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Orange Roughy East (*Hoplostethus atlanticus*) stock assessment using data to 2016

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Contents

SUMMARY III

1 INTRODUCTION 5

1.1 The Fishery 5

1.2 Previous Assessments 5

1.3 Modifying the September 2017 Initial Base-Case 6
  1.3.1 Balancing Variances and Adjusting Biases 6
  1.3.2 Estimation of RBC and long Term RBC 7

2 METHODS 8

2.1 Biological parameters 8

2.2 Available Data 9

2.3 Catches 9

2.4 Age composition data 12
  2.4.1 Ageing Error 12

2.5 Acoustic survey abundance estimates 14

2.6 Stock Assessment 14
  2.6.1 Population model and parameter estimation 14
  2.6.2 Iterative Reweighting of data variances 16

2.7 Estimate RBC through Forecasting the Model Forward 17

3 RESULTS 18

3.1 The Initial Base-Case Analysis 18
  3.1.1 Fishing Mortality 18

3.2 Iterative Re-weighting 19
  3.2.1 Age-Composition Data 19
  3.2.2 Recruitment Deviates 21
  3.2.3 Indices of AbuNdance 22

3.3 Likelihood Profiles 24
  3.3.1 Natural Mortality 24
  3.3.2 Steepness 27
  3.3.3 Selectivity 29

3.4 Final Base-Case 31
  3.4.1 SPR Phase Plot 31
  3.4.2 Comparison with the initial base-case 31

3.5 Forecasts and Cross-Catch Risk Assessment 34
  3.5.1 Cross-Catch Projection Risk Analysis 38

4 DISCUSSION 39
4.1.1 Future Developments 40

APPENDIX A 41

REFERENCES 43

5 APPENDIX -ALTERNATIVE ORE FORECASTS 48

5.1 Introduction 48

5.2 Results and Discussion 49

Summary

The stock assessment for Eastern Zone Orange Roughy (*Hoplostethus atlanticus*, Collett 1889) uses an integrated stock assessment model implemented using the Stock Synthesis 3.3 software (SS3.30.07, a revision of the 3.24z version used previously). As in the last assessment it assumes a stock structure that combines the Eastern Zone (primarily St Helens Hill and St Patricks Head) and Pedra Branca from the Southern Zone (all seasons), because the Total Allowable Catch was set for this combination and needs updating. New data included since the previous stock assessment (Upston et al., 2015) are recent research and commercial catches; relative spawning biomass estimates from the 2016 acoustic towed surveys at St Helens Hill and St Patricks Head, a revised index of spawning biomass from the 2013 towed acoustic survey (which derived from a re-calibration of the survey gear), and new age composition data from catches taken in 2012 and 2016. In addition, further changes were made to the assessment and these were to include an extra recruitment residual in the analysis and a revised ageing error matrix. A new base-case was generated by adding each of these model changes and data streams sequentially to the previous final base-case assessment model to document the effect of each new source of information in a formal bridging analysis.

The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can lead to the acoustic biomass estimate differing from the biomass available to survey on average. The Francis (2011) data weighting method was applied, as is becoming standard practice, to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices and reduced weight to the age-composition data when the model was fitted. The other new data input was an updated ageing error matrix using data from the new ageing data from 2012 and 2016. This ageing error found no evidence of a major bias in the early age readings for Eastern Zone Orange Roughy.

An initial base-case model was developed that involved including recent catches, a new acoustic survey index from 2016, a revised acoustic survey estimate for 2013, new age composition data for 2012 and 2016, a new ageing error matrix, and an increase in the variability that the recruitment deviates could express. Unusual aspects of the model outcome include a pattern of recruitment that switches from predicted high levels of recruitment to low levels rising back up to predicted average levels about six years prior to the start of the fishery. This unusual pattern appears to derive from the extremely high fishing mortality rates imposed at the start of the fishery leading to a very rapid decline in available biomass. The model attempts to partially explain this rapid decline by implying the recruitment prior to fishing was lower than average. This effect should decrease as the time series of ageing data increases which will discount this effect.

The model estimates a continuing trend of recent increases in spawning biomass. The revised acoustic point estimates for 2013 (revised upwards) reduces the difference between the observed abundance and that predicted by the model and that, combined with the more recent 2016 estimate reinforces the estimates of recent increases in stock biomass.

After examination of the likelihood profiles around the fixed parameters of natural mortality (M) and the stock recruitment relationships steepness (h), a better fit and more plausible biological model was used as a final base-case that used an $M = 0.036$ rather than 0.04 and an $h = 0.6$ instead of 0.75. In the end after rebalancing of variances and

effective sample sizes this had only minor effects on the model fit to the data (although minor improvements did occur). However, the productivity of the model was reduced so that the implied increase in the stock between 2014 and 2017 was no longer so great and yet still constituted a 5% increase in stock biomass from about 25%B_0 to about 30%B_0.

Even though the model fits to the available data were reasonable the model remains uncertain with relatively wide confidence intervals the fitted data time-series and consequently around the median stock estimates. This reflects the uncertainties in the available data. The indices of abundance are variable with significant inter-annual variation in abundance estimates. The ageing data is intrinsically noisy, especially as the sample sizes are typical of SESSF fisheries but there are 80 year classes and samples of up to 600 fish still generate age-composition distributions with a very spiky appearance. Despite the limited data available the outcome from the model is relatively robust and stable although highly dependent upon the assumptions made about natural mortality and the steepness of the stock recruitment relationship (**Table 1**). Two base-cases were developed and presented. The first used a natural mortality of 0.04 and steepness of 0.75 (M=0.04, h=0.75) and the second less productive version used a natural mortality of 0.036 and steepness of 0.6 (M=0.036, h=0.6).

In both base-cases over-fishing was not occurring and neither was over-fished. In addition, in both cases the stock was continuing to recover. Where they did differ was in their current state of depletion with the two base-cases following a nearly parallel spawning biomass recovery trajectory with the more productive base-case being about 4% above the less productive case (**Table 1**). A dip in recruitment due to the severe depletion that occurred in the mid-1990s is predicted to have an impact of recovery rates from about 2025 onwards, slowing recovery until it starts to climb again in about 2051.

Applying the projected catches from one base-case into the other base-case enables a test of the potential risk of applying the catches from one model when the other model is more correct. However, according to the predictions made by the current assessment model (within the precision of estimates currently possible), any differences derived from applying either predicted RBC time series (or average) over the next three years would be difficult to distinguish from applying the correct catches. Prolonged application of the wrong catches would lead to either a cessation of recovery and on-going depletion from about 2027 should the higher catches be applied but the lower productivity model be more correct. Or, conversely, if the lower catches are applied to the higher productivity model then stock recovery would be speeded up and the target achieved possibly by 2050.

Table 1. The predicted RBCs (tonnes) from forecasting the initial base-case and the final base-case model forward under the 20:35:48 HCR.

