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Natural mortality estimates for orange roughy in ORH 1 (Bay of Plenty)

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1. EXECUTIVE SUMMARY

Natural mortality (*M*) of orange roughy was estimated to be 0.037 (95% confidence intervals 0.02–0.06) using data collected by Ministry of Fisheries observers on commercial fishing vessels in the Bay of Plenty area in 1996. Trawling data were not random, but the analysis assumed that they were, and this uncertainty is not contained in the confidence intervals above.

2. INTRODUCTION

This document presents estimates of natural mortality (*M*) for Bay of Plenty orange roughy (*Hoplostethus atlanticus*) using age estimates obtained from reading zones on otolith thin sections. A previous estimate of *M* for New Zealand orange roughy (Doonan 1994) was based on otolith data from a stratified random trawl survey of orange roughy on the Chatham Rise. This survey was in 1984, 5–6 years after the fishery had started.

It has been noted that the *M* estimate could be considered biased because the exploitation of the Chatham Rise stock before 1984 could have selected out older fish which could then make our *M* value an underestimate (Clark 1996). An opportunity to obtain a revised estimate of *M* from a relatively unexploited population of orange roughy arose in 1995 when a commercial fishery developed in the Bay of Plenty in 1994 (Figure 1).

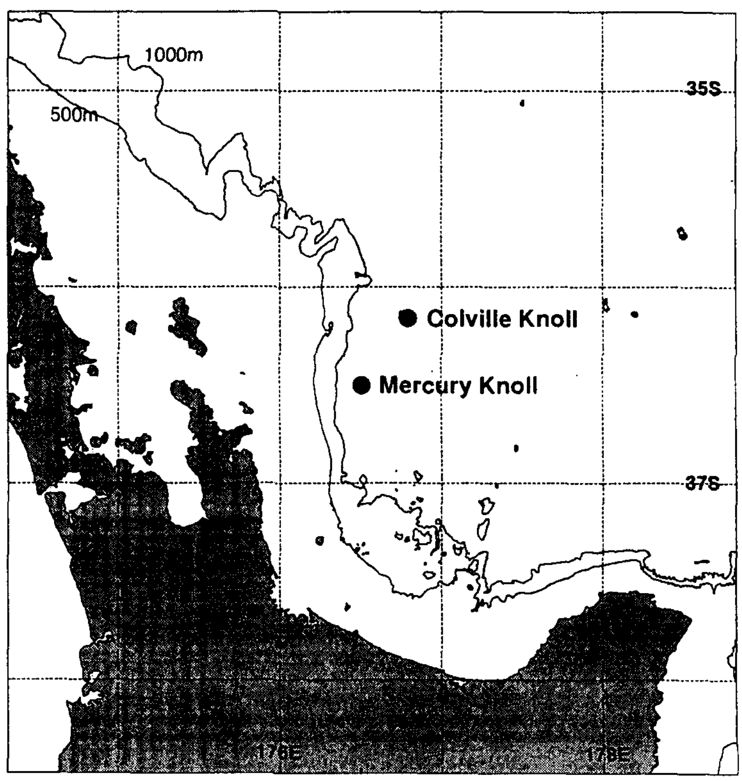

Figure 1: Survey area showing the Colville and Mercury Knolls where the fish used in the analysis were sampled.

Before the 1993–94 fishing year, there was no established orange roughy fishery in the Bay of Plenty area and reported landings for the northern North Island (ORH 1) were generally small (Annala & Sullivan 1997). In winter 1994 a commercial vessel made several large catches of orange roughy (totalling 138 t) on knolls in the Bay of Plenty. Subsequent investigative research surveys were carried out on this vessel under a Special Permit with MAF Fisheries in July and September of the same year (Clark & Field in press) and about 45 t of orange roughy was caught, mostly off the Mercury Knoll. At this stage the existing TACC for ORH 1 was 190 t. The distribution of orange roughy aggregations was mapped during the research surveys and recommendations were made on whether the set TACC should be revised.

From 1995 to 1996 ORH 1 became subject to a five year adaptive management programme, and the TACC was increased to 1190 t (Annala & Sullivan 1997). A catch limit of 1000 t was applied to an area in the Bay of Plenty (Mercury-Colville 'box'). Black cardinalfish (*Epigonus telescopus*) have been a significant bycatch in this fishery.

