CSIRO
MARINE RESEARCH

Stock assessment of the Cascade Plateau orange roughy

Sally Wayte

Deepwater Assessment Group

August 2004

DAG2004/2

1 SUMMARY

This paper presents the first formal quantitative assessment of the Cascade Plateau population of orange roughy. An integrated assessment model, with an age- and sex-structured population dynamics model was applied. All available data have been used – catch records, length-frequency data from 1998-2003, an age-frequency sample from 1999, and the 2003 absolute acoustic biomass estimate.

The fish used for the age-frequency distribution appear to be generally longer than those used in the length-frequency distribution for the same year. The reasons for this discrepancy were investigated, but not resolved. This raises doubts about whether the age frequency sample is representative of the population. The model was run without fitting to information from the age frequency data to test the effect on model results. Other sensitivities tested were data-set weightings, values of biological parameters, and the value of the acoustic biomass estimate. The different values of the acoustic biomass estimate used correspond to different assumptions about orange roughy target strength, proportion spawning and turnover of the population.

For runs in which the age data were used, natural mortality was estimated to be 0.02 – half that estimated for orange roughy in the Eastern Zone. When no age data were used, natural mortality was fixed at 0.04. Over all scenarios used in the sensitivity analyses, current biomass was estimated to be between 36 and 60 % of pre-fishery biomass. The pre-fishery population (1989) is not estimated to be large (between 20,000 and 38,000 t). The value of the acoustic biomass estimate was the input that had the greatest impact on the stock assessment results. Bayesian posteriors and future stock projections were calculated for the four scenarios in which the acoustic biomass estimate varied, as well as for two in which no age data were used.

The comparatively small pre-fishery population size (much less than half those estimated in the Eastern or Southern zones) and the estimated low stock productivity (half that of other stocks) indicates that sustainable catches are likely to be much lower than other areas and well below current catch levels. It is likely that a sustainable long-term annual catch level for the Cascade Plateau could be between 200 and 400 t.

A suggested management target for the Cascade Plateau is that the biomass 10 years into the future should be greater than 30% of pre-fishery biomass, with a probability greater than 90%. All scenarios tested in the Bayesian projections indicate that the current catch of 1,600 t will not meet the management target and that an immediate catch reduction is required if the resource is to be fished sustainably. The most optimistic scenario, which uses the highest acoustic biomass estimate, uses the higher Eastern zone stock productivity, and uses the highest proportion spawning correction, suggests the management target will be reached if catches are reduced to 1,200 t in 2005 and 800 t thereafter. All other scenarios indicate that a long-term catch of 400 t or less is required to meet the management target. A sensible first step would be to reduce the catch in 2005 to 1,200 t and in the meantime await analysis of the 2004 age frequency sample, and acoustic biomass estimate, which will improve the reliability of

this analysis. It is recommended that a third acoustic biomass estimate be taken in 2005 with appropriate experiments to test factors contributing to the snapshot biomass estimates such as acoustic target strength, proportion spawning and turnover.

2. INTRODUCTION

2.1 The Fishery

Orange roughy inhabit deep, cold waters over steep continental slopes and oceanic ridges. In Australia, they occur in depths of 700 m to 1400 m, on the continental slope between Port Stephens in NSW and Cape Naturaliste in WA, and on the South Tasman Rise, the Cascade Plateau and the Lord Howe Rise (Kailola et al., 1993). Adult fish form dense winter spawning aggregations, commonly associated with submerged hills or pinnacles. They also form non-spawning aggregations. Orange roughy are slow-growing, long-lived and have low fecundity.

Orange roughy fisheries are generally high-value, targeted fisheries. Most of the Australian catches of orange roughy occur off southern and eastern Tasmania, at reliable spawning locations. Each fishery appears to be based on a separate stock, and is thus managed separately.

The Cascade Plateau is a rocky seamount approximately 125 nautical miles ESE of Hobart, Tasmania. With a current total allowable catch (TAC) of 1,600 t, it is now Australia's largest domestic orange roughy fishery. Initial fishing on the Plateau was in 1990 by foreign vessels that caught approximately 2,000 t of roughy. Substantial fishing did not occur again until 1996, when almost 1,000 t of orange roughy were caught. Since then, the Plateau has been fished consistently, subject to a TAC.

The Cascade Plateau fishery has been monitored since 1998 using funding from a voluntary industry levy. 100 t of the 1,600 t quota is set aside for research surveys. Biospherics Pty. Ltd. collected and analysed data on catches, length, weight, gonad staging, acoustic observations and environmental variables on industry-led surveys from 1999-2004. In 2003, Biospherics Pty. Ltd. and industry members conducted the first quantitative survey of the Cascade Plateau, using acoustic equipment on industry vessels that could be directly compared to standardised scientific equipment.

2.2 Previous Assessments

An analysis of catch per shot data from 1997 to April 2001 showed no trend, due in part to high intervessel variability and variability for individual vessels between years (Wayte, 2001). Catch per shot data for the remainder of 2001 are not directly comparable with earlier years' data as fishing practices changed following the loss of quarterly TACs. There will be no reliable relative abundance index for this fishery for several years.

Industry-led surveys in 1999, 2000, 2001 and 2002 described the dynamics of the spawning aggregation and the fishery (e.g. Prince, 2002). Preliminary acoustic biomass estimates for 2000 suggested a spawning biomass in the range of 5,000 – 15,000 t. The volume of the 2001 spawning biomass was more than double that recorded in 2000 and 5 times that recorded in 1999. While there is no direct link between volume and biomass (packing density has been shown to be variable), these results suggest that the biomass of fish spawning on the Plateau is variable and may have increased in recent years.

Simple deterministic population modelling indicated that the prefishery biomass would have to have been about 30,000 t or larger and the biomass in 2002 about 20,000 t or larger for the current catch of 1,600 t to be within the preliminary management target for this fishery (ie. $B_{2010} > 0.30\ B_{1988}$) (Wayte, 2003). Note that the biological parameters and management target used for this analysis were different from those used in the current analysis, so these analyses are not comparable.

There has been no indication of a declining trend in catch or catch rate in this fishery, but any decline would be disguised by the high variability in catch rate data. Given the lack of a clear signal in the data, and the changed fishing practices, the Orange Roughy Assessment Group (ORAG) recommended that annual acoustic and biological surveys of the spawning aggregation continue until such a time that current biomass estimates are refined and a formal stock assessment is completed. Industry members indicated their support for continuing surveys and continuing support for a voluntary closure of the spawning area during spawning in 2003 to facilitate this survey.

Biospherics Pty. Ltd. and industry members conducted the first quantitative survey of the Cascade Plateau in 2003, using acoustic equipment on industry vessels that could be directly compared to standardized scientific equipment (Honkalehto and Ryan, 2003). The survey was supported by industry through the 100 t research quota. ORAG provided funds for the acoustic biomass estimate.

3. METHODS

3.1 The Data and Model Inputs

3.1.1 Catches

The Cascade Plateau was first fished in 1989/90 when 2,000 t of roughy were caught by mostly foreign vessels. Smaller catches were reported by domestic vessels from the Cascade Plateau between 1991 and 1994, but these data are believed to be misreported. Substantial fishing did not occur again until 1996, when 863 t were caught. In April

1997 a precautionary trigger limit of 1,000 t set by the South East Trawl Management Advisory Committee (SETMAC) was reached. An ORAG proposal to increase fishing to a 1,600 t competitive TAC (400 t per quarter with no carryover of uncaught quota between quarters or years) based on a strategic fishing and research program, was accepted by SETMAC for 1998 and subsequently approved by the Australian Fisheries Management Authority (AFMA). Individual Transferable Quotas (ITQs) replaced the competitive TAC from 1 April 2001, and the quarterly distribution of quota was lost, increasing effective fishing effort in the fishery.

