

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

*New Zealand Fisheries Assessment Research Document 88/45*

**Biomass and yield estimates for North Chatham Rise orange roughy**

P.M. Mace and I.J. Doonan

MAFFish Fisheries Research Centre  
P O Box 297  
Wellington

December 1988

MAFFish, N.Z. Ministry of Agriculture and Fisheries

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

BIOMASS AND YIELD ESTIMATES FOR NORTH  
CHATHAM RISE ORANGE ROUGHY

Biomass estimates calculated using assumptions 3-6 (see 1987 orange roughy stock assessment manuscript) for the "Otago Buccaneer" North Chatham Rise orange roughy surveys of 1984-87 are given in Table 1.

TABLE 1: Biomass estimates (CVs) for 1984-87 under four sets of assumptions about the efficiency of trawl gear

	Assumption			
	3	4	5	6
1984	205,695 (24)	192,457 (17)	247,897 (19)	1,133,220 (31)
1985	123,075 (23)	156,425 (15)	168,035 (16)	599,579 (36)
1986	62,364 (37)	113,453 (17)	122,492 (19)	208,674 (47)
1987	43,343 (32)	86,444 (17)	86,444 (17)	86,444 (17)

Assumption 4 (wingtips, no correction for blown windows or school height, Figure 1a) has been used in the determination of the statistical significance of the decline (see 1987 document). Assumption 6 (wingtips, correction for blown windows, school height adjustment, Figure 1b) has been used as the basis for calculating catch quotas.

A decline of the magnitude implied by assumption 6 is extremely difficult to explain given the catch history of orange roughy on the Chatham Rise (Table 2).

TABLE 2: Reported catches of Chatham Rise orange roughy over the period 1978/79 to 1986/87

	Reported catch (tonnes)
Up to 1978/79	negligible??
79/80	11,800
80/81	31,100
81/82	28,200
82/83*	32,605
83/84*	32,535
84/85	29,340
85/86	23,420
86/87	(34,000 quota)

\* 15-month catch period used, to account for the changeover in fishing year from 1 April-31 March to 1 October-30 September.

But even the other, more conservative, indices imply an extremely rapid decline.

The following hypotheses have been advanced to explain the decline:

1. Sampling problems (survey design).
2. Annual estimates of absolute biomass (and consequently virgin biomass) were overestimated in 1984, 1985 and possibly 1986.
3. Fishing mortality has been grossly underestimated due largely to the commercial fishing fleet toying too long after trawl windows have burst, lost bags of fish, production losses and understatements of product weight.
4. Natural mortality has been underestimated, particularly that of mature fish.
5. Stock biomass was unusually high at the time when fishing began; i.e. the virgin population represented an accumulation of one or more years of exceptional recruitment.

6. There has been several years of poor (below average) recruitment to the spawning stock (recruitment failure).
7. Fish are no longer returning to the North Chatham Rise spawning area.

Hypotheses 5 and 6 cannot be treated separately because they relate to average recruitment levels which cannot be determined without a considerably longer time series and a reliable mechanism for ageing the fish. Hypothesis 7 is functionally equivalent to Hypothesis 6, it is the juveniles that leave and don't return, or to Hypothesis 4 if it is the adults that leave and don't return. This leaves five hypotheses to explain the decline, of which two or more may be applicable simultaneously.

#### Survey design

We have devised a spatial sampling simulation model in collaboration with J. Fenaughty to investigate the effects of survey design under various hypotheses about orange roughy migration patterns. The particular aspect of survey design that we have concentrated on to date is the timing of the survey in relation to the timing of fish arrival in the survey and spawning areas. This focus was chosen because of the belief that the 1986 survey may have underestimated biomass by occurring early in relation to spawning activity (i.e. the fish spawned late).

The model has been formulated so that sampling anomalies can be investigated in isolation from other problems related to the assumptions used to translate estimates of relative biomass into absolute biomass;

i.e. vulnerability to trawl gear is known exactly and there is zero measurement error within trawl samples. A brief description of the model follows.

Initially the survey area contains only a constant background density of resident fish. Migrants begin moving in from east and west, but mostly east, on day 1 of the simulation. The stock continues to migrate into the survey area at regular intervals over a specified time period. The time step of the simulation depends on the specified average speed of fish movement and the spatial resolution. We have used a spatial resolution of one nautical mile square and a time step equivalent to the average amount of time taken to move a distance of 1 nm (arbitrarily set at 5 hours for the preliminary runs). At each time step fish move to one of the adjacent eight squares or remain in the current square with probabilities dependent on directional preference, depth preference and density preference. A series of parameters are chosen such that directional preference is towards the spawning pinnacles before spawning and away from them afterwards; depth preference is greatest for the depth ranges where orange roughy are most commonly captured and smallest elsewhere; and the propensity to concentrate in areas of high density is strong prior to spawning and weak afterwards. Thus prior to spawning fish move along depth contours towards the spawning grounds, gradually concentrating in density. After spawning they move back along the depth contours in the opposite direction, gradually dispersing. During spawning specified "spawning squares" act as attractors to all unspawned fish in the vicinity. Fish that arrive on the spawning grounds before the "spawning switch" is

turned on move randomly within a bounded set of squares somewhat larger than the spawning area.

The majority of fish enter the simulation grid from the southeast corner (where depth contours happen to be in the preferred range) and move towards the northwest area (where the spawning pinnacles are located), and reverse this pattern after spawning. The trawl survey design adopted for the 1984-87 "Otago Buccaneer" surveys starts in the northwest and moves towards the southeast covering most stations, with relatively smaller sampling density on the return trip.

