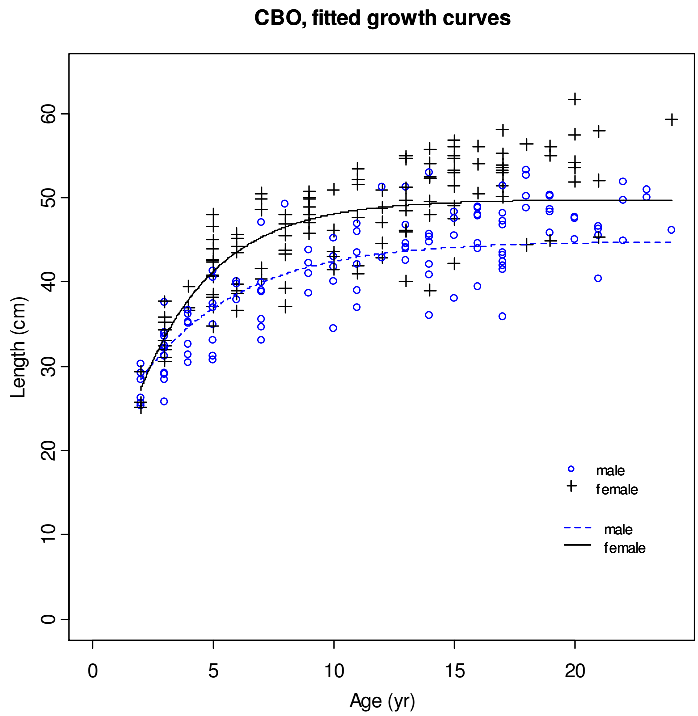

Figure 8: Observed length at age with the estimated von Bertalanffy curves for male and female Bollons's rattail (CBO).

Chapman-Robson estimates of the instantaneous total mortalities for the two sexes were 41% per year for males and 35% per year for females, using threshold ages of 17 and 15 years respectively (see Table 7). The survey catch at age proportions for Bollons's rattail used for the estimates of total mortality *Z* are plotted in Figure 9.

The oldest male Bollons's rattail was aged as 24 years old, and 11.1% (13 fish) of males were aged as 20 years or older. The oldest female was also estimated as 24 years old and 7.2% (9 fish) of females were aged as 20 years or older. Estimates of longevity for Bollons's rattail, using the Cailliet method, are 17 years for males and 14 years for females. These are underestimates because the oldest age estimate was 24 years for both sexes, and may have resulted from inaccurate estimates of the von Bertalanffy parameters k and t_0.

Length-weight parameters for male and female Bollons's rattail are given in Table 6. Plots of weights against length show good fits for both sexes (Figure 10).

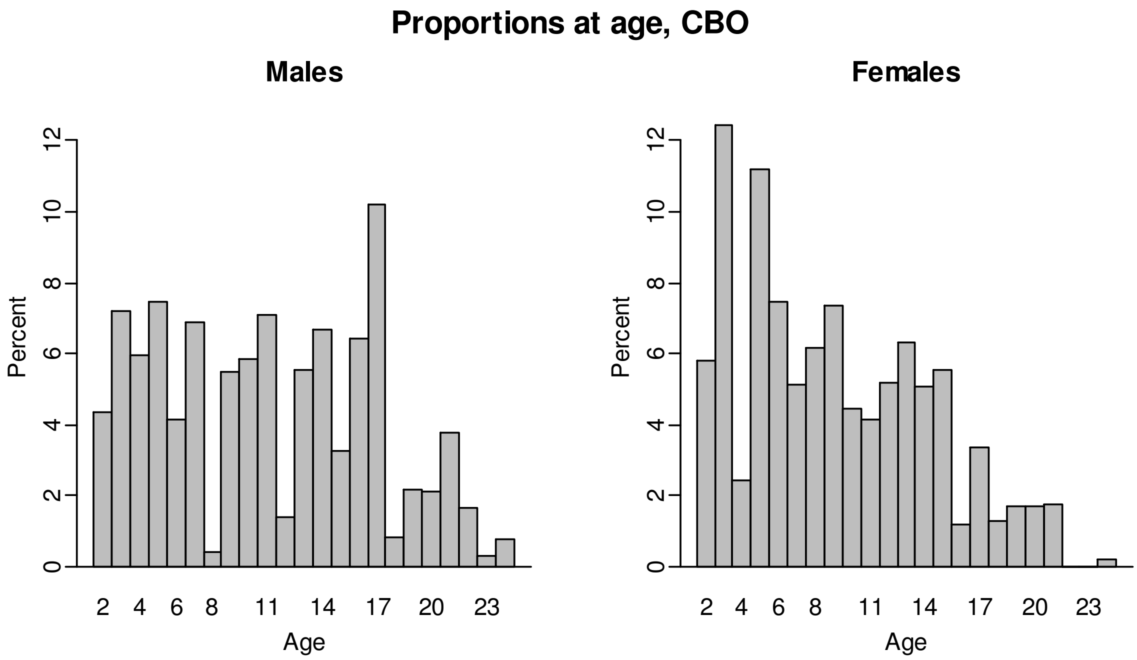

Figure 9: Catch at age proportions for Bollons's rattail (CBO) from the 2009 Chatham Rise survey.

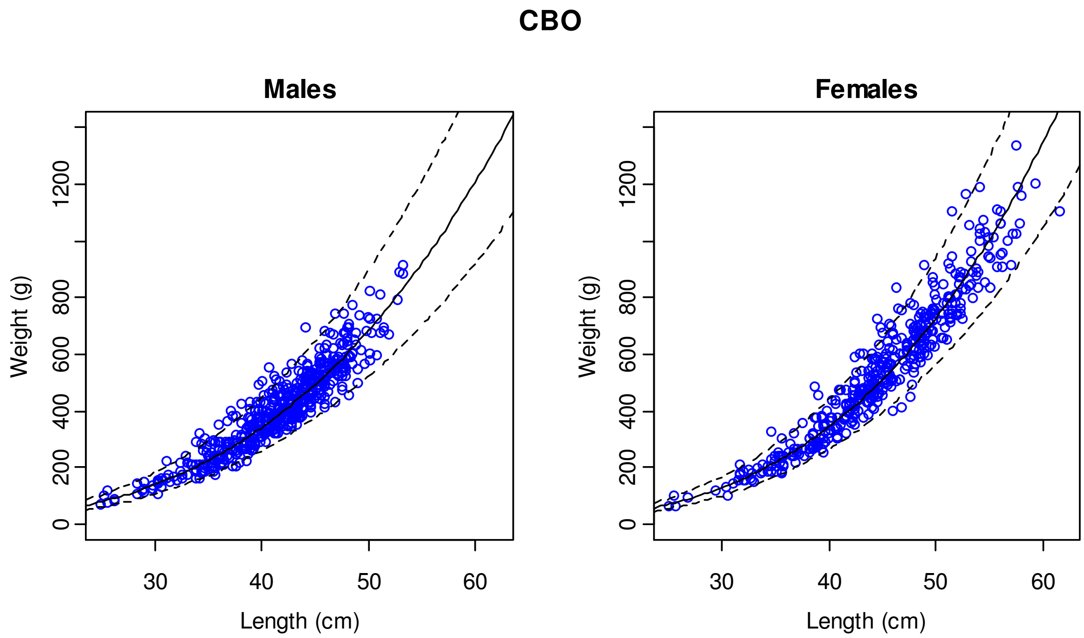

Figure 10: Plots of weight (g) against length (cm) for male and female Bollons's rattail (CBO), with the fitted line (solid line) and 95% predicted interval bounds (dashed lines).

The ratios of pre-anal length to total length for Bollons's rattail for males and females were 33.3% and 33.5%, respectively (Table 9).

3.1.3 Javelinfish (JAV)

Representative otolith thin sections of male and female javelinfish are given in Figure 11. Of the 197 javelinfish thin sections that were read by both readers, 44.2% of readings were identical, 85.3% were within one year, and 93.9% were within two years of each other. Of the 197 thin sections that were read twice by Reader A, 55.3% of readings were identical, 80.7% were within one year, and 91.0% of readings were within two years of each other.

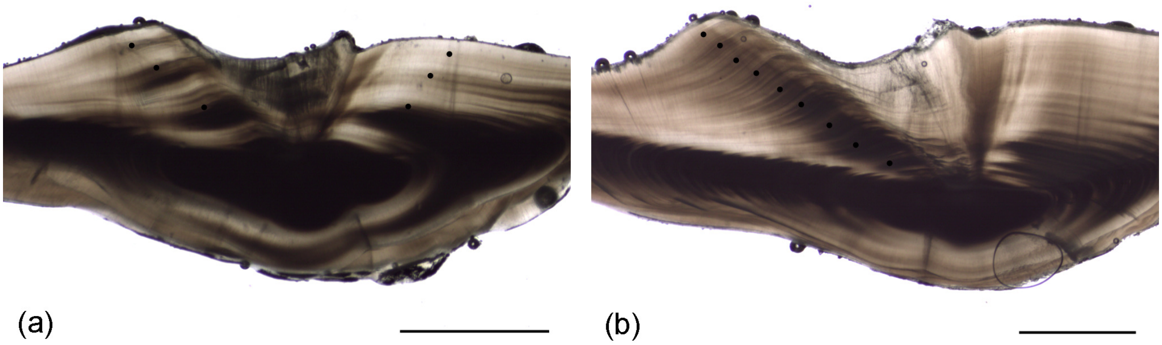

Figure 11: Thin transverse otolith sections of (a) a 425 mm TL male *Lepidorhynchus denticulatus* aged 3+ years, and (b) a 562 mm TL female aged 9+ years. Circles denote opaque zones. Scale bar = 1 mm.

The within and between-reader agreement was poorer than expected given that this species appears to be short lived and the otolith sections were easier to interpret than those of the longer lived species. There was some bias between readers (Figure 12) especially for the older fish (aged 8 years or more). Reader A's first readings were generally lower than his second readings and also lower than the readings by Reader B, for older fish. For younger fish, there was evidence that both readings by Reader A were slightly higher than those by Reader B. However, the mean ageing c.v. was 11%, which is similar to that for Bollons's rattail and less than that for the other two species (see Table 5).

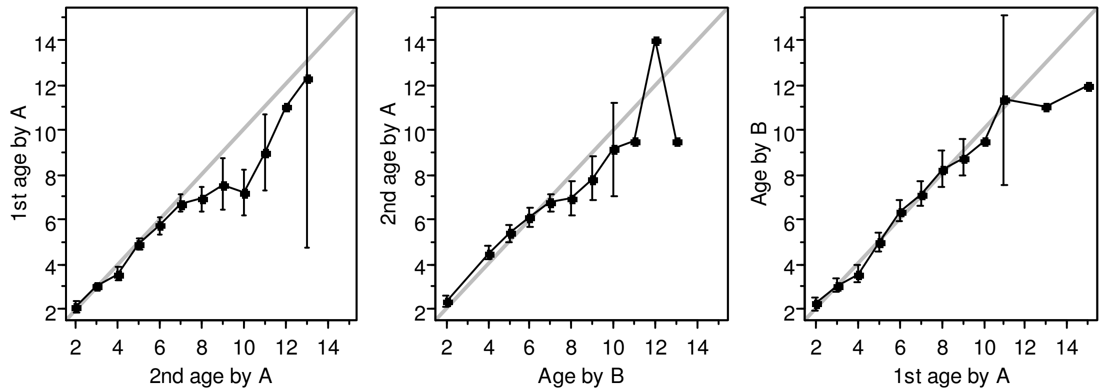

Figure 12: Bias plots for javelinfish (JAV). Error bars are 95% confidence intervals and are drawn only when there is more than one fish with the x-axis age.

