John Annala

Not to be cited without permission of the author(s)

New Zealand Fisheries Assessment Research Document 94/19

Life history parameters of orange roughy: estimates for 1994

I. J. Doonan

MAF Fisheries Greta Point
P O Box 297
Wellington

September 1994

MAF Fisheries, N.Z. Ministry of Agriculture and Fisheries

Life history parameters of orange roughy: estimates for 1994

I. J. Doonan

N.Z. Fisheries Assessment Research Document 94/19. 13 p.

1. Executive Summary

New ageing data have allowed the life history parameters of orange roughy to be revised.

Re-estimated life history parameters for orange roughy

	Symbol	New estimate Male	Female	Both sexes	Past estimate Both sexes
Natural mortality	M	–	–	0.045	0.040
Age at maturity	A_m	33	34	–	22.2
Gradual maturity	S_m	9	8	–	6.6
Age at recruitment	A_r	33	34	–	22.2
Gradual recruitment	S_r	9	8	–	6.6
Growth	L_∞	36.4	38.0	–	37.3
	K	0.070	0.061	–	0.07
	t_0	–0.37	–0.55	–	–0.3

2. Introduction

New ageing data have allowed some life history parameters of orange roughy to be updated for the current stock assessment. (The emphasis is on current; they may well change again for the next assessment.) Punt (1994) reduced recruitment variability from 1.2 to 1.1, so it is not considered further here.

The new data are ages of adult fish sampled from the 1984 survey of the north Chatham Rise, 5–6 years after the fishery there started, and allow natural mortality (M) to be estimated for a New Zealand stock. Last year, an estimate of M from Australian data was used (Doonan 1993). The change in the revised M from last year's assessment is modest.

Ages of adult fish which were estimated last year were not consistent between readers, but counts of rings to a transition zone[1], assumed to mark the onset of maturity, were.

[1] This transition zone was defined as the point where the band width decreases markedly from wide dark bands to fine lighter banding (P.L. Horn, MAF Fisheries, pers. comm.). In the longitudinal section on most otoliths this point was clear and unambiguous, and was generally found where the otolith surface begins curving. If band widths decreased steadily rather than suddenly, the transition zone was assigned to the point where the surface began curving, i.e., the most likely site.

Thus the age of maturity, but not M, was estimated from these data last year (Francis et al. 1993). This year, with the tightening of the protocol for reading otoliths, ages were more consistent between readers. The maturity and recruitment parameters are estimated separately for each sex.

Growth was re-estimated by sex. Last year, the von Bertalanffy parameter, L_∞, was estimated from otolith weight and fish length data (Francis 1993). L_∞ is now estimated from adult ages.

3. Data

In July 1984, MAF Fisheries conducted a trawl survey on the north Chatham Rise using FV *Otago Buccaneer* to estimate the biomass of orange roughy: 116 random trawls were completed in a stratified random design.

Orange roughy otoliths were collected and fish lengths recorded from all stations where orange roughy were caught. Up to 20 fish were sampled from each station.

A subsample (*see* Methods) of these otoliths from adult fish was prepared for ageing. Ages were determined as counts of (assumed) annual rings in thin sections. Maturity age was also recorded, where possible. This is the number of rings up to a transition zone which is assumed to occur at the onset of maturity. Otoliths were read blind by two readers who each read each otolith twice, 1–2 months apart. Otoliths were subjectively coded for readability: 1 being perfect and 5 very difficult. Otoliths given a readability code of 5 by either reader were excluded (10 out of 442 otoliths for the first reading).

For growth estimation, data from juvenile fish which were used last year to estimate the von Bertalanffy parameters K and t_0 (Francis 1993) were also available. The juvenile data consist of ages from J.M. Kalish (Australian National University, Canberra, pers. comm.) which came from 21 otoliths collected on the 1990 *Cordella* survey; 1132 otoliths from surveys for juvenile orange roughy, 1988–90 (MAF Fisheries unpublished data); and 56 otoliths used by Mace et al. (1990) which they found "easy" to read but had estimated ages of less than 20 years.

4. Methods

4.1 Subsampling of otoliths for ageing

Only 450 otoliths were subsampled from the 1984 survey because of the time needed to prepare otoliths for ageing. For a stratified survey, the mean age is a weighted average of the ages, with the weight, called the station-weight, proportional to the catch size, the inverse of the number of stations in the stratum, and the area of the stratum. For optimal sampling, the subsample size from each station should also be proportional to the station-weight. This was not possible because the maximum sample size was 20 fish, whatever the catch size, and so a few stations with large catches had their optimal subsample size constrained. Unfortunately, these were the most important stations for estimating the population mean age.