Examples of three sets of runs for survey durations of approximately 20 days are shown in Figure 2. These results suggest that biomass is more likely to be underestimated rather than overestimated. Part of the reason is that there are few occasions when the entire stock is within the survey area. For the usual survey track the ratio between estimated and true biomass ranged from 0.60 to 1.14. The lowest estimate for the biomass ratio (0.60) was attained for a survey completed about the time that spawning began (as was suspected in 1986). To achieve a ratio of 1.0, the best strategies are apparently to start the surveys either 25 days or so before spawning or else immediately at the beginning or end of the spawning period. To achieve consistency between years surveys should be conducted at the time when the curve is relatively flat; i.e. during the second half of the spawning period. However we need to refine and tune the model further before recommending adoption of any particular sampling strategy.

A survey track in reverse column order (east to west) would follow the bulk of the fish towards the spawning grounds if it was started

early and miss most of them if it was started late (Figure 2). The reverse would apply for a survey track in ascending column order (west to east). Of course the most accurate estimate would be obtained by completely randomising the order of station occupancy, but this is not practical given time constraints and fuel costs.

An attempt to evaluate the effects of survey design and survey timing empirically was made during the 1987 "Otago Buccaneer" survey (Fenaughty et al., ms). The usual survey time was extended by about two weeks and some of this time was used to occupy an additional 45-51 random stations both before and after the main survey of 110 stations. The additional stations were sampled from east to west on the first traverse and from west to east on the second traverse. Biomass estimates based on assumption 4, 5 or 6 (which give identical results) are given below for these survey phases, individually and in combination.

	No. stations	Biomass	CV	Duration
First traverse	51	105,631	34	27 Jun-04 Jul
Main survey	110	86,444	17	04 Jul-22 Jul
Last traverse	45	136,547	49	27 Jul-05 Aug
First and main	161	97,237	15	
Last and main	155	107,519	24	
All combined	206	110,331	19	

The order of station occupancy, timing of the survey phases and cursory examination of gonad staging data suggests that the first traverse followed fish moving into the spawning grounds while the last traverse followed them when they were leaving. The main survey may have

run counter-current, so to speak, to the predominant directions of fish movement in both the west-east and east-west phases. According to the simulation results (Figure 2, broken lines) the sampling scenarios of the first and last traverses could both lead to relatively high estimates of biomass (given that assumptions about vulnerability to trawl gear are correct). The main survey, which started several (at least 8-12) days prior to the beginning of the main spawning period, may have underestimated biomass (Figure 2, solid line).

Unfortunately it is difficult to delineate the spawning period using research data because the majority of sampling occurs outside the spawning grounds. We need catch sampling from the commercial fishing fleet to determine the timing and duration of spawning precisely. At the research stations stage 5 (ovulated) females were rare until about 10 days after the beginning of the main survey. Six days later spent fish dispensing from the spawning grounds were beginning to be found in quantity. Both spent and ovulated fish continued to be found until sampling ceased on 9 August, although ovulating females became increasingly rare after about 1 August. This suggests that the spawning period may be more protracted than the 10 days assumed in the simulation model.

The ratio between the highest and lowest biomass estimates in the above table is 1.6. In the simulations it ranged from 1.9 for the usual cruise track (Figure 2, solid line) to 2.8 for the east-west cruise track (Figure 2, dashed line). However, it is unlikely that these extremes apply to the "Otago Buccaneer" surveys of 1984-87. Although we have not yet analysed the gonad staging data in detail, cursory



examination suggests that the timing of surveys has not varied substantially in relation to the timing of spawning. In particular, survey timing has not become progressively earlier or later in relation to spawning activity. Thus while differences in timing may affect the reliability of individual estimates of biomass, they cannot by themselves explain the persistent and regular decline in the estimates in Table 1.

#### Estimation of Absolute Biomass

The most recent estimate of virgin biomass was based on the 1985 "Otago Buccaneer" survey using assumption 6 (wingtips, correction for blown windows, school height adjustment, Figure 1b), with 19,000 t added to account for biomass outside the survey area, and 189,000 t added to account for catches from 1979/80 to 1985/86, for a total of 935,000 t (Robertson 1986). The procedure of adding in the catch history directly ignores recruitment and will produce an overestimate of virgin biomass, unless recruitment actually was negligible over the history of the fishery. Using a Beverton-Holt model similar to that outlined in the 1987 assessment manuscript but with revised growth parameters:

$$\begin{aligned}L_{\infty} &= 41.2 \\k &= .26 \\t_0 &= .65,\end{aligned}$$

ages of recruitment and maturity of 6 years,  $M = 0.1$ , and constant recruitment based on virgin population size and stable age structure, the estimate of virgin biomass is 875,000. Thus Robertson's (1986) estimate would represent a 7% overestimate.

Of greater concern is the validity of the assumptions used to produce the 1984-87 estimates of absolute biomass. In other orange roughly assessments, and in general for deepwater species, the estimate of absolute biomass is calculated as the average of wingtip and doorspread estimates, and no corrections are applied for blown windows or school height. Since biomass is proportional to the inverse of area swept, the average of wingtip and doorspread estimates does not assume that all fish out to the midpoint between wings and doors are captured by the gear. For a wingtip of 19 m and a doorspread of 100 m, the assumption that widths swept is the mid-point of wings and doors leads to a biomass estimate that is 32% of the wingtip estimate, whereas the average of the two biomass estimates is 60% of the wingtip estimate. Taking the average of wingtip and doorspread estimates assumes that the width swept is 31.9 m, not 59.5 m. The ratio between the wingtip estimate of biomass and the average of wingtip and doorspread estimates is 1.7.

