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Assessment of the Chatham Rise (QMA 3B) orange roughy fishery for the 1989/90 and 1990/91 fishing years

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ASSESSMENT OF THE CHATHAM RISE (QMA 3B) ORANGE ROUGHY FISHERY FOR THE 1989/90 AND 1990/91 FISHING YEARS

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1. Introduction

1.1 Overview

This document updates the stock assessment of Chatham Rise orange roughy (Quota Management Area 3B) and provides yield estimations for the next (1990/91) fishing year.

After the status of this stock was reviewed in March 1988 a recommendation was made to reduce the TAC to 17 430 tonnes for the 1987/88 season. In response and after industry consultation, arrangements were made by MAF for fishing companies with quota in area 3B to surrender some of it for one year in exchange for quota over two seasons in area 7A, and the quota for area 3B was reduced to 22 000 tonnes for the 1987/88 fishing year. However the arrangement allowing this reduction was only for the 1987/88 season. Pending the 1989 assessment, and in the absence of any changes to the TAC, the total allocated catch for the Chatham Rise orange roughy fishery for the 1988/89 year reverted to 34 000 tonnes, the original amount allocated prior to the 7A – 3B trade.

Crown holdings (5513t) have now been retired reducing the TAC to 32 787 t. The current (89/90) allocation of 32 787 t, is held by 23 quota holders.

The results of the 1989 assessment (Robertson 1989) are consistent with the previous recommendations for reduction and provided a series of scenarios for stepped reductions of the annual catch. Although agreement has been reached between the Government and the fishing industry that a reduction of 4000 tonnes will be made in the year commencing 1 October 1989, the present TAC is still too high (32 787 t at 27 April 1990) and is therefore a cause for some concern.

In 1989 a further trawl survey was completed in the area, earlier progress made with ageing of orange roughy was confirmed and pre–recruit sampling continued. The results of this recent work are considered here and a new assessment is presented for the 1990/91 season with scenarios for the following seasons.

The most significant new factors to be taken into account in this present assessment are the results of the 1989 *Cordella* survey, the application of a new stock reduction analysis (Francis 1990), and a measure of recruitment variability.

This assessment continues the use of the trawl survey data from the last six years as indices of relative biomass. This assumes that the abundance indices are representative of the population being assessed, i.e. the Chatham Rise fished orange roughy population.

1.2 Description of the fishery

Orange roughy are trawled below about 750m along the northern, eastern and south eastern slopes of the Chatham Rise. Most fish are taken between mid–June and mid–August immediately before, during and after the spawning aggregations appear at depths of 800 – 1000m, in an area about 70 miles north of the Chatham Islands. Since 1983 about 20% of the total catch has been taken, mostly outside the spawning season, in similar depths on or near pinnacles and rough ground on the south Chatham Rise.

Orange roughy are caught below 1200m, the normal depth limit of trawl surveys. Commercial catches and trawl survey data suggest that some orange roughy move up from depths greater than 1200m to spawn between 800 – 1000m, then disperse back to deep water after spawning. Commercial catch–effort data from depths greater than 1200m were analysed for the 1989 assessment to determine whether the fishery below these depths is important during the survey periods. While there are catches reported down to 1400m these are rare except in June and October on the north Chatham Rise. Even during these months, the number of tows in these depths was not very great, about 2.8% of the total number of tows in the area for the period 1979 – 1987. However, in one year, before and after the July survey period in 1987, approximately 16% of the north Chatham Rise catch was taken from depths greater than 1200m.

1.3 Recent Papers

In addition to the published material discussed in previous stock assessment reports (Robertson and Mace 1988, Robertson 1989), a recent paper by Francis (1990) provides a more effective way of treating the trawl survey time series in a stock reduction analysis. Smith et al (in press) showed that between 1982 and 1988 there was a substantial loss of genetic diversity in Chatham rise orange roughy, and that this must be associated with a large decrease in biomass.

2. Review of the Fishery

2.1 Total reported catch

Annual reported catches and TACs for the Chatham Rise orange roughy fishery for 1978/79 to 1988/89 are shown in Table 1.

Table 1. Annual reported catches of orange roughy from QMA 3B. (Catches are from Robertson and Mace (1988) with the figures for the last four years updated from Fisheries Statistics Unit and Quota Monitoring System data).

Fishing year	Reported catch (tonnes)	Gazetted TAC (tonnes)
before 78/79	negligible	
79/80	11 800	
80/81	31 100	
81/82	28 200	23 000
82/83*	32 605	23 000
83/84*	32 535	30 000
84/85	29 340	30 000
85/86	30 075	29 865
86/87	30 689	38 065
87/88	24 214	38 065
88/89	32 785	38 300

(* Catch for 1982/83 and 83/84 are 15 month totals to accommodate the change over from an April – March fishing year to an October – September fishing year. The gazetted TAC for this interim season was 16 125 t)

For this assessment an over–run adjustment of 30% is applied to the above reported catches when used in the analysis. This is because of concern that an incorrect product conversion factor, and other fishing, processing and reporting practices are leading to understatement of the true levels of fishing mortality. Although a slight adjustment was made recently to the orange roughy conversion factor for converting headed & gutted weight to green weight, there is still no basis for adjusting the 30% over–run value since the other problems appear to still exist, e.g. for freezer trawlers, an apparent drip loss during freezing is contributing to the over–run. (A value of 30% over–run was estimated and used in previous assessments, Robertson 1986; Robertson et al. 1988).

2.2 Catch and effort data

Catch–effort data for the main spawning fishery have not so far been of use in biomass estimation or as a measure of stock abundance because the fishery targets on dense aggregations and catch rates can be expected to remain high while stock size decreases. A preliminary (unstandardised) analysis of monthly catch rates for 1979 – 1987 for factory trawlers showed no clear trends. A detailed analysis of CPUE (Doonan, unpubl. data) has since been carried out (see section 3.3.2 below). This study shows a declining trend in standardised catch rate in all the data but much less of a trend when only spawning fish are considered.

2.3 Other Information

No age and very little size information exists from the commercial catches on the Chatham Rise. In 1989 the Stock Monitoring Programme made a number of measurements from the commercial fleet. These have not yet been analysed as no samples of all age classes have been successfully aged. Additional data exist on changes in length frequency of the spawning population over the period 1982 – 1989. Preliminary analysis shows a small increase in mean length between 1984 – 1987, and a levelling off in 1988–89. Further data exist on the winter biomass outside the main spawning area but these are not yet ready for inclusion here.

2.4 Maori and Recreational Fishing

There is no known Maori or recreational catch of orange roughy.

3. Research

3.1 Stock Structure

The orange roughy found on the Chatham Rise have been considered as a single separate stock since 1983. However, some data (Fenaughty 1987) suggest that orange roughy on the south Chatham Rise may be spawning at the same time as those on the north Rise and may therefore be a separate spawning stock. This question will be addressed at Fisheries Research Centre by P. Smith in a mitochondrial DNA project currently underway.

No information exists on the relationship between the Chatham Rise populations and those treated as separate fisheries on the Ritchie Bank, Wairarapa and Kaikoura fishery management areas. Spawning occurs concurrently on both Ritchie Bank and Chatham Rise, but no spawning is known in the Wairarapa or Kaikoura areas. It is assumed that Wairarapa and Kaikoura fish do not spawn on the Chatham Rise. These stock relationship issues are also being addressed by P. Smith with mDNA work and by B. Jones in a study of parasite infestation rates designed to test for differences between orange roughy populations. For the reasons outlined in previous assessments, the Chatham Rise is considered discrete from the other three management areas.

For the purpose of biomass estimation in the application of the stock reduction analysis, the north and south Chatham Rise populations are here treated as one stock.

3.2 Resource surveys

A number of surveys have been conducted on the Chatham Rise orange roughy fishery (Table 2).

Table 2: Major research cruises which have provided data on Chatham Rise orange roughy since 1982.