Some stations were assigned a subsample size of zero because of their small catch. Given the distribution of catches in the 1984 survey, a sample size of 450 would result in about 60% of the stations being assigned a zero subsample size. Small catches often have a distribution of fish lengths different from that of larger ones, so ignoring them can create a small bias in the mean length, and, presumably, in mean age too.

To overcome this bias, stations with a zero subsample size were collected into a separate class: 12 stations were picked randomly, and one otolith was randomly selected from each.

4.2 Estimation of maturity parameters, A_m and S_m, and recruitment parameters, A_r and S_r

Age at maturity, A_m, was estimated as the mean number of rings inside the maturity transition zone and gradual maturity, S_m, as twice the standard deviation.

It is unlikely that age at maturity is stratified in any sense, so the data were treated as a simple random sample (growth data were treated the same way). This simplified the calculation for the sample mean and standard deviation.

Before A_m and S_m were estimated, some data were excluded because of bias. As a cohort approaches maturity, only the faster maturing members will be in the sample (i.e., have a transition zone) which will bias the mean low. Only data from otoliths with no rings outside the transition zone were biased low (Figure 1), so they (1%) were excluded when estimating the maturity parameters.

Age at recruitment, A_r, and gradual recruitment, S_r, were set equal to the corresponding parameters for maturity.

4.3 Estimation of *M*

4.3.1 Mean age from stratified sampling

The mean age for fish aged T_c and greater is given by:

$$\bar{A} = \frac{\Sigma_s V_s \Sigma_i W_{i,s} \frac{n^*_{i,s}}{n_{i,s}} \bar{A}_{i,s}}{\Sigma_s V_s \Sigma_i W_{i,s} \frac{n^*_{i,s}}{n_{i,s}}}$$

where V_s = area / no. tows for stratum *s*; $n_{i,s}$ the number of otoliths subsampled from fish over 24 cm standard length in tow *i*, stratum *s*; $n^*_{i,s}$ the number of subsampled fish with ages over T_c; $W_{i,s}$ proportional to the catch rate of fish with lengths over 24 cm; and $\bar{A}_{i,s}$ is the mean age for fish with ages greater than T_c.

Data from fish smaller than 24 cm were excluded because such fish would not be mature or aged over T_C. This reduces the data, but at the expense of an increase in notational complexity.

The formula is derived by ignoring the length-weight relationship to convert catch, given as a weight, into fish numbers. The fraction, $n^*_{i,s} / n_{i,s}$ adjusts $W_{i,s}$ so that it accounts only for fish with ages greater than T_C.

For stations in the separate class containing the 60% of stations with small catches, $\bar{A}_{i,s}$ is available only for the few stations subsampled, each of which is based on one fish. Therefore, $\bar{A}_{i,s}$ is replaced with the mean age from all ages subsampled from this class, and $n^*_{i,s} / n_{i,s}$ replaced by the fraction of fish subsampled in this class.

4.3.2 Estimation of natural mortality, *M*

Assuming (1) that fish are fully recruited and available to sampling after age T_C, and (2) an age structure that results from constant recruitment and a constant mortality rate, M, over all ages and years, then the maximum likelihood estimate is given by the Chapman-Robson estimator (Chapman & Robson 1960);

$$\hat{M} = \log\left(\frac{1 + \bar{A} - T_c}{\bar{A} - T_c}\right)$$

where $\bar{A}$ is the mean age.

This estimator ignores two sources of error. The first is the non-constant recruitment which perturbs the age structure. The fluctuations in recruitment are unknown and so are treated as errors which have a log-normal distribution. Simulations with log-normally distributed recruitment (zero mean, standard deviation $\sigma_R = 1$) and $M = 0.05$ show that the Chapman-Robson estimator is unbiased, but that the standard error for the estimate is 2–3 times greater than for constant recruitment.

The second source, ageing errors, is divided into reading error and bias. Bias is that systematic difference in ages between agencies (e.g., fishery institutes in different countries) and is not considered directly; its effect was examined with a sensitivity analysis. When reading error is included in the simulations, the estimate of M from the Chapman-Robson method is biased low; the magnitude of the bias increases for larger reading error and larger true values of M. For example, with a 10% reading error, the bias was –4% at an M of 0.035, increasing to –13% for an M of 0.075. For the sample size used and our estimate of M, these biases were well within sampling error and so no corrections were made.