A catch that required both a blown window adjustment and a school height adjustment would be a factor of approximately  $2 \times 10 \times 1.7 = 34$  times the estimate used in other assessments. It is however rare to apply both corrections at once. The school height adjustment ( $10 \times 1.7$ ) on its own was applied to 10.5%, 6.2%, 0.8% and 0% of the catches in 1984-87 respectively. Whether the adjustment is appropriate is impossible to evaluate without data on herding and vulnerability to trawl gear. But as will be shown below the decline in biomass estimates based on assumption 6 is virtually impossible to explain under any reasonable combination of hypotheses.

Virgin biomass was calculated using the above model and parameters for the cases of constant and zero recruitment based on the assumption that the 1987 biomass estimate is exact. These estimates and those for the years when surveys took place are given in Table 3.

TABLE 3: Biomass estimates for two recruitment options based on the assumption that the 1987 survey estimate (based on assumptions 4, 5 or 6) was exact

	Constant recruitment	Zero recruitment
1979/80 (Virgin)	253,150	284,850
83/84	145,610	177,500
84/85	122,500	154,420
85/86	105,670	122,210
86/87	86,440	86,440

Note that the zero recruitment series conforms more closely than the constant recruitment series to the survey estimates from assumption 4 (and 5) in Table 1. But in both cases the rate of decline does not even approach that of assumption 6.

The  $\frac{1}{2}MB_0$  formulation would give an MSY of 12,600-14,200 but could not be applied to the current stock which is below  $\frac{1}{2}B_0$ .

#### Fishing mortality

Robertson (1986) estimated that removals from the North Chatham Rise may be about 30% higher than reported landings. This estimate was based on measurement of conversion factors and on a series of guesses, most of which were considered to be conservative. Using the same model and parameters as above, to drop to a biomass of 86,400 t in 1987 from virgin biomass levels of 935,000 t and 875,000 t in 1980, actual removals from the stock would need to be 4.9 and 4.6 times reported

catch for the case of constant recruitment or 4.4 and 4.1 times reported catch for the case of zero recruitment. Although it is possible to imagine that saturation fishing conditions could lead to mortality rates of 4-5 times landings, it seems unlikely. Sometimes the cod-end window may burst after a few minutes of towing while the gear continues to fish for much longer (e.g. one hour). The proportion of fish passing through the cod-end window that would subsequently die is impossible to estimate but would probably be less than 100%. Most trawlers also occasionally lose nets that have been overfilled.

In reality the reporting discrepancy needed to explain the decline is even greater than the 4.1-4.9 range above. If the discrepancy had been known or assumed in 1986, the estimate of virgin biomass obtained by adding the catch history to the 1984/85 survey estimate would have been considerably larger than 935,000 t (Table 4). With constant recruitment the rate of decline over the period 1984-87 is most similar to that for assumption 4 in Table 1 when the ratio removals : reported landings is about 1.5-2.0. With zero recruitment the corresponding range of ratios is 1.0-1.3. Thus it is not necessary to postulate high recording discrepancies to explain the decline for assumption 4, particularly in the case of zero recruitment. But a ratio higher than 5.0 is needed to match the rate of decline for assumption 6.

TABLE 4: Virgin biomass, ratio of current stock size to virgin biomass and 1986/87 fishing mortality for various levels of discrepancy in the ratio of removals to reported landings

(a) assumptions as above, with constant recruitment

removals/ reported	virgin biomass	current/ virgin	86/87 fishing mortality
1.0	253,150	.34	.39
1.3	304,000	.28	.50
1.5	338,000	.26	.58
2.0	424,000	.20	.76
3.0	598,000	.14	1.10
4.0	773,500	.11	1.43
5.0	951,000	.091	1.72

(b) assumptions as above with zero recruitment

1.0	284,850	.30	.39
1.3	342,000	.25	.50
1.5	381,000	.23	.58
2.0	476,000	.18	.76
3.0	671,000	.13	1.10
4.0	868,000	.099	1.43
5.0	1,066,000	.080	1.72

The estimate of virgin biomass (and consequently  $\frac{1}{2}MB_0$ ) does not increase substantially until the ratio exceeds 2.0 (Table 4).

#### Natural mortality

One hypothesis that can readily explain the decline in biomass is that orange roughy have high post-spawning natural mortality. If post-spawning mortality were sufficiently high, the spawning population in each year would consist almost entirely of new recruits; i.e. a single year class. There are two reasons for advancing this hypothesis:

(i) On first impression, the shape of the spawning population length-frequency distribution appears to have been invariant with time. Unless recruitment is constant or post-maturation growth rates are

extremely slow or the spawning population comprises a single year-class, the length frequency should be affected by the relative sizes of incoming year classes.

(ii) There is no definitive ageing system for orange roughy, and therefore no basis for determining growth rates. Cursory examination of length-frequency distributions suggests the presence of three separable groups, with modes at about 14, 27 and 35 cm. Do these represent three year classes or three school types? Perhaps orange roughy recruit to "juvenile schools", "pre-recruit schools" and "mature schools" at specific sizes.