Date month/year	Area km^2	Survey Type	Vessel	North or South Rise	Species
8–9/1982	25,000	biomass	Kaltan	N	ORH
7/1984	5,000	biomass	Otago Buccaneer	N	ORH
7/1985	5,000	biomass	Otago Buccaneer	N	ORH
7/1986	5,000	biomass	Otago Buccaneer	N	ORH
11/1986	47,100	biomass	Arrow	S	Oreos/ORH
7/1987	5,000	biomass	Otago Buccaneer	N	ORH
11/1987	47,500	biomass	Amaltal Explorer	S	Oreos/ORH
2/1988	na	juvenile	James Cook	N	ORH
5–6/1988	na	juvenile	James Cook	N	ORH
7/1988	5,000	biomass	Cordella	N	ORH
9/1988	na	juvenile	James Cook	N	ORH
9/1988	72,000	biomass	Cordella	N & S	ORH/Oreos
1/1989	na	juvenile	James Cook	N	ORH
4/1989	na	juvenile	James Cook	N	ORH
7/1989	25,532	biomass	Cordella	N & S	ORH
8/1989	na	juvenile	James Cook	N	ORH
10/1989	na	juvenile	James Cook	N	ORH
12/1989	na	juvenile	James Cook	N	ORH

The *James Cook* surveys are part of a continuing series designed to locate and sample small juveniles (pre–recruits) to estimate growth rates of orange roughy, age structure and recruitment variability. Recent results from these surveys (Mace et al. 1990) indicate that orange roughy grow more slowly than was previously assumed (Robertson et al. 1988).

3.3 Other Studies

3.3.1 Recruitment Variability

Preliminary age frequency data from the Chatham Rise pre–recruit surveys were used to estimate σ_R, a parameter that represents the degree of recruitment variability and is used in the risk analysis simulations below.

The age frequencies and mean lengths of fish of length less than or equal to 10 cm are shown in Table 3. Assuming negligible mortality over this size range, it is possible to obtain an estimate of the relative cohort strength for the 1985–1988 cohorts. The log–likelihood for these observations is (ignoring constant terms)

$$\lambda \quad = \Sigma_{ij} N_{ij} \log(C_{ij} S_i / K_j)$$

where N_{ij} = the number of fish of cohort i in sample j (for j = 1,...,7, and i = 1985,...,1988),

C_{ij} = the relative catchability of cohort i in year j,
S_i = the size of of cohort i relative to the 1988 cohort (so S_{1988} = 1.0), and
K_j = $\Sigma(C_{ij}S_i)$.

Table 3. Numbers of fish and mean lengths, by cohort, for samples from 8 Chatham Rise pre–recruit surveys. (The year given for each cohort is the year of birth, assuming birth in July; new hyaline rings first counted between October & December; first ring counted during second year of life). * = not present in sample; – = not fully represented in sample. (A study of length at age indicated that a cohort was not fully represented in the sample when its mean length exceeded 8 cm).

Sample	Date	Number of fish				Mean length (cm)			
	Cohort:	1988	1987	1986	1985	1988	1987	1986	1985
1	2/88	*	2	38	5	*	2.1	4.5	6.8
2	5/88	*	68	41	6	*	3.1	5.1	7.8
3	9/88	*	70	33	8	*	3.4	5.6	7.6
4	1/89	14	539	161	–	2.7	4.2	6.4	8.5
5	5/89	15	154	88	–	3.2	5.1	7.6	9.1
6	8/89	17	146	–	–	3.5	5.7	8.0	9.4
7	10/89	8	98	–	–	3.5	5.7	7.6	9.0
8	12/89	27	128	–	–	4.0	6.3	7.5	8.7

Parameter estimation was by maximum likelihood (i.e. by searching for parameter values that maximised λ).

Initially, the C_i were estimated using the simplest assumption about the catchabilities, i.e. that they were the same for all cohorts in all samples. Then, to allow for the possibility that the smallest fish may have been less catchable, catchability was assumed to be an increasing function of the mean length of the cohort, i.e.,

$$C_{ij} = 1 - \exp(-(L_{ij} - A)/B)$$

where, L_{ij} = the mean length of cohort i in sample j, and A and B are parameters to be estimated (A must be <= all the L_{ij}, and B >=0; catchability is zero at L_{ij} = A, and increases towards 1 for larger L_{ij}).

This more complex model was assumed only when it gave a significantly better fit to the data than the assumption of constant catchability (which is equivalent to setting B = 0).

σ_R was calculated from the C_i – it is simply the standard deviation of the natural log of the C_i.

The analysis was carried out using three data sets as follows:

a) The whole data set.

b) Without the first sample.

c) Without the first and fourth samples.

(The first and fourth samples gave the worst fit to the model).

The results are presented in Table 4. Though the estimated relative cohort sizes changed somewhat for the three data sets, the estimates of σ_R were very similar.

Table 4. Estimates of relative cohort size, catchability parameters, and recruitment variability derived from the pre–recruit data in Table 3. B = 0 means that catchability was the same for fish of all sizes.

Data subset	Relative cohort size, C_i 1985	1986	1987	1988	Catchability parameters A	B	Recruitment variability σ_R
a	0.7	3.6	10.0	1.0	0.042	6.59	1.22
b	1.2	5.2	13.0	1.0	–	0	1.22
c	0.8	4.4	7.9	1.0	–	0	1.12

In the risk analysis simulations below σ_R = 1.2 was used to describe variability in recruitment to the fishery (at age about 23 years).There are two reasons why this may be an overestimate. First, density–dependent mechanisms can be expected to increase (or decrease) mortalities between ages 1 and 23 years for exceptionally large (or small) cohorts. Second, individual variability in development rates will cause the recruitment from any one year class to be spread over several years. However, the simulation model makes no allowance for auto–correlation in recruitment. (There is auto–correlation when recruitment in the year following a year of poor (or good) recruitment is likely to be below (or above) average. Several consecutive years of poor recruitment are the most likely cause of the increase in mean length of Chatham Rise orange roughy observed by Mace et al (1990)). Such auto–correlation tends to magnify the effects of recruitment variability. It was thought that an overestimate in σ_R may compensate for the lack of an auto–correlation term in the model.

3.3.2 Catch per unit effort

In a preliminary analysis of CPUE data from 1978 – 1988 for the NE Chatham Rise, Doonan (unpubl. data) followed a method similar to that of Allen and Punsley (1984). Three variables were found to be significant in explaining variation in CPUE: time within a year, year, and the nationality of the fishing vessel. A nation–time interaction term was also found to be significant.

3.4 Estimation of Biomass

Virgin biomass, B_0, was estimated using the stock reduction method of Francis (1990).
The set of biomass indices from the biomass surveys was used. (Table 5). For this analysis the catch data in Table 1 was rearranged into October–September years (Table 5).

Growth, mortality and recruitment parameters used here are the same as those used in 1989 assessment, (except that length and age at maturity were redefined as described in Clark & Francis (1990)):

natural mortality (M) = 0.05 $year^{-1}$,
age of recruitment (A_r) = 23 years,
age at maturity (A_m) = 23 years
L_{inf} = 42.50 cm.
k = 0.059 $year^{-1}$,
t_0 = –0.346 year,
a = 0.0963
b = 2.68
Recruitment "steepness" = 0.95

(A recruitment "steepness" of 0.95 means that when the biomass is reduced to 20% of its virgin size the mean recruitment is 95% of its virgin level. The value of this parameter affects the estimate of MCY, but not of virgin biomass.)

In calculating the trawl survey indices, vertical and areal availabilities were set to 1. (Since the biomass estimates are used in a relative way the figure used is immaterial; the important assumption is that there has been no trend in either of the availabilities over the period of the surveys). Vulnerabilities were taken as (wingtip spread)/(door spread): 0.19 for the *Otago Buccaneer* surveys and 0.25 for the *Cordella* surveys (for definitions of vulnerability and availability see Francis (1989)). For the 1989 survey, a net mouth correction, similar to that used for the 1988 survey in the previous assessment (Robertson 1989), was applied to catches from stations 26, 40, 56, & 78. These were the tows for which the net monitor indicated that the fish schools were higher than the headline of the net. Catches for these tows were multiplied by 0.67, the ratio between the net mouth areas of the *Otago Buccaneer* and the *Cordella.*

Table 5. Total catches and biomass indices used in the stock reduction analysis (coefficients of variation shown in parentheses). Catches are for October–September years (1980 means October 1979 – September 1980) and do not include the 30% catch overrun. The index for each year is assumed proportional to the mid-season biomass for that year's spawning season.

Year	Catch (tonnes)	Trawl survey index	Survey vessel
1979	11 800		
1980	31 100		
1981	28 200		
1982	24 888		
1983	15 434		
1984	24 818	164 835 (16)	Otago Buccaneer
1985	29 340	149 425 (15)	Otago Buccaneer
1986	30 075	102 975 (16)	Otago Buccaneer
1987	30 689	80 397 (15)	Otago Buccaneer
1988	24 214	97 108 (25)	Cordella
1989	32 785	66 291 (18)	Cordella
1990	28 637 –(assumed)		

Parameter estimates from the stock reduction analysis are given in Table 6 and estimated biomass in Fig. 1.

The decline in biomass estimated using the trawl survey indices (Fig. 1) is similar to the minimum mortality inferred by Smith et al (in press): 54% (95% confidence interval 38–64%) between 1982 and 1988, compared to 63% (36–88%).