The estimates of the von Bertalanffy parameters for male and female javelinfish have large c.v.'s (see Table 6) which is an indication of poor parameter estimation. When t_0 is not well estimated, k is also not well estimated. The growth curves for the two sexes are not very different, the differences at each age varying between about 3–6cm over the age range 2 to 10 years (Figure 13).

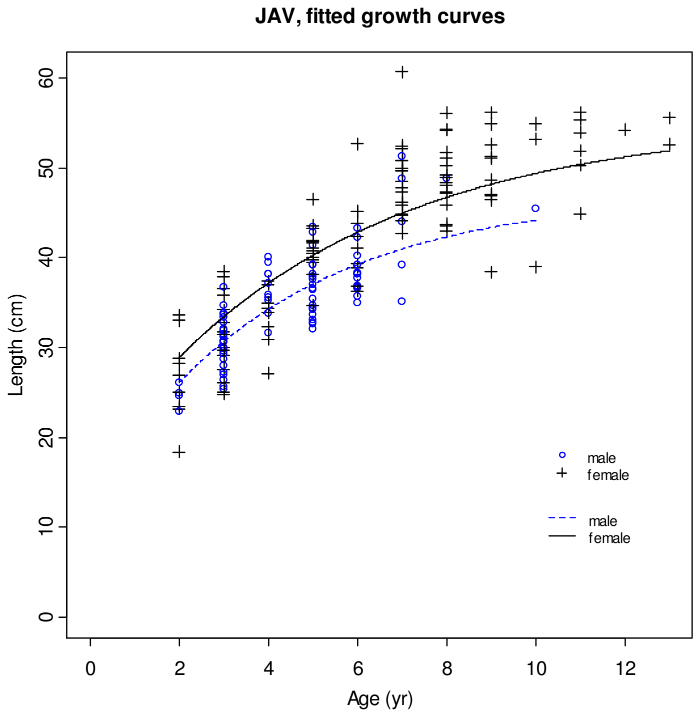

Figure 13: Length at age points with the fitted von Bertalanffy curves for male and female javelinfish (JAV).

Chapman-Robson estimates of total mortality, Z, for male and female javelinfish together with their sampling c.v.'s are respectively 51% per yr (c.v. = 11%) and 29% per year (c.v. = 9%) (see Table 7). The threshold ages for both males and females was 3 years, and were chosen from the survey catch at age proportions (Figure 14).

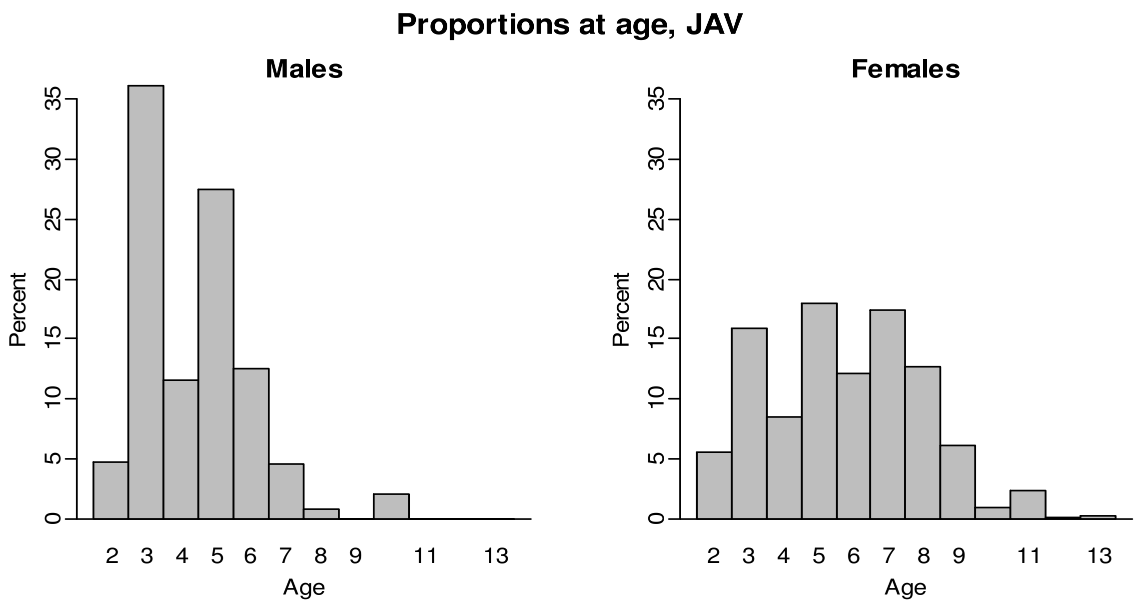

Figure 14: Catch at age proportions for javelinfish (JAV) from the 2009 Chatham Rise survey.

The oldest male javelinfish was aged as 10 years old. The oldest female was aged as 13 years old and 10.4% (12 fish) of female fish were aged as 10 years or older. However, javelinfish were difficult to sex and some of the samples are likely to have been sexed incorrectly. Estimates of longevity using the Cailliet method were 18 years for males and 23 years for females.

Length-weight parameters for male and female javelinfish are given in Table 8. Plots of weights against length show good fits for both sexes (Figure 15).

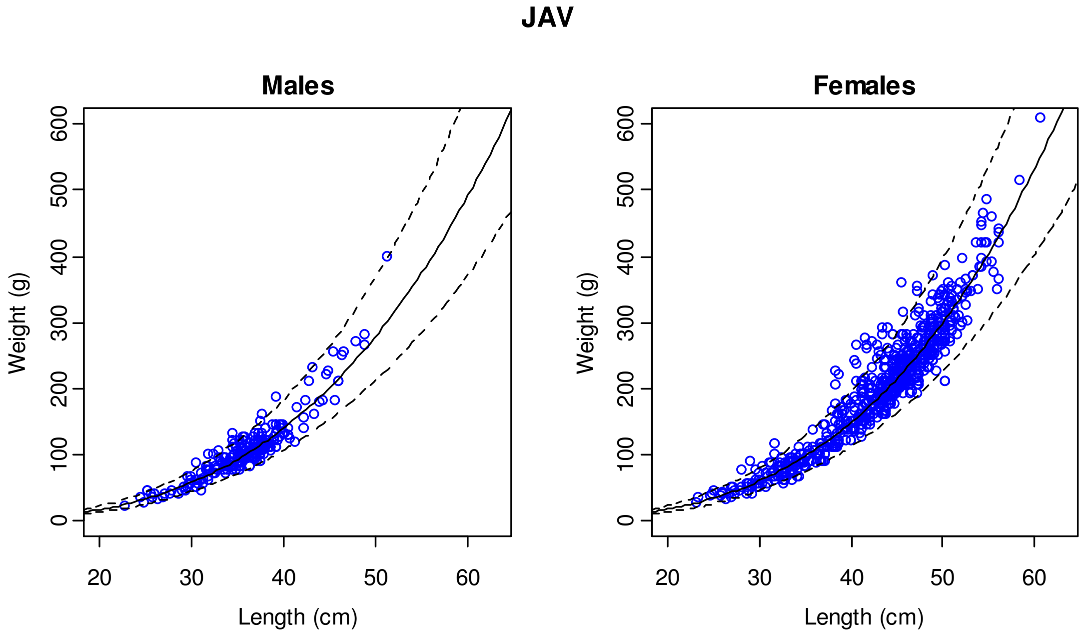

Figure 15: Plots of weight (g) against length (cm) for male and female javelinfish (JAV), with the fitted line (solid line) and 95% predicted interval bounds (dashed lines).

The ratios of pre-anal length to total length for javelinfish for males and females were 23.0% and 24.4%, respectively (Table 9).

3.1.4 Ridge-scaled rattail (MCA)

Representative otolith thin sections of male and female ridge-scaled rattail are shown in Figure 16. Of the 248 thin sections that were read by both readers, only 14.9% of readings were identical, 36.3% were within one year, 52.4% of readings were within two years, and 64.5% of readings were within three years of each other. Of the 246 thin sections that were read twice by Reader A, only 19.9% of readings were identical, 42.7% were within one year, 61.4% of readings were within two years, and 72.4% of readings were within three years of each other. There was poor within and between-reader agreement as this species was relatively long-lived and difficult to age with numerous split bands and areas of poor increment resolution (Figure 17). There was some within-reader disagreement apparent from the bias plot (Figure 17, left panel) but the evidence is not strong because of the large intervals, meaning large variation. Agreement between readers was also apparent but, again, there is large variation. There was little apparent ageing bias within Reader A, but there was some evidence of a small bias between reader B and the first reading by Reader A (Figure 17, right panel) with Reader B tending to give older ages. Reader A generally aged ridge-scaled rattail slightly older than reader B.

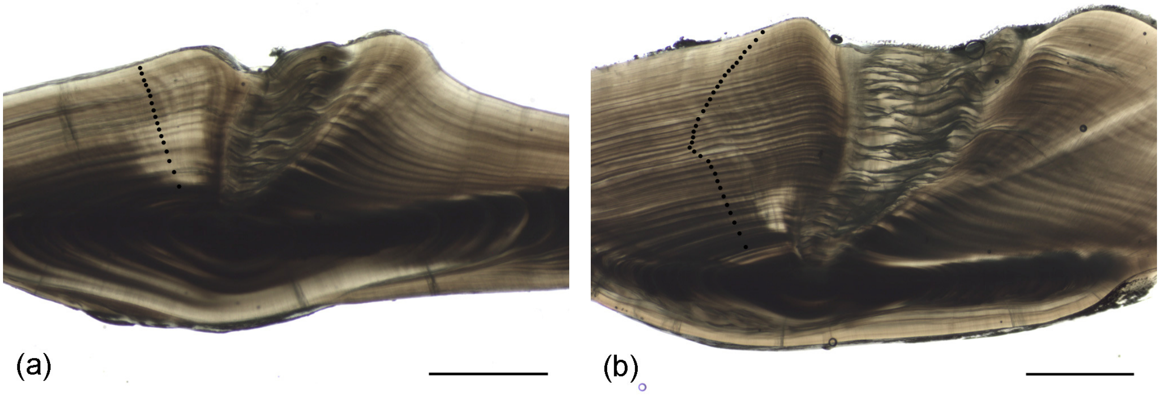

Figure 16: Thin transverse otolith sections of (a) a 682 mm TL male *Macrourus carinatus* (MCA) aged 17+ years, and (b) a 849 mm TL female aged 34+ years. Circles denote opaque zones. Scale bar = 1 mm.