To date, there have been five studies of orange roughy otoliths that have produced five different interpretations of otolith check rings. None of the interpretations have been validated, so there are no criteria to allow one system to be accepted in preference to another. The only traditional technique for age "validation" that can be used with present data is that of modal analysis. But the technique is not straightforward with orange roughy data because research surveys concentrate on spawning populations which are almost invariably unimodal (with a mode at about 34-36 cm). It wasn't until we began summarising available data on juvenile orange roughy that we realised it might be possible to use individual tows as the basis for modal analysis. Whereas the overall survey length frequencies have little structure, individual length frequencies appear to contain peaks and troughs with potentially more information about age and growth. We have therefore put considerable effort into developing modal analysis techniques that may allow us to resolve the orange roughy ageing problem.

The modal analysis technique is an extension of that developed by Fournier and Breen (1983) and Schnute and Fournier (1980). In both of these studies the analysis was based on a single random sample representative of the entire population. In contrast, we assume that sampling is random within trawls but not necessarily over the whole survey. Observed frequencies from each trawl are treated as multinominal samples from an unknown distribution; i.e. each trawl sample doesn't necessarily have the same mean vector. Proportions-at-age are based on the recruited population rather than the entire population. These generalisations allow us to examine cases where

(i) fish schools segregate by size/age and sampling is not representative, and

(ii) there may be missing year-classes (due to poor recruitment or because fish of a certain size/age occur outside the survey area).

Briefly, the analysis assumes that length-at-age is distributed normally for each age. The variance at age is constrained such that

$$\sigma_i = a + b\sqrt{i}$$

where  $i$  = age and  $a$  and  $b$  are unknown parameters. Growth is constrained to a von-Bertalanffy function. For all ages beyond recruitment proportions at age are assumed to conform to

$$p_i = e^{-iZ} + \epsilon$$

where  $Z$  = total mortality and  $\epsilon$  is a normally distributed error term. A  $\chi^2$  statistic has been derived to test goodness of fit.

Input to the model includes specification of the number of modes and initial estimates of the location of modes. The problem is one of non-linear parameter estimation and as such takes a considerable amount of computer time to solve. We have not yet completed the analyses.

All otolith studies to date suggest the presence of at least 15 age classes in the population. We are unable to fit more than 15 modes because orange roughy samples range in size from about 10-40 cm and are measured in 1 cm intervals. The revised growth estimates used in this document were based on analyses involving 15 modes. We are currently attempting to determine the upper limit of the number of modes necessary to obtain significant improvements in the fit of the model to the data.

Once this analysis is completed we will be able to:

- (i) Examine previous ageing results and, perhaps, reject one or more of them, and
- (ii) Compare the proportions of fish in each recruited age class over time, perhaps using several assumptions about the number of age classes present.

Pending final results from the modal analysis we have used an arbitrary approach to examine the shapes of length-frequency distributions of mature fish. Our objective was to determine whether there is any evidence at all of a consistent change in the shape of the distribution. If the shape has remained much the same over time, it suggests the presence of a single year class. If the distribution has been progressively distorted to the left or right, a progression of year



classes of variable size is implied. The existence of several year classes, high fishing mortality and constant recruitment would lead to a downward shift in the distribution, whereas several year classes, moderate fishing mortality and low recruitment would show up as an upward shift.

To select "mature schools", a (generous) spawning area for the north Chatham Rise was defined by the co-ordinates  $42^{\circ}40'S$ ,  $43^{\circ}00'S$ ,  $176^{\circ}30'W$  and  $177^{\circ}10'W$ , and a cut-off of 30 cm applied thereafter. Samples were weighted by catch, added together and normalised individually for males and females and for both sexes combined.

Sex ratio has remained similar over the period 1984-86, with an unexplained reversal in ratios in 1987 (Table 5). Mean length has increased slightly over the period 1982 to 1987 both for males and females individually and for the sexes combined. This increase is 1.71 cm for the entire length frequency (from the spawning area) and 1.76 cm for that portion above the 30 cm cut-off. This translates into appreciable changes in the proportions of fish above and below 35 cm. The change has been consistent for females, but less so for males.

Repeating the exercise using a cut-off of 35 cm shows similar but less pronounced trends (Table 6). Again the pattern is more consistent for females.

These results suggest that the spawning population comprises more than one age-class and that recruitment has been progressively declining, but are inadequate to allow us to reject the hypothesis of a single year class. We are unable to refine the analysis until we have

completed the modal analysis and applied significance tests to the results.

TABLE 5: Relative trends in orange roughy size and sex ratio for the north Chatham Rise "spawning area" (see text) using length classes of 30-34 cm and 35+ cm. Overall mean length is given at the bottom of the table.

	1982	1984	1985	1986	1987
% 30-34 cm					
total	60.9	39.1	38.9	35.8	28.3
male	-	47.9	50.0	46.4	39.1
female	-	28.4	25.4	21.8	19.7
% C> 35 cm					
total	39.1	60.9	61.1	64.3	71.7
male	-	52.1	50.0	53.7	60.9
female	-	71.6	74.7	78.2	80.3
Mean length C> 30 cm					
total	34.02	35.14	35.22	35.34	35.78
male	-	34.58	34.54	34.65	35.03
female	-	35.82	36.04	36.23	36.35
Sex ratio C> 30 cm					
male : female	-	55:45	55:45	57:43	45:55
Mean length C> 1 cm					
total	33.69	34.96	34.98	35.17	35.40
male	-	34.40	34.29	34.50	34.63
female	-	35.64	35.84	36.05	36.05

TABLE 6: Relative trends in orange roughy size and sex ratio for the north Chatham Rise "spawning area" (see text) using length classes of 35-36 cm and 37+ cm.