With the trawl survey data the new stock reduction method gives estimates slightly different from those of the previous method. If the new method had been used at the time of the last assessment it would have given an estimate of B_0 of 419 000 t (with catchability, q = 0.57, and estimated coefficient of variation for the trawl surveys, c = 17%) compared to the estimate of 389 000 t in Robertson (1989).

The 1989 survey result is very close to what would have been predicted by projecting forward from 1987/88 assuming B_0 = 419 000 t. The projected mid-season biomass for 1988/89 (based on the official 1988/89 catch of 32 785 t, plus 30% overrun) is 121 113 t which, when multiplied by the estimated catchability of 0.57 gives a predicted trawl survey estimate of 69 034 t, just 4% higher than was observed, 66 291 t (Table 5).

Table 6. Results of stock reduction analysis using trawl survey indices from Table 5.

Parameter	Trawl survey
Catchability (q)	0.59
Coefficient of variation of biomass index (c)	15%
Virgin biomass (B_0)	411 000 t
95% confidence interval for B_0 with: c = 15%	362 000 – 543 000 t
c = 19%	360 000 – 680 000 t

The coefficient of variation, c, estimated for the trawl surveys indices as 15% (Table 6), is probably an underestimate. It is lower than all but one of the estimates derived from the trawl survey data (Table 5) and these, because of the two–phase methodology, tend to be underestimates themselves. However, an upper bound for c may be calculated using the fact that the coefficient of variation of a two–phase survey is known to be lower than that of a conventional survey with the same number of stations (Francis 1984). For each of the surveys in Table 5 the quantity $c_1(N_1/N)^{0.5}$ was calculated as an estimate of the coefficient of variation that would have been obtained had conventional surveys been used (where c_1 is the coefficient of variation, and N_1 is the number of stations, for phase 1 of the survey; and N is the total number of stations in the survey). The median of these estimates, 19%, was taken as an upper bound for c and 95% confidence intervals for B_0 were calculated (following Francis 1990) using both this value and the estimated 15% (Table 6). The interval based on c = 15% is used below in calculating confidence intervals for yields. Probability distributions for B_0 are given in Fig. 2.

Because there is considerable uncertainty about the true value of M (natural mortality) for orange roughy, the stock reduction analysis was repeated with M = 0.025, 0.075, and 0.1 (and using the trawl survey indices). The resulting estimates of B_0 were 452 000 t, 372 000 t, and 336 000 t and the probability distributions for these estimates are shown, in comparison with that for the original estimate (with M = 0.05), in Fig. 3. These results are used in the risk analyses below.

3.5 Yield Estimates

3.5.1 Yield per recruit analysis

A yield per recruit analysis was carried out using the model of Mace et al (1990) with a 'plus' group to include all age classes with age over 70 years. The resulting estimate of $F_{0.1}$ was 0.073. (This is slightly different from the estimate in Robertson (1989) because of the change in the assumed age at recruitment).

The results from the yield per recruit analysis, together with the assumed Beverton and Holt stock-recruitment relationship were used to calculate the long term stable yield (i.e. assuming no recruitment variation) under an $F_{0.1}$ fishing policy. This is 2.4% of B_0 and occurs at a mid-season biomass of 33.1% of B_0.

This analysis also provides an estimate of the fishing mortality, F_{msy}, required to achieve the deterministic maximum sustainable yield (MSY). This gives F_{msy} = 0.197, which achieves a long term stable yield of 2.7% of B_0 at a mid-season biomass of 13.9% of B_0.

3.5.2 Estimation of MCY

MCY was calculated using method 3 of the "Guide to biological reference points for the 1990 Fisheries Assessment Meetings".

Thus MCY = 2/3 MSY
= 0.67 * 0.027 * 411 000
= 7 500 t

with 95% confidence interval 6 600 – 9 900 t. (Note that this estimate of MCY is the same as that obtained from method 1, MCY = 0.25 $F_{0.1}B_0$)

3.5.3 Estimation of CAY

The estimated beginning of season biomass for 1990/91 was calculated by projecting forward assuming a 1989/90 catch of 32 785 t (the TAC), plus 30% overrun. The CAY for 1990/91 was then calculated using the Baranov catch equation (method 1 of the "Guide to biological reference points for the 1990 Fisheries Assessment Meetings") with this biomass and $F_{0.1}$ = 0.073:

1990/91 beginning of season biomass = 80 000 t

$$CAY_{90/91} = 5\ 500 \text{ t}$$

with a 95% confidence interval 2 000 – 14 900 t.

3.5.4 Sensitivity Analysis

The above confidence intervals (for B_0, MCY, and CAY) derive from the errors associated with the trawl survey results as relative estimates of biomass. They do not include any uncertainty in the growth, mortality, or recruitment parameters. The effect of these uncertainties was investigated with a sensitivity analysis (Table 7).

Table 7: Percentage changes in estimated yields and biomass for given changes in growth, mortality and recruitment.

Change in Parameters	Change in yields (%) Current Annual Yield (CAY)	Maximum Constant Yield (MCY)	Change in biomass (%) Virgin Biomass (B_0)	Current[$] Biomass ($B_{curr}$)
L_{inf} (+ 2.11); @ k (– 0.006)	–5	–4	+1	+0
L_{inf} (– 2.11); @ k (+ 0.006)	+4	+4	–1	–0
A_r (+1); A_m (+1)	+2	+2	–0	–0
A_r (–1); A_m (–1)	–2	–2	+1	+0
M (+ 0.01)	+18	+17	–4	–2
M (– 0.01)	–18	–17	+4	+1
steepness = 0.99	*	+9	*	*
steepness = 0.75	*	–25	*	*

$ at the end of the 1989/90 season.
@ these changes in L_{inf} and k represent ± 1 standard error.
* unchanged by changes in this parameter.

Since estimates of the growth parameters L_{inf} and k are always highly negatively correlated, changes in these parameters (which were ± 1 standard deviation (Mace et al, 1990)) were combined and set in opposite directions.

Two conclusions may be drawn from the sensitivity analysis. First, there is greater certainty about biomass estimates than about yields, since changes in model parameters affect the latter much more than the former. Second, the greatest uncertainty derives from the natural mortality, M. Uncertainty in the growth and recruitment parameters is unlikely to change the yields by much more than 10%, and so will have little effect on the above confidence intervals. However, the range of possible values of M is probably wider than that used in the sensitivity analysis and so the true confidence intervals will be wider than given.

3.6 Risk analyses

The current policy for this stock is to reduce the TAC during the 1989/90 fishing year by 4000 t then by 5000 t per year (starting in 1990/91) unless new data make a different rate of reduction advisable. The following risk analyses are designed to evaluate the risks associated with a range of rates of TAC reduction. In these analyses the target level to which the TAC is to be reduced is 7500 t, the current estimate of MCY.

'Risk' will be expressed here as the probability that the fishery will 'collapse' within five years, i.e. in 1994/95 or before. 'Collapse' is taken to mean that the TAC is not catchable. For the purpose of these analyses the TAC is deemed not catchable if it would require an instantaneous fishing mortality, $F > 1$ (this is equivalent to saying that the TAC is not catchable if it is greater than about 2/3 of the recruited biomass at the beginning of the season).

Two sources of uncertainty were included in the simulations used to estimate risk: uncertainty in B_0, and uncertainty in future recruitment.

The procedure for the simulation was as follows:

1. A value of the virgin biomass, B_0, was chosen at random from the distribution described by a solid line in Fig. 3:

2. The fishery was simulated from this value of B_0 up to the present (i.e. up to and including the 1988/89 season) using the catches in Table 5 (plus 30% overrun) and deterministic recruitment.

3. Simulations then continued, with random recruitment, up to and including the 1994/95 season. (Recruitment was assumed to be log–normally distributed with the mean given by the Beverton–Holt relationship and the standard deviation of the logarithm of recruitment, $\sigma_R = 1.2$ – see section 3.3.1 above). The catch was set equal to the TAC (28 637 t) for 1989/90 and was then reduced in steps of 5000 t each year until it reached 7500 t, the target level. These simulations were carried out with overruns of 0%, 15% and 30%.

4. Steps 1–3 were repeated 200 times. The probability of collapse was calculated as the proportion of these 200 runs in which the fishery collapsed.

5. Steps 1–4 were repeated for a range of rates of TAC reduction.

As might be expected, the risk of collapse is strongly dependent on both the rate of TAC reduction and the assumed catch overrun in future seasons (Fig. 4 and Table 8). If the TAC is reduced at 5000 t/yr (as currently proposed) the risk of collapse is 0.24 with zero overrun in the future, 0.36 with 15% overrun, and 0.45 with 30% overrun.