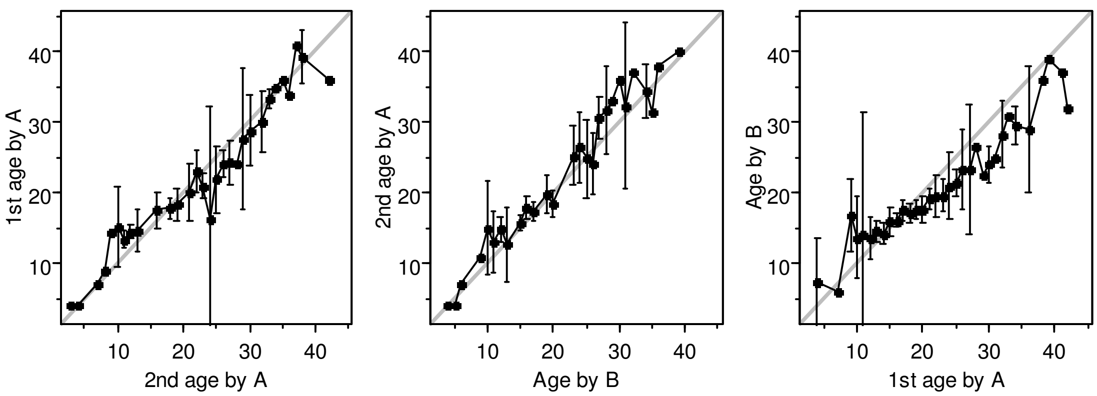

Figure 17: Bias plots for ridge-scaled rattail (MCA). Error bars are one standard error of the vertical age and are drawn only when there is more than one fish with x-axis age.

The estimates of the von Bertalanffy parameters for male and female ridge-scaled rattail have relatively large sampling c.v.'s (see Table 6). The large negative t_0 estimate for female ridge-scaled rattails was -6.8 years and this resulted in a lower estimate of k (the instantaneous growth rate as a proportion of the difference between L_∞ and length). The growth curves for male and female fish differ, with females being larger at a given age than males (Figure 18). This discrepancy is likely to be less pronounced in juvenile fish, but given the lack of small fish in the sample, this was not determined.

Population c.v.'s, as a proportion of mean length, were 12% and 15% for males and females respectively, which are larger than those for the other species, indicating greater variation in lengths at age for this species.

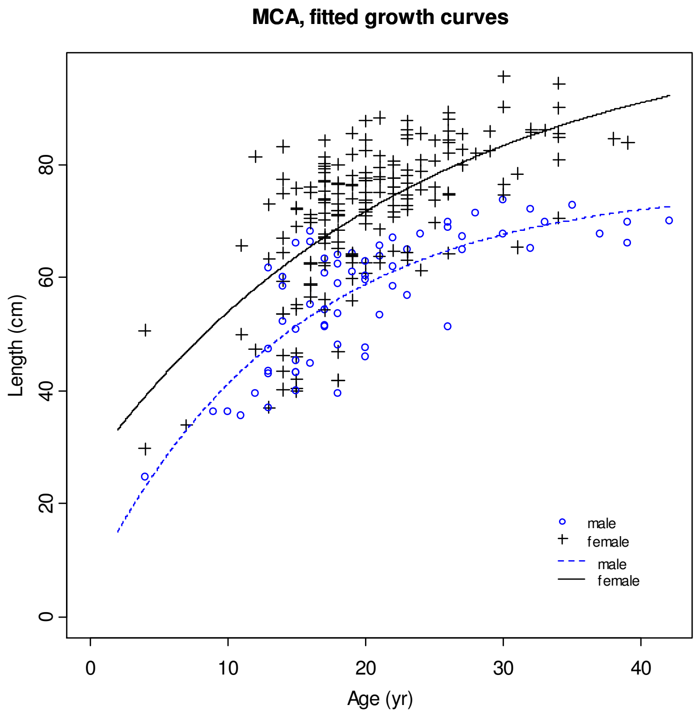

Figure 18: Length at age points with the fitted von Bertalanffy curves for male and female ridge-scaled rattail (MCA).

Chapman-Robson estimates of total mortality, Z, for male and female ridge-scaled rattail together with their sampling c.v.'s were respectively, 15% per year (c.v. = 12%) and 17% per year (c.v. = 7%) (see Table 7). The much smaller values are to be expected because of the greater longevity of this species. The threshold ages for the estimates were 15 years for males and 17 years for females, and were chosen from the survey catch at age proportions (Figure 19).

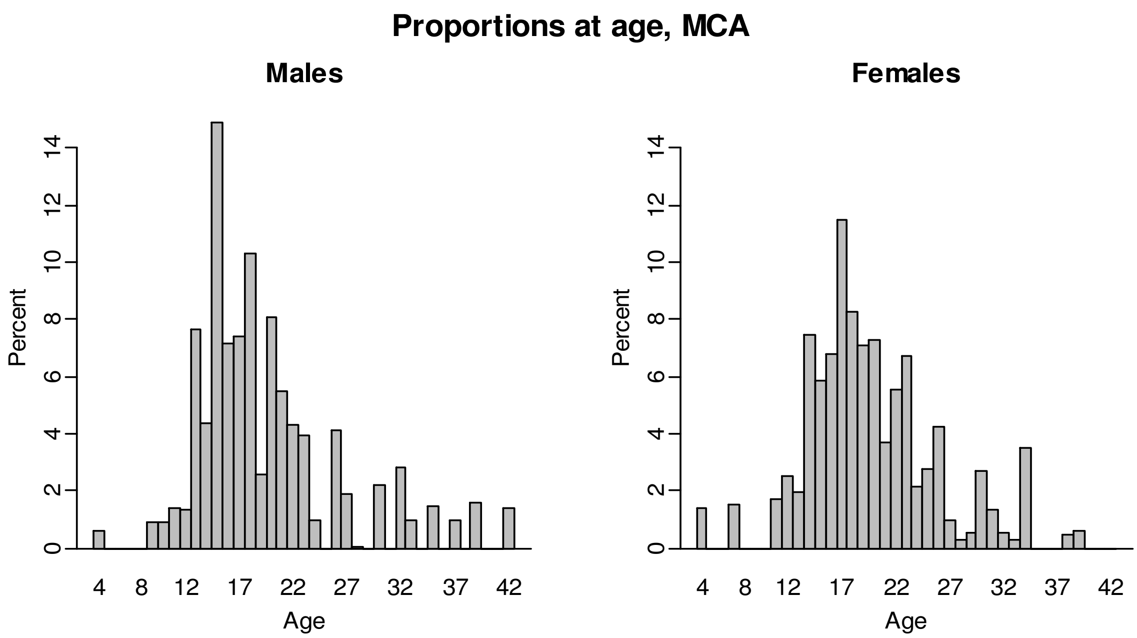

Figure 19: Catch at age proportions for ridge-scaled rattail (MCA) from the 2006 Sub-Antarctic survey.
The oldest male ridge-scaled rattail was aged as 42 years old. The oldest female was aged as 39 years old. Estimates of longevity using the Cailliet method are 65 years for males and 101 years for females.

These estimates are very high and do not seem feasible. The largest ridge-scaled rattail aged in the current study was 96 cm and was estimated to be 30 years of age. The reported maximum size for this species is about 105 cm (NIWA Marine Species Information Database) and it seems unlikely given the growth rates reported here that a 105 cm female (females grow larger than males) would be 59 years older than the maximum reported age in this study.

Length-weight parameters for male and female ridge-scaled rattail are given in Table 8. Plots of weights against length show good fits for both sexes (Figure 20)

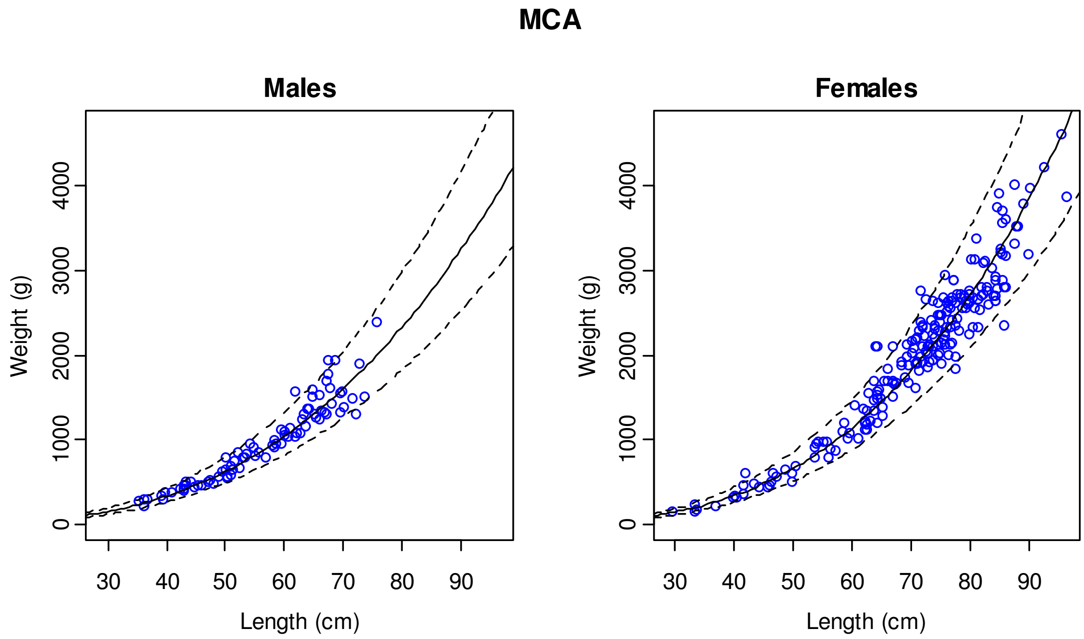

Figure 20: Plots of weight (g) against length (cm) for male and female ridge-scaled rattail (MCA), with the fitted line (solid line) and 95% predicted interval bounds (dashed lines).

The ratios of pre-anal length to length for the ridge-scaled rattail for males and females were 36.6% and 37.2%, respectively (Table 9).

3.2 Maturity

3.2.1 Two saddle rattail (CBI)

Most CBI samples were collected in January and March/April, plus a small number in July. The high numbers of gonad stages 3, 4, and 7 indicate some spawning is occurring during summer, autumn, and possibly longer (Tables 10 and 11). Active stages (3–7) were present at all times but only one running ripe female was recorded. No clear pattern of gonad stage progression is evident to indicate a single major peak spawning activity. The pattern of spawning behavior is unclear. The major period of spawning could occur at some other time or spawning could occur in batches throughout the year. There is no compelling reason to reject any of the available time periods so all trips were included in the analysis.

Table 10: Sample size by trip code and gonad stage for two saddle rattail (TGBG, Tasman Bay and Golden Bay; WCSI, West Coast South Island; CHAT, Chatham Rise; NWCR, North West Chatham Rise). All samples were used in the maturity analysis.