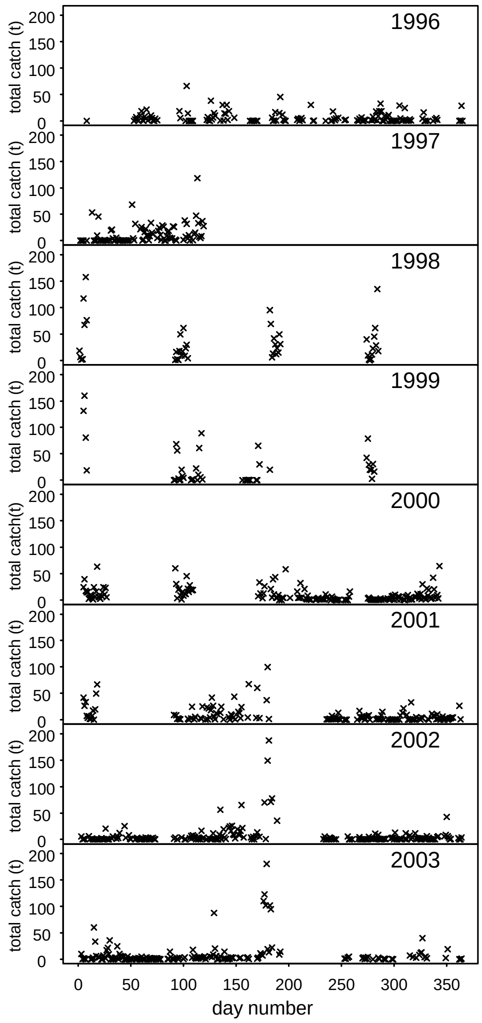
Information on catches reported here (Table 3.1) has been obtained from the AFMA catch landings database (SEF2). These figures include the 100 t research quota. Total reported catches to the end of 2003 are 13,847 t.

Table 3.1. Cascade Plateau catches and quota (the catches include the 100 t research quota)

Year	Agreed TAC (t) (before adjustment)	Management method	landed catch (t)
1989	none	none	260
1990	none	none	1,858
1991	none	none	0
1992	none	none	0
1993	none	none	0
1994	none	none	0
1995	none	none	0
1996	none	none	972
1997	1,000	trigger limit	1,178
1998	1,600	4 openings	1,560
1999	1,600	4 openings	1,689
2000	1,600	4 openings	1,639
2001 (first quarter)	400	1 opening	310
2001 (after April 1)	1,165	ITQs	1,156
2002	1,600	ITQs	1,592
2003	1,600	ITQs	1,638

Figure 3.1 shows the total orange roughy catch on the Cascade Plateau by day over the years 1998-2003. This shows that from April 2001, when ITQs replaced the quarterly TAC, most of the catch has been taken in the spawning season in the middle of the year.

Figure 3.1 Total daily orange roughy catch on the Cascade Plateau, 1996-2003. Survey shots are included.

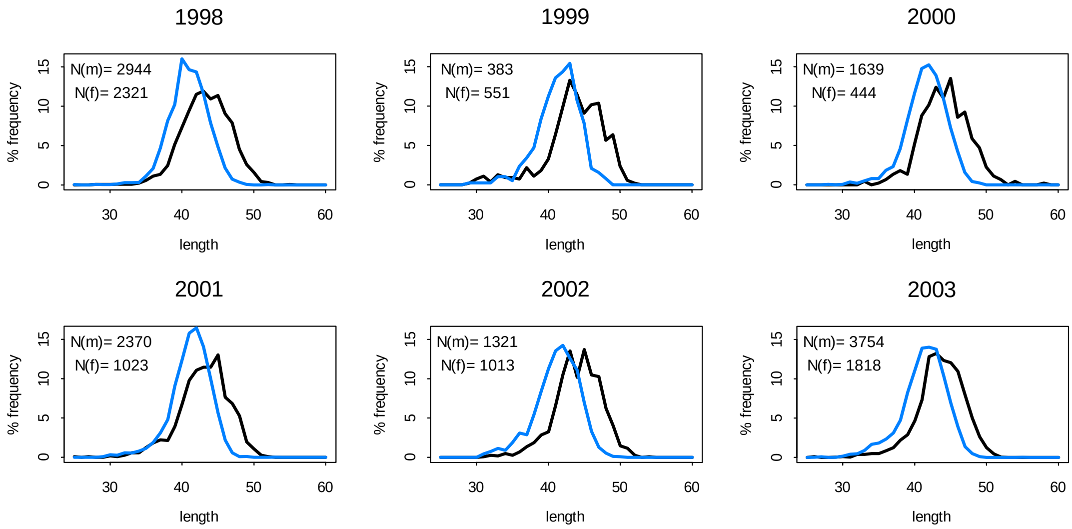


3.1.2 Length frequencies

Length frequency data (Figure 3.2) have been collected from the industry surveys run by Biospherics Pty. Ltd. from 1998-2003 (eg. Prince, 2002). Sub-samples of 100-200 fish were taken from large catches; all fish were measured in smaller samples. The data from each shot are considered to be uniform and representative of the population, thus no weighting by proportion of catch sampled has been performed (J.Prince, pers.comm.).

In stock assessments of orange roughy in New Zealand (Smith et al, 2002), effective sample sizes calculated from bootstrap resampling of the length frequency samples were used in place of the actual sample sizes in the likelihood. This was done in an attempt to take sampling error into account. Due to time constraints the bootstrap re-sampling procedure has not yet been done for the Cascade Plateau dataset. Instead, the effective sample sizes are approximated by multiplying the actual sample sizes by 0.01 (the average of the ratios of effective to actual sample sizes calculated in New Zealand orange roughy length-frequency samples). Sensitivity to this weighting is investigated.

Figure 3.2 Female (black) and male (grey) length frequencies, with sample sizes.



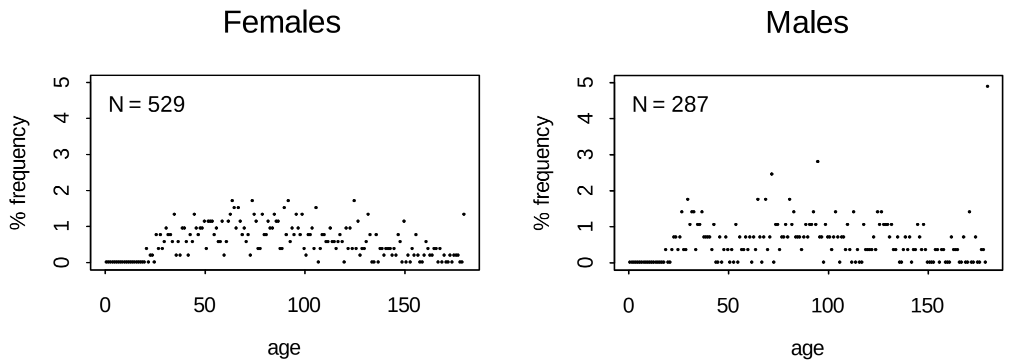
3.1.3 Age frequency

816 otoliths (529 female and 287 male) taken in 1999 have been aged (Figure 3.3) by the Central Ageing Facility in Queenscliff.