	1982	1984	1985	1986	1987
% 35-36 cm					
total	64.7	57.5	53.5	52.4	48.4
male	-	69.0	64.1	64.0	61.2
female	-	47.5	45.0	42.0	40.7
% C> 37 cm					
total	35.3	42.5	46.5	47.6	51.6
male	-	31.0	35.9	36.1	38.9
female	-	52.5	55.0	58.0	59.3
Mean length C> 35 cm					
total	36.26	36.55	36.66	36.70	36.86
male	-	36.14	36.22	36.27	36.37
female	-	36.90	37.02	37.09	37.13
Sex ratio C> 35 cm					
male : female	-	47:53	45:55	47:53	38:62

## Recruitment failure

It is suggested that recruitment failure is a necessary (and perhaps sufficient) explanation for the demise of the orange roughy fishery. Survey design may under- or over-estimate biomass but there is no reason to believe that the biomass estimates are not an index of relative changes in abundance. The assumptions used to calculate virgin biomass and sustainable yield are almost certainly wrong yet a pronounced and consistent decline is still evident under more conservative assumptions (e.g. assumption 4). Large discrepancies between removals and recorded landings can explain the decline but are unnecessary under the assumption that recruitment has been negligible. High post-spawning natural mortality cannot be ruled out but seems unlikely on the basis of current ageing results.

It is difficult to draw hard and fast conclusions about recruitment patterns when

- (i) there is little sampling of pre-recruits, and
- (ii) fish age is unknown.

Ageing is so fundamental to the analysis of population dynamics that until the ageing problem is solved we can only speculate about the mechanics of the decline. It appears that there has been at least four successive years (1984-87) of poor recruitment to the spawning population. If orange roughy recruit at age 3 it would be the 1981-85 year classes that were small. If age of recruitment is 6 the corresponding year classes would be 1978-81+. In either case it appears

that recruitment began to decline before substantial amounts of fish had been removed from the stock. This suggests that recruitment may have been unusually high in the years immediately preceding the initiation of the New Zealand fishery in 1979. If recruitment has been declining the effect of fishing will have been to accelerate the decline in spawning biomass.

### Implications of hypotheses

#### Survey design

Although the range in biomass estimates obtained by varying survey design is not large relative to other sources of error, the simulation runs show that the results are sensitive to the timing of the survey in relation to the timing of fish migration (Figure 2). This suggests that surveys should be conducted when fish distributions are more stable; i.e. during a non-migratory stage. Presumably orange roughy would also be more dispersed at this stage so that the necessity of correcting for school height or blown windows would be minimised. Unfortunately we don't know the distribution of North Chatham Rise orange roughy outside of the spawning season. We can probably speculate that they cover a large expanse, possibly including areas outside the EEZ. We suggest that the feasibility of determining the limits of orange roughy distribution outside the spawning season should be evaluated.

### Estimation of absolute biomass

The range in biomass estimates produced under assumptions 1-6 (see 1987 manuscript) can vary by a factor of 28 (1984; wingtips, correction for blown windows, school height adjustment vs doorspread, no correction for blown windows or school height). It is essential that assumptions about herding and fish vulnerability to trawl gear be investigated either directly through use of in situ cameras or indirectly through comparison with acoustic estimates. At this stage the latter seems more feasible. Further research into acoustic techniques should be encouraged. One major problem yet to be resolved is that of determining species composition. Orange roughy, which have oil-filled swim bladders, co-exist with numerous other abundant species (e.g. rattails) that have air-filled swim bladders and may produce stronger acoustic signals.

In the meantime we will probably need to rely on biomass estimates based on one of the six assumptions about vulnerability. We suggest using assumption 4 (Table 1, Figure 1a) because the huge exponential decline in biomass based on assumption 6 (Table 1, Figure 1b) is all but impossible. The estimates based on assumption 4 are about 1.7 times higher than estimates used in other deepwater assessments but this does not necessarily mean they are overestimates. The average of unadjusted wingtip and doorspread estimates for the 1987 North Chatham Rise survey is 51,400 t. If this is assumed to be a mid-year estimate of biomass and the quota of 34,000 t has been realised, it would imply a fishing mortality based on reported catches of approximately  $F = 0.65$ . Even the assumption that all fish between the wingtips are captured may be conservative.

### Fishing mortality

Whether or not the ratio of removals to reported landings is high, fishing practices that lead to wasteful fishing mortality should be discouraged. The Code of Practice agreed to by the fishing industry in June 1987 stipulated that "burst panels are not to be used". Yet we know that their use continued to be common on the North Chatham Rise in July/August.

As mentioned above high fishing mortality will exacerbate the problem of declining recruitment. If assumption 4 is used to estimate (mid-year) biomass it implies that fishing mortality has far exceeded  $F = M = 0.1$  (the assumption of the  $\frac{1}{2}MB_0$  formulation) even if removals have not exceeded reported landings. The range for 1984-87 is approximately  $F = 0.17$  to  $0.65$ . If our current assumptions about growth rates and natural mortality are correct, fishing mortality will need to be reduced substantially to enable recovery of the stock.

### Natural mortality

A different management strategy is implied if orange roughy have high post-spawning natural mortality. The optimum strategy would be to prohibit fishing during a suitable portion of the spawning season (to allow some pre-determined level of escapement) and then to totally fish out the remainder of the population. However it is possible that the spawning population has already been reduced below the optimal stock size. In the latter event fishing mortality should be minimised until the stock is able to rebuild.