Table 8. Results of risk analysis. Probability of fishery collapse within 5 years (before the 1995/96 season) if the TAC is stepped down to 7500 t (current estimate of MCY) at various rates: with either 0%, 15%, or 30% catch overrun in the future.

Rate of TAC reduction (t/yr)	TAC					Probability of collapse		
	year					overrun		
	90/91	91/92	92/93	93/94	94/95	0%	15%	30%
3000	25 637	22 637	19 637	16 637	13 637	0.44	0.58	0.67
5000	23 637	18 637	13 637	8 637	7 500	0.24	0.36	0.45
7000	21 637	14 637	7 637	7 500	7 500	0.11	0.20	0.29
9000	19 637	10 637	7 500	7 500	7 500	0.06	0.15	0.19
12000	16 637	7 500	7 500	7 500	7 500	0.06	0.09	0.13

The risk of collapse was, however, relatively insensitive to variation in the assumed value of c (the coefficient of variation of the trawl surveys). The analysis was repeated with c = 19% (i.e. using the dotted line, rather than the solid line, in Fig. 2 to derive random values of B_0) . This had little effect on the estimated risk (Fig.5).

The effect on the estimated risk of changing the assumed value of M (natural mortality) is more complex. The analysis was repeated using M = 0.025, 0.075, and 0.1 (the corresponding curves in Fig. 3 were used to generate random values of B_0). For the slower rates of TAC reduction (3000 or 5000 t/yr) changes in M had little effect on the risk of fishery collapse; for the higher rates of reduction (7000 to 12000 t/yr) the risk is higher for higher values of M (Fig. 6). Thus, although varying M has a large effect on estimates of yield and biomass (Table 7), it has much less effect on the estimated risk to the fishery. Where it does have a significant effect, this is to increase the estimated risk.

It is of interest to ask how much of the estimated risk is associated with our uncertainty about B_0, and how much derives from random recruitment. To evaluate this, the analysis was repeated with random B_0 but no recruitment variability. It was found that, for the case where future catch overrun is 30%, the contribution of uncertainty in B_0 to the estimated risk decreases with increasing rate of TAC reduction: from about 88% (0.59/0.67) at 3000 t/yr to only 31% (0.04/0.13) at 12000 t/yr (Fig. 7).

The risks shown in Table 8 and Fig. 4 only cover the period up to October 1995. An examination of the biomass at the end of those simulation runs where the fishery survived shows that there is a substantial probability that this biomass is still dangerously low.

For example, with TAC reduced at 5000 t/year and no future TAC overrun, the probability that the October 1995 biomass is less than 20% of virgin biomass is 0.71 (Fig. 8). Thus the medium term risks to the fishery are higher than the short term (five year) risks shown in Table 8 and Fig. 4.

It is of interest to ask 'If the fishery is going to collapse within the next five years what is the most likely year of collapse?'. The answer to this question, for a TAC reduction of 5000 t/year, is shown in Fig. 9: the most likely years of collapse are 1991 and 1992. For all the rates of TAC reduction considered, collapse is more likely before October 1992 than after.

4. Management Implications

The 1989 trawl survey confirms the conclusion of last year's assessment (Robertson 1989) that a substantial reduction in catch is needed to protect this stock. The 1989/90 mid-season biomass is expected to be only 20% of the virgin level. If the stock is allowed to recover to about 33% of its virgin size then it could sustain an average yield of about 9900 t under an $F_{0.1}$ fishing policy. However, the immediate need is for a reduction in catches.

4.1 Risks in Stepping Down the TAC

The above analyses indicate that there is likely to be a considerable risk to the fishery if the TAC is reduced no faster than the currently proposed rate of 5000 t/yr (Table 8).

The analyses shows that, if it collapses within the next five years, the fishery is more likely to do so before, than after, October 1992. The likelihood of collapse decreases with increasing rate of TAC reduction. Thus it would be unwise to delay an increase in this rate.

The analyses have been done assuming either 30% overrun in future catches (the figure used for historical catches), 15% or zero overrun. The actual overrun is likely to lie between 30% and 15% but closer to the former. Though one of the factors leading to historical overruns, the conversion factor, has been adjusted in the correct direction, other factors have not.

Though these are the best available estimates of risk, they should not be taken literally. They indicate, given the assumed life history parameters and the catch history, the probability that a simple age–structured model of the fishery (not the fishery itself) will collapse under different rates of TAC reduction. Fortunately, these results do not seem to be very sensitive to changes in the parameters for which there is most uncertainty. What is not known is how well such a simple model is able to predict the behaviour of a real fish population. It may be that the true risks are substantially different from those given above. It is also possible that another year's data will change our view of the state of the stock.

However, the true risk of fishery collapse is just as likely to be greater than the risks estimated here, as it is to be less than them. Thus it would seem prudent to move to a faster rate of TAC reduction than 5 000 t/yr.

4.2 Recruitment Assumptions

A weakness of the above analyses is the way in which they treat recruitment. In the stock reduction analyses, and in simulating up to the present for the risk analyses, recruitment was assumed to be deterministic. Further, recruitment to the population (at age 1) was assumed to depend on the size of the spawning (= recruited) biomass according to a Beverton–Holt stock–recruitment relationship. This means that, over the years that the fishery has been operating (1979-1989), recruitment to the fishery (at age 23) has been assumed to be constant (since it depended on stock sizes 22 years earlier – between 1956 and 1967). This is inconsistent with observed trends in the mean length of the recruited population.

If recruitment was constant while biomass declined at the rate indicated by the surveys, mean length of the recruited population should have exhibited a decrease. In fact, mean length increased by about 1 cm over the years 1982–87 (Mace et al. 1990).

As stated in the 1989 FARD, if the present analyses were re–run using less optimistic assumptions about recruitment, the estimates of B_0, $B_{90/91}$, $CAY_{90/91}$ and MCY would all be higher. The critical issue is whether the estimated virgin biomass was the norm and recruitment has been abnormally low since then, or virgin biomass was unusually high and subsequent recruitment has been normal. If the former applies then steps should be taken to conserve the stock until recruitment improves to normal levels. If the latter applies then the long–term outlook for the fishery is even worse than indicated by the analyses in this document.

Working Group Assessment Data : Data, models and simulation parameters are filed in the FRC computer in: /grp3/orh/workingGroup/Chat8990. For access contact D.A. Robertson, Convenor, Orange Roughy Working Group.

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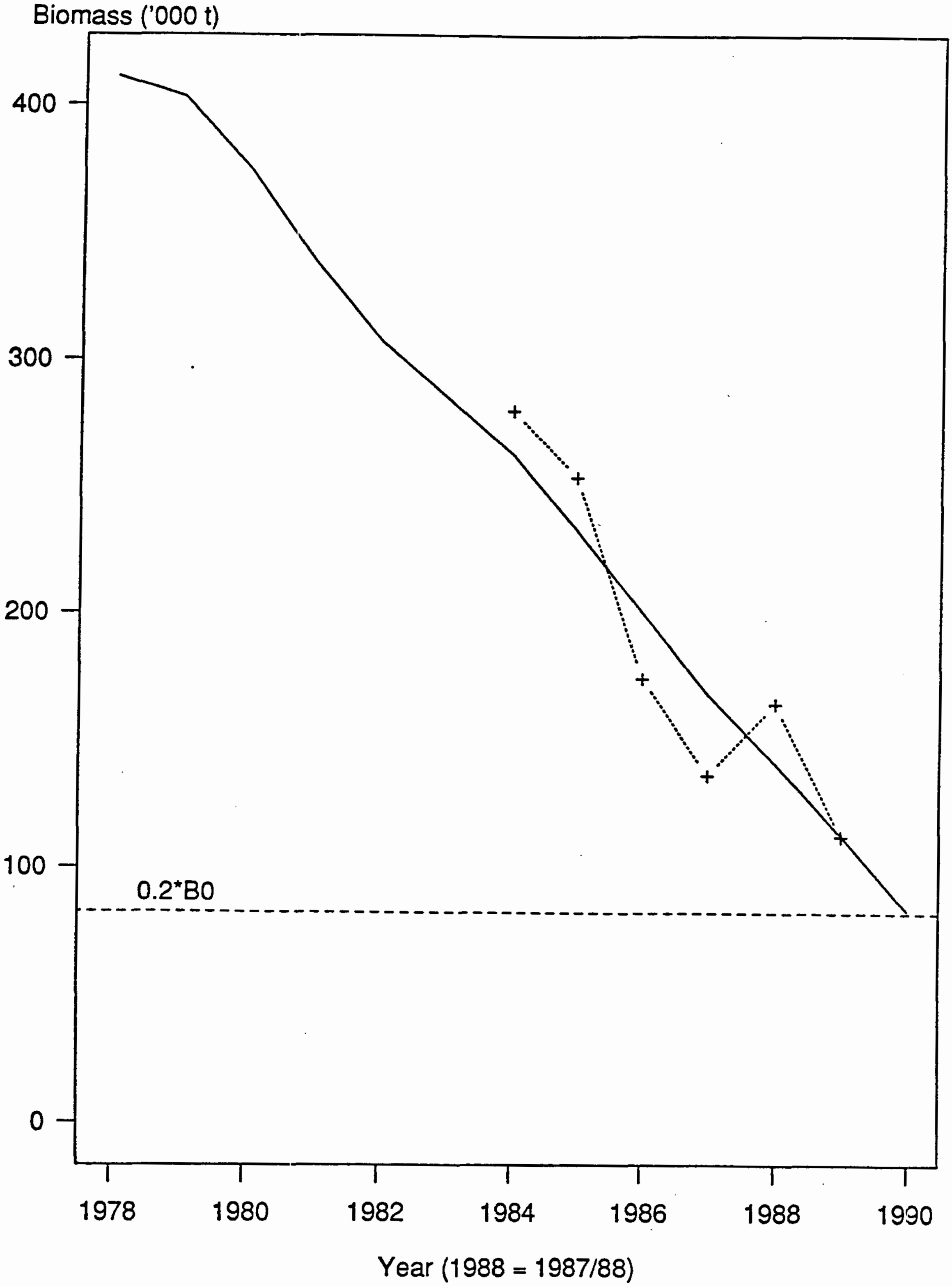