Year	M=0.036, h=0.6	M=0.04, h=0.75
2018	709	1314
2019	776	1347
2020	834	1375
Average next 3 years	773	1345
MSY	1472	2314
Long term at 0.48B_0	1276	1784
Depletion start of 2017	0.298B_0	0.338B_0

1 Introduction

1.1 The Fishery

The three most recent stock assessments for Eastern Zone Orange Roughy (*Hoplostethus atlanticus* Collett 1889) were completed in 2006 (using data up to July 2006 and using an estimate of catch for calendar year 2006; Wayte 2007), in 2011 (using data up to December 2010; Upston & Wayte 2012a, b), and in 2014 (Upston et al, 2015), which used data up to the end of 2013 (**Table 2**). The stock defined in the 2014 base-case as 'Orange Roughy East' was primarily comprised of the St Helens Hill, St Patricks Head, and also Pedra Branca off the south of Tasmania. This stock structure was suggested by an Orange Roughy workshop held early in 2014, and is used in this assessment as management, including Orange Roughy Management Areas and TACs, have been set for this stock arrangement (AFMA, 2017).

The history of the fishery for Orange Roughy in the Australian Fishing Zone, can be found in CSIRO & TDPIF (1996), Bax (2000), Wayte (2007) and Upston et al. (2015). The important change for the Eastern zone described in the 2014 assessment was that the stock had rebuilt to have an estimated median estimate of female spawning depletion at the start of 2015 (SB_{2015}/SB_0) of approximately $0.25B_0$, which, being above the Commonwealth spawning biomass limit reference point (of $0.2B_0$), eventually led to a limited re-opening of the eastern fishery starting in 2015 with a three year TAC of 465 t (for the 2015, 2016, and 2017 seasons) in the Eastern zone with a further allocation of 35 t at Pedra Branca in the Southern Zone; this is in contrast with a 25 t TAC in 2014 (AFMA, 2017), of which only about 7 tonnes were caught. An Eastern Orange Roughy Management Area (ORMA) was declared along with a Pedra Branca ORMA (AFMA, 2017, p 83-84), and these declared the specific areas opened to fishing within the 700m deepwater closure.

The fishery had been closed to commercial fishing at the end of 2006 with Orange Roughy listed as conservation dependent using the 'Environment Protection and Biodiversity Conservation Act' (with the exception of a 500 t TAC for the Cascade Plateau Zone, whose stock was deemed to be above the biomass Target Reference Point). A 5-year conservation plan was put in place in 2007 and was reviewed in 2012/13 (AFMA, 2014). A workshop organised by AFMA (including NZ participants) was held at CSIRO Hobart in May 2014 to discuss the fishery and the then upcoming Eastern Zone Orange Roughy stock assessment, including the development of a potential base-case model specification. That workshop preceded the production of the 2014 stock assessment (Upston et al., 2015). That, in turn led on the production of this current stock assessment that aims to determine whether the Eastern zone Orange Roughy stock continues to recover and to meet the needs of setting the TAC for 2018 onwards.

1.2 Previous Assessments

Early stock assessments for the Eastern stock of Orange Roughy (Bax, 2000) used stock reduction analysis (Kimura et al., 1984) to generate plausible estimates of unfished biomass and current biomass and then considered the outcome of projecting the modelled stock forward under different TAC scenarios. Later stock assessments from after the start of the 2000's used relatively simple age-structured stock assessment models that were fitted using maximum likelihood methods and Bayesian approaches. In 2006 and onwards, fully integrated stock assessments using the stock synthesis software were conducted (**Table 2**), though their structure remained relatively simple.

Table 2. A summary of previous integrated stock assessment and their outcomes for Eastern Zone Orange Roughy. The year of assessment is usually the year after the final year of data collection, while the year listed under Authors is the year the assessment was more formally reported. B0 is the unfished female spawning biomass, except in 2011. The B_0 in 2011 is total biomass rather than just female spawning biomass. The RBC is the potential yield in the following year.

Year	Authors	B0 (t)	Depletion	RBC (t)
2001	Wayte & Bax (2002)			
2006	Wayte (2007)	40,746	$0.1B_0$	0 t
2011	Upston & Wayte (2012a) Upston & Wayte (2012b)	92,675*	$\sim 0.165B_0$	0 t
2014	Upston et al., (2015)	38,931	$0.25B_0$	381 t

1.3 Modifying the September 2017 Initial Base-Case

An initial base-case was developed for presentation to the SE RAG in September 2017 (Haddon, 2017), and this present document describes the changes made to that initial base-case following further exploration of sources of variation and the implications of the various assumptions regarding the biological properties affecting productivity. These adjustments derived mainly from conducted a series of likelihood profiles on parameters that have significant influence on the stock dynamics. Some exploration of the effects of the iterative re-weighting of the different data streams was also undertaken.

It is now standard practice in Australia, New Zealand, and at least the west coast USA to place more emphasis on any indices of relative abundance (standardized commercial CPUE and the trawl or acoustic survey indices; Francis, 2011) relative to the weight placed on age and length composition data. This relates to the proportional emphasis given to the different data streams available when fitting the model and, in this case, different arrangements can lead to different assessment outcomes in terms of estimates of female spawning biomass and depletion levels. The changes are described in a set different manipulations and changes to the old assessment (Haddon, 2017). For Orange Roughy East there are no length samples currently considered to represent a random sample from the whole stock. Although length data from the acoustic surveys are available they were not included in this assessment as what they represent still needs to be clarified before they can be usefully included.

1.3.1 BALANCING VARIANCES AND ADJUSTING BIASES

As adding significant amounts of new data can alter the relative contribution of different data sets within the model fitting process and thus disturb the apparent model outcomes (depletion and unfished biomass estimation, etc). SS3.3 now automatically balances the input variances of the survey data with those predicted by the model, but the age-composition data still requires rebalancing using the Francis (2011) weights in an iterative process outside of the model fitting process. At the final stage of the September base-case (basecase17) the input variance of the different sets of age composition data were re-balanced relative to the predicted variance until they all reached equilibrium to generate the initial base-case. Equilibrium in this case was taken to be changes in the variance multipliers or replacements of < 1.0%.

In addition, the model generates predicted deviations from the expected mean stock recruitment for each year in response to differences in year class strength from the ageing data and changes in the relative abundance indices. Being log-normally distributed these predicted values tend to be biased relative to actual values. Early in the time-frame used by the model to describe the fishery there is less information to inform the values of these predicted recruitment deviates and so any bias is expected to be lower, similarly towards the end of the time-series a ramping down of any bias is also expected (Methot & Taylor, 2011). The model variance balancing and bias adjustment of the recruitment deviates also involves changing the maximum recruitment variation (the so-called σ_R). Such changes in recruitment variability can be directional and to maintain biological plausibility are given pre-defined maxima and minima. With Orange Roughy the upper limit of 0.7 was required otherwise it would have continued increasing to implausible levels. The recruitment bias adjustment was deemed to have reached equilibrium when the changes were either < 1% or, with regard the estimates of in which years changes occurred absolute differences less than 0.75 of a year. While these thresholds are arbitrary any changes to the assessment become insignificant once the adjustments reach this minor degree of change in likelihoods. The key character being searched for is stability and such small thresholds lead to stability.