4.3.3 Variance of the estimate of *M*

Part of the total variance comes from variability induced from recruitment variability, σ_R, and part from reading error: these are not easily evaluated because of the complicated sampling scheme. Hence, the first step is to simplify the problem to an equivalent one based on simple random sampling. Variability due to σ_R and reading error is then easily included in a simulation to give total variance.

First, a variance which ignores σ_R and reading error is found using a bootstrap method (*after* Francis 1993). Sample sizes and mean ages are separated into three groups based on the values of their associated catch rates. Catch rates are simulated by resampling the residuals of the catch rates (treated as log-normally distributed within strata, but with a common variance over strata) and adding these to the mean catch rate for the stratum. Depending on which group these simulated catch rates fall into, the sample sizes and mean ages are resampled from those for that station-weight group. The station-weights are calculated, then the population mean age and M estimated. This is repeated 100 times (1000 if a 95% confidence interval is wanted) to give a sample distribution for M from which a variance is calculated.

One change was made to the above scheme. Instead of resampling the sample sizes, I resampled sample size and the proportion of fish in the catch aged T_c or older. This pair defines a binomial distribution from which the number of fish in the sample aged T_c or older can be randomly generated.

A sample size for simple random sampling, n_{eq}, that gives the same variance as above was then found. The sampling was from an age structure generated with log-normal recruitment (zero mean, variance σ_R^2) and a natural mortality with the same value as the estimate of M.

Finally, variance, which includes reading error and recruitment variability, was estimated as follows. From the estimate of M, 1000 age structures were simulated using log-normal recruitment (zero mean, variance σ_R^2), and a simple random sample was drawn from each structure, size n_{eq}, to which reading error was applied. The Chapman-Robson estimator was applied to each sample to obtain 1000 estimates of M from which the total variance can be found.

4.4 Estimation of growth

Growth was modelled separately for each sex with a von Bertalanffy curve, $f(x)$.Its parameters, L_∞, K, and t_0, were found by minimising the sum of squares:

$$\sum_i [l_i - f(t_i)]^2$$

where l_i is the length for fish i, t_i its age, and $f(x) = L_\infty \left(1 - e^{-K(x-t_0)}\right)$.

The youngest fish cannot be sexed, so their data were included in both the male and female data sets.

5. Results and Discussion

5.1 Consistency of adult age estimates from otoliths

The subsample size from the 1984 survey was 432 otoliths; 10 of the original 450 otoliths were excluded because they had a readability code of 5, and a further 8 were chosen but they were either missing or could not be prepared for ageing.

For age estimates to be useful, they must be consistent between readers from the same laboratory and within a reader. This need not imply that such ages are accurate.

For the 1984 data, there were four sets of ages for each otolith, i.e., two readers read each otolith twice. Three of these sets were consistent, but the fourth gave older ages (second reading from one reader, "Reader 2 b", Figure 2) because of higher counts in the region from the maturity transition zone to the outer edge of the otolith (the maturity age from both readers remained almost constant from the first to the second readings (Table 1)). Although this discrepancy is disturbing and requires investigating, consistency in three out of four sets allows us to proceed with the analysis using the three consistent readings.

5.2 Life history parameters

The estimates of life history parameters were made from the average of the first readings by the two readers (Table 2).

Estimates of maturity were based on ages from 393 otoliths, which excludes those with no rings past the transition zone. Maturity age increased by 11–12 years (about 50%), depending on sex, from that used in the previous assessment. Gradual maturity increased by 21%. The asymptotic standard errors for these estimates are 0.2 for A_m, and 0.3 for S_m. The distribution of maturity ages appears normal (Figure 3).

Estimates of M were based on ages from 321 otoliths, which includes only those aged 42 or older. The cutoff age, T_c, was taken to be 42 for both sexes (equal to $A_r + S_r$) as this is when orange roughy are assumed to be fully recruited and, therefore, fully available for sampling. The estimate of M is 12.5% larger than the previous estimate. The frequency of ages older than T_c has a trend that declines exponentially (Figure 4), like it should for the assumptions in the Chapman-Robson estimator. For estimating the variance of M, σ_R was set to 1.0 and reading error to 10%. Reading error was taken as the between-reader error because ages were the average of the first reading from two readers. For comparison, the within reader *c.v.*s were 5% and 11% (the latter included a bias from the first to the second reading, *see* last section). The partial *c.v.* from the bootstrap procedure was 13%, which resulted in an n_{eq} of 50. From this n_{eq}, the total *c.v.* was 18%. The 95% confidence limit was from 0.030 to 0.060.