It was assumed that the orange roughy population was at equilibrium in the Mercury-Colville area in 1995 when the otolith samples were taken, i.e., that fishing for orange roughy had not reached a level where the age structure of the orange roughy population had been altered substantially by fishing.

2.1 Literature review

Previous estimates of M for orange roughy were given by Doonan (1994) and Bax (1997).

3. DATA

For this study, orange roughy otoliths, fish length, and sex data were collected from October 1995 to July 1996 by the Ministry of Fisheries Scientific Observer Programme. Samples came from several commercial tows in the area and a subsample of those otoliths (*see* Methods) used to estimate age came from catches on the Colville and Mercury Knolls (*see* Figure 1). Where possible, at least 10 otolith samples were collected for each tow from catches ranging in size from under 2 t (55% of the catches) to a maximum catch of 32 t (*see* Table 1).

4. METHODS

A sample of 447 otoliths from 43 commercial tows on the Mercury and Colville Knolls was selected for sectioning. All otoliths sampled from catches over 2 000 kg were included in the sample. To provide an adequate sample size, otoliths were also selected from tows with very small catches. The maximum sample size from a catch was 19 fish, whatever the size catch. Optimal otolith sampling is to have the subsample size from each station proportional to the catch, but this was not possible in this study.

The preparation method for otolith sections was described by Francis & Horn (in press). Total zone counts were obtained from the primordium to the transition zone and from the transition zone to the edge. All samples were read by two readers and ages used to estimate M were the mean of the two readings.

Estimating natural mortality

The method was modified from that used previously for orange roughy (Doonan 1994). This method required a weighted population mean age where the weighting was related to catch size and stratum area because the age data were derived from fish sampled by a stratified random trawl survey. Here, there was no random trawling, but the data was treated as if they were random, i.e., age samples needed to be weighted by catch size. Also, data from the two knolls were treated as if from two strata of the same area.

The population mean age for fish that were fully recruited (x), i.e., ages greater than or equal to T_c, the age of full recruitment, was given by

$$x = \frac{\sum_i W_i \ f_i \ age_i}{\sum_j W_j \ f_j}$$

where i and j index stations,

$$W = N * \frac{area_s}{n_s}$$

and N is the catch rate in numbers of fish, $area_s$ is the area of stratum s (a nominal value of 1 km^2 was used for both strata in this analysis), n_s is the number of tows done in that stratum, f is the fraction of fish with ages over T_c, and age is the mean age of fish aged T_c and over. N was approximated by dividing the catch by the mean weight of the fish in the otolith sample.

M was then estimated from

$$\log \frac{1 + x - T_c}{x - T_c}$$

Estimating the variance was complex because there were several sources of uncertainty, including recruitment variation, reading error, and sampling error all mixed into a random stratified design where stations were not treated equally but were weighted by their catch size and stratum area. Two steps were used in estimating variance (Doonan 1994). First, the stratified random survey was reduced to an equivalent one based on simple random sampling. Second, simple random sampling was used to add in the recruitment variability and reading error for an estimate of the total variance. This approach avoided having to model spatial distribution of age classes, their distribution by catch size, and changes to distributions because of cohort size.

In greater detail, the first step, which quantified the error due to sampling, was as follows. The sampling *c.v.* of M due to the stratified survey design was estimated by bootstrap methods. Then, the sample size, n_{eq}, was found that gave the same *c.v.* (as the survey estimate) for estimating M from a simple random sample that was drawn from an age structure made up from constant recruitment and M (as estimated above).

The second step added error due to recruitment and reading otoliths, by drawing random samples of size n_{eq} from an age structure generated by log normal recruitment, constant M (as estimated above), and a linear selection ogive from T_{min} to T_c, and then added reading error to the selected ages.

5. RESULTS

For the sample, 362 otoliths were readable and 85 were not readable. The maximum age was 145 years for a 39 cm male. The data were divided into two strata of equal area, Colville and Mercury Knolls, and scaled to catch size. The knolls were separated into two strata because they differed in three ways: 1) trawling on Colville Knolls was shallower and the target species were a mixture of black cardinalfish and orange roughy, whereas on Mercury Knoll the target species were all orange roughy; 2) the Mercury Knoll had data from the June-July spawning season; 3) trawling was restricted to a portion of sectors on each knoll and targeted fish, so the areal extent is unknown for each knoll. Thus we gave each strata the same nominal area.