The transfer to Stock Synthesis 3.30.07 turned out to be both valuable (automating the variance balancing of the index data) and problematic (where the in-practice methods for balancing some of the data streams had changed and took both time, some experimentation, and interacting with the authors of SS3.3 in the USA to solve. Nevertheless, this is now streamlined and relatively straightforward in its application.

1.3.2 ESTIMATION OF RBC AND LONG TERM RBC

Once the final base-case is approved by the SE RAG (or valid modifications suggested) its dynamics are projected forwards for a large number of years (55 for Orange Roughy). This enable estimates of both the RBCs for the next few years, that would match the Commonwealth Harvest Control Rule for Tier 1 assessments, and usually would produce the long term RBC that would, at equilibrium, keep the stock to the MEY Commonwealth proxy target of 48%B_0 (DAFF, 2007). In the case of Orange Roughy 55 years were not enough for it to recover to $B_{48\%}$ so equilibrium surplus production estimates were used instead to estimate the long term yield.

In addition, it is standard to conduct sensitivity analyses on those parameters that are assumed to be fixed in the base-case assessment. These are conducted to provide a test of the structural assumptions made in the formulation of the assessment model. In the case of Orange Roughy East the parameters of interest include the natural mortality (M), the stock recruitment curve's steepness (h), and the length at which 50% of fish are selected (S_{50}). Rather than conduct sensitivity analyses where single values above and below the fixed value in the model, likelihood profiles are made to clarify the effects of these model parameters and determine whether they are having a major influence on the model fit or its outputs. These likelihood profiles highlighted concerns over some of the more important constants within the assessment leading eventually to biologically more plausible values to be used, although the selection of such constants remains in need of a detailed review.

2 Methods

2.1 Biological parameters

In the September 2017 original base-case (Haddon, 2017) the biological parameters were originally set the same as in Upston et al (2015); the estimated values are naturally rather different (**Table 3**) because of the new data included. Male and female Orange Roughy are assumed to have the same biological parameters except for their length-weight relationship (**Table 3**). In the absence of representative length data none of the four parameters relating to the Von Bertalanffy growth equation are estimated within the model-fitting procedure.

Table 3. The estimated and pre-specified model parameters for the Eastern Zone Orange Roughy preliminary base-case stock assessment (Sep 2017; Haddon 2017). The assumed stock structure includes the Eastern Zone (primarily St Helens Hill and St Patrick's Head) plus Pedra Branca from the Southern Zone. Normal priors are defined by N(mean, standard deviation). There is assumed to be no auto-correlation among the recruitment deviations. 82 parameters were estimated.

Estimated parameters	**Pars**	**Estimate**	**Prior**	**Source**
Unexploited recruitment; log(R0)	1	9.0773	N(9.3, 10)	Uninformative
Recruitment deviations 1905-1981	77		N(0, σ_R)	See section 5.3.2.1
Selectivity logistic inflection	1	35.456	N(35.0, 99)	Uninformative
Selectivity logistic width	1	1.0021	N(3.0, 99)	Uninformative
q Acoustic towed catchability	1	0.97659	N(0.95, 0.3)	Upston et. al. (2015)
q Hull catchability	1	1.68159	N(0.95, 0.9)	Upston et. al. (2015)
Fixed parameters		**Values**		
Recruitment steepness, *h*		0.75		Annala (1994) cited in CSIRO & TDPIF (1996)
Recruitment variability , σ_R		0.58		
Rate of natural mortality, *M*		0.04 yr^{-1}		Stokes (2009)
Maturity logistic inflection		35.8 cm		Estimated selectivity
Maturity logistic slope		-1.3 cm^{-1}		Smith et al. (1995)
Von Bertalanffy *K*		0.06 yr^{-1}		Smith et al. (1995)
Length at 1 year Female		8.66 cm		
Length at 70 years Female		38.6 cm		
Length-weight scale, *a*		3.51×10^{-5}	Female	Lyle et al. (1991)
		3.83 x 10-5	Male	
Length-weight power, *b*		2.97, 2.942	Female, Male	Lyle et al. (1991)
Plus-group age (years)		80		
Length at age CV for young		0.07		Estimated from data
Length at age CV for old		0.07		Expected offset from young
q egg survey catchability		0.9		Bell et al. (1992), Koslow et.al (1995), Wayte (2007)

Maturity is modelled as a logistic function, with 50% maturity at 35.8 cm. The assumption is made that the maturity would approximately match the selectivity as estimated on the spawning aggregations (which are assumed to be mature).

Fecundity-at-length is assumed to be directly proportional to weight-at-length, which is important for the estimation of the Spawning Potential Ratio, which can act as a proxy for fishing mortality; a requirement for the determination of stock status.

2.2 Available Data

No changes have been made to the data available since September 2017, however, tables and plots relating to the data are included here for ease of reference.

An array of different data sources are available for the Eastern Zone Orange Roughy assessment including catch (landings plus discards, which are minor and included in the catches), three indices of abundance (the egg estimate treated as an absolute abundance, while the two acoustic biomass estimates are treated as relative abundance indices), and age composition data from the acoustic surveys and on-board sampling (**Figure 1**). Length data collected form the acoustic surveys is now available now but was not included in this assessment and remain a possible option for future exploration.