If a sample of otoliths has been re-aged it is possible to estimate imprecision in ageing using an ageing error matrix. A cell (j,k) of the ageing error matrix gives the proportion of fish originally aged j, that have been re-aged as age k. These proportions are then used to 'smear' the 'true' age frequencies from the model, before the age distribution component of the likelihood is calculated. Consideration was given to including an ageing error matrix in the model, but as only 250 of the 816 otoliths were re-aged, and 180 age classes were used in the model, the ageing error matrix would mostly have re-assigned ages rather than effectively 'smearing' the age frequency as intended.

Actual sample sizes are multiplied by 0.1 to approximate effective sample sizes, based on the same reasoning described for the adjustment of length frequency sample size, but retaining greater emphasis on the age data, as the age data are considered to contain more information than the length frequency data. Sensitivity to this weighting is investigated.

Figure 3.3 Female and male age frequencies, with sample sizes.



3.1.4 Acoustic biomass estimate

Biospherics Pty. Ltd. and industry members conducted the first quantitative survey of the Cascade Plateau in 2003, using acoustic equipment on industry vessels that could be directly compared to standardized scientific equipment (Honkalehto and Ryan, 2003). A number of absolute biomass estimates were obtained, depending on the value of target strength (TS) used, and the method used to classify orange roughy schools.

Orange roughy target strength is not well understood, and thus two alternative published values were used in the acoustic biomass estimation calculations: "Hampton" and "Doonan". Acoustic data were echo integrated for biomass estimation using a classification scheme based on a 3-tiered ranking of confidence of orange roughy echosign. The estimates from scheme OR1, obvious roughy schools, are used in the stock assessment, as these are the most defendable biomass estimates. An acoustic deadzone correction was applied to the data. The biomass estimate was calculated as the mean of 3 snapshot surveys taken over a period of eight days.

The estimate of biomass using the "Hampton" TS is 9,520 t, and the estimate using the "Doonan" TS is 6,283 t. Both the "Doonan" and "Hampton" TS estimates are extrapolations of fish at 35 cm SL and it would be advisable to review these estimates with an acoustic scattering model and "in-situ" measurements of the larger Cascade orange roughy.

The acoustic biomass estimate of orange roughy in schools at the time of the survey is a snapshot biomass estimate. To convert the snapshot acoustic biomass estimates into a Cascade population estimate requires accounting for the proportion of adult fish that do not come to spawn and the turnover of adult fish in the schools. Quantitative measures of the proportion of fish that will spawn each year are not available for the Cascade fishery but it is estimated to be between 0 to 30%. The Eastern Zone assessment assumed 20-30% of fish do not spawn each year. The turnover of fish on the spawning grounds based on limited information from the Eastern Zone and New Zealand fisheries is estimated to be in the range of 0 to 50%. In this assessment the snapshot acoustic surveys are doubled (100%) to provide an upper bound taking into account the proportion of adult fish that do not come to the spawning grounds and the turnover of fish in the schools. Future surveys should look at testable hypotheses to quantify and narrow the bound of this range.

3.1.5 Biological parameters

Orange roughy from the Cascade Plateau are noticeably larger than those from the Eastern Zone so it was necessary to calculate values for biological parameters from fish collected from the Plateau, rather than use values used in the Eastern Zone stock assessments.

Length-weight relationship

The length-weight relationship was calculated by Honkalehto and Ryan (2003) from length-weight data from 1,003 female roughy collected during the 2000 spawning survey of the Cascade Plateau:

$$\text{weight(g)} = 0.382 * \text{length(cm)}^{2.3409}$$

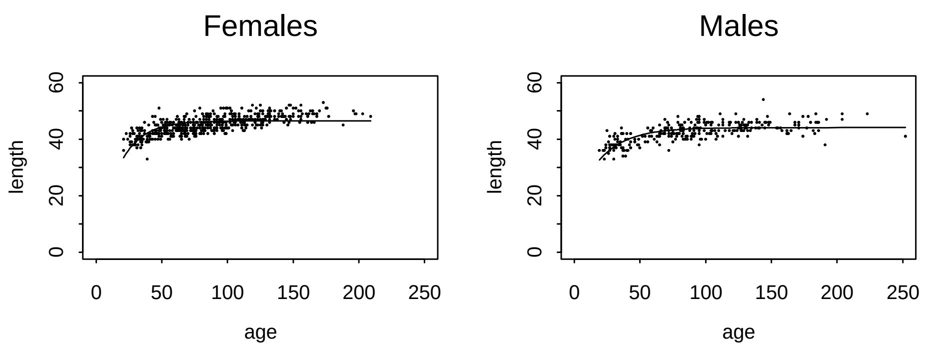
Growth

The Von Bertalanffy growth curve was fitted separately for males and females using the age and length data from the 1999 age composition sample (Figure 3.4). Due to the lack of data for younger ages it was not possible to estimate a sensible value for t_0 which was therefore fixed at 0. Sensitivity to fixing t_0 at –10 (and altering the other growth parameters accordingly) is investigated.

Males: $l_t = 43.8(1 - e^{-0.064t})$

Females: $l_t = 46.5(1 - e^{-0.061t})$

Figure 3.4 Female and male growth curves.



Other biological parameters

The fixed biological parameters used in the stock assessment are summarised in Table 3.2. As there was only one year of age-composition data it was not possible for the model to estimate both natural mortality and age at 50 % recruitment. The values used for age at 50% recruitment and gradual recruitment are those used in assessments of Eastern Zone orange roughy. Sensitivity to these values is investigated. Values for stock-recruit steepness and recruitment variability parameters are the same as those used in other Australian orange roughy assessments.

Table 3.2 Fixed biological parameters used in the assessment

Parameter	symbol	male	female	both sexes
von Bertalanffy growth	L_∞	43.8 cm	46.5 cm	-
	k	0.064 yr^{-1}	0.061 yr^{-1}	-
	t_0	0 yr	0 yr	-
length -weight	a			0.382 g/cm^3
	b			2.3409
age at 50% recruitment	A_r			32
gradual recruitment	S_r			8
stock-recruit steepness	d			0.75
recruitment variability	σ_R			1.0
length-at-age cv	σ_l			0.05
plus-group age	z			180

3.2 The Assessment Model

3.2.1 Model Structure

Population model and likelihood function

The population dynamics model is identical to that used in previous assessments of Australian orange roughy stocks (Wayte and Bax, 2002). It is an age- and sex-structured model with gradual recruitment according to age. The model does not estimate different numbers at age by sex, as the sex ratio at birth is assumed to be 50:50, and the same selectivity parameters are used for males and females. However, it was considered necessary to have different growth curves for males and females, as there are clear differences in the length compositions between the sexes (Figure 3.1). In other words, the fitted age compositions are the same for males and females, but the fitted length compositions can differ between the sexes.

The acoustic abundance index is assumed to be independently and log-normally distributed about the estimated abundance. The length-frequency and age-composition data are included in the likelihood function based on the robust likelihood formulation of Fournier et al. (1998). The formulation is modified as in Smith et al. (2002), so that the variance depends on the observed rather than the predicted proportions.