We are currently researching methods for determining whether or not fish are spawning for the first time. One possibility is to measure thymus size which decreases markedly in most vertebrates with the onset of sexual maturity. If we find a relationship, we may then be able to determine what proportion of the spawning population consists of new recruits.

#### Recruitment failure

The implications of recruitment failure are obvious: the stock is declining and will continue to do so unless recruitment improves.

#### Yield calculations

The North Chatham Rise virgin biomass based on assumption 4 ranges from 253,000 t for constant recruitment to 285,000 t for zero recruitment. Corresponding MSYs based on  $\frac{1}{2}MB_0$  are 12,650 t and 14,250 t, but could not be applied to the current North Chatham Rise stock (86,444 t) which is below  $\frac{1}{2}B_0$ . With the particular set of growth parameters used in the current analysis the value of F corresponding to  $\frac{1}{2}B_0$  is actually  $F = .08$ . Corresponding long-term yields based on  $\frac{1}{2}FB_0$  are approximately 10,120 t and 11,400 t for the two virgin biomass estimates.

Analyses in this document have not yet included the South Chatham Rise, which is part of the same management area as the North Chatham Rise. A preliminary estimate of South Chatham Rise orange roughy biomass based on the November 1987 "Amata Explorer" survey is 10,364 t (wingtips, CV = 24%), down from 29,192 t (wingtips, CV = 31%) in

November 1986. If the 1987 South Rise estimate is added to the 1987 North Rise estimate a total Chatham Rise biomass of 96,808 t is obtained.

At  $F = .08$  current yield from both portions of Chatham Rise would be about 7,745 t. At  $F = .10$  the yield would be about 9,680 t. A yield-per-recruit analysis using 20 age classes, with

$$W = .0963L^{2.68}$$

$$L = 41.2 (1 - e^{-.26(t - .65)})$$

$$M = 0.1$$

and either (a)

Age	1	2	3	4	5	6	7	8+
Partial recruitment	0	0	0	.2	.4	.6	.8	1.0

or (b)

Age	1	2	3	4	5	6+
Partial recruitment	0	0	0	0	0	1.0

results in  $F_{0.1} = .178$  for (a) and  $F_{0.1} = .186$  for (b). Corresponding current yields are approximately 17,230 t and 18,010 t. The same analysis using 15 age classes results in  $F_{0.1} = .229$  for (a) and  $F_{0.1} = .241$  for (b). Corresponding current yields are approximately 22,170 t and 23,330 t. The current estimate of  $F$  is 0.35. In the long-term, a fishing mortality that exceeds  $F = 0.25$  will reduce the stock to less than 20% of virgin biomass.



### Predictions

Can we make any predictions about the future of the North Chatham Rise orange roughy fishery? Again, the ability to age orange roughy is fundamental to answering this question. To make predictions about future stock size we also need to be able to sample pre-recruits (and/or new recruits) quantitatively and derive indices of recruitment.

A mesh size of 125 mm has been used on all research surveys on the north Chatham Rise. Therefore sampling of juveniles and pre-recruits has been too sporadic to allow quantitative comparisons. Nevertheless we will speculate about future recruitment based on the occurrence of juveniles in the samples.

The 1982 "Kaitan" survey covered a considerably larger area than the 1984-87 "Otago Buccaneer" surveys. To increase congruence between survey results, length frequencies were selected from an area bounded by  $42^{\circ}40'S$ ,  $43^{\circ}15'S$ ,  $175^{\circ}00'W$  and  $177^{\circ}30'W$ , which defines the four corners of the "Otago Buccaneer" surveys. Samples were weighted by catch size, added together and normalised for each year (see Figures 3-7). Yet another arbitrary division of length classes was chosen for the purpose of examining trends in proportions-at-length (Table 7), pending results of the modal analysis. The percentages of fish in each length class were summed over pre-defined length intervals. For the second to fifth length intervals the mid-points correspond approximately to the modes from a modal analysis that assumes 15 age classes. Thereafter 2 cm intervals were used. The first mode occurs at about 14 cm.

A "modal progression" of small length classes is not evident in the series (compare 1985 and 1986 estimates in Table 7) . One reason for

this may be that the capture of fish less than 25-30 cm is fortuitous rather than quantitative. High proportions of small fish may be indicative of future high recruitment, but the evidence is far from conclusive.

The 1987 proportions were compared to the averages for the other four years (Table 7). Over the length range 26-35 cm the proportions are all lower than average, whereas above 36 cm they are higher than average. If the size of recruitment is about 26-30 cm, then the former length range includes all newly-recruited fish, along with those about to recruit in 1988. Note that this length range is low both as a proportion and in terms of total biomass. Unless these four length intervals comprise only one or two age classes the prospects for good recruitment in the near future look bleak. Orange roughy in the length interval 36-4055+44 cm will be rapidly depleted as they are subjected to both fishing and natural mortality, with relatively little growth occurring.

TABLE 7: Percentage composition of orange roughy sampled by length interval for 1982-87. See text for criteria used to select length frequencies and length intervals

Size range (cm)	1982	1984	1985	1986	1987
≤16	.043	.036	.0058 <sup>L</sup>	.19 <sup>S</sup>	.43 <sup>S</sup>
17-21	.27	.27	.082 <sup>L</sup>	.74 <sup>H</sup>	.57 <sup>MH</sup>
22-25	.82	.99	.55 <sup>L</sup>	1.93 <sup>H</sup>	.97 <sup>A</sup>
26-28	1.74	1.35	1.69	2.14 <sup>H</sup>	1.36 <sup>L</sup>
29-31	9.91	6.42	7.20	6.73	5.14 <sup>L</sup>
32-33	23.01	17.17	17.13	16.78	14.08 <sup>L</sup>
34-35	30.78	32.77	30.79	29.03	28.35 <sup>L</sup>
36-37	22.37	26.72	26.48	26.94	30.18 <sup>H</sup>
38-39	8.92	10.64	12.22	12.45	14.69 <sup>H</sup>
40+	2.14	3.65	3.85	3.09	4.22 <sup>H</sup>

L - lower than average  
 A - average  
 MH - moderately high  
 H - higher than average  
 S - suggestive.