Age of full recruitment (T_c) was set to 42 years, i.e., 8 years over the sum of the age of recruitment (A_r) and "Gradual" recruitment (S_r). $A_r + S_r = 30 + 4 = 34$ (Orange Roughy (ORH) in Annala & Sullivan 1997). The age distribution is given in Figure 2. In theory, the age distribution should have high frequencies around the age of full recruitment (T_c), with a subsequent exponential decline with increasing age. This was seen to some extent in both plots.

The length frequency distribution for the otolith sample exhibited a similar size structure to the total length frequency distribution of the Bay of Plenty observer length frequency samples (O. Anderson, NIWA, unpublished results). A length frequency distribution of the Bay of Plenty population from random trawl survey data also shows a similar size structure (Clark & Field, in press).

Natural mortality, *M*

Estimates of mortality parameter values made from the average of the readings of the two readers are given in Table 2.

The variability of recruitment was assumed to be 1.1 in the log scale and reading error was estimated from the between-reader variability to be 7.2%, i.e., 10.2%, divided by $\sqrt{2}$ (the age estimate was the average from two readers). *M* was estimated to be 0.037 with a total *c.v.* of 26% and 95% confidence limits of 0.025 to 0.062.

M sensitivity analysis

Increasing T_C to 45 and 50 years resulted in a 3% decrease (Table 3). Decreasing T_C to 34 years (minimum age of recruitment) also results in a 3% decrease. A 10% reading bias in the estimated ages would change the estimate of *M* by 10%. There were some differences in estimating *M* resulting both from using data for one reader or the other, and for the Colville Knolls and Mercury Knoll. All differences were well within the estimated confidence region. The analysis was also carried out excluding the samples taken from the trips that caught large catches during June/July to ensure a spawning fish estimates did not differ from the overall result. The spawning fish estimate of 0.049 was well within the confidence region.

M was re-estimated five times. For a re-estimate, the data from one trip were excluded, leaving the data from the remaining four trips. This was done for each of the five trips. The lowest estimate was 0.031 (trip 888) and the highest 0.049 (trip 919) (*see* Table 3). However, the other three estimates were between 0.036 and 0.038, so the influential data for our *M* estimate came from trips 888 and 919, with trip 919 more influential than trip 888 (based on the shift in the *M*s). This structure is not completely taken into account in the sampling variance, so the stated confidence limits are conservative.

6. DISCUSSION

There is some uncertainty in the estimates of *M* because orange roughy age estimates were unvalidated, but it is highly likely that the clear zones visible in otolith sections (*see* Doonan 1994) represent some constant time interval. Results of reading orange roughy otoliths by Australian workers have been very similar to ours (Tracey & Horn, unpublished results). Results of comparing otolith thin section readings with radiometric analyses reported by Fenton *et al.* (1991) support the conclusion that orange roughy is a long lived and slow growing species.

The estimate here is not statistically different from that estimated from the North Chatham Rise data (t-test).

7. ACKNOWLEDGMENTS

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Table 1: The Bay of Plenty stations and total orange roughy catch from which otolith samples were selected for age estimation

Trip Number	Station	Catch (kg)	No. of otoliths sampled
888	2	500	10
	6	5 000	11
	15	250	10
	18	500	10
	24	23 000	15
	25	2 000	10
	27	5 000	15
	39	60	5
	49	4 000	10
	50	4 000	10
	51	6 000	15
	52	15 000	15
	67	1 000	10
	78	1 000	10
	79	2 000	13
	81	3 000	19
889	3	27	18
897	4	8 000	12
	12	150	5
	13	2	2
	14	10	5
	21	5	2
	22	500	15
	23	180	5
	24	200	7
	26	30	5
	31	15	15
	37	5	2
	38	400	15
	40	10	3
	46	2	1
918	3	2 500	10
	4	1 500	10
	8	240	10
	14	1000	10
	22	500	10
	35	6 000	10
919	49	5 000	15
	56	15 000	5
	58	18 900	17
	60	29 000	15
	64	32 000	17

Table 2: Estimates of orange roughy natural mortality parameter values from Bay of Plenty data.