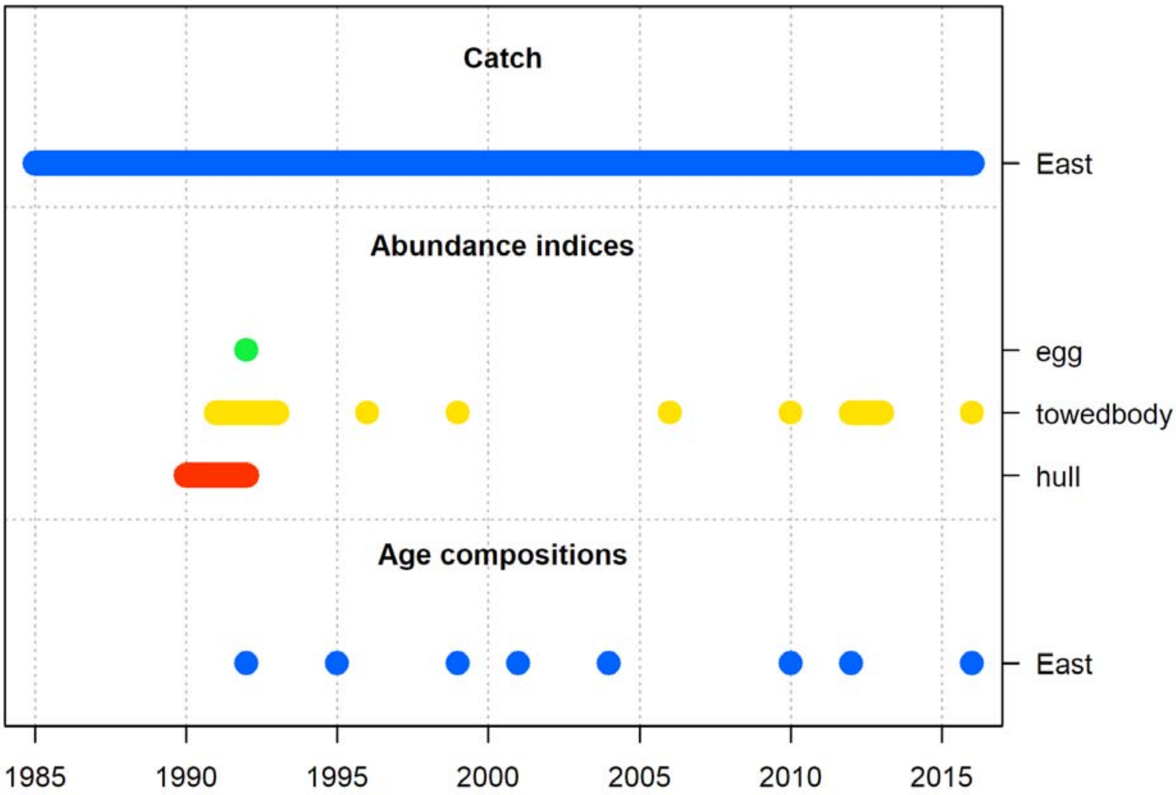

Figure 1. Data availability for Orange Roughy East by type and year. This illustrates the full data set as used in the basecase17 scenario.

2.3 Catches

Commonwealth Commercial logbook data for the years 1985 to 1991 and Catch Documentation Records for landings across the years 1992 to 2016 provide information on Orange Roughy retained catch in the SESSF (**Figure 2**; **Table 4**).

The Eastern Orange Roughy zone and Pedra Branca (**Figure 3**) catch history is used in the base-case assessment. The catch values reported originally have been adjusted as a result of estimates of burst bags and other initially unreported catches; Wayte (2007) provides details about how the catches from 1989 – 1994 were adjusted. The justification for these adjustments to the catch history leading to the “agreed” catch history are also given in CSIRO & TDPIF (1996) and descriptions of earlier stock assessments (for the years 1995, 1996 and 1997 – see Bax 1997, Bax 2000a and 2000b). The extreme catches that occurred during 1989 – 1993 (**Figure 2**) had a disruptive influence on the stock and such rapid changes are both difficult to model appropriately and add an extra source of uncertainty to the assessment.

In 2007 the quota year was changed from calendar year to the year extending from 1 May to 30 April, the assessment, however, continues to be conducted according to the calendar year as most catches occurred prior to 2007.

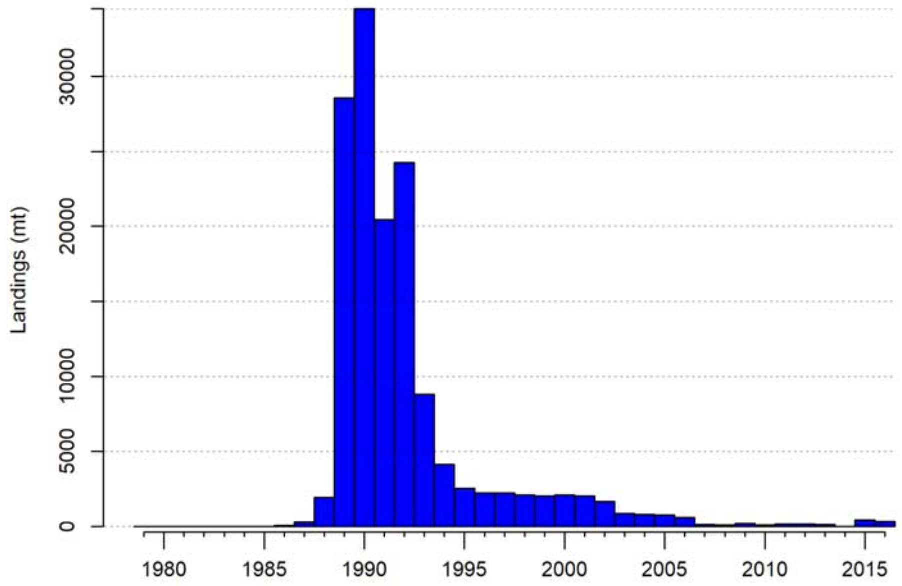

Figure 2. Total reported landed catch of Eastern Zone Orange Roughy 1985 - 2016; see **Table** 4).

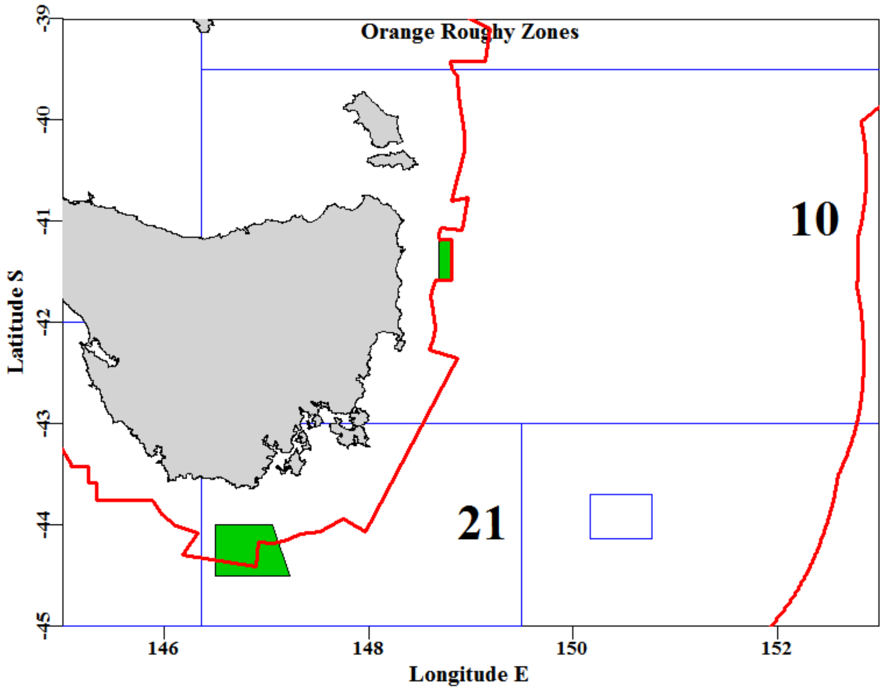

Figure 3. A sketch map of the Orange Roughy zones 10 (Eastern Zone) and 21 (part of Southern Zone) around Tasmania. The red lines denote the current definition of the 700 m deepwater closure and the green regions denote the Orange Roughy Management Areas for Pedra Branca in the south and the Eastern Orange Roughy Management Area in the north, encompassing both St Helen's Hill and St Patrick's Head. Some low catches also occur in other open areas but mostly in the green regions.