The relatively high proportions of fish in the first three length intervals in 1987 suggest that above-average recruitment may occur at some time in the future. This observation is very tenuous however, and if any of the current otolith interpretations are correct it will take at least four years before these small fish recruit to the spawning population. The most optimistic prediction is that all ageing studies to date have over-estimated age and fish in the first three length intervals will recruit to the spawning population in 1989.

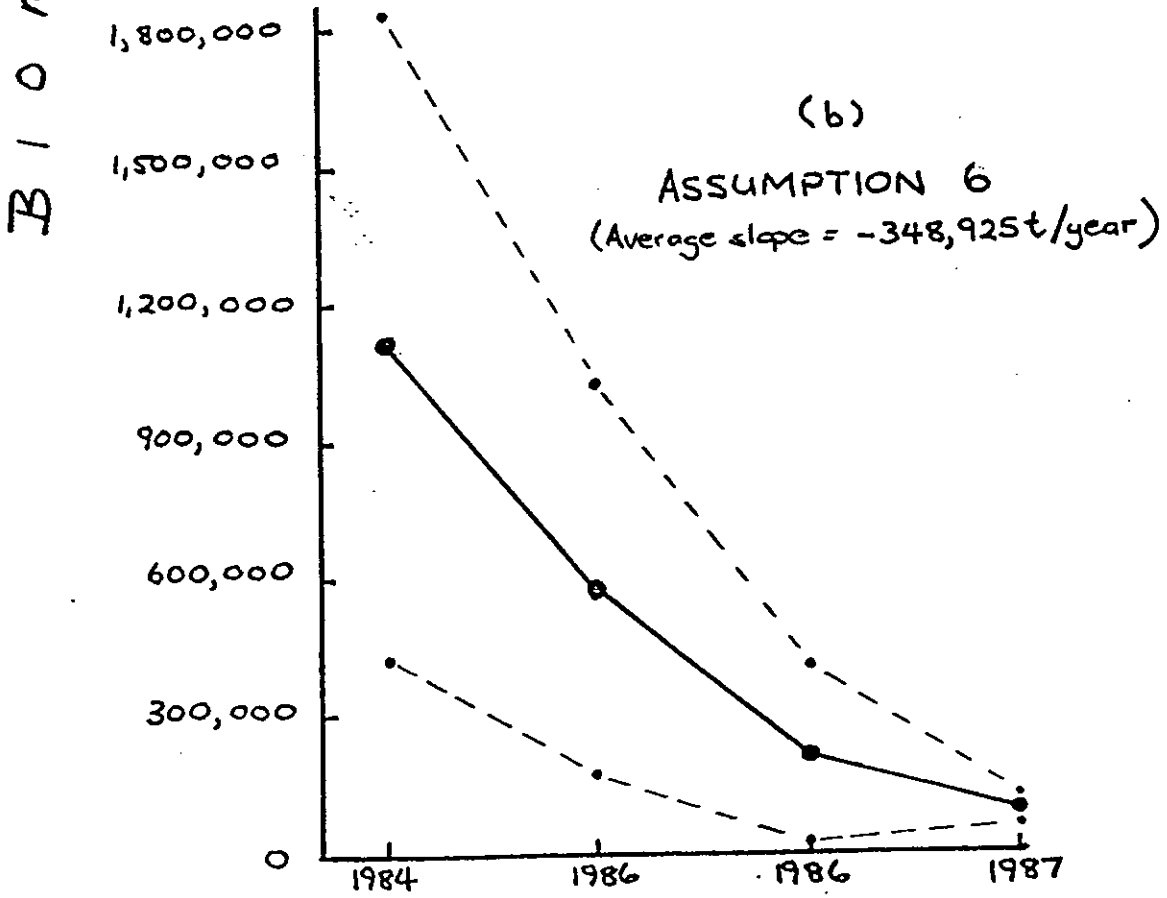
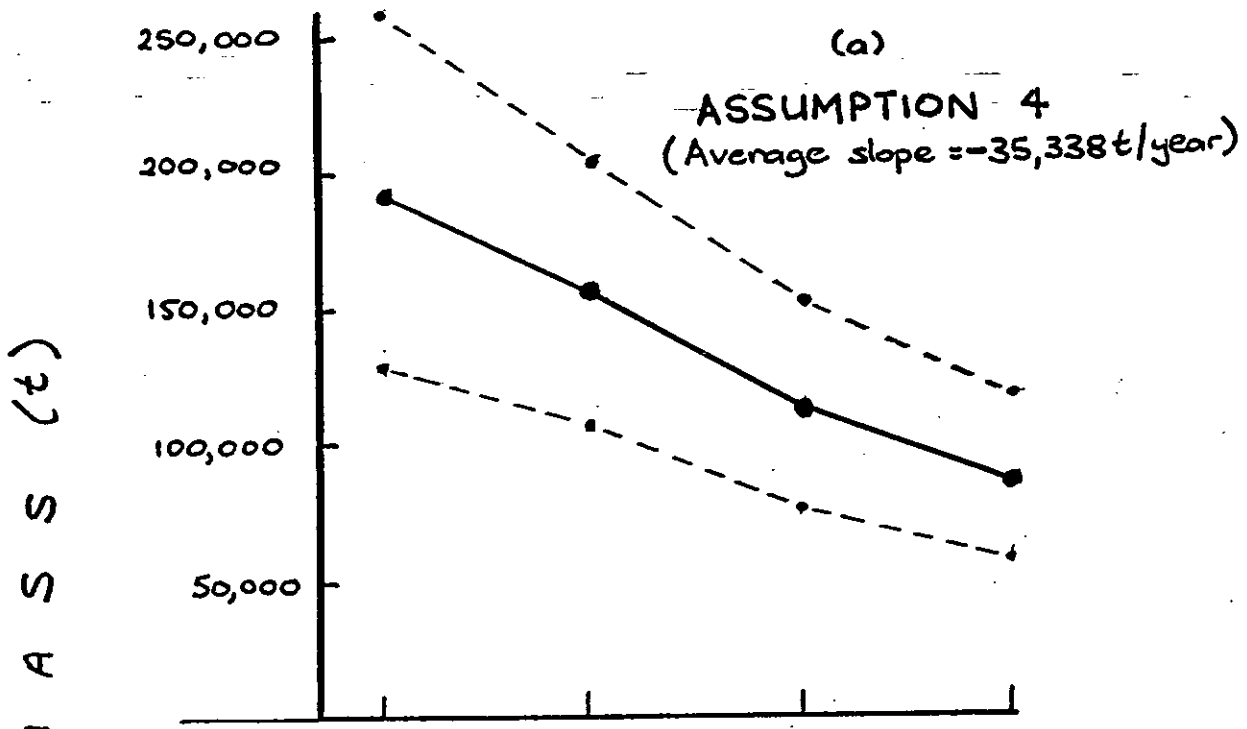