Parameter	Symbol (unit)	Value
Minimum age sampled	T_{min} (years)	16
Age at full recruitment	T_c (years)	42
Length-weight parameters	a	0.0921
	b	2.71
Stratified sampling variance for M	*c.v.* (%)	17.7
Equivalent sample size for simple random sampling	n_{eq}	35
Recruitment variability	*r(log)*	1.1
Variance for reading error	*c.v.* (%)	7.2
Total variance of M	*c.v.* (%)	26
Natural mortality	M (yr^{-1})	0.037
95% confidence limit for M	(yr^{-1})	0.025–0.062

Table 3: Orange roughy *M* sensitivity analysis

Case	M
T_c = 34	0.036
T_c = 45	0.036
T_c = 50	0.036
Reading bias: - 10%	0.033
Reading bias: + 10%	0.040
Reader 1	0.032
Reader 2	0.041
Colville Knolls only	0.053
Mercury Knoll only	0.032
Lowest M (trip 888)	0.031
Highest M (trip 919)	0.049

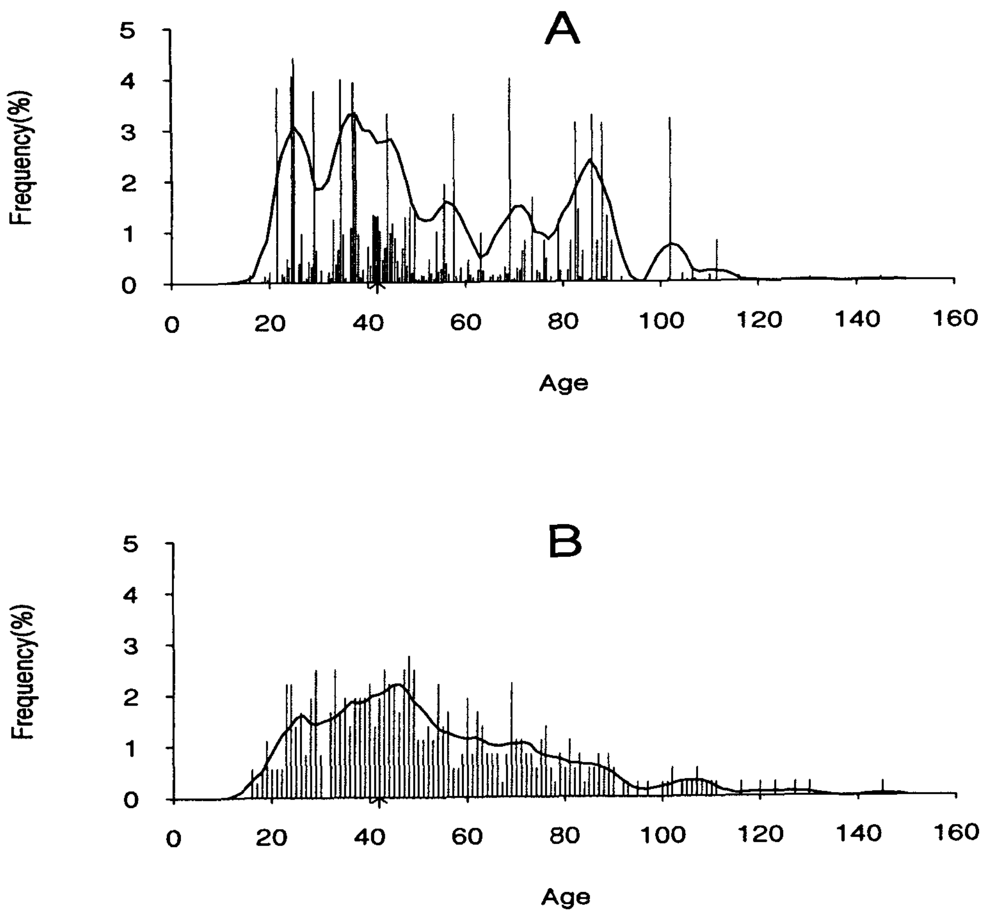

Figure 2: **Bay of Plenty population age (years) distribution (vertical lines) for males and females combined, weighted by stratum area and catch size (A), and without weighting (B) The curved lines are smoothed versions of the age frequency. The arrows mark the age of full recruitment, T_c.**