Figure 1. Estimated biomass (solid line) and biomass indices converted to absolute estimates (dotted lines) from stock reduction analysis. ('+', from trawl survey indices.)

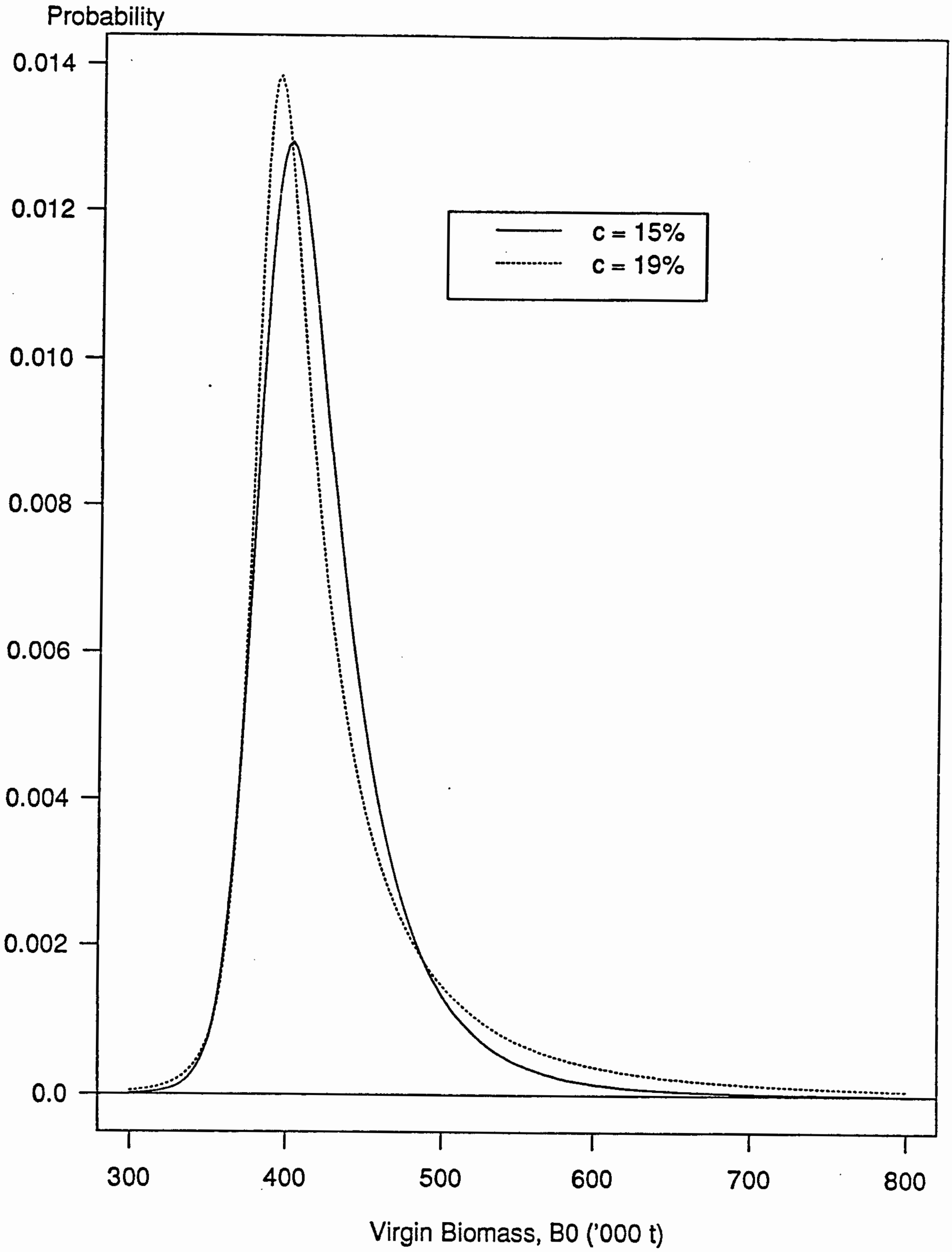

Figure 2. Distribution of probable values for the virgin biomass, B_0, according to the stock reduction analysis results in Table 6. The estimated probability that B_0 lies between any two values is equal to the area between these values and underneath the appropriate curve. (The total area under each curve is 1.)