Table 4. Year agreed catches, in tonnes, of Eastern Zone Orange Roughy, where the Eastern Zone stock includes Pedra Branca (PB) from the Southern Zone. The starred years 1989 – 1994 (horizontal shading) denote catches that incorporate adjustments for the proportion lost due to lost gear and burst bags/ burst panels, other losses, and misreporting (CSIRO & TDPIF 1996; Wayte 2007). The shaded column has the catch history included in the Current Eastern Zone Stock Assessment.

Year	Reported	East Agreed	East+PB Agreed	PB Agreed
1985	6	6	6	0
1986	33	33	60	27
1987	310	310	310	0
1988	1949	1949	1949	0
1989*	18365	26236	28575	2339
1990*	16240	23200	34502	11302
1991*	9727	12159	20436	8277
1992*	7484	15119	24265	9146
1993*	1971	5151	8798	3647
1994*	1682	1869	4140	2271
1995	1959	1959	2544	585
1996	1998	1998	2231	233
1997	2063	2063	2250	187
1998	1968	1968	2087	119
1999	1952	1952	2052	100
2000	1996	1996	2109	113
2001	1823	1823	2027	204
2002	1584	1584	1674	90
2003	772	772	877	105
2004	767	767	797	30
2005	754	754	772	18
2006	614	614	615	1
2007	113	113	129	16
2008	98	98	98	0
2009	193	193	193	0
2010	113	113	113	0
2011	160	160	162	2
2012	163	163	163	0
2013	150	150	150	0
2014	7.4	7.3	7.3	0
2015	415	415.8	460.4	44.6
2016	345	340.3	360	19.7

2.4 Age composition data

Otolith samples with useable numbers of observations have been taken from spawning aggregations in 1992, 1995, 1999, 2001, 2004, 2010, 2012, and 2016. This has permitted the age-composition of the sampled stock to be estimated for both males and females. These are included in the assessment and are assumed to be simple random samples of the catch (Figure 4; and in Appendix A:Table 15). The age-compositions for St Helens Hill and St Patricks Head have been combined and weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (Wayte, 2007). The age samples for 1992 and 1995 are from St Helens only where the major proportion of the catch was taken (Upston & Wayte 2012a).

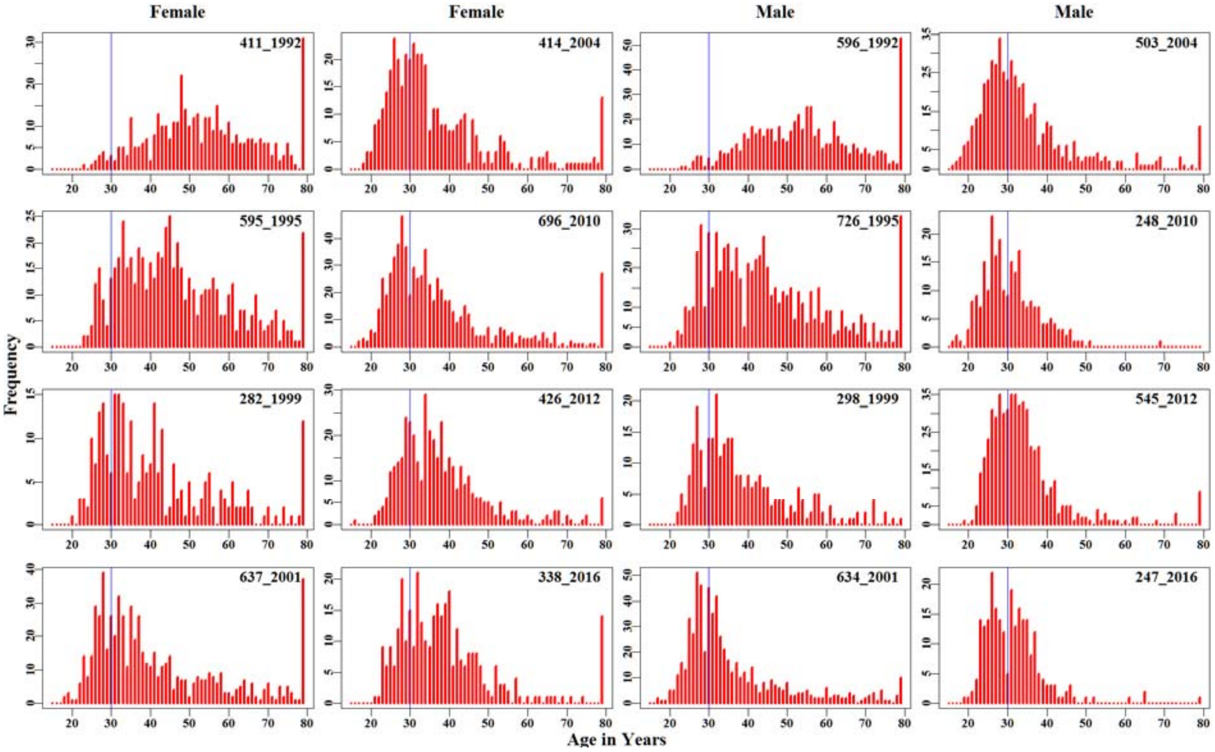

Figure 4. All currently available Eastern Zone Orange Roughy ageing data by year and gender. The vertical blue line identifies age 30 to aid comparisons. The numbers at top-right of each plot are the sample size and the year. The age-composition data (the frequency of fish at age) are detailed in **Table 15**. Note the large numbers in the plus group in different years, more so with the females than the males.

2.4.1 AGEING ERROR

Orange Roughy live for such long time that reading their otoliths is intrinsically difficult and the presence of ageing errors, made up of differences between readers and differences between years brought about by changing experience, is a real risk (Francis, 2006). Upston et al, (2015) describe an investigation of this potential risk. It is now standard practice to include an ageing error matrix into age-structured stock assessments (Francis and Hilborn, 2002), and this is used to adjust the observed distribution of ages in the model fitting process. An estimate of the standard deviation of age reading error was calculated from data supplied by Kyne Krusic-Golub of Fish Ageing Services (A.E. Punt, pers comm.). The estimate was updated from that used in the 2011 preliminary assessment, to include data from the new ageing data from 2012 and 2016 (the difference between the age error matrices was minor).

The age estimates are assumed to be unbiased but subject to random age-reading errors (Punt et al., 2008). Standard deviations for ageing error by reader have been estimated from the latest sets of age reading, producing the age-reading error matrix (A.E. Punt, pers. comm.; **Table 5**; **Figure 5**).