The fit of the growth data is shown for each sex in Figure 5. Little change is evident from the previously estimated growth curve. The changes in the estimates of growth parameters from last year are small.

5.3 Sensitivity tests of the estimates

Sensitivity tests (*see* Table 1) showed that there are only small differences in estimates of parameters using the various sets of ages separately, except for M from one set. Although the change in M for the latter is relatively large, it is within the 95% confidence interval of the estimate of M from the first reading.

A reading bias of ± 20% directly affects the estimates of M and the maturity parameters (and, by assumption, A_r and S_r). For M, the changes are within the 95% confidence interval. The estimate of K is also directly affected. If reading bias applies to only the adult ages (i.e., the 1984 sample) then there is only a slight change in L_∞.

If reading error is doubled to 20%, the bias in the estimate of M is –17%, smaller than the standard error of the estimate of M.

6. References

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

Doonan, I.J. 1993: The accuracy of an estimate of natural mortality for orange roughy. N.Z. Fisheries Assessment Research Document 93/12. 9 p.

Francis, R.I.C.C., Robertson, D.A., Clark, M.R., Doonan, I.J., Coburn, R.P., & Zeldis, J.R. 1993: Assessment of the ORH 3B orange roughy fishery for the 1993/94 fishing year. N.Z. Fisheries Assessment Research Document 93/7. 28 p.

Mace, P. M., Fenaughty, J. M., Coburn R. P., & Doonan, I. J. 1990: Growth and productivity of orange roughy (*Hoplostethus atlanticus*) on the north Chatham Rise. *N.Z. Journal of Marine and Freshwater Research 24*: 105–119.

Punt, A.E. 1994: A note on confidence intervals for oer for Chatham Rise Orange Roughy. Draft manuscript submitted to the orange roughy Working Group, 31 March 1994.

Table 1: Sensitivity of re-estimated life history parameters to different readers, readings, and reading bias in the 1984 ageing data. Data are for both sexes combined except for growth (L_∞, K, t_0) which is for females. Bias is expressed as age = (true age)(1 + bias). Adult fish for this table are those aged 42 or older. –, not estimated

Reader	Reading	bias	A_m	S_m	T_c	M	L_∞	K	t_0
Both	a	0	33.6	8.4	42	0.046	38.0	0.061	–0.55
Reader 1	a	0	33.0	8.1	41	0.046	–	–	–
Reader 2	a	0	34.4	10.8	45	0.044	–	–	–
Reader 1	b	0	33.3	8.1	41	0.045	–	–	–
Reader 2	b	0	35.0	10.5	46	0.037	–	–	–
Growth when all ages are biased									
Both	a	–0.2	–	–	–	–	38.0	0.077	–0.44
Both	a	0.2	–	–	–	–	38.0	0.051	–0.66
Growth when only adult ages were biased									
Both	a	–0.2	27.5	8.6	33	0.057	39.0	0.065	–0.35
Both	a	0.2	41.3	13.0	49	0.038	37.3	0.060	–0.66

Table 2: Re-estimated life history parameters for orange roughy from the average of the first readings by two readers. –, not estimated

		New estimate			Past estimate
Parameter	Symbol	Male	Female	Both sexes	Both sexes
Natural mortality	M	–	–	0.045	0.040
Age at maturity	A_m	33	34	–	22.2
Gradual maturity	S_m	9	8	–	6.6
Age at recruitment	A_r	33	34	–	22.2
Gradual recruitment	S_r	9	8	–	6.6
Growth	L_∞	36.4	38.0	–	37.3
	K	0.070	0.061	–	0.07
	t_0	–0.37	–0.55	–	-0.3