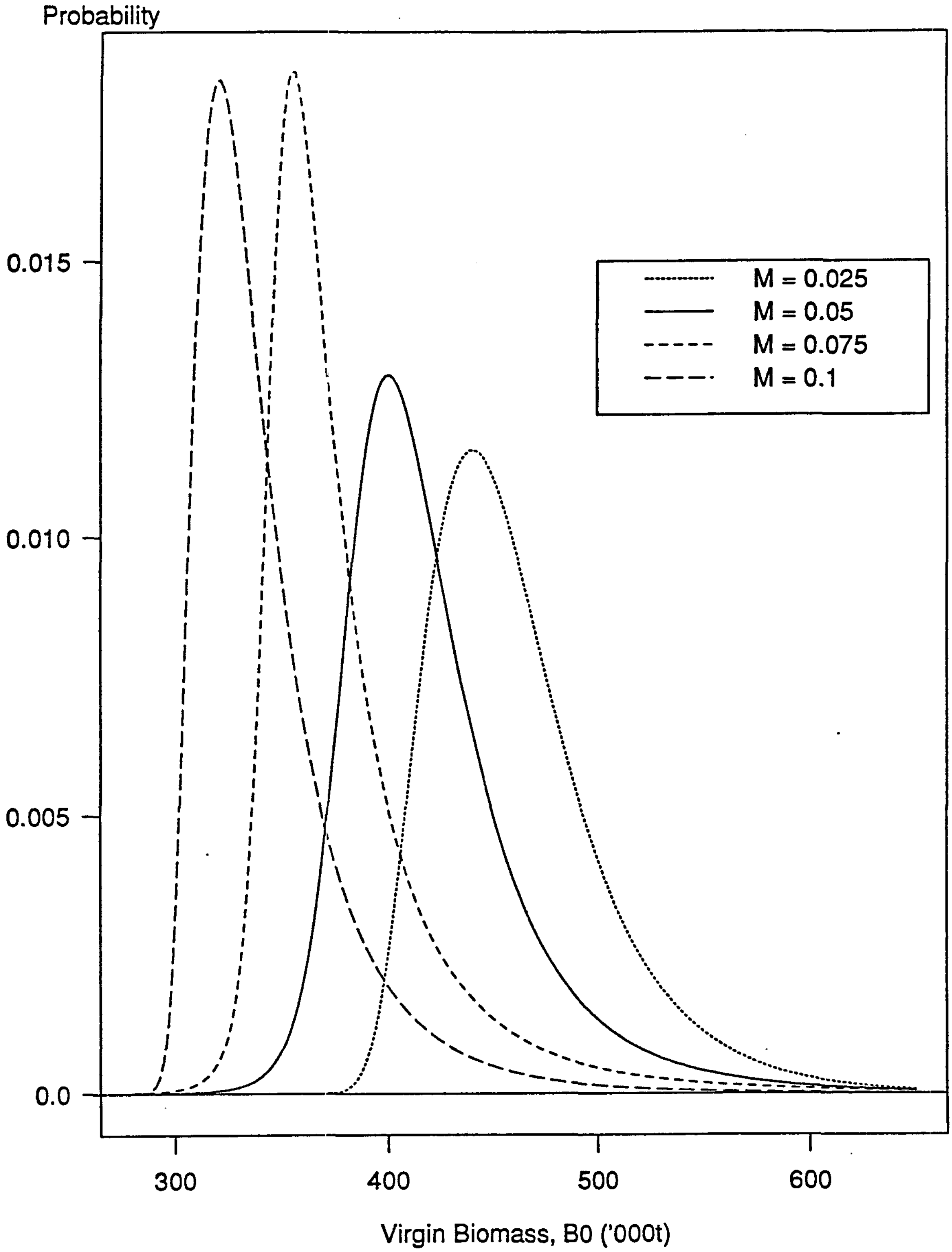

Figure 3. Distribution of probable values for the virgin biomass, B_0, according to stock reduction analyses based on various values of natural mortality, M. The solid curve (M = 0.05) is the same as that in Fig. 2.

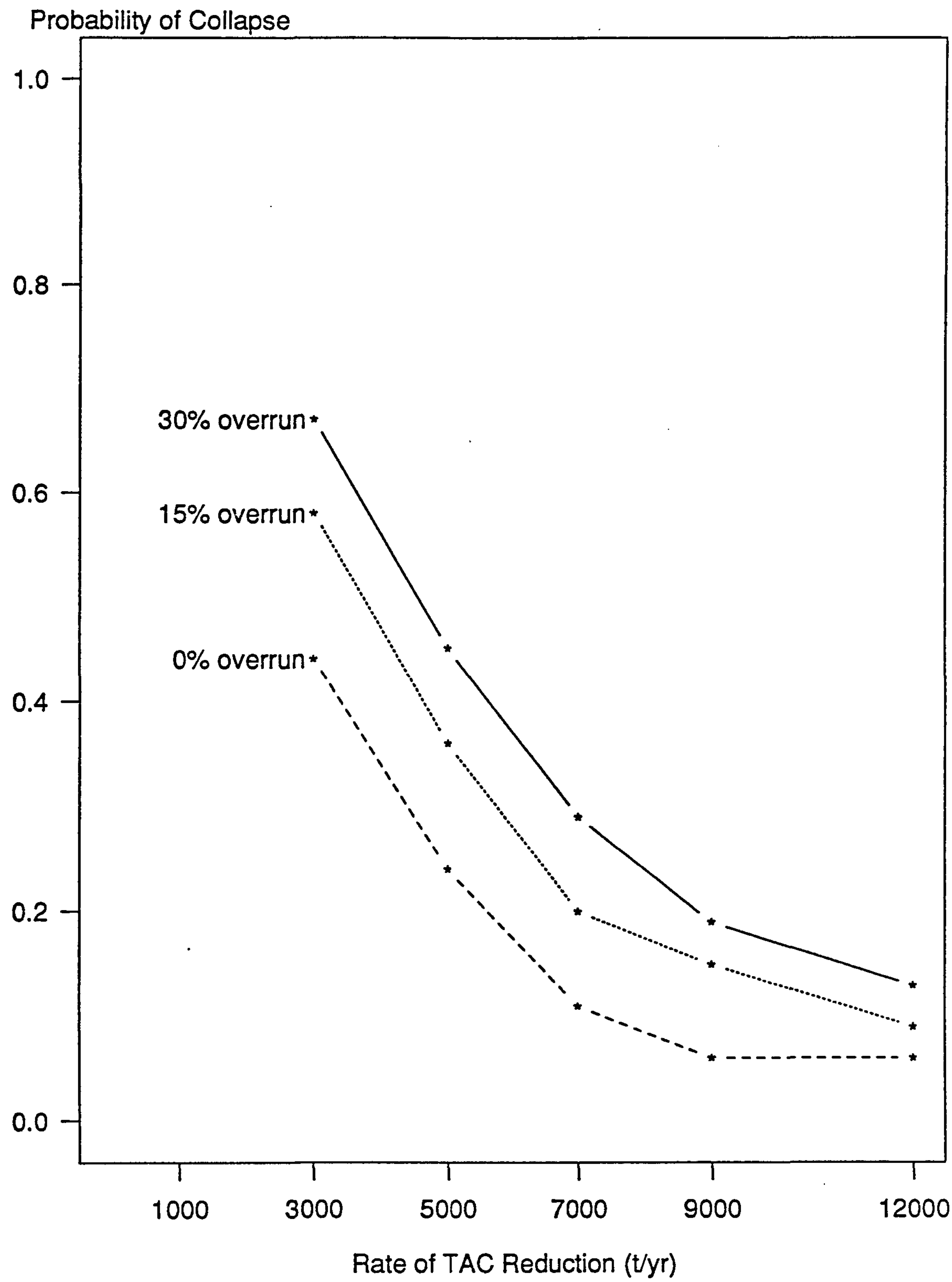

Figure 4. Results of risk analysis. Probability of fishery collapse within 5 years (before the 1995/96 season) if the TAC is stepped down to 7500 t (current estimate of MCY) at various rates: with either 0% (broken line), 15% (dotted line), or 30% (solid line) catch overrun in the future.

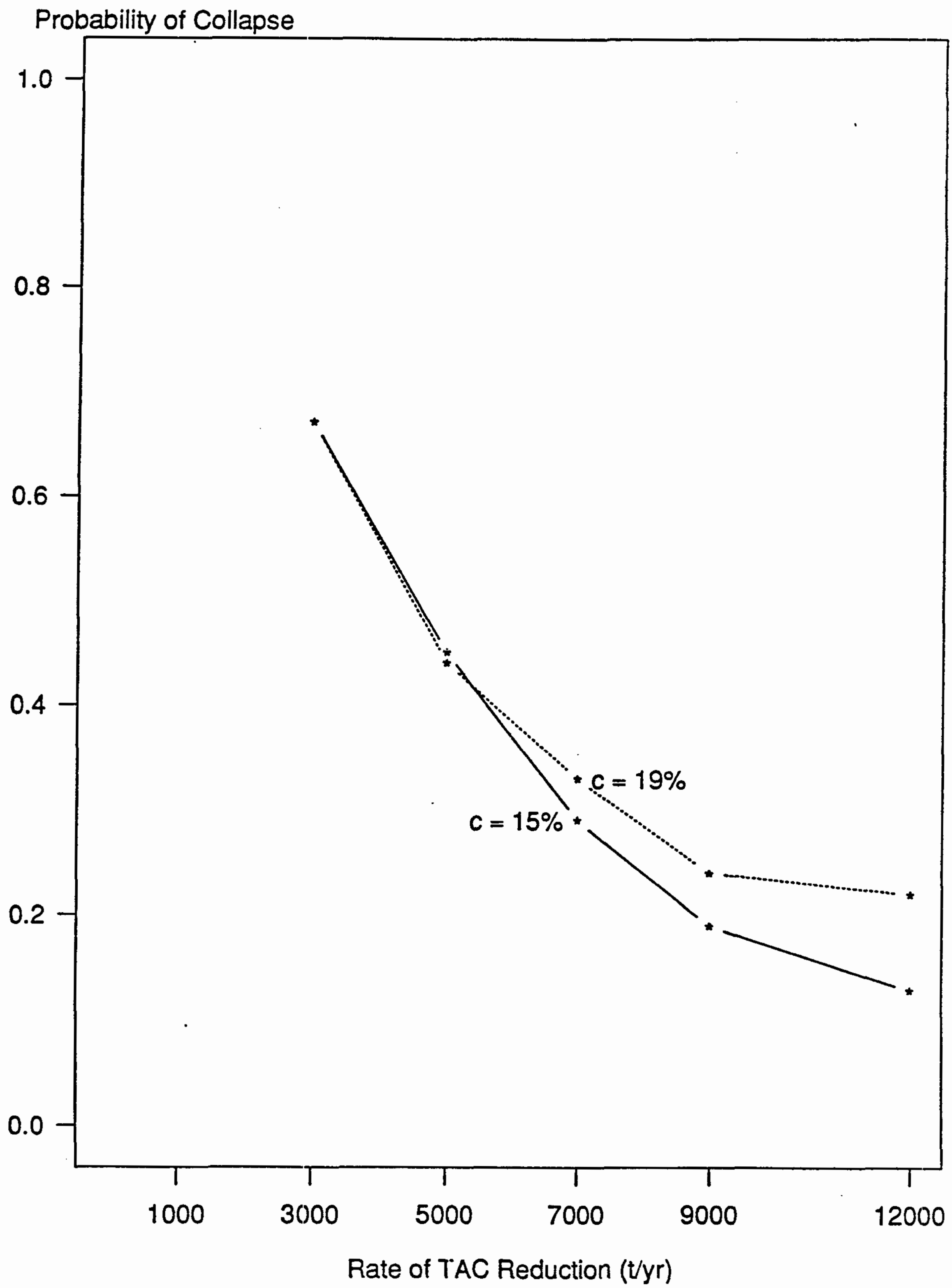

Figure 5. Effect on risk analysis of varying c, the coefficient of variation of the trawl survey indices. The solid line (c = 15%) is the same as the solid line in Fig. 4.