Trip code	Areas	Timing	Gonad stage 1	2	3	4	5	6	7	All
KAH0304	*TGBG,WCSI*	*Mar-Apr*	*1*	*2*	-	-	-	-	-	*3*
KAH0704	*TGBG,WCSI*	*Mar-Apr*	-	*15*	*5*	*16*	*1*	*5*	*3*	*45*
KAH0904	*TGBG,WCSI*	*Mar-Apr*	*2*	*22*	*3*	-	-	-	-	*27*
TAN0007	*WCSI*	*Jul-Aug*	-	*1*	-	-	-	-	*1*	*2*
TAN0701	*CHAT*	*Jan*	*5*	*50*	*20*	*3*	-	-	*26*	*104*
TAN0709	*NWCR,CHAT*	*Jul*	*4*	-	*3*	*1*	-	-	*1*	*9*
TAN0901	*CHAT*	*Jan*	*12*	*15*	*20*	*19*	-	*11*	*65*	*142*
TAN1001	*CHAT*	*Jan*	*3*	*6*	*2*	*26*	-	-	-	*37*
Total			27	111	53	65	1	16	96	369

Table 11: Average fish length (total length in cm) trip code and gonad stage for two saddle rattail (TGBG, Tasman Bay and Golden Bay; WCSI, West Coast South Island; CHAT, Chatham Rise; NWCR, North West Chatham Rise). All samples were used in the maturity analysis.

Trip code	Areas	Timing	Gonad stage 1	2	3	4	5	6	7	All
KAH0304	*TGBG,WCSI*	*Mar-Apr*	*39*	*47*	-	-	-	-	-	*44*
KAH0704	*TGBG,WCSI*	*Mar-Apr*	-	*39*	*45*	*43*	*50*	*44*	*46*	*42*
KAH0904	*TGBG,WCSI*	*Mar-Apr*	*31*	*39*	*47*	-	-	-	-	*39*
TAN0007	*WCSI*	*Jul-Aug*	-	*41*	-	-	-	-	*53*	*47*
TAN0701	*CHAT*	*Jan*	*33*	*47*	*51*	*52*	-	-	*52*	*48*
TAN0709	*NWCR,CHAT*	*Jul*	*33*	-	*42*	*62*	-	-	*49*	*41*
TAN0901	*CHAT*	*Jan*	*32*	*42*	*43*	*46*	-	*49*	*41*	*42*
TAN1001	*CHAT*	*Jan*	*29*	*41*	*38*	*47*	-	-	-	*44*

Table 12: Summary of maturity results by species with total length in (cm) and age in (years). Species names are given in Table 1.

	CBI	CBO	JAV	MCA
L50 $_{2\text{-}7}$	30.7	34.5	34.3	55.8
L50 $_{2\text{-}7w}$	**30.7**	**34.4**	**34.7**	**56.2**
L50 $_{3\text{-}7}$	37.9	46.1	49.5	67.5
L50 $_{3\text{-}7w}$	35.9	45.9	49	67.2
Age $_{2\text{-}7}$	1.9	3.2	3.2	10.9
Age $_{2\text{-}7w}$	**1.9**	**3.2**	**3.3**	**11.1**
Age $_{3\text{-}7}$	3	7.6	10.1	17.2
Age $_{3\text{-}7w}$	2.6	7.5	9.7	17

The logistic weighted and unweighted growth curves using gonad stages 2–7 are knife edged, with little separation for most of their length range (Figure 21).

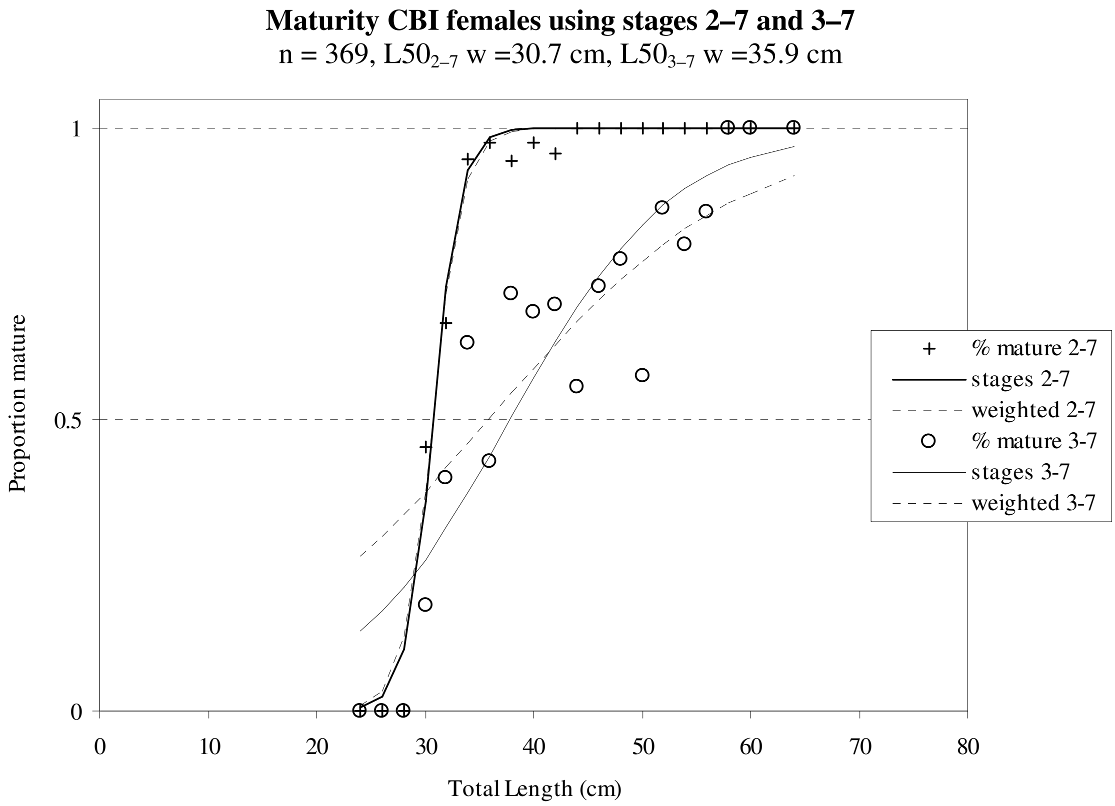

Figure 21: The proportion of female two saddle rattail (CBI) at maturity stages 2–7 (+) and 3–7 (o); and fitted logistic growth curves unweighted (line) and weighted by sample size (dashed line).

The curves using stages 3–7 are truncated at both ends of the length range, most noticeably the weighted curve at the lower end. The weighted curve is less steep, and overlaps with the unweighted curve only where they cross at about the 60% maturity level. There are too few samples at both ends of the length range and considerable scatter in the middle range which contains most samples, leading to uncertainty in the age estimates. Individual L50 values are listed in Table 12.

3.2.2 Bollons's rattail (CBO)

There were 521 female gonad samples, 355 of which came from the January Chatham Rise surveys. There were also samples from a March/April east coast North Island survey, a July Chatham Rise survey, a July west coast South Island survey, and November/December Sub-Antarctic surveys (Tables 13 and 14).

The only ripe and running ripe females recorded were in July, some partially spent and spent females were recorded in November/December, and spent fish were recorded in January and March/April. This suggests a winter/spring spawning period. The January samples were excluded from the analysis as they were too far removed from the likely spawning time.

Table 13: Sample size by trip code and gonad stage for Bollons's rattail (WCSI, West Coast South Island; CHAT, Chatham Rise; NWCR, North West Chatham Rise; ECNI, East Coast North Island). Samples in italics were used in the maturity analysis.

Trip code	Area	Month	Gonad stage							
			1	2	3	4	5	6	7	All
TAN0007	*WCSI*	*Jul*	*1*	*18*	*17*	*9*	*4*	-	*3*	*52*
TAN0201	CHAT	Jan	-	4	-	-	-	-	-	4
TAN0317	Sub-Antarctic	Nov-Dec	-	2	-	-	-	-	-	2
TAN0501	CHAT	Jan	38	152	5	-	-	-	-	195
TAN0601	CHAT	Jan	1	10	-	-	-	-	-	11
TAN0617	*Sub-Antarctic*	*Nov-Dec*	*2*	*22*	*4*	-	-	*7*	*18*	*53*
TAN0709	*NWCR,CHAT*	*Jul*	*1*	-	*2*	-	-	-	*1*	*4*
TAN0901	CHAT	Jan	22	105	6	-	-	-	2	135
TAN0911	*Sub-Antarctic*	*Nov-Dec*	-	*3*	-	-	-	-	*8*	*11*
TAN1001	CHAT	Jan	1	9	-	-	-	-	-	10
TAN1003	*ECNI*	*Mar-Apr*	*8*	*21*	-	-	-	-	*14*	*43*
Total			74	346	34	9	4	7	46	520

Table 14: Average fish length (total length in cm) trip code and gonad stage for Bollons's rattail (WCSI, West Coast South Island; CHAT, Chatham Rise; NWCR, North West Chatham Rise; ECNI, East Coast North Island). Samples in italics were used in the maturity analysis.

Trip code	Area	Month	Gonad stage							
			1	2	3	4	5	6	7	All
TAN0007	*WCSI*	*Jul*	*27.8*	*41.9*	*49.8*	*52.6*	*51.6*	-	*56.0*	*47.6*
TAN0201	CHAT	Jan	-	49.4	-	-	-	-	-	49.4
TAN0317	Sub-Antarctic	Nov-Dec	-	61.9	-	-	-	-	-	61.9
TAN0501	CHAT	Jan	36.9	48.8	49.9	-	-	-	-	46.5
TAN0601	CHAT	Jan	34.1	48.7	-	-	-	-	-	47.4
TAN0617	*Sub-Antarctic*	*Nov-Dec*	*34.0*	*50.1*	*52.5*	-		*56.7*	*58.1*	*53.2*
TAN0709	*NWCR,CHAT*	*Jul*	*29.2*	-	*49.2*	-	-	-	*50.6*	*44.5*
TAN0901	CHAT	Jan	36.9	48.4	48.1	-	-	-	48.2	46.5
TAN0911	*Sub-Antarctic*	*Nov-Dec*	-	*60.4*	-	-	--	-	*60.9*	*60.7*
TAN1001	CHAT	Jan	40.9	52.1	-	-	-	-	-	51
TAN1003	*ECNI*	*Mar-Apr*	*36.5*	*43.1*	-	--	-	-	*50.3*	*44.2*

The logistic weighted and unweighted growth curves (Figure 22) using gonad stages 2–7 are knife edged, with very little separation.

The curves using stages 3–7 are less steep than for stages 2–7. The weighted curve overlaps with the unweighted curve with little separation. Individual L50 values are listed in Table 12.