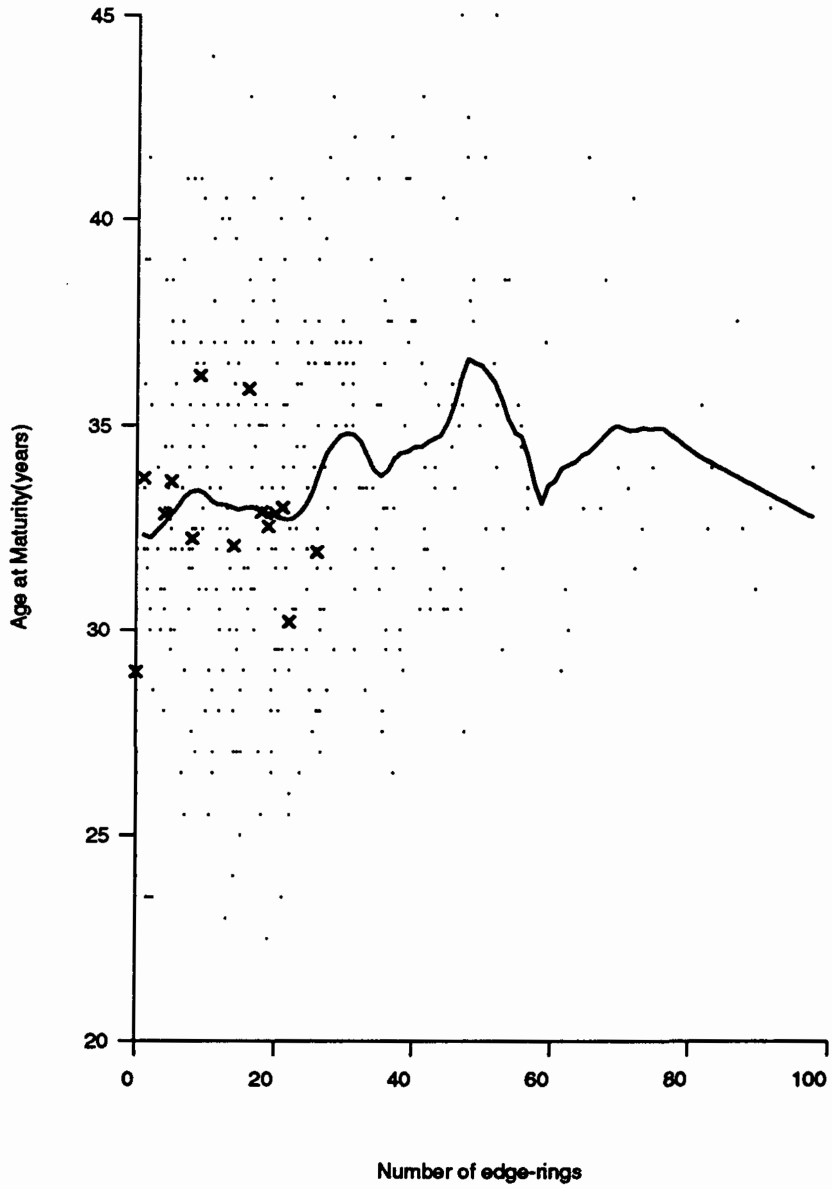

Figure 1: **Individual age at maturity vs. the number of rings outside the transition zone in the otolith (edge-rings). Crosses are the mean maturity age for a given number of edge-rings where there are 10 or more samples; the leftmost cross is the mean for zero edge-rings. The line is a smooth for all data excluding the data with zero edge-rings.**