3.2.2 Parameter estimation

Results are summarised by the mode of the posterior density function (the MPD estimates) and by full Bayesian posterior distributions, calculated using the AD Model Builder package. The base-case analysis estimates 181 parameters (B_0, M and 179 recruitment deviations). The parameters estimated in the base-case analysis are listed in table 3.3. The recruitment deviations were bias-corrected when conducting the Bayesian analyses, but not when conducting the MPD analyses.

Table 3.3 Parameters estimated in the base-case analysis

Parameter	symbol	prior
Natural mortality	M	U[0.005; 0.1]
Virgin biomass	B_0	U[0; 50,000]
Recruitment deviations (a=1,2,…,179)	ε_a	$N(0;\sigma_R^2)$

Sensitivity tests involve modifying the data set choices, changing the weighting of data sets, or changing the fixed values of some biological parameters, as described in section 3.1.

The posterior distributions for quantities of interest were determined using the Markov Chain Monte Carlo (MCMC) algorithm. The results are based on 2,000,000 cycles of the MCMC algorithm, the first 500,000 of which were discarded as a ‘burn in’ period. The remaining 1,500,000 cycles were sampled every 1,000 cycles to produce 1,500 draws from the posterior. The MCMC algorithm was checked for convergence by examining plots of estimated quantities against cycle number, and by calculation of a range of convergence statistics (Gewecke, Raftery and Lewis, Heidelberger and Welch and Gelman).

3.3 Projections

Forward projections were carried out for a 10-year period with the catch held at a range of levels (Table 3.4).

Table 3.4 Catch series used in the forward projections.

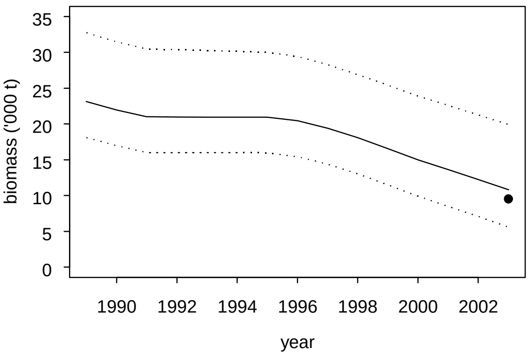
Year	catch series 1	catch series 2	catch series 3	catch series 4
2004	1600	1600	1600	1600
2005	1600	1200	1200	1200
2006	1600	800	800	800
2007	1600	800	400	400
2008	1600	800	400	200
2009	1600	800	400	200
2010	1600	800	400	200
2011	1600	800	400	200
2012	1600	800	400	200
2013	1600	800	400	200

4. RESULTS

4.1 Base-case analysis

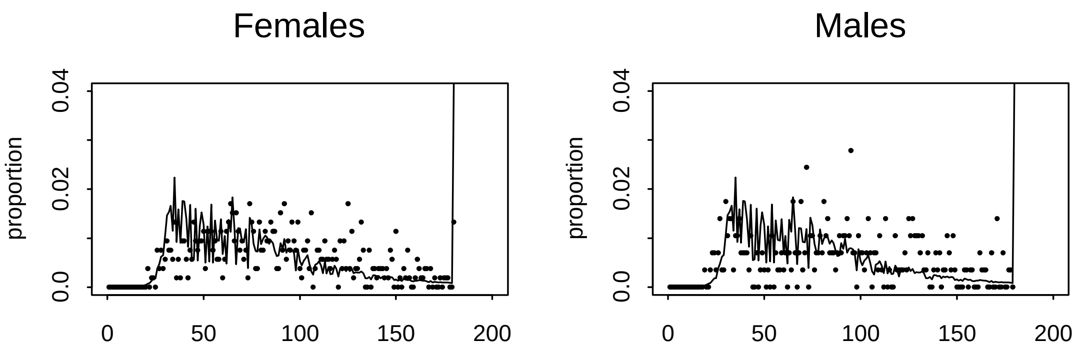
The base-case analysis includes all the data, and estimates all 181 free parameters. Figure 4.1 shows the Bayesian fit to the absolute acoustic index. As this is the only abundance index in the model it is not surprising that the estimated biomass is very close to the observed value. Estimated current stock size will be determined by the value of this index.

Figure 4.1 The base-case fit to the acoustic biomass estimate. The solid line is the posterior median and the dotted lines are 90% probability intervals.



The base-case MPD fits to the age frequency data are shown in figure 4.2. The fit to the female age composition data is better than that to the male data. This is not surprising since the sample size for females is almost twice that for the males. The relatively poor fit to the age frequency data is partly due to the inconsistency between the data for the two sexes regarding which are strong and weak year-classes. As described previously, the model does not allow for differences between the sexes in the fitted age composition. The model appears to under-estimate the proportion of fish in the older age classes (>125 years). This is due to a contradiction between the age and length composition data. If the length frequency data are omitted from the fit, then the model can fit the age data perfectly, but over-predicts the catch of larger animals (i.e. does not fit the right hand side of the length frequency composition well).

Figure 4.2 MPD fits (solid lines) to the age frequency data (dots) for the base-case analysis.



The fits to the length frequency compositions are generally good (Figure 4.3), although there is a tendency for the model to under-predict the catch of smaller fish (< 42 cm for males, and < 45 cm for females). Again, this arises from the inconsistency between the age and length composition data. If we compare the lengths from the 1999 length frequency sample with the lengths of fish that were aged in 1999, it is clear that the fish in the age sample were larger than the fish in the length frequency sample (Figure 4.4). As the age-length data from this sample was used to estimate the growth parameters, this is probably the reason why the model under-predicts the catch of smaller fish.

The reasons for this apparent difference in length have been investigated. The standard length measurement for orange roughy (from the tip of the snout to the distal end of the hypural bone) was reported as being used to measure both samples. According to field scientists who took the samples, different samples of fish were used for the length frequency and the ageing (G.Diver pers.comm.). The length frequency fish were measured at sea, whereas the age frequency fish were measured when the otoliths were taken from the frozen frames (F.Ewing pers.comm.). It has been established for some species that measuring frozen fish produces a different result from measuring fish at sea (Gordon, 1994). However, the usual result is that the frozen fish shrink. Field scientists cannot recall whether the fish for ageing were put aside at sea, or selected by a factory worker in Devonport. If the latter, then it is possible the fish may not be a representative sample of the population. Another year of age-length data may resolve the discrepancy.

Figure 4.3 MPD fits (solid lines) to the length frequency data (dots) for the base-case analysis.