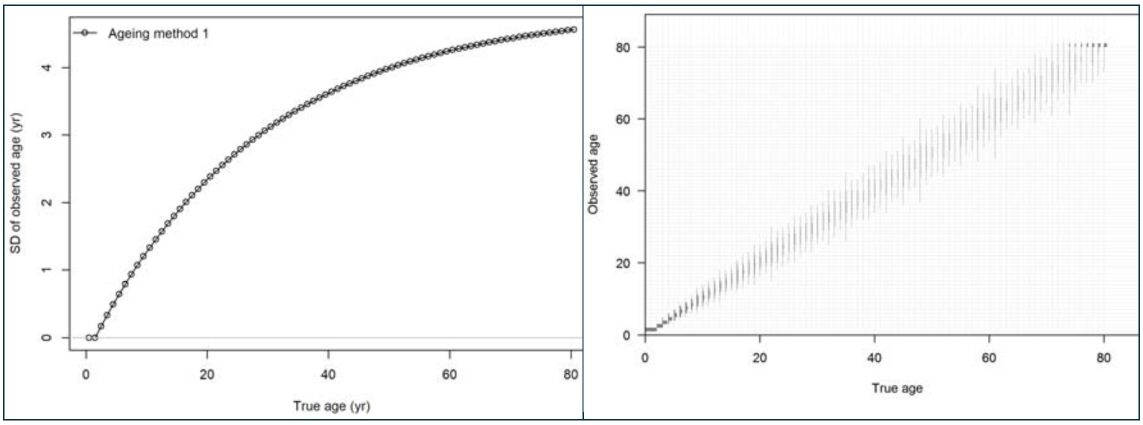

Figure 5. Two ways of viewing the increase in ageing error with age (see **Table 5**). The plot on the right illustrates the distribution of observed ages at the agreed true age (ageing error type 1). The plus group is set at 80 years and hence the truncation at the top of the matrix.

Table 5. The estimated standard deviation of normal variation (age-reading error) around age-estimates for the different age classes of Eastern Zone Orange Roughy.

Age	StDev.	Age	StDev.	Age	StDev.	Age	StDev.
0	0.0008	21	2.4719	42	3.7268	63	4.3217
1	0.0008	22	2.5553	43	3.7663	64	4.3404
2	0.1704	23	2.6357	44	3.8044	65	4.3585
3	0.3340	24	2.7133	45	3.8412	66	4.3759
4	0.4920	25	2.7881	46	3.8767	67	4.3928
5	0.6444	26	2.8604	47	3.9110	68	4.4090
6	0.7916	27	2.9302	48	3.9440	69	4.4247
7	0.9336	28	2.9975	49	3.9760	70	4.4398
8	1.0706	29	3.0624	50	4.0068	71	4.4544
9	1.2028	30	3.1251	51	4.0365	72	4.4685
10	1.3305	31	3.1856	52	4.0652	73	4.4821
11	1.4536	32	3.2440	53	4.0928	74	4.4952
12	1.5725	33	3.3004	54	4.1196	75	4.5079
13	1.6872	34	3.3548	55	4.1453	76	4.5201
14	1.7979	35	3.4073	56	4.1702	77	4.5319
15	1.9048	36	3.4579	57	4.1942	78	4.5433
16	2.0079	37	3.5068	58	4.2174	79	4.5543
17	2.1074	38	3.5540	59	4.2398	80	4.5649
18	2.2035	39	3.5995	60	4.2614		
19	2.2962	40	3.6435	61	4.2822		
20	2.3856	41	3.6859	62	4.3023		

Table 6. The number of observations made of the ages of the two sexes in different

Year	Female	Male
1992	411	596
1995	595	726
1999	282	298
2001	637	634
2004	414	503
2010	696	248
2012	426	545
2016	338	247

2.5 Acoustic survey abundance estimates

There are now ten estimates of relative abundance, for the St Helens Hill and St Patricks Head area, from the towed body acoustic surveys (**Table 7**). The CV estimates for the individual abundance estimates are initially used in the model fitting process, but when balancing the output variability with that input, these values are slightly modified.

Table 7. The three abundance indices used in the Eastern Zone Orange Roughy assessment. Values up to 2012 were sourced from Upston et al (2015). The original 2013 Towed acoustic survey value was increased by 18% as a result of a recalibration of the equipment (Kloser, pers. comm), and the 2016 estimate is from Kloser et al, (2016). DEPS is the daily egg production survey. The DEPS is treated as an absolute abundance estimate while the others are treated as relative abundance indices.

System	**Year**	**Biomass**	**CV**	**Catchability**
Hull	1990	120239	0.63	N(0.95, 0.92)
Hull	1991	71213	0.58	N(0.95, 0.92)
Hull	1992	48985	0.59	N(0.95, 0.92)
Towed	1991	59481	0.49	N(0.95, 0.3)
Towed	1992	56106	0.50	N(0.95, 0.3)
Towed	1993	22811	0.53	N(0.95, 0.3)
Towed	1996	20372	0.45	N(0.95, 0.3)
Towed	1999	25838	0.39	N(0.95, 0.3)
Towed	2006	17541	0.31	N(0.95, 0.3)
Towed	2010	24000	0.25	N(0.95, 0.3)
Towed	2012	13605	0.29	N(0.95, 0.3)
Towed	2013	14368*	0.29	N(0.95, 0.3)
Towed	2016	24037	0.17	N(0.95, 0.3)
DEPS	1992	15922	0.50	0.9 (fixed)

2.6 Stock Assessment

2.6.1 POPULATION MODEL AND PARAMETER ESTIMATION

A two-sex stock assessment for Eastern Zone Orange Roughy has been implemented using the software package Stock Synthesis (SS, previously version 3.24z was used now this has been updated to version 3.3; Methot and Wetzel, 2013, Methot et al, 2017).While it is a two-sex model, differences by gender are restricted to weight at length, which, along with the age data being separated by gender, is used to inform the relative biomass of each gender. Spawning biomass, and its depletion levels is thus able to be presented as female spawning biomass. Stock Synthesis is a statistical age- and length-structured model that can be used to fit the various data streams now available for Eastern Orange Roughy simultaneously. The population dynamics model, and the statistical approach used in the fitting of the model to the various types of data, are described in the SS operating manual (Methot et al, 2017) and the more technical description (Methot and Wetzel, 2013) and these are not reproduced here.

A single stock of Orange Roughy was assumed to occur across Orange Roughy zone 10 and 21 (where 21 is the eastern half of the southern zone; **Figure 3**). The stock was assumed to have been unexploited prior to 1985, initial catches from 1985 – 1987 were relatively minor. The input CVs of the catch rate index and the biomass survey were initially set to the survey estimates (**Table 7**), while the CVs for the catches were set to 0.05, which is effectively an arbitrary small value as catches are assumed to be known without significant error.