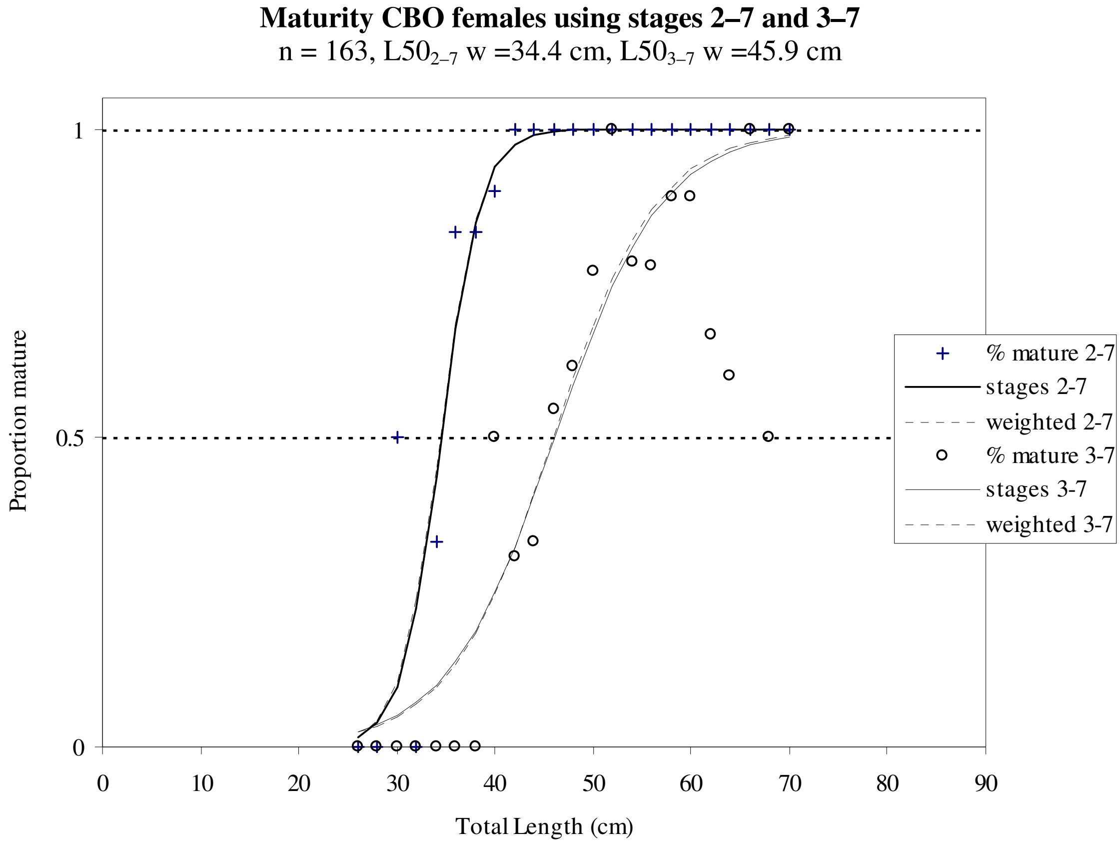

Figure 22: The proportion of female Bollons's rattail (CBO) at maturity stages 2–7 (+) and 3–7 (o); and fitted logistic growth curves unweighted (line) and weighted (dashed line) by sample size.

3.2.3 Javelinfish (JAV)

Staging javelinfish data collected at sea before 2007 was problematic due to the difficulty in identifying males. For this reason data collected before 2007 were excluded from this analysis. Javelinfish are most likely winter spawners as all of the stage 4 and 5 females were from the winter ORH trip TAN0709 (Tables 15 and 16). This was supported by recent results from TAN1003 which contain a high proportion of early stage 3 and late stage 2 female gonads. The January trips TAN0501, TAN0601, and TAN0901 were excluded due to timing (too early to see development). TAN0911 was eliminated due to doubts about the accuracy of javelinfish staging on that trip. The March-April trip TAN1003 was excluded as females were still transitioning from stage 2 to stage 3.

Table 15: Sample size by trip code and gonad stage for javelinfish (CHAT, Chatham Rise; SWCR, South West Chatham Rise; SECR, South East Chatham Rise; WCSI, West Coast South Island; NWCR, North West Chatham Rise; ECNI, East Coast North Island). Samples in italics were used in the maturity analysis.

Trip code	Area	Month	Gonad stage							Total
			1	2	3	4	5	6	7	
SHI8602	CHAT	Jun-Jul	-	35	-	-	1	-	-	36
TAN9713	SWCR,SECR	Nov-Dec	4	5	-	-	-	-	-	9
TAN0007	WCSI	Jul-Aug	-	1	-	-	-	-	-	1
TAN0501	CHAT	Jan	8	79	-	-	-	-	-	87
TAN0601	CHAT	Jan	-	7	3	-	-	-	-	10
TAN0617	Sub-Antarctic	Nov-Dec	23	103	-	-	-	-	8	134
TAN0709	*NWCR,CHAT*	*Jul*	*17*	*17*	*12*	*94*	*6*	-	-	*146*
TAN0813	*Sub-Antarctic*	*Nov-Dec*	*27*	*214*	*41*	-	-	-	-	*282*
TAN0901	CHAT	Jan	29	153	7	-	1	-	2	192
TAN0911	Sub-Antarctic	Nov-Dec	119	189	1	-	-	-	-	309
TAN1003	ECNI	Mar-Apr	15	71	53	-	-	-	-	139
Total			242	874	117	94	8	-	10	1345

The weighted and unweighted curves (Figure 23) using gonad stages 2–7 are steep but not as knife edged as for CBI. There is very little separation at lengths over 35 cm, but there is up to 1 cm separation at lengths less than 35 cm.

Table 16: Average fish length (total length in cm) trip code and gonad stage for javelinfish (CHAT, Chatham Rise; SWCR, South West Chatham Rise; SECR, South East Chatham Rise; WCSI, West Coast South Island; NWCR, North West Chatham Rise; ECNI, East Coast North Island). Samples in italics were used in the maturity analysis.

Trip code	Area	Month	Gonad stage							All
			1	2	3	4	5	6	7	
SHI8602	CHAT	Jun-Jul	-	47.8	-	-	56.0	-	-	48.1
TAN9713	SWCR, SECR	Nov-Dec	47.9	50.4	-	-	-	-	-	49.3
TAN0007	WCSI	Jul-Aug	-	63.0	-	-	-	-	-	63.0
TAN0501	CHAT	Jan	38.7	47.6	-	-	-	-	-	46.8
TAN0601	CHAT	Jan	-	54.6	56.9	-	-	-	-	55.3
TAN0617	Sub-Antarctic	Nov-Dec	40.0	42.0	-	-	-	-	45.2	41.9
TAN0709	*NWCR,CHAT*	*Jul*	*49.5*	*50.0*	*47.3*	*49.7*	*53.1*	-	-	*49.7*
TAN0813	*Sub-Antarctic*	*Nov-Dec*	*37.6*	*44.8*	*47.2*	-	-	-	-	*44.4*
TAN0901	CHAT	Jan	34.3	47.5	48.0	-	47.3	-	50.2	45.5
TAN0911	Sub-Antarctic	Nov-Dec	30.9	40.5	54.6	-	-	-	-	36.9
TAN1003	ECNI	Mar-Apr	49	53	53	-	-	-	-	53

The curves using stages 3–7 are less steep than for stages 2–7. The unweighted curve does not cross the weighted curve lying almost parallel to it with a maximum separation of 0.5 cm on the x axis. Individual L50 values are listed in Table 12.

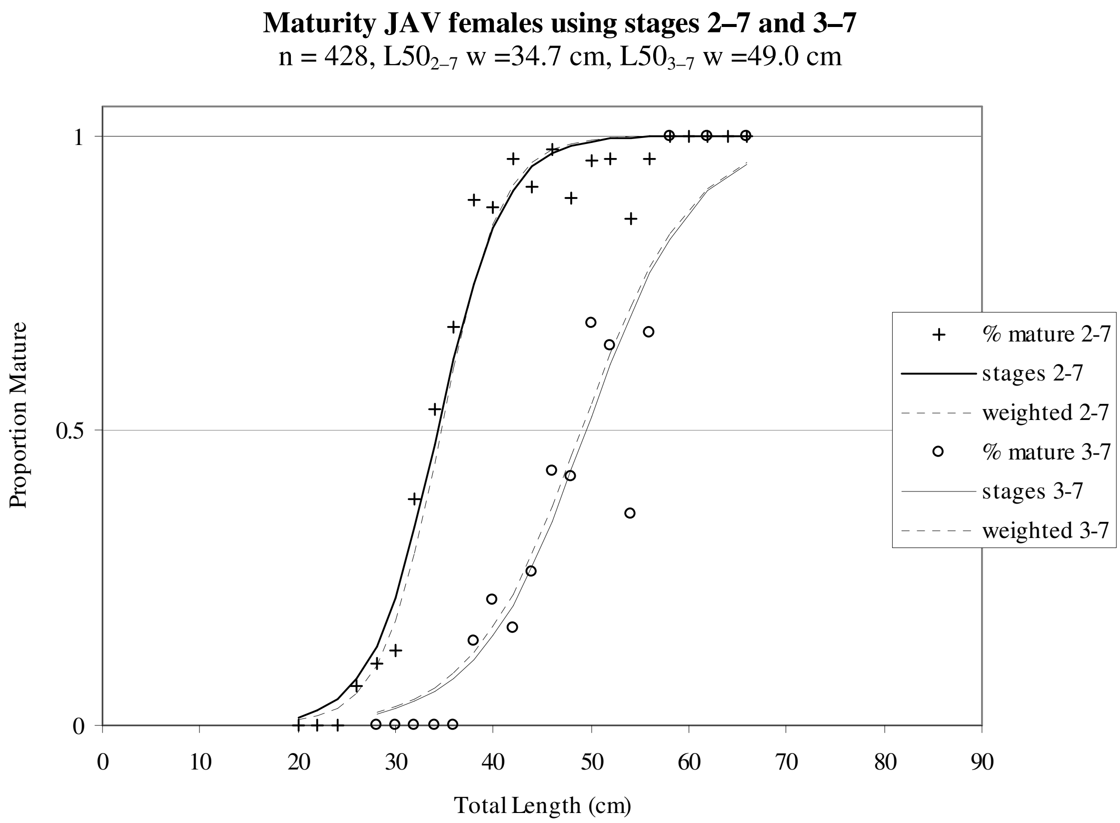

Figure 23: The proportion of female javelinfish (JAV) at maturity stages 2–7 (+) and 3–7 (o); and fitted logistic growth curves unweighted (line) and weighted by sample size (dashed line).

3.2.4 Ridge-scaled rattail (MCA)

Macrourus carinatus would appear to be suitable for maturity estimation using macroscopic staging as it has large eggs, spawning is prolonged (from late autumn to spring), the accumulation of yolk in the oocytes lasts more than 1 year and, immediately before spawning, yolked oocytes for the next reproductive cycle are already present (Alekseyeva et al. 1993). All available trip data were included in the analysis (Tables 17 and 18).

The growth curves using gonad stages 2–7 are less steep than JAV (Figure 24). There is a little separation where the curves bend as they approach either end of the Y axis.

The curves using stages 3–7 are almost identical to those for stages 2–7 apart from being displaced to the right by about 11 cm. Individual L50 values are listed in Table 12.

Table 17: Sample size by trip code and gonad stage for ridge-scaled rattail (SWCR, South West Chatham Rise; SECR, South East Chatham Rise; NWCR, North West Chatham Rise; CHAT, Chatham Rise; ECNI, East Coast North Island). All samples were used in the maturity analysis.