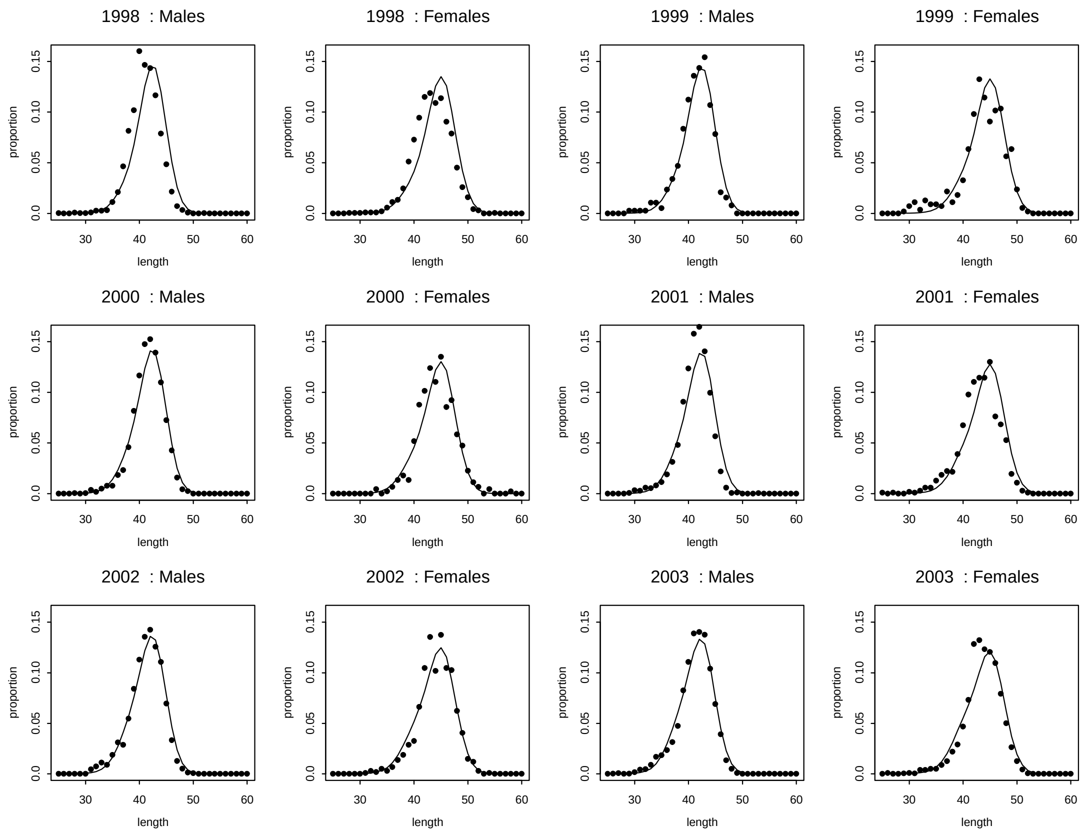
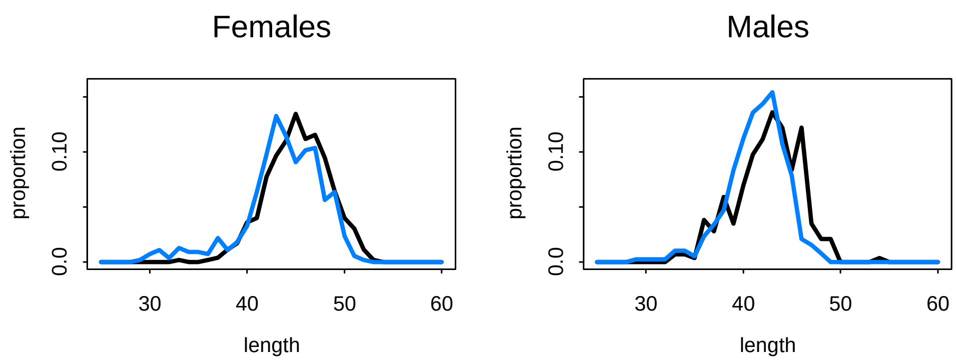


Figure 4.4 Length frequencies from the LF data (grey) compared with the length frequency from the data used for ageing (black).



In an attempt to resolve the contradictions in the data, the age composition was re-calculated using an age-length key calculated from the 1999 length frequency data. However this produced anomalous results – the re-calculated male age frequency was skewed to the right, and the re-calculated female age frequency was skewed to the left. This is considered to be highly implausible, and an artifact of the dataset used. As the sample sizes for the age and length frequency data are similar, there seems no compelling reason to modify the original age frequency data. However, for the sake of completeness, the model was run using the re-calculated age composition. The model was also run without using information from the age composition data, with natural mortality fixed at 0.04 (the estimate obtained in the Eastern zone stock assessment), for both the base case acoustic biomass estimate and double that estimate, to provide an upper bound on the results.

4.2 Sensitivity tests

Table 4.1 summarises the results of the sensitivity tests. The results reported for each analysis are the estimates of M and B_0, 1989 and 2003 recruited mid-season biomass, and the ratio of the 2003 biomass to the pre-fishery biomass (B_{1989}). Also shown is the contribution of each data source to the objective function.

For all analyses using the base-case acoustic estimate of 9,520 t, current biomass is estimated to be between 41 and 57 % of pre-fishery biomass. Using unweighted sample sizes for the age and length frequencies gives rise to large and unrealistic spikes in the recruitment deviations, and therefore a very poor fit to the age data. When both the age and length frequency sample sizes are multiplied by 0.01, the model gives a very poor fit to the age frequency. The use of Von Bertalanffy growth parameters corresponding to t_0 = -10 makes virtually no difference to the fit. Changing age at recruitment from 32 to either 39 or 25 leads to a poorer fit to the age frequency. Fixing natural mortality at 0.04 also gives a worse fit to the age frequency. Not estimating recruitment deviations leads to a very poor fit to the age frequency, but a slightly better fit to the length frequency data.

Ignoring the length frequency data has little impact on the results, apart from a slightly improved fit to the age frequency. Similarly, ignoring the age frequency data improves the fit to the length frequencies but has little impact on biomass estimates. Natural mortality was fixed to 0.02 for both these analyses. Ignoring the age frequency data and fixing the natural mortality at 0.04 gave a better fit to the length frequency data, although a worse fit to the acoustic biomass estimate. Estimated biomasses are higher than for the base-case. For the most optimistic scenario (“double Hampton TS” and M=0.04), current biomass is estimated to be 60 % of pre-fishery biomass.

Using the age frequency calculated from the age-length key results in an unrealistically low estimate of natural mortality, and (visually) a poorer fit to the age frequency data. This is not surprising since the age compositions from the age-length key show quite different distributions for males and females, but the model is unable to estimate different age distributions by sex.

Different absolute acoustic biomass indices have virtually no effect on the fit to the age or length composition data, but do give rise to different biomass estimates and levels of depletion. For the smallest biomass index (“Doonan TS”), current biomass is estimated to be 36 % of pre-fishery biomass, whereas for the largest biomass index (“double Hampton TS”), current biomass is estimated to be 60 % of pre-fishery biomass.

Table 4.1 Specifications and results for the sensitivity tests. SS= sample size. M is estimated unless indicated otherwise. A_r is fixed. Growth parameters are fixed. The lower the likelihood, the better the fit to the data.