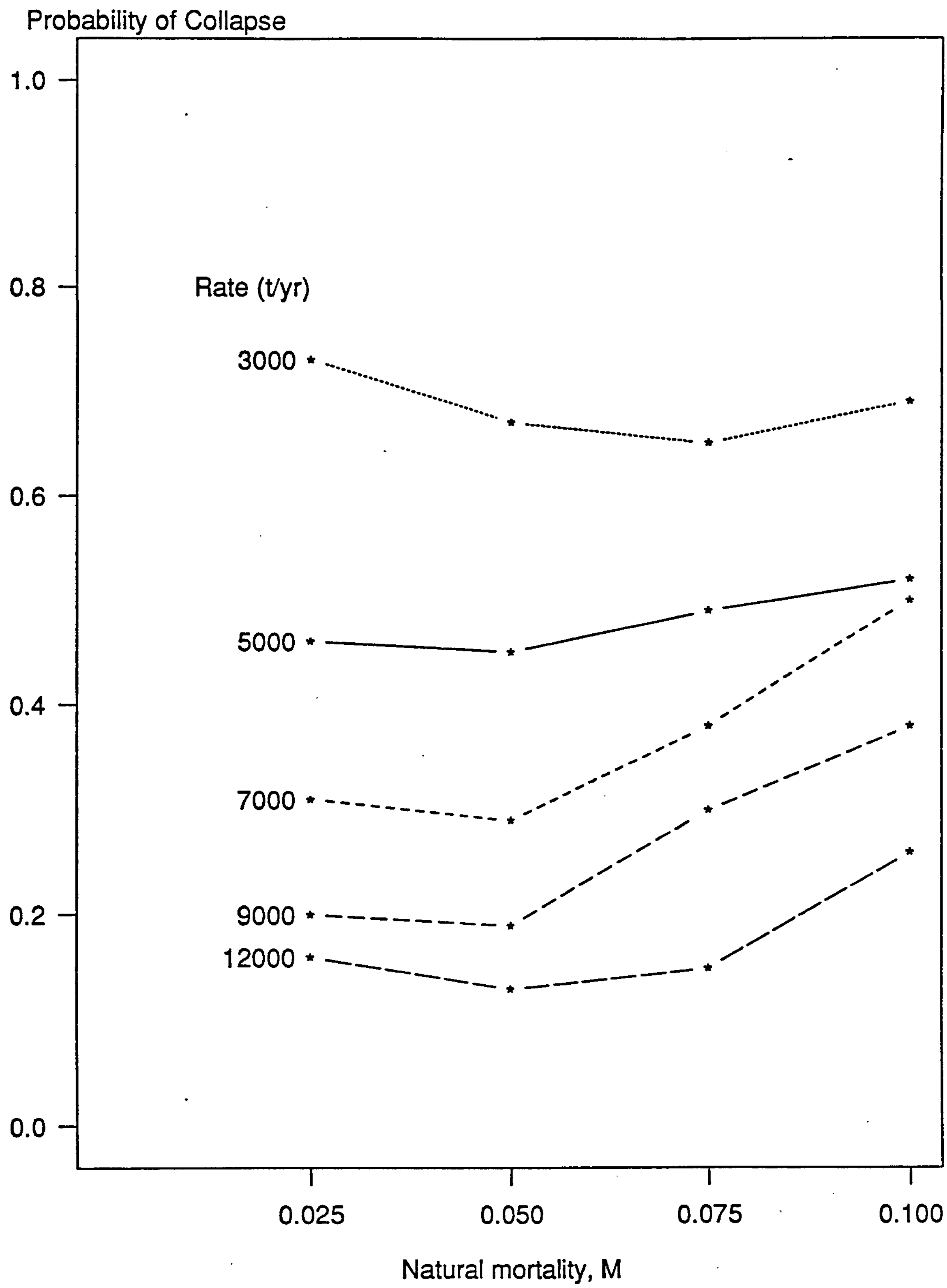

Figure 6. Effect on risk analysis of varying M, the natural mortality (for rates of TAC reduction of 3000, 5000, 7000, 9000, and 12000 t/yr). The points for M = 0.05 correspond to the solid line in Fig. 4.

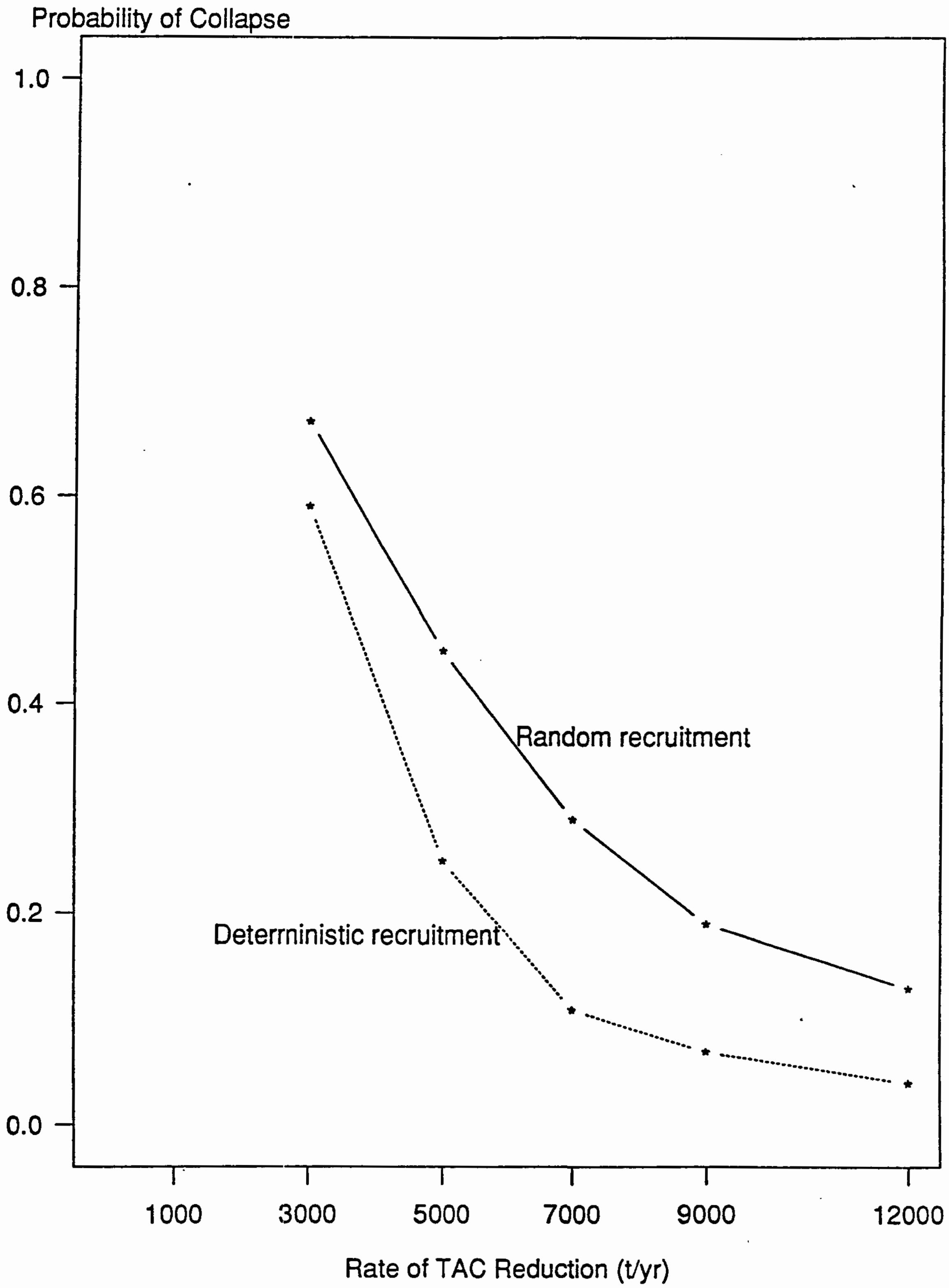

Figure 7. Effect on risk analysis of random recruitment. The solid line is the same as the solid line in Fig. 4 and thus shows the effect of using random B_0 (virgin biomass) and random recruitment; the dotted line shows what happens with random B_0 and deterministic recruitment.