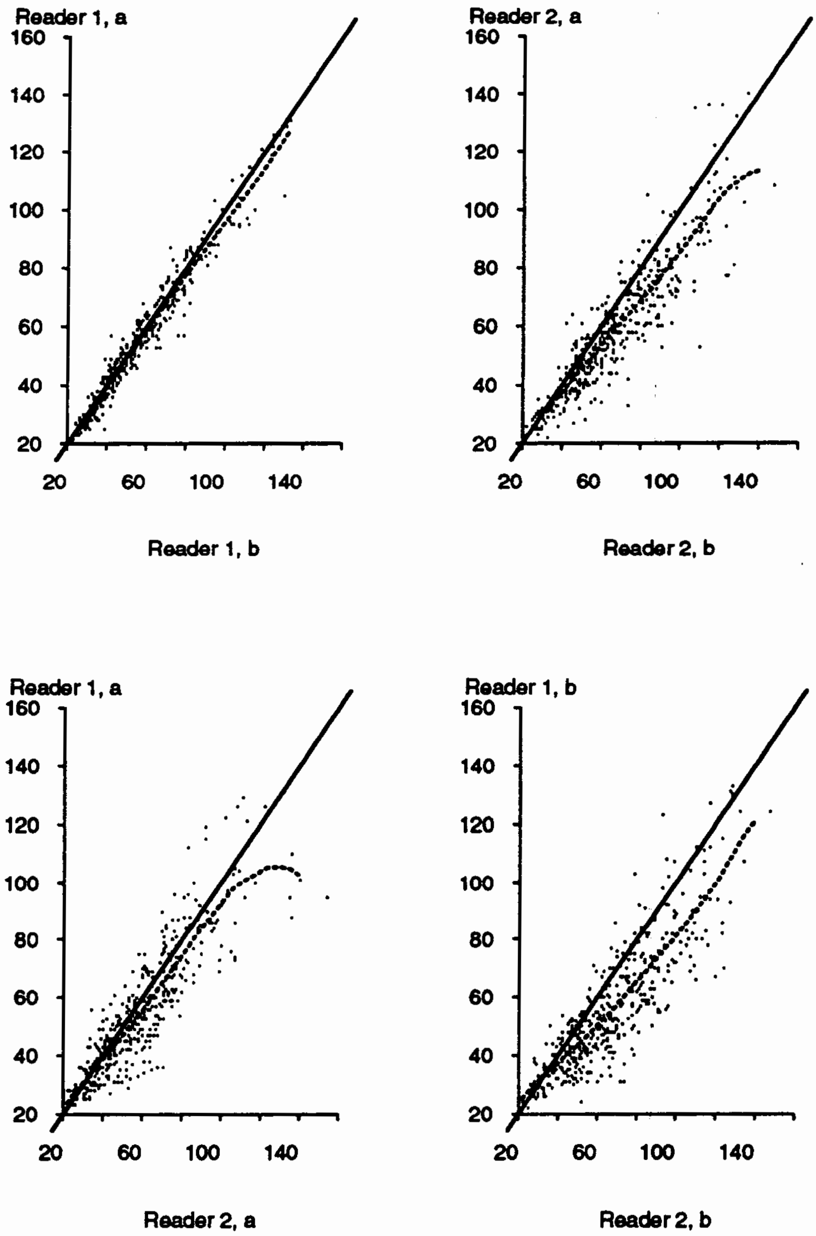

Figure 2: **Comparison of ages from the 1984 *Otago Buccaneer* data: between readers (Reader 1, Reader 2), and between readings (a,b). For example, the top, left-hand plot shows the first reading ("Reader 1 a") of one reader against the second reading ("Reader 1 b") of the same otolith from the same reader. The solid line is the 1:1 line. The dotted line is a smooth through the points.**