	Base-case Hampton TS	Actual age & length SS	Age & length SS*0.01	Double Hampton TS	Doonan TS	Double Doonan TS	t_0=-10	A_r=39
Data								
Acoustic index	9,520	9,520	9,520	19,040	6,283	12,566	9,520	9,520
Length frequencies	yes, SS*0.01	yes, actual SS	yes,SS*0.01	yes, SS*0.01	yes, SS*0.01	yes, SS*0.01	yes, SS*0.01	yes, SS*0.01
Age frequency	yes,SS*0.1	yes, actual SS	yes,SS*0.01	yes,SS*0.1	yes,SS*0.1	yes,SS*0.1	yes,SS*0.1	yes,SS*0.1
Recruitment devs	yes	yes	yes	yes	yes	yes	yes	yes
Parameters								
M	0.021	0.028	0.024	0.022	0.021	0.021	0.021	0.024
A_r	32	32	32	32	32	32	32	39
L_∞ (m,f)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(46.9,44.1)	(43.8,46.5)
k (m,f)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.045,0.046)	(0.064,0.061)
t_0 (m,f)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(-10,-10)	(0,0)
Biomass								
B_0	21,640	28,568	22,083	30,336	18,719	24,396	22,212	20,053
B_{1989}	22,623	29,301	22,349	31,347	19,736	25,375	23,869	20,020
B_{curr}	9,946	16,713	10,406	18,738	7,009	12,728	10,750	8,177
B_{curr}/B_0	0.46	0.59	0.47	0.61	0.37	0.52	0.48	0.41
B_{curr}/B_{1989}	0.44	0.57	0.47	0.60	0.36	0.50	0.45	0.41
Likelihood components								
Acoustic index	0.006	0.99	0.025	0.001	0.037	0.001	0.046	0.072
Length frequencies	-1130.7	-1863.0	-1134.4	-1130.8	-1130.5	-1130.7	-1130.5	-1128.6
Age frequency	-1317.2	-1610.0	-890.2	-1317.2	-1317.2	-1317.2	-1317.4	-1312.3
Recruitment devs	8.3	29.3	0.758	8.33	8.26	8.28	8.5	10.3
total	*-2439.5*	*-3443.7*	*-2023.7*	*-2439.6*	*-2439.4*	*-2439.6*	*-2439.4*	*-2430.5*

	A_r=25	M=0.04	no recruitment deviations	no fit to LF	no fit to age composition	no fit to age composition; M=0.04	no fit to age composition; M=0.04; double Hampton TS	use age-length key age-composition
Data								
Acoustic index	9,520	9,520	9,520	9,520	9,520	9,520	19,040	9,520
Length frequencies	yes, SS*0.01	yes, SS*0.01	yes, SS*0.01	no	yes, SS*0.01	yes, SS*0.01	yes, SS*0.01	yes, SS*0.01
Age frequency	yes,SS*0.1	yes,SS*0.1	yes,SS*0.1	yes,SS*0.1	no	no	no	a-l key,SS*0.1
Recruitment devs	yes	yes	no	yes	yes	yes	yes	yes
Parameters								
M	0.014	0.04 (fixed)	0.02 (fixed)	0.02 (fixed)	0.02 (fixed)	0.04 (fixed)	0.04 (fixed)	0.006
A_r	25	32	32	32	32	32	32	32
L_∞ (m,f)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)	(43.8,46.5)
k (m,f)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)	(0.064,0.061)
t_0 (m,f)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
Biomass								
B_0	22,145	29,171	21,546	21,382	20,728	24,425	34,608	21,173
B_{1989}	23,937	29,813	21,416	22,641	20,913	27,116	37,806	21,107
B_{curr}	11,034	13,764	9,381	9,613	9,607	12,834	22,700	8,604
B_{curr}/B_0	0.50	0.47	0.44	0.45	0.46	0.53	0.66	0.41
B_{curr}/B_{1989}	0.46	0.46	0.44	0.42	0.46	0.47	0.60	0.41
Likelihood components								
Acoustic index	0.068	0.425	0.001	0.0	0.0	0.279	0.097	0.032
Length frequencies	-1128.4	-1133.6	-1132.7	-	-1134.3	-1135.2	-1135.5	-1134.6
Age frequency	-1315.4	-1296.7	-1279.2	-1319.3	-	-	-	-1327.5
Recruitment devs	7.3	13.9	-	9.56	0.71	1.93	1.4	4.2
total	*-2436.4*	*-2415.9*	*-2411.9*	*-1309.7*	*-1133.6*	*-1132.9*	*-1134.0*	*-2457.7*

This page intentionally left blank

4.3 Bayesian results

Bayesian posterior distributions were computed for the four scenarios with different acoustic biomass estimates, and two scenarios using no age data. The Bayesian analysis was run for the most optimistic scenario (no age data, M=0.04 and “double Hampton TS” acoustic biomass estimate) in order to provide an upper bound for the results. The convergence statistics and plots for the base case (Figure 4.5) gave no evidence that the MCMC algorithm failed to converge.

Figure 4.6 shows the medians and 90% probability intervals for the time-trajectories of mid-season recruited biomass for these scenarios. Table 4.2 lists the posterior medians for B_0, B_{1989}, B_{2003}, B_{2003}/B_{1989}, and the probability that B_{2003} is less than 0.3 B_{1989}, 0.4 B_{1989} , 0.5 B_{1989} and 0.6 B_{1989}. The pre-fishery biomass (B_{1989}) is used as the reference level, rather than B_0, as this is consistent with previous orange roughy assessments and assessments for other fisheries (e.g. blue grenadier). B_0 is the pre-exploitation equilibrium biomass and includes no information about recruitment patterns in the fishery, whereas B_{1989} is the recruited biomass estimated to be present at the beginning of the fishery.

Figure 4.5 Traces for the negative of the logarithm of the posterior density, virgin biomass and natural mortality for the base-case analysis.

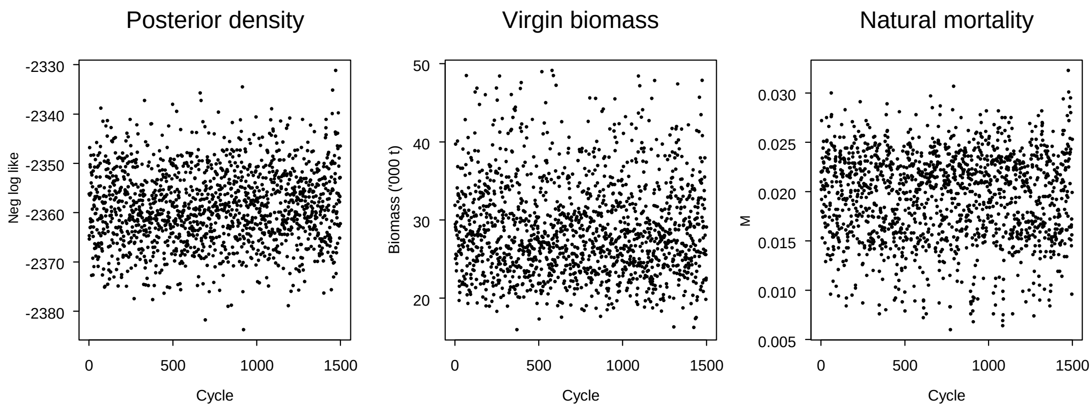


Figure 4.6 Posterior medians and 90% probability intervals for the time-trajectory of mid-season recruited biomass for the six Bayesian analyses.