Trip code	Area	Month	Gonad stage							All
			1	2	3	4	5	6	7	
TAN9713	*SWCR, SECR*	*Nov-Dec*	*3*	-	-	-	-	-	-	*3*
TAN9805	*Sub-Antarctic*	*Apr*	-	*5*	*6*	-	-	-	-	*11*
TAN9812	*SECR*	*Oct*	*1*	-	-	-	-	-	-	*1*
TAN0012	*Sub-Antarctic*	*Nov-Dec*	*10*	*12*	*6*	-	-	-	*24*	*52*
TAN0208	*NWCR*	*Jun-Jul*	*3*	*1*	-	-	-	-	-	*4*
TAN0219	*Sub-Antarctic*	*Nov-Dec*	-	*1*	*13*	-	-	-	-	*14*
TAN0317	*Sub-Antarctic*	*Nov-Dec*	-	*2*	-	*2*	-	*1*	*21*	*26*
TAN0414	*Sub-Antarctic*	*Nov-Dec*	*1*	*5*	*1*	-	-	-	-	*7*
TAN0615	*SWCR*	*Oct*	*5*	*4*	-	-	-	-	-	*9*
TAN0617	*Sub-Antarctic*	*Nov-Dec*	*14*	*44*	*130*	*11*	*2*	*10*	*13*	*224*
TAN0709	*NWCR, CHAT*	*Jul*	*8*	*1*	-	-	-	-	-	*9*
TAN0714	*Sub-Antarctic*	*Nov-Dec*	*7*	*25*	*61*	-	-	*2*	*4*	*99*
TAN0813	*Sub-Antarctic*	*Nov-Dec*	*1*	*16*	*50*	*1*	-	-	-	*68*
TAN0901	*CHAT*	*Jan*	*7*	-	-	-	-	-	-	*7*
TAN0911	*Sub-Antarctic*	*Nov-Dec*	*1*	*30*	*28*	*4*	*2*	*1*	*13*	*79*
TAN1001	*CHAT*	*Jan*	-	*1*	-	-	-	-	-	*1*
TAN1003	*ECNI*	*Mar-Apr*	*138*	*35*	*6*	-	-	-	-	*179*
Total			200	182	301	18	4	14	75	793

Table 18: Average fish length (total length in cm) trip code and gonad stage for ridge-scaled rattail (SWCR, South West Chatham Rise; SECR, South East Chatham Rise; NWCR, North West Chatham Rise; CHAT, Chatham Rise; ECNI, East Coast North Island).

Trip code	Area	Month	Gonad stage							All
			1	2	3	4	5	6	7	
TAN9713	SWCR, SECR	Nov-Dec	52.9	-	-	-	-	-	-	52.9
TAN9805	Sub-Antarctic	Apr	-	71.5	79.5	-	-	-	-	75.8
TAN9812	SECR	Oct	49.4	-	-	-	-	-	-	49.4
TAN0012	Sub-Antarctic	Nov-Dec	34.6	47.1	75.0	-	-	-	79.1	62.7
TAN0208	NWCR	Jun-Jul	53.8	66.7	-	-	-	-	-	57.0
TAN0219	Sub-Antarctic	Nov-Dec	-	69.4	77.5	-	-	--	-	76.9
TAN0317	Sub-Antarctic	Nov-Dec	-	57.7	-	68.9	-	72.3	83.1	79.6
TAN0414	Sub-Antarctic	Nov-Dec	57.1	81.2	88.5	-	-	-	-	78.8
TAN0615	SWCR	Oct	49.2	63.7	-	-	-	-	-	55.0
TAN0617	Sub-Antarctic	Nov-Dec	43.4	59.6	76.5	81.3	75.3	73.6	77.5	71.3
TAN0709	NWCR, CHAT	Jul	45.9	59.1	-	-	-	-	-	47.4
TAN0714	Sub-Antarctic	Nov-Dec	39.8	63.5	77.5	-	-	79.8	83.8	71.6
TAN0813	Sub-Antarctic	Nov-Dec	55.5	72.3	79.9	79.9	-	-	-	77.8
TAN0901	CHAT	Jan	59.6	-	-	-	-	-	-	59.6
TAN0911	Sub-Antarctic	Nov-Dec	56.4	73.9	77.5	76.8	72.4	81.4	80.0	76.2
TAN1001	CHAT	Jan	-	82.7	-	-	-	-	-	82.7
TAN1003	ECNI	Mar-Apr	51	69	81	-	-	-	-	56

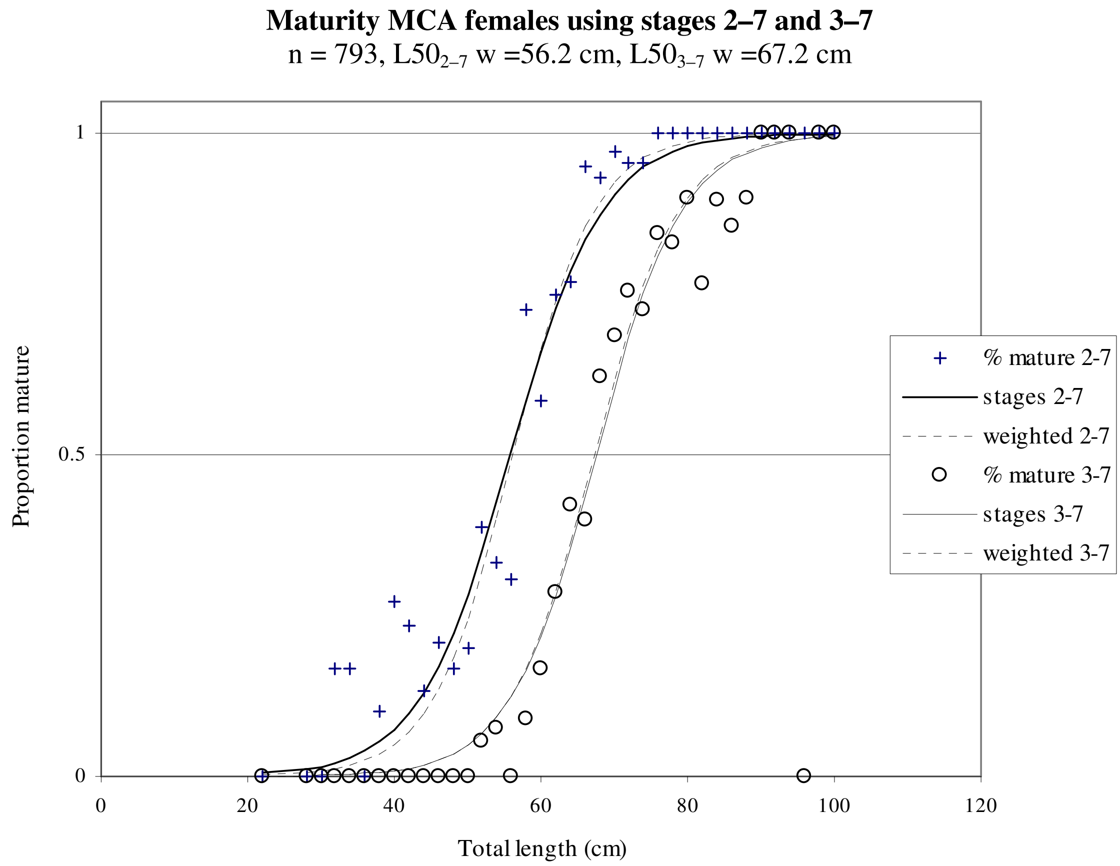

Figure 24: The proportion of female ridge-scaled rattail (MCA) at maturity stages 2–7 (+) and 3–7 (o); and fitted logistic growth curves unweighted (line) and weighted by sample size (dashed line).

3.3 Biomass trends

Three series of trawl surveys were analysed because they were within the species main distributional range and sufficient numbers of the species for analysis had been caught. The three surveys were the annual Chatham Rise summer hoki survey, 1992–09 (see Stevens et al. 2009 for survey area), the annual sub-Antarctic survey 2000–2009 (see O'Driscoll & Bagley 2008 for survey area), and the west coast South Island autumn inshore survey series, occurring every two or three years, in 2000, 2003, 2005, 2007, and 2009 (see Stevenson & Hanchet 2010 for survey area). The Chatham Rise series is the longest and the west coast South Island series is the shortest in terms of data useful for rattail biomass calculations (Table 19).

The Chatham Rise survey series provided biomass estimates for Bollons's rattail and javelinfish (Table 19). Two saddle rattail was caught in shallow localised areas in the Chatham Rise survey series, but not in great numbers; nevertheless, the biomass estimates were calculated. Two saddle rattail was more widespread inshore on the west coast South Island, and as a result, the WCSI inshore time series was chosen to examine biomass trends (Table 19). Only the five most recent surveys were used to estimate biomass as before 2000 two saddle rattail was usually not identified separately from the other rattail species and was often recorded under the generic code RAT. Biomass estimates for ridge-scaled rattail were obtained from the sub-Antarctic survey series where they are locally abundant (Table 19). Javelinfish were also caught in large numbers in the sub-Antarctic and biomass estimates for this region are provided.

Table 19: Biomass estimates (t) with c.v.'s (%) in parentheses for the three survey series. Species names are given in Table 1.

	Chatham Rise series				WCSI inshore series		SubAntarctic series		
Year	Trip	CBI	JAV	CBO	Trip	CBI	Trip	JAV	MCA
1992	TAN9106	156 (29)	8 960 (15)	10 840 (13)					
1993	TAN9212	268 (45)	8 620 (10)	11 620 (8)					
1994	TAN9401	234 (37)	6 690 (18)	16 832 (9)					
1995	TAN9501	327 (41)	4 814 (11)	5 068 (11)					
1996	TAN9601	216 (40)	9 616 (11)	8 768 (11)			TAN9605	24 298 (12)	9 213 (9) *
1997	TAN9701	210 (58)	5 181 (10)	6 936 (20)					
1998	TAN9801	54 (55)	8 015 (12)	9 424 (11)			TAN9805	18 890 (10)	5 102 (18) *
1999	TAN9901	217 (39)	10 799 (12)	13 621 (13)					
2000	TAN0001	338 (39)	10 965 (13)	12 137 (8)	KAH0004	614 (36)	TAN0012	18 773 (12)	9 278 (11)
2001	TAN0101	232 (67)	15 520 (9)	14 036 (10)			TAN0118	14 313 (12)	12 356 (29)
2002	TAN0201	58 (36)	22 759 (20)	16 238 (12)			TAN0219	7 525 (11)	12 892 (12)
2003	TAN0301	165 (36)	13 175 (12)	8 186 (10)	KAH0304	212 (26)	TAN0317	7 713 (10)	1 511 (26) †
2004	TAN0401	177 (45)	10 954 (10)	7 705 (10)			TAN0414	17 415 (22)	888 (29) †
2005	TAN0501	353 (12)	11 791 (15)	5 823 (9)	KAH0504	1 148 (25)	TAN0515	14 390 (10)	12 377 (59)
2006	TAN0601	229 (44)	20 380 (20)	10 326 (10)			TAN0617	14 573 (28)	2 581 (17) †
2007	TAN0701	34 (47)	14 279 (14)	8 071 (11)	KAH0704	1 663 (28)	TAN0713	12 066 (12)	8 544 (19)
2008	TAN0801	511 (21)	8 381 (20)	7 020 (10)			TAN0814	48 659 (15)	11 198 (37)
2009	TAN0901	423 (35)	20 541 (11)	12 646 (10)	KAH0904	1 157 (24)	TAN0911	21 663 (16)	7 610 (28)

* TAN9605 and TAN9805 were in autumn
† The deep stratum, Stratum 26, was not sampled

Only javelinfish on the Chatham Rise showed a significant trend (p-value = 0.001), with an estimated instantaneous rate of increase of 6% of biomass per annum (Figure 25). Estimated rates of increase for the other series and species had p-values between 0.14 and 0.53. The estimated rates were positive for javelinfish biomass from the sub-Antarctic, and for Bollons's rattail and two saddle rattail biomass on the Chatham Rise. Two saddle rattail biomass from the west coast and ridge-scaled rattail biomass from the sub-Antarctic both showed declines, but were less than -2%.