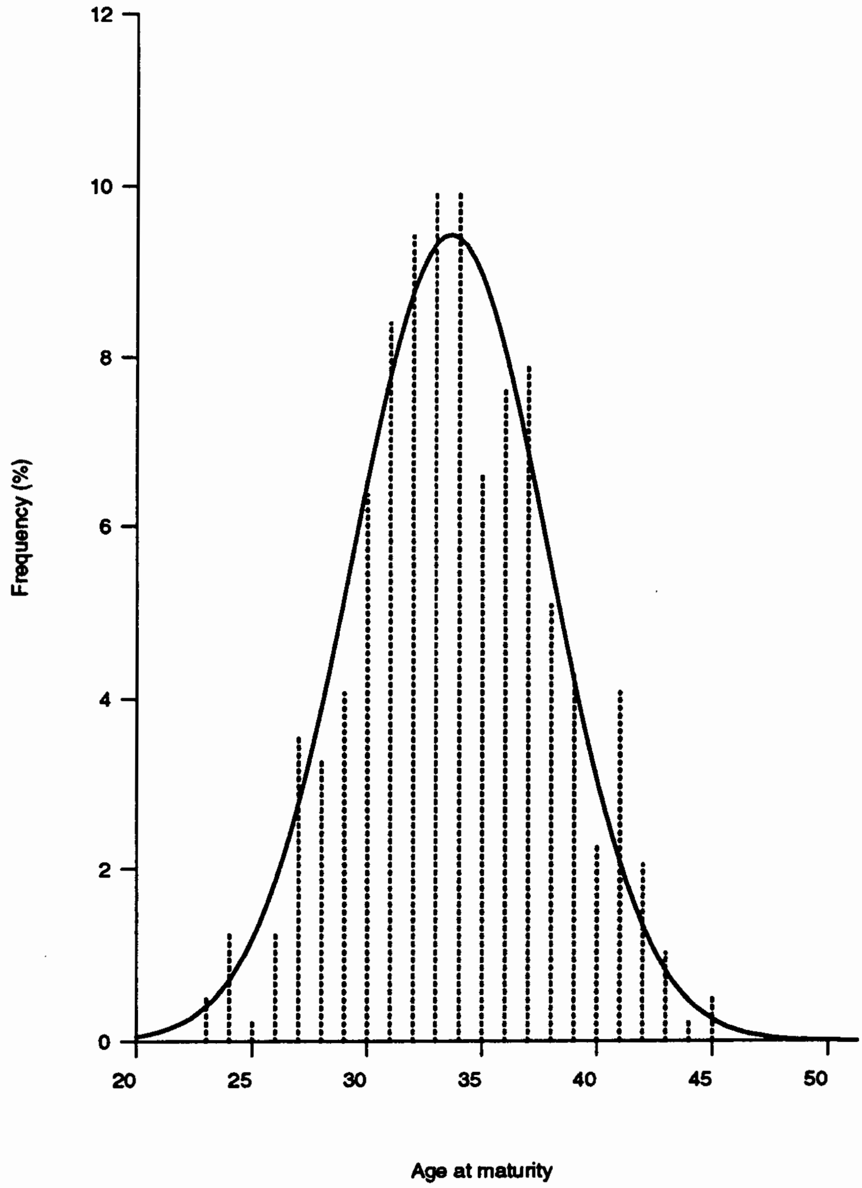

Figure 3: **Distribution of maturity ages for fish with one or more rings after the transition zone. Ages are the mean of the first readings from two readers. Data are from the 1984 *Otago Buccaneer* survey. The curve is the normal distribution using the sample mean and variance.**