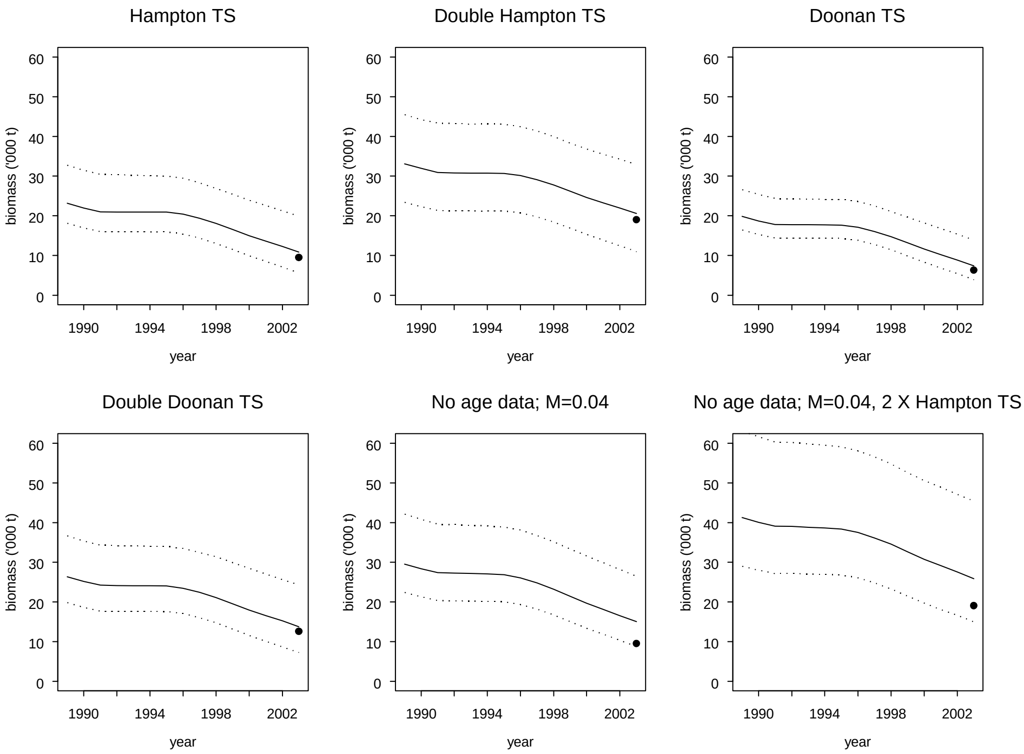


Table 4.2 Posterior medians for the quantities B_0, B_{2003}, B_{2003}/B_{1989}, and the probability that B_{2003} is less than 0.3 B_{1989}, 0.4 B_{1989}, 0.5 B_{1989} and 0.6 B_{1989}. B_0 is the pre-exploitation equilibrium biomass, whereas B_{1989} is the pre-fishery biomass.

	Hampton TS	**Double Hampton TS**	**Doonan TS**	**Double Doonan TS**	**Hampton TS; no age data; M=0.04**	**Double Hampton TS; no age data; M=0.04**
B_0	27,822	39,903	23,460	31,497	31,259	44,203
B_{1989}	23,133	33,110	19,880	26,345	29,551	41,245
B_{2003}	10,835	20,612	7,406	13,796	15,032	25,864
B_{2003}/B_{1989}	0.47	0.62	0.37	0.52	0.51	0.63
$P(B_{2003}<0.3B_{1989})$	0.039	0.001	0.215	0.008	0.004	0.0
$P(B_{2003}<0.4B_{1989})$	0.237	0.014	0.619	0.096	0.080	0.003
$P(B_{2003}<0.5B_{1989})$	0.625	0.105	0.904	0.394	0.458	0.052
$P(B_{2003}<0.6B_{1989})$	0.924	0.392	0.993	0.789	0.864	0.367

4.4 Forward projections

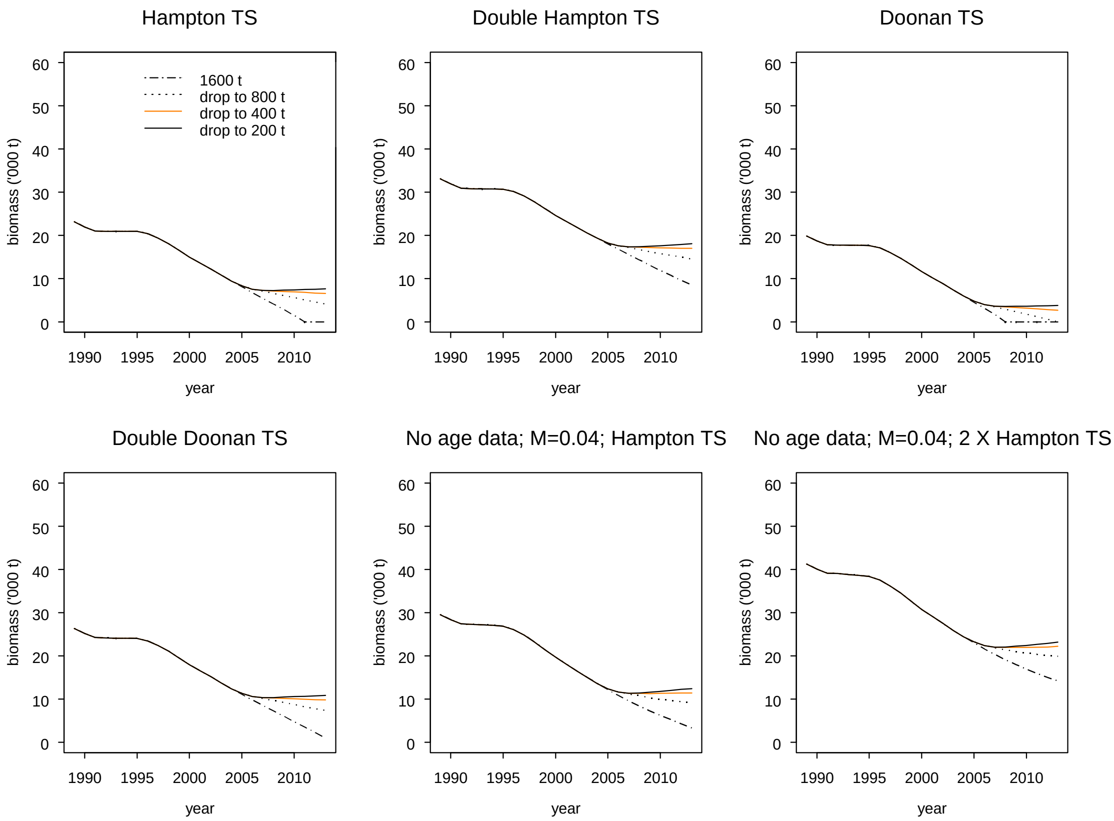
Forward projections were carried out for the six Bayesian assessments for a 10-year period with the catch held at a range of levels (listed in Table 3.4). Figure 4.7 shows the projected mid-year recruited biomasses for all catch levels and Bayesian scenarios. Table 4.3 gives the probabilities that B_{2013} is greater than 0.3 B_{1989}, 0.4 B_{1989} and 0.5 B_{1989}.