Biomass of Bollons's rattail is generally lower after 2003, but this appears to be within the longer term variation, which may be due to low recruitment in those years, and thus is not indicative of a declining trend.

The sub-Antarctic series for ridge-scaled rattail was inconsistent because the surveys in 2003, 2004, and 2006 did not trawl in the deep stratum, where the largest catches are generally made. The absence of sampling in this stratum was reflected in the anomalously low biomass estimates in those years. These points were not included in the trend analysis, nor were they joined to the rest of the series in Figure 25.

Javelinfish biomass on the Chatham Rise has increased after 1999, and the fitted curve has a constant instantaneous rate of increase that is highly significant (p-value < 0.01). A very large biomass was also estimated in 2008 for the sub-Antarctic.

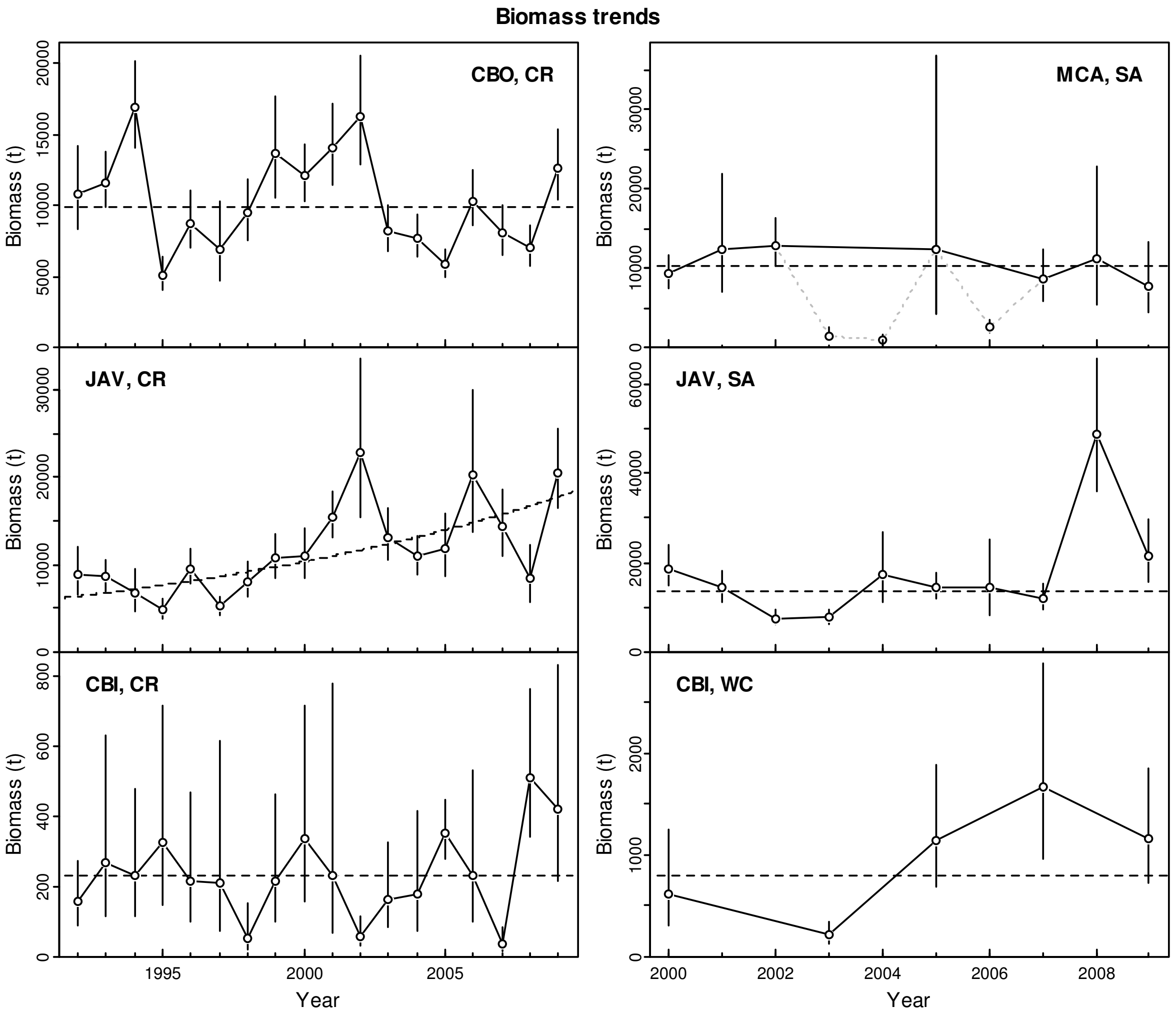

Figure 25: Biomass trend plots for the four rattail species. Three survey series were used: Chatham Rise hoki survey (CR), Sub-Antarctic survey (SA), and the inshore west coast South Island survey (WC). Vertical line segments through each point represent approximate 95% confidence intervals for the biomass estimate. Horizontal fitted lines are drawn for all series which had no significant trend and for the javelinfish series on the Chatham Rise the curve of the fitted constant rate of increase (6% per year) is shown (JAV, CR). Species names are given in Table 1.

The two saddle rattail biomass series had very large c.v.'s, especially for the Chatham Rise series where only small catches were taken in a relatively confined area on the northwest of the Rise. The west coast South Island data series showed an increase, but it was not significant because of the large uncertainty in estimates.

4. DISCUSSION

Macrourid fishes are often referred to as long-lived, although only a few species have had age estimates validated (Swan & Gordon 2001). Radiometric analysis of otolith cores supported annual increment formation in *Coryphaenoides acrolepis* for ages estimated up to 56 years (Andrews et al. 1999), and marginal increment analysis of a few northern hemisphere species supported annual zone formation (Swan & Gordon 2001).

Our age estimates are unvalidated. If we accept the hypothesis that opaque zones are deposited annually, then javelinfish and two saddle rattail are relatively short lived with maximum age estimates of 13 and 15 years, with few fish over 8 years of age. Bollons's rattail lives to at least 24 years, with many fish aged 10 years or older. Ridge-scaled rattail are long-lived, with a maximum age estimate of 42 years, and many fish aged 20 or older. Longevity may be higher than reported here as the sample sizes were small and, in the case of two saddle rattail and ridge-scaled rattail, spatially restricted. The largest javelinfish and Bollons's rattail aged were 61 cm and 64 cm respectively, but data collected from trawl surveys show that both grow to over 70 cm. The largest two-saddle rattail aged was 71 cm, and is the maximum reported size for this species (New Zealand Ministry of Fisheries trawl database records), although only two other fish in the aged samples were over 60 cm. The largest ridge-scaled rattail aged was 96 cm, but they can grow to over 100 cm.

There are no published studies with which to compare the age estimates for javelinfish, two saddle rattail, or Bollons's rattail. This is not surprising given that these species are not targeted commercially and two have restricted distributions. Javelinfish are also reported from Hawaii and Australia, while two saddle rattail and Bollons's rattail are endemic to New Zealand. There are a few ageing studies on other *Coelorinchus* species: the northern hemisphere species *C. coelorinchus* and *C. labiatus* are reported to live to 11 years and 16+ years respectively, *C. simorhynchus* (misidentified as *C. fasciatus*) from Namibia lives up to 14 years, and *C. fasciatus* from the Falkland Islands lives up to 19 years (see review by Swan & Gordon 2001, Laptikhovsky et al. 2008). These species have similar longevity to the New Zealand species examined here.

A number of studies have estimated the age of *Macrourus* species, in particular the roughhead grenadier, *M. berglax*, an important bycatch species in some North Atlantic fisheries. Most studies give maximum age estimates for this species of between 20 and 34 years, with females having higher estimates than males (see review by Swan & Gordon 2001, Murua 2003). Marriott et al. (2003) estimated the age of *Macrourus whitsoni* from the Ross Sea and found they were slow-growing and long-lived, with maximum age estimates of 55 years for males and 51 years for females. *M. carinatus* from around Heard and McDonald Islands had an estimated maximum age of 25 years (van Wijk 2003). However, the largest fish sampled was only 67 cm and maximum age is likely to be underestimated. Morley et al. (2004) studied the biology of *M. holotrachys* around South Georgia and found they were moderately slow growing with maximum ages of 15 years for males and 25 years for females. Around the Falkland Islands *M. holotrachys* and *M. carinatus* had estimated maximum ages of 26 and 37 years respectively, with females living longer than males (Laptikhovsky et al. 2008). All these studies used unvalidated age estimates. The current study has similar age estimates for ridge-scaled rattail, *M. carinatus,* from the New Zealand sub-Antarctic. However, on the 2006 sub-Antarctic trawl survey, a key stratum for large *M. carinatus* was not sampled. Consequently, the sample may not be representative of the population, and with fewer large fish we may have underestimated longevity.

The maturity data for female rattails was derived from data collected opportunistically at sea over several research trawl surveys. Gonads were staged macroscopically and often by several researchers with various levels of experience. Nevertheless, the results are likely to be indicative of size and age at maturity.

The curves for maturity stages 2–7 have the best fit and generally have a knife-edge profile, with decreasing slope for longer lived species. Apart from ridge-scaled rattail the curves for maturity stages contain a lot of variability, which tends to decrease the slope of the line and increase the $L50_{3\text{-}7}$ estimate.

Based on the $L50_{2\text{-}7}$ results, female javelinfish mature at about 35 cm in length and 3 years of age; female two saddle rattail at about 31 cm and 2 years of age; female Bollons's rattail at about 34 cm and 3 years of age; and female ridge-scaled rattail at about 56 cm and 11 years of age. Based on the catch at age proportions estimated for the 2009 Chatham Rise survey and, for ridge-scaled rattail, the 2006 sub-Antarctic survey, most individuals of these species were sexually mature when captured.

Rather than use $L50_{3\text{-}7}$, a better alternative estimate of first maturity from these data may be to use $L50_{2\text{-}7}$ then add an appropriate amount of time to allow for gonad maturation, in the range of 3–6 months for a short lived species (e.g., two saddle rattail) or 1.5–2 years for a long-lived species with an extended maturation cycle (e.g., ridge-scaled rattail). However, this would require more detailed information on individual maturation and was beyond the scope of this study.

The only species in the current study with published data on length and age at maturity is *M. carinatus*. Alekseyeva et al. (1993) estimated length at maturity as 58–59 cm, which corresponded to an age of about 12.5 years. *Macrourus carinatus* from the South Atlantic had an estimated age at maturity of 55–60 cm and about 10.5 to 13 years (Cousseau 1993). Laptikhovsky et al. (2008) estimated first maturity at 20.18 cm pre-anal length which corresponds to a total length of about 56.6 cm and about 12 years of age. These estimates seem comparable to our $L50_{2\text{-}7}$ estimate of 56.2 cm and 11.1 years with their curves displaced to the right by 1–2 years.