Figure 1: Biomass estimates  $\pm 2$  S.D. based on (a) assumption 4 and (b) assumption 6 for 1984-87.

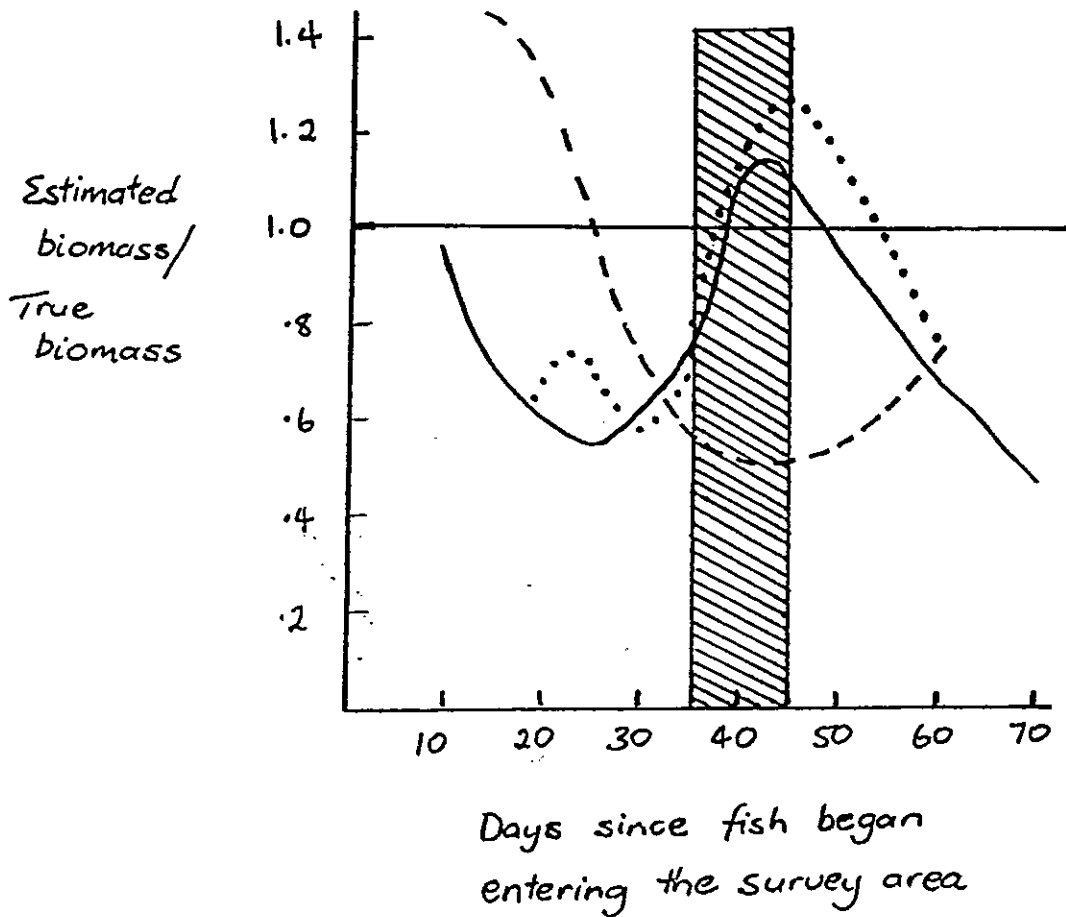


Figure 2: Ratio estimated: true biomass from simulation results for standard survey track (—), tows in reverse column order (east to west, - - - -), tows in column order (west to east, ·····). Hatched area represents the spawning period.