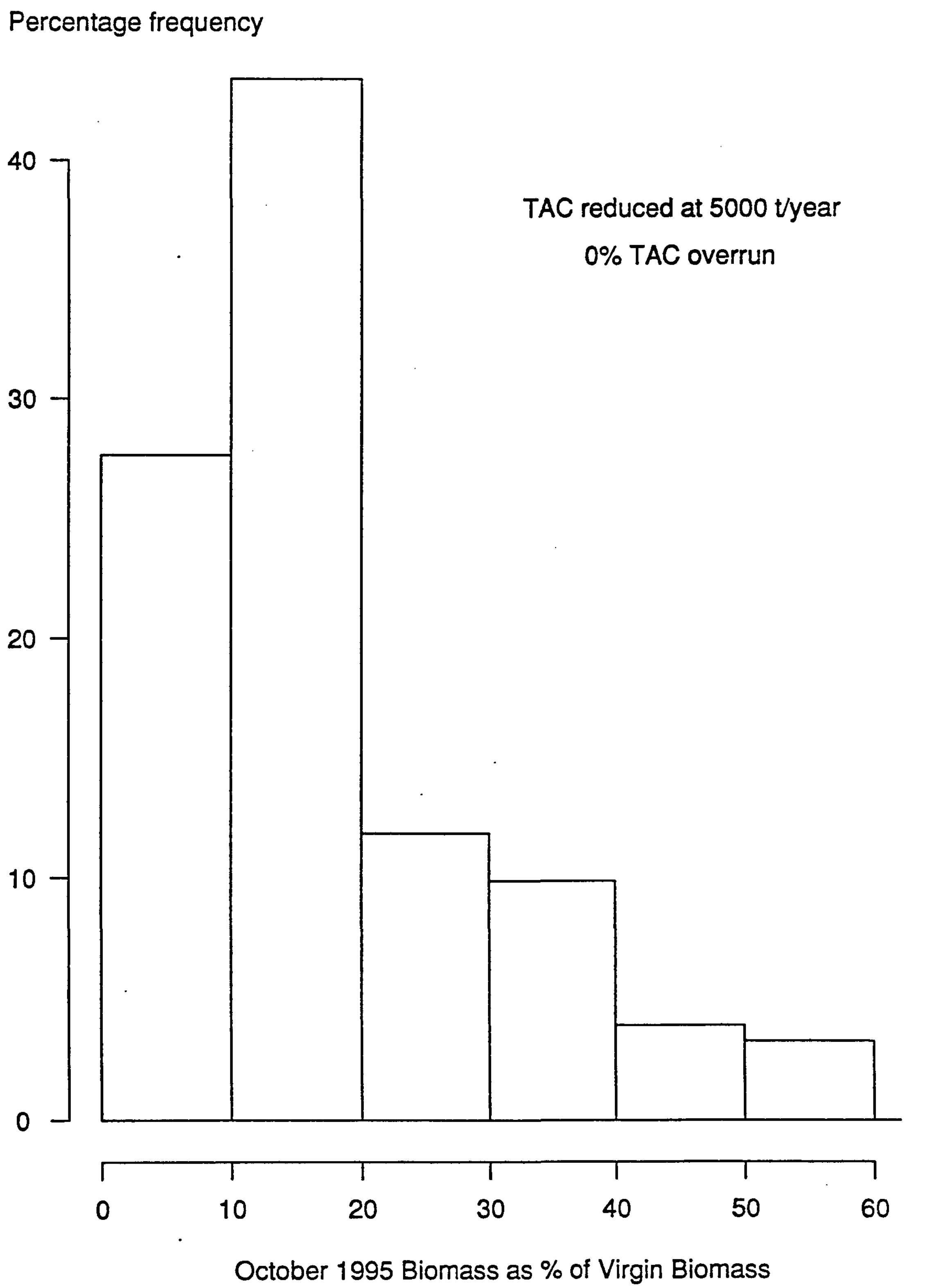

Figure 8. Final biomass (as a percentage of the virgin biomass) for those simulation runs for which the fishery does not collapse; TAC reduced at 5000 t/year, no TAC overrun in future.

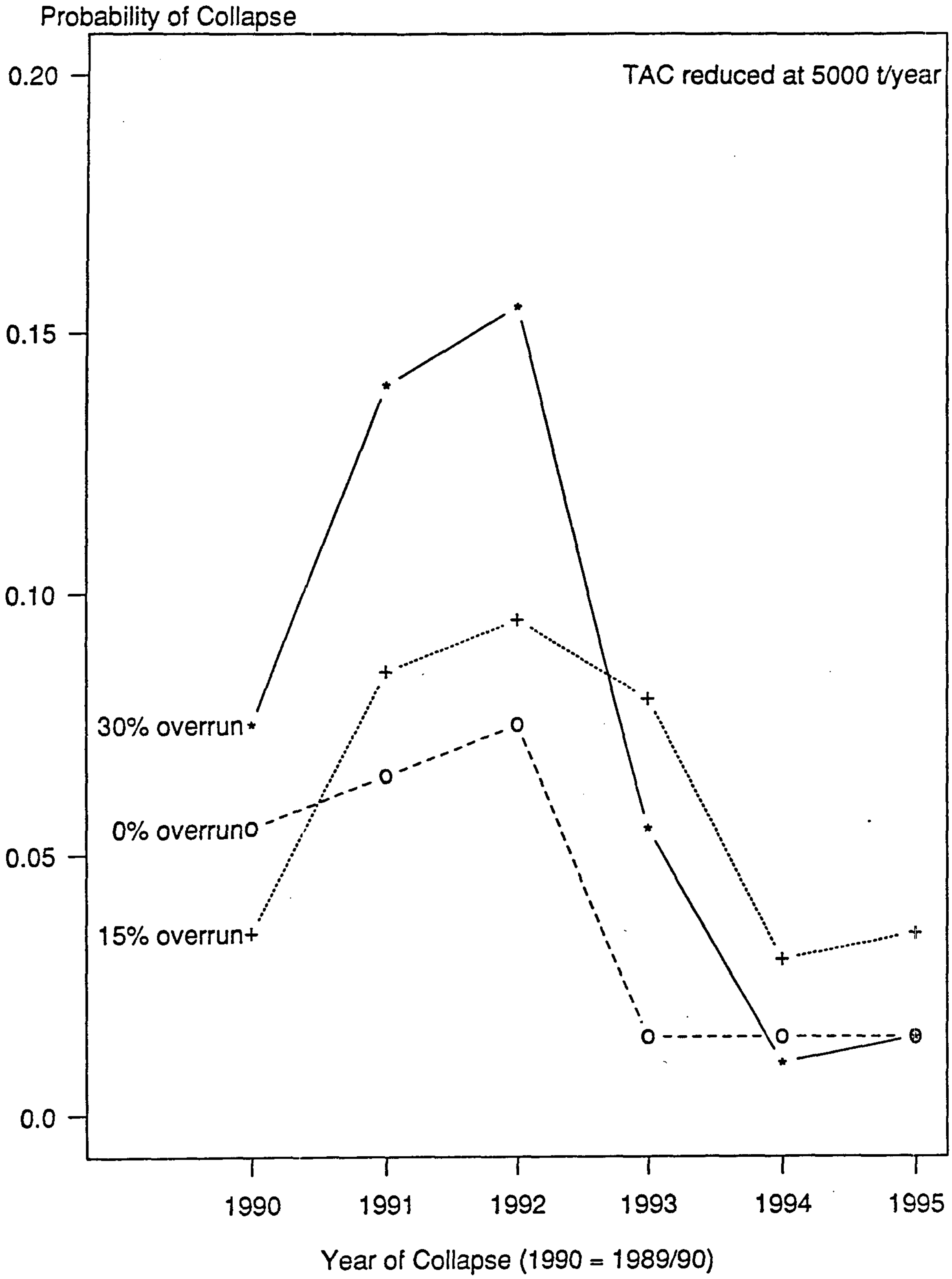

Figure 9. Year of collapse for those simulation runs for which the fishery does collapse; TAC reduced at 5000 t/year.