Middle depth research trawl surveys use a demersal trawl with 60 mm codend mesh, while most deepwater commercial trawls use a minimum of 100 mm codend mesh. Therefore, gear selectivity should be higher for research than commercial trawls. Nevertheless, few juvenile rattails and no 1-year old rattails of any species were captured for this study; consequently, the lower ends of our growth curves are not well defined. Juveniles may be in a location not adequately sampled by the trawl survey, off the bottom and therefore above the demersal trawl, or their small size (1 year old fish of all four species are likely to be less than 20 cm in length based on the growth curves presented here) and slender build may mean they are more likely to pass though the trawl meshes.

Javelinfish were very difficult to sex in the field because the gonads of both sexes are macroscopically similar. This is likely to have resulted in some sexing errors and may explain the presence of very large males and small older females in the age and maturity samples.

Male rattails were generally less common than females in the samples. This is probably because female rattails generally reach a larger maximum size than males (Kelly et al. 1997, Marriott et al. 2003, Murua 2003, Laptikhovsky et al. 2008), and are therefore likely to be more vulnerable to trawl capture than the smaller males. Males may also have been off the bottom or in a location not adequately sampled by the trawl survey.

Fitting of the von Bertalanffy curves for both sexes suffered from a lack of small fish, although the effect was stronger for males because they are generally smaller. This resulted in lower than expected estimates of t_0. Consequently, the estimates of k were also smaller. If fitting were to be done by fixing t_0 at a negative value closer to 0, then more sensible estimates for k would result but it would also result in unrealistically small L_∞ estimates.

The overall appearance of biomass trends for the four rattail species is one of little change over the periods of the survey series. The exception is javelinfish in the Chatham Rise series, where there was strong evidence of a positive increase (estimated to be 6% per year). However, there is little evidence of any increase for javelinfish in the sub-Antarctic series. The increase on the Chatham Rise could be due to a number of factors, including increased local recruitment or movement of fish into the survey area.

Our sample sizes were small and our age estimates were unvalidated, but this study does provide indicative data on the age and growth of four of the most important rattail bycatch species. While these species are taken as bycatch in target fisheries for other species, they are likely to be important in the production of fishmeal and, for ridge-scaled rattail, potential exists for a localised commercial fishery in the New Zealand sub-Antarctic. There are a number of other important deepwater rattail bycatch species, e.g., *Coelorinchus aspercephalus, C. oliverianus, Coryphaenoides subserrulatus,* and *Trachyrincus aphyodes*, and future research should investigate biological parameters of these species.

5. ACKNOWLEDGMENTS

We thank Peter McMillan, and Rosie Hurst (both NIWA), and Mary Livingston and Marianne Vignaux (both MFish) for providing constructive comments on this document, Michael Stevenson and Neil Bagley (NIWA) for extracting biomass data for the west coast and sub-Antarctic survey series, and Ian Doonan and Alistair Dunn (NIWA) for useful comments on the data analysis methods. This research was funded by the Ministry of Fisheries under project ENV2007/03.

6. REFERENCES

Alekseyeva, Y.I.; Alekseyev, F.Y.; Konstantinov, V.V.; Boronin, V.A. (1993). Reproductive biology of grenadiers *Macrourus carinatus, M. whitsoni, Coelorinchus fasciatus* (Macrouridae), and *Patagonotothen guentheri shagensis* (Nototheniidae) and the distribution of *M. carinatus. Journal of Ichthyology 33*: 71–84.

Anderson, O.F.; Bagley, N.W.; Hurst, R.J.; Francis, M.P.; Clark, M.R.; McMillan, P.J. (1998). Atlas of New Zealand fish and squid distributions from research bottom trawls. *NIWA Technical Report 42*. 303 p.

Andrews, A.H.; Cailliet, G.M.; Coale, K.H. (1999). Age and growth of the Pacific grenadier (*Coryphaenoides acrolepis*) with age estimate validation using an improved radiometric ageing technique. *Canadian Journal of Fisheries and Aquatic Sciences 56:* 1339–1350.

Atkinson, D.B. (1995). The biology and fishery of roundnose grenadier (*Coryphaenoides rupestris* Gunnerus, 1765) in the Northwest Atlantic. Pages 51–112 *In:* Hopper, A.G. ed. Deep-water fisheries of the North Atlantic oceanic slope. Kluwer Academic Publishers, Dordrecht.

Ballara, S.L.; O'Driscoll, R.L.; Anderson, O.F. (2010). Fish discards and non-target fish catch in the trawl fisheries for hoki, hake, and ling in New Zealand waters. *New Zealand Aquatic Environment and Biodiversity Report 48*.

Cailliet, G.M.; Mollet, H.F.; Pittenger, G.G.; Bedford, D.; Natanson, L.J. (1992). Growth and demography of the Pacific angel shark (*Squatina californica*), based upon tag returns off California. *Australian Journal of Marine and Freshwater Research 43:* 1313–1330.

Campana, S.E. (2001). Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology 59*: 197–242.

Campana, S.E.; Annand, M.C.; McMillan, J.I. (1995). Graphical and statistical methods for determining the consistency of age determinations. *Transactions of the American Fisheries Society 124:* 131–138.

Chapman, D.G.; Robson, D.S. (1960). The analysis of a catch curve. *Biometrics 16*: 354–368.

Cousseau, M.B. (1993). Las especies del orden gadiformes del Atlántico sudamericano comprendido entre 34° y 55°S y relación con las de otras áreas. *Frente Maritimo 13:* Sec. A: 7–108.

Dunn, A.; Francis, R.I.C.C.; Doonan, I.J. (2001). Comparison of the Chapman–Robson and regression estimators of Z from catch-curve data when non-sampling stochastic error is present. *Fisheries Research 59*:149–159.

Dunn, M.; Horn, P.; Connell, A.; Stevens, D.; Forman, J.; Pinkerton, M.; Griggs, L.; Notman, P.; Wood, B. (2009). Ecosystem-scale trophic relationships: diet composition and guild structure of middle-depth fish on the Chatham Rise. Final Research Report for Ministry of Fisheries Research Project ZBD2004-02 Objectives 1–5. 353 p. (Unpublished report held by MFish, Wellington.)

Francis, M.P.; Hurst, R.J.; McArdle, B.H.; Bagley, N.W.; Anderson, O.F. (2002). New Zealand demersal fish assemblages. *Environmental Biology of Fishes 65:* 215–234.

Francis, M.P.; Mulligan, K.P. (1998). Age and growth of New Zealand school shark, *Galeorhinus galeus. New Zealand Journal of Marine and Freshwater Research 32:* 427–440.

Francis, M.P.; Mulligan, K.P.; Davies, N.M.; Beentjes, M.P. (1999). Age and growth estimates for New Zealand hapuku, *Polyprion oxygeneios. Fishery Bulletin 97:* 227–242.

Francis, M.P.; Ó Maolagáin, C. (2000). Age, growth and maturity of a New Zealand endemic shark (*Mustelus lenticulatus*) estimated from vertebral bands. *Marine and Freshwater Research 51:* 35–42.

Iwamoto, T. (2008). A brief history of grenadiers. *In:* Orlov, A.M.; Iwamoto, T. (eds) Grenadiers of the world oceans: biology, stock assessment, and fisheries. *American Fisheries Society Symposium 63,* Bethesda, pp3–13.

Kelly, C.J.; Connolly, P.L.; Bracken, J.J. (1997). Age estimation, growth, maturity and distribution of the roundnose grenadier from the Rockall trough. *Journal of Fish Biology 50:* 1–17.

Kock K.-H.; Kellermann, A. (1991). Reproduction in Antarctic notothenioid fish. *Antarctic Science 3*: 125–150.

Koslow, J.A.; Boehlert, G.W.; Gordon, J.D.M.; Haedrich, R.L.; Lorance, P.; Parin, N. (2000). Continental slope and deep-sea fisheries: implications for a fragile ecosystem. *ICES Journal of Marine Science 57:* 548–557.

Laptikhovsky, V.; Arkhipkin, A.; Brickle, P. (2008). Biology and distribution of grenadiers of the Family Macrouridae around the Falkland Islands. *American Fisheries Society Symposium 63:* 261–284.

Livingston, M.E.; Bull, B.; Stevens, D.W.; Bagley, N.W. (2002). A review of hoki and middle depth trawl surveys of the Chatham Rise, January 1992–2001. *NIWA Technical Report 113.* 146 p.

Marriott, P.; Horn, P.L.; McMillan, P. (2003). Species identification and age estimation for the ridge-scaled Macrourid (*Macrourus whitsoni*) from the Ross Sea. *CCAMLR Science 10:* 37–51.

Merrett, N.R.; Haedrich, R.L. (1997). Deep-sea demersal fish and fisheries. Chapman & Hall, New York.

Morley, S.A.; Mulvey, T.; Dickson, J.; Belchier, M. (2004). The biology of the bigeye grenadier at South Georgia. *Journal of Fish Biology 64*: 1514–1529.

Murua, H. (2003). Population structure, growth and reproduction of roughhead grenadier on the Flemish Cap and Flemish Pass. *Journal of Fish Biology 63:* 356–373.

O' Driscoll, R.L.; Bagley, N.W. (2001). Review of summer and autumn trawl survey time series from the Southland and Sub-Antarctic areas, 1991–98. *NIWA Technical Report 102.* 115 p.

O'Driscoll, R.L.; Bagley, N.W. (2008). Trawl survey of hoki, hake, and ling in the Southland and Sub-Antarctic areas, November–December 2006 (TAN0617). *New Zealand Fisheries Assessment Report 2008/30.* 61 p.

Stevens, D.W.; Francis, M.P.; Shearer, P.C.; McPhee, R.P.; Hickman, R.W.; Tait, M. (2005). Age and growth of two endemic flatfish (*Colistium guntheri* and *C. nudipinnis*) in central New Zealand waters. *Marine and Freshwater Research 56:* 143–151.

Stevens, D.W.; O'Driscoll, R.L.; Horn, P.L. (2009). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2009 (TAN0901). *New Zealand Fisheries Assessment Report 2009/55.* 91 p.

Stevens, D.W.; Dunn, M.R. (2010). Different food preferences in four sympatric deep-sea Macrourid fishes. *Marine Biology* doi: 10.1007/s00227-010-1542-1.

Stevenson, M.L.; Hanchet, S.M. (2010). Inshore trawl survey of the west coast of the South Island and Tasman and Golden Bays, March-April 2009 (KAH0904). *New Zealand Fisheries Assessment Report 2010/11.* 77 p.

Swan, S.C.; Gordon, J.D.M. (2001). A review of age estimation in macrourid fishes with new data on age validation of juveniles. *Fisheries Research 51:* 177–195.

Tomkiewicz, J.; Morgan, M.J.; Burnett, J.; Saborido-Rey, F. (2003). Available information for estimating reproductive potential of Northwest Atlantic groundfish stocks. *Journal of Northwest Atlantic Fishery Science 33:* 1–21.

van Wijk, E.M.; Williams, R.; Constable, A.J. (2003). Age, growth, and size at sexual maturity of *Macrourus carinatus* caught as by-catch in Australian sub-Antarctic trawl fisheries. *CCAMLR Science 10:* 139–151.