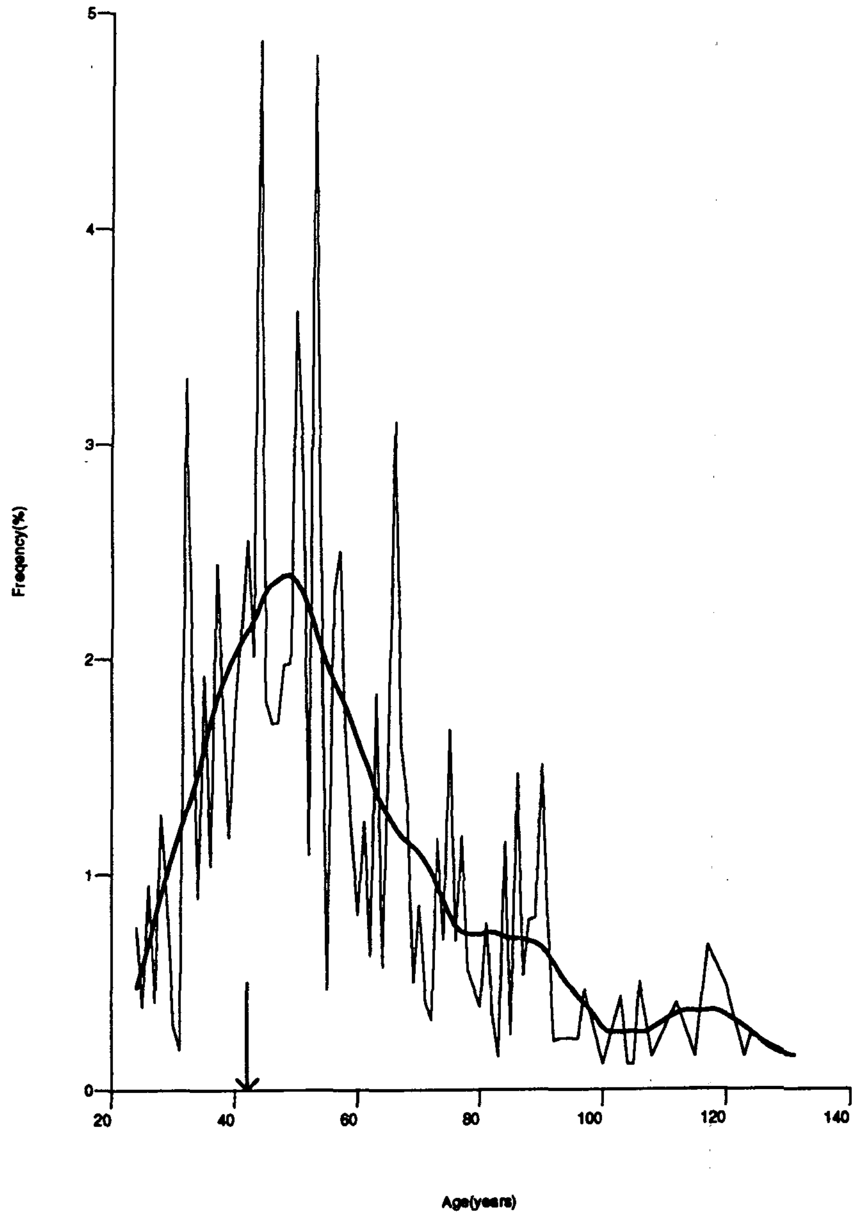

Figure 4: **Population age distribution from the 1984 *Otago Buccaneer* survey. The thick line is a smooth version. Ages are the mean of the first readings from two readers. The arrow marks the age of full recruitment, T_c; only ages this old and older are used to estimate M.**

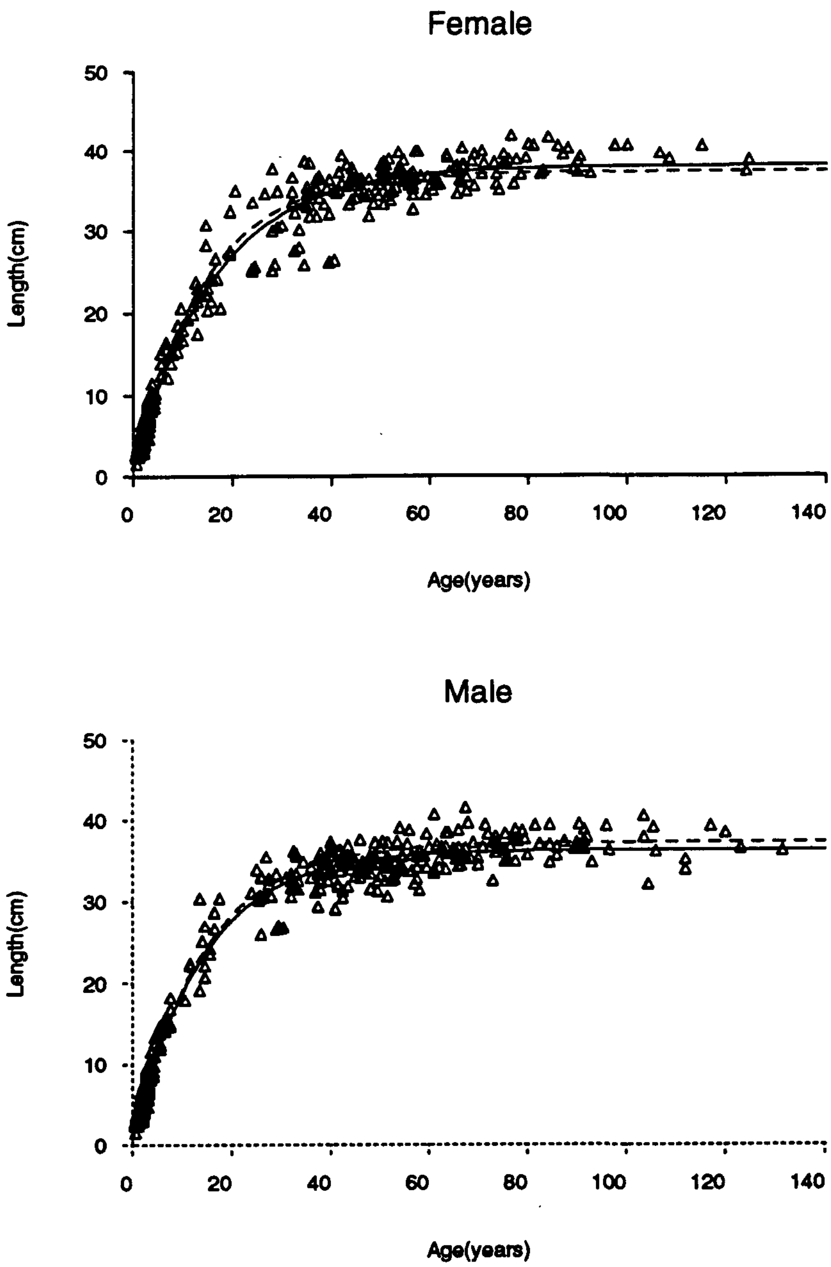

Figure 5: The fit of the estimated growth (line) to the data (triangles), by sex. For comparison, last year's estimated growth (both sexes) is given (dashed line).