Table 4.3 The probability that B_{2013} is greater than 0.3 B_{1989}, 0.4 B_{1989} and 0.5 B_{1989} , for the six Bayesian assessments. Contrasts with probabilities greater than 0.9 for B_{lim} are bolded.

scenario	Hampton TS	Double Hampton TS	Doonan TS	Double Doonan TS	Hampton TS; no age data; M=0.04	Double Hampton TS; no age data; M=0.04
catch series 1 (1,600 t)						
$P(B_{2013}>0.3B_{1989})$	0.03	0.38	0.0	0.09	0.13	0.62
$P(B_{2013}>0.4B_{1989})$	0.0	0.16	0.0	0.01	0.02	0.35
$P(B_{2013}>0.5B_{1989})$	0.0	0.03	0.0	0.0	0.0	0.13
catch series 2 (to 800 t)						
$P(B_{2013}>0.3B_{1989})$	0.23	0.80	0.05	0.45	0.51	**0.93**
$P(B_{2013}>0.4B_{1989})$	0.08	0.60	0.01	0.22	0.25	0.76
$P(B_{2013}>0.5B_{1989})$	0.02	0.29	0.0	0.06	0.05	0.42
catch series 3 (to 400 t)						
$P(B_{2013}>0.3B_{1989})$	0.46	**0.93**	0.15	0.69	0.79	**0.98**
$P(B_{2013}>0.4B_{1989})$	0.21	0.78	0.05	0.42	0.45	0.90
$P(B_{2013}>0.5B_{1989})$	0.06	0.53	0.01	0.17	0.18	0.64
catch series 4 (to 200 t)						
$P(B_{2013}>0.3B_{1989})$	0.59	**0.97**	0.24	0.80	**0.90**	**0.99**
$P(B_{2013}>0.4B_{1989})$	0.30	0.86	0.07	0.53	0.58	0.94
$P(B_{2013}>0.5B_{1989})$	0.10	0.64	0.02	0.25	0.25	0.73

The most optimistic scenario can provide a 90% probability of being above 30% pre-fishery biomass by 2013, but only if catches are reduced to 800 t. The second-most optimistic assessment (“double Hampton TS”) can provide a greater than 90% probability of being above 30% pre-fishery biomass by 2013 but this requires a reduction in catches to 400 t.

Figure 4.7 Biomass trajectories and future projections for the four future catch series for the six Bayesian analyses. Note that all future catch series (with the exception of maintaining current catch) involve a gradual stepping down of catch from 1,600 t to 1,200 t to 800 t and so on.



5. DISCUSSION AND CONCLUSIONS

The base-case assessment is fitted to all data available for the Cascade Plateau stock – catches, length frequencies, 1999 age frequency and 2003 acoustic biomass estimate. The model fits these data sets reasonably well, despite evidence of a contradiction between the length frequency and age frequency data. The fish that have been aged appear to be larger (by about 1.5 cm) than those in the length frequency sample for the same year. The reason for this discrepancy has been investigated, but not resolved.

The results are not particularly sensitive to the assumptions or data-set choices, with the exception of the choice of acoustic biomass estimate, and the value of natural mortality. Estimates of pre-fishery biomass from the Bayesian analyses range from 23,000 t to 44,000 t, and estimates of current stock depletion are between 0.32 and 0.59.

Natural mortality is estimated to be about 0.02 – half that estimated for roughy in the Eastern Zone. Orange roughy on the Cascade do appear to be both larger and older than those observed elsewhere. Since the aged fish are generally larger than the fish in the length frequency for the same year, there is some doubt over whether the sample of fish aged is representative of the population in that year. When the model is run using no information from the age data, current biomass is estimated to be 48% of pre-fishery biomass.

Four out of the six Bayesian analyses show that there is a greater than 50% probability that current biomass is less than 60% of pre-fishery biomass (Table 4.2), whereas none of the analyses show that there is a greater than 50% probability that current biomass is less than 30% of pre-fishery biomass. In other words, the analyses suggest that it is likely that biomass is currently between 30 and 60% of pre-fishery biomass.

The SEFAG Harvest Strategies Working Group (SHSWG) (Smith and Smith, 2002) suggested the following objective for managing a fish stock: stocks should be maintained above a well-defined and appropriate minimum biologically acceptable level B_{lim} with acceptable levels of probability. B_{lim} is called a limit reference point, and defines a level of biomass that you wish to avoid, thus the probability of being above B_{lim} should be set high. The SHSWG recommends that a possible proxy for B_{lim} is 20% pre-fishery biomass. However, the report also recommends that a more conservative level should be set for long-lived species with low productivity, such as orange roughy.

A management target that is suggested for the Cascade Plateau is that the biomass ten years into the future should be greater than 30% of pre-fishery biomass (B_{lim}), with a probability greater than 90%. This target is consistent with the SHSWG recommendations. This management target is not reached for any of the Bayesian scenarios for future catch series 1 (current catch level). For catch series 2 (decrease to 800 t), the target is reached only for the most optimistic scenario. For catch series 3 (decrease to 400 t), the target is reached only for the two most optimistic scenarios. For catch series 4 (decrease catch to 200 t), the target is reached in three of the six scenarios.

Half of the scenarios suggest that a precautionary long-term annual catch level for the Cascade Plateau should be less than 200 t. The most optimistic scenario is included in the analysis mainly to bound the results, and should not be used as a target until supported by appropriate research. However, even this scenario suggests that the current catch level of 1,600 t is too large, and that catches should be reduced to 800 t to meet the management target. All future catch scenarios 9with the exception of maintaining current catch) included a gradual stepping-down of catch to 1,200 t in 2005 and 800 t in 2006. It would seem reasonable to choose this catch regime, and in the meantime await analysis of the 2004 age frequency sample and acoustic biomass estimate. A second biomass estimate and age composition, plus the opportunity to collect better information on orange roughy target strength, proportion spawning and turnover, will reduce uncertainties in this assessment. It is recommended that a third acoustic biomass estimate be taken in 2005 to increase precision of the assessment, and to provide a series of biomass estimates that can be used as a relative index, removing some of the assumptions of the current absolute biomass estimate.

6. ACKNOWLEDGEMENTS

Rudy Kloser, Nic Bax, Robin Thomson, Chris Francis, Neil Klaer and Andre Punt are thanked for helpful discussions and advice. Geoff Tuck and Tony Smith are thanked for reviewing the analysis.

7. REFERENCES

Fournier, D.A.; Hampton, J.; Sibert, J.R. (1998) MULTIFAN-CL : a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga. Canadian Journal of Fisheries and Aquatic Sciences 55 : 2105-2116.*

Gordon, D.A. (1994) Lingcod fishery and fishery monitoring in Southeast Alaska. *Alaska Fishery Research Bulletin, vol. 1, no. 2, pp. 140-152*

Honkalehto, T. and Ryan, T. (2003) Analysis of industry acoustic observations of orange roughy (*Hoplostethus atlanticus*) spawning aggregations on the Cascade Plateau off southeastern Tasmania in June and July 2003. Unpublished report to DAG.

Kailola, P.J.; Williams, M.J.; Stewart, P.C.; Reichelt, R.E.; McNee, A.; Grieve, C. (1993) Australian Fisheries Resources. BRS, Canberra.

Prince, J. (2002) Orange roughy spawning at the Cascade Plateau : 2002 Cruise Report. Biospherics Pty. Ltd. (unpublished report to ORAG)

Smith, A.D.M.; Punt, A.E.; Wayte, S.E.; Starr P.J.; Francis, R.I.C.C.; Stokes, T.K.; Hilborn, R.; Langley, A. (2002) Stock assessment of the northeast Chatham Rise orange roughy for 2001. *New Zealand Fisheries Assessment Report 2002/25.*

Smith, A.D.M. and Smith, D. (2002) Towards an improved basis for setting TACs in the South East Fishery. Unpublished report of the SEFAG Harvest Strategies Working Group to the AFMA Board.

Wayte, S.E. (2001) Preliminary analysis of orange roughy catches on the Cascade Plateau, 1996-2001. Unpublished report to ORAG.

Wayte, S.E. and Bax. N. (2002) Stock Assessment Report 2002 : Orange roughy (*Hoplostethus atlanticus*). Unpublished report to SEFAG.

Wayte, S.E. (2003) Deterministic population modelling of the orange roughy population on the Cascade Plateau . Unpublished report to ORAG.