The selectivity pattern for the trawl fleet was modelled as constant through time; although this may change in the future as recent (2016) catch data indicates that the fishery is now spreading across the year rather than being focussed in the spawning season of June - August. This change in fishing behaviour has importance because the modelled selectivity is a combination of both the selectivity of the fishing gear combined with the properties of the fish available to that gear, which will change through the year, so this may need attention in future assessments. Both selectivity-at-length parameters were estimated within the assessment. It is also possible that the availability (which affects selectivity in the model) may be better modelled by time blocking the early years of the fishery to allow for larger older fish to be more available. This was deemed suitable for future work, and may help address some unusual aspects of the recruitment patterns exhibited by the model.

The rate of natural mortality, M, was assumed to be constant with age, and also constant through time. The natural mortality rate is fixed in the initial base-case analysis to be the same as that used in 2014 (**Table 3**) but after the likelihood profiles was changed to 0.036 (**Table 11**).

Recruitment was assumed to follow a Beverton-Holt type stock-recruitment relationship, parameterised by the average recruitment at unexploited spawning biomass, R_0, and the steepness parameter, h. Steepness for the initial base-case analysis was assumed to be 0.75. While changing steepness had little effect on the model fit it was very influential on the productivity and in the final base-case a steepness of 0.6 was used as being biologically more plausible. Like the natural mortality the value of this constant requires further more detailed review.

Deviations from the average recruitment at a given spawning biomass (recruitment deviations) were estimated from 1905 – 1980 in the last assessment, with only one extra year being included in this assessment; more were attempted but their estimation proved too uncertain and were dropped. The value of the parameter determining the magnitude of the potential variation in annual recruitment, σ_R (SigmaR) was initially set equal to 0.58. During the rebalancing of variances (Methot and Taylor, 2011) the model continued to suggest increasing the SigmaR value so it could have increased well above 0.7, which was set as an upper limit. This has the appearance of very high variation, which intuitively seems inconsistent with the long-term, inherently stable biology of Orange Roughy. However, the recruitment dynamics derive from the model exhibiting an unusual large rise implied for the years prior to exploitation. These large positive deviations arise as the model attempts to account for the extremely high catches taken across the early years 1989 - 1993. The recruitment deviates for more recent years cannot be estimated well because it can take decades for larval fish to grow and enter the fishery. Hence, it can take 30 - 40 years before information about relative recruitment levels becomes available to the model.

Age 80 is treated as a plus group into which all animals predicted to survive to ages greater than 80 are accumulated. Growth of Orange Roughy was also assumed to be time-invariant, that is there has been no change over time in the expected mean size-at-age, with the distribution of size-at-age being determined from the prescribed values entered as fixed values into the model. The potential for age-reading errors (Punt *et al.*, 2008) is accounted for within the model by the inclusion of an age-reading error matrix (**Table 5**).

2.6.2 ITERATIVE REWEIGHTING OF DATA VARIANCES

Iterative rescaling (reweighting) of input and output CVs or input and effective sample sizes is a repeatable method for ensuring that the expected variation of the different data streams predicted by the assessment model is comparable to what is input. Most of the indices (CPUE, surveys, age- and length-composition data) used in fisheries underestimate their true variance by only reporting measurement or estimation error and not including process error (e.g. between year and between area variation). With composition data an important source of variation occurs because samples are necessarily limited in their coverage across the fishery and fish caught together in the same shot are often more similar to each other (in terms of age or length) than samples from separate shots. Often such total samples have a lower variance than expected in the stock assessment model. Iterative re-weighting is the process used to adjust for such self-correlated sampling. With composition data (ages, lengths, or conditional age-at-length) this adjustment entails reducing the apparent sample size, which increases the variance of the sample (when the multinomial statistical distribution is used to describe the proportional distribution of data among age or length classes, the larger the sample the smaller the variance). This is what is meant in discussions of reducing the ‘effective sample size’. In iterative reweighting, the effective annual sample sizes are tuned/adjusted so that the input sample size was equal to the effective sample size calculated by the model (the multinomial variances are matched).

In SS3.3 there is now an automatic adjustment made to survey or CPUE CVs enabled through selecting a particular option in the control file. The process used for Orange Roughy East in SS3.3 entailed the following steps:

1. set the standard error for the relative abundance indices (CPUE, acoustic abundance survey, or FIS) to their estimated standard errors for each survey (**Table 7**), or for CPUE and FIS values to the standard deviation of a loess curve fitted to the original data (which will provide a more realistic starting estimate to that obtained from the original statistical analysis. Software procedures within SS3.3 then adjust the relative abundance variances appropriately (by adding to, or more rarely subtracting from, the input standard deviation or CV).

   The present standard is to apply the Francis weighting procedure (Francis, 2011), which has three guiding principles:

   1. do not let other data stop the model from fitting abundance data well;

2. when weighting age or length composition data, allow for correlations; and
3. do not down-weight abundance data because they may be unrepresentative.

An automated tuning procedure was used for the remaining adjustments. For the recruitment bias adjustment ramps:

4. adjust the recruitment variance (σ_R) by replacing it with the RMSE or a defined set minimum or maximum (in the final base-case the maximum was set to 0.7) and iterating to convergence (keep altering the recruitment bias adjustment ramps as predicted by SS3.3 at the same time). A set maximum was necessary because in an attempt to account for the unusual early predicted rise in recruitment the assessment continually recommended larger and larger values for σ_R.

Finally for the age and length composition data:

5. multiply the initial samples sizes by the sample size multipliers for the age composition data using Francis weights (Francis 2011) generated by the R4SS package.
6. similarly multiply the initial samples sizes by the sample size multipliers for the length composition data (not needed with Orange Roughy East).
7. repeat steps 4 to 6, until all are converged and stable (proposed changes are < 1 – 2%).

This procedure may change in the future after further investigations but constitutes current best practice (see Results section). Future assessments may use the Dirichlet distribution (named after Dirichlet, a German mathematician who died in 1859) rather than the multinomial distribution to describe composition data (it is in fact, a conjugate prior of the multinomial distribution). This has the advantage that the effective sample size should no longer be a problem.

2.7 Estimate RBC through Forecasting the Model Forward

To estimate the RBC for the next few years (assuming a multi-year TAC) requires the optimally fitting model to be projected forward a number of years. In addition, if the likely long-term yield is also wanted for future planning then the projection needs to go forward a large number of years. Here a projection of 55 years from 2018 onwards was used during which the usual 20:35:48 Tier 1 harvest control rule (HCR) was applied. The 20:35:48 format, starting from the right hand side implies a 48% target reference point above which a constant fishing mortality ($F_{48\%}$) is applied. The 35% is where the change in fishing mortality with changes in stock size is altered, below 35% the fishing mortality is dropped below the $F_{48\%}$ while above the 35% fishing mortality is fixed at the maximum, finally there is the 20% limit reference point after which no targeted fishing occurs. The origin of the 20:35:48 HCR is described in Day (2009).

Once completed the predicted catches that if taken would project the dynamics along the expected biomass recovery trajectory can be read from the output files.

Because the year 2017 is not complete the total catch within that year is unknown so it was assumed that 465 t would be taken in 2017 even if that turns out not the case.

3 Results

3.1 The Initial Base-Case Analysis

Details of the September initial base-case are given in Haddon (2017), however, in summary the median female spawning biomass was estimated as being recovered to a level of about 33%B_0, although this includes the assumptions about natural mortality, steepness, and other structural assumptions (**Figure 6**; Haddon, 2017).

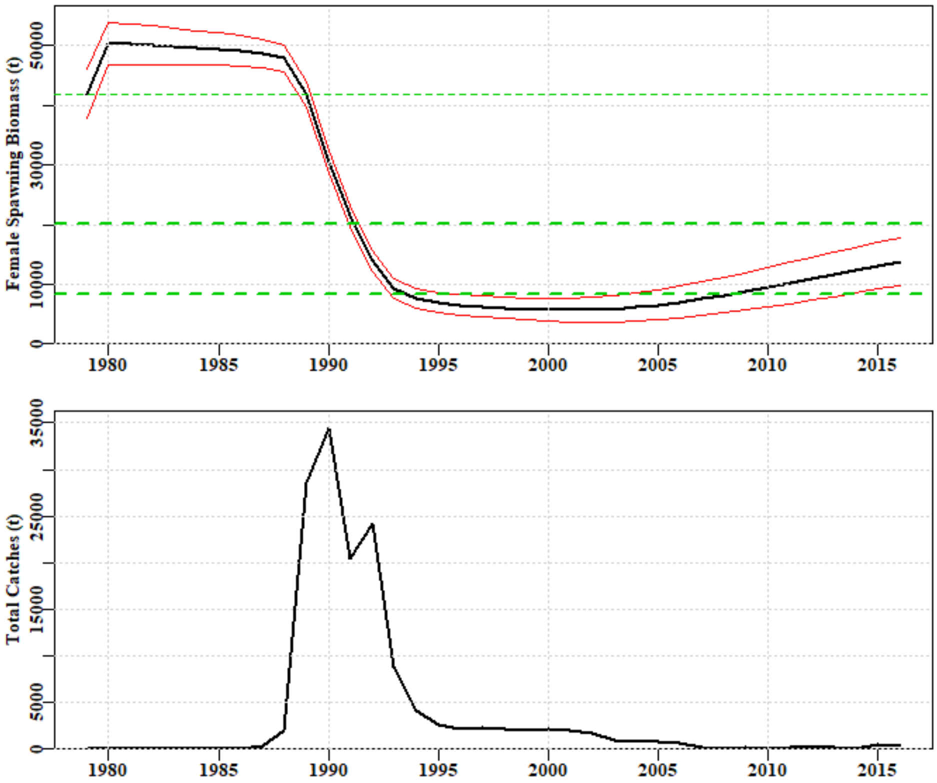

Figure 6. The predicted female spawning biomass (top plot) with its 95%CI based on asymptotic standard errors, compared with the limit and target biomass reference points for Eastern zone Orange Roughy. The bottom plot allows a comparison of the biomass trajectory with the catch removals through time.

3.1.1 FISHING MORTALITY

In addition, using the relationship between *F* and 1-SPR it is possible to plot an approximation to the classical Kobe phase plot with B_{year}/B_{target} on the x-axis and $(1-SPR)/(1-SPR_{48\%})$ on the y-axis (as a proxy for fishing mortality relative to the target fishing mortality; **Figure** 7).

Such a phase plot (**Figure** 7) suggests that the stock is still below the biomass target (although above the limit) biomass reference point and so is not over-fished. At the same time it is below the $(1-SPR_{48\%})$ target and so it can be claimed that over-fishing is not occurring.

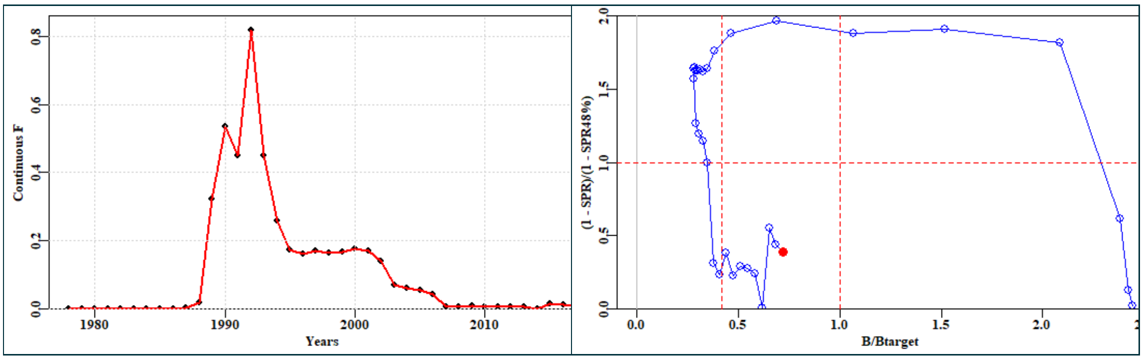

Figure 7. Plots of the instantaneous fishing mortality rate and the Spawning Potential Ratio as the complement of the SPR as a ratio with the expected (1-SPR) at a depletion of $0.48B_0$, which acts as a proxy for fishing mortality. The horizontal dashed line indicates the target fishing mortality SPR proxy, and the two vertical dashed lines are the target biomass and limit reference points.

3.2 Iterative Re-weighting

3.2.1 AGE-COMPOSITION DATA

The relative weights attributed to the different data sets, which in Orange Roughy East are limited to the different indices of abundance (egg-estimate, hull-mounted acoustic estimates, and tow-body acoustic estimates) and the age samples taken from the fished aggregations. The iterative re-weighting the indices of abundance are now conditioned automatically within SS3.3 so there is only the age-composition data to work with (**Table 6**). The effect of the iterative re-weighting can be seen by comparing the relative fits to the data streams and recruitment residuals (**Table 8**).

Table 8. Statistics from each iteration of the Orange Roughy East initial base-case assessment model in which the effective sample size of the age-composition data was reduced sequentially until all changes in the likelihoods were reduced to within less than 1% of the previous iteration. A postfix 'L' implies a likelihood, the other rows are derived statistics. The multiplier is applied to derive the effective sample size.

Statistic	Iteration 0	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Priors L	1.2104	0.2099	0.1989	0.1970	0.1965
Softbounds L	0.0103	0.0073	0.0073	0.0073	0.0073
Catch L	1.11E-09	1.64E-10	1.48E-10	1.44E-10	1.43E-10
TOTAL L	877.2390	38.5853	40.6316	39.1266	38.9495
Survey L	-10.0348	-10.1655	-10.0682	-10.0732	-10.0778
Age_comp L	866.5760	46.7998	46.1524	44.8979	44.6976
Recruitment L	19.4772	1.7338	4.3412	4.0976	4.1259
Multiplier	1	0.04803	0.04697	0.04555	0.04530
Depletion	0.3035	0.3297	0.3388	0.3388	0.3388
B_0	36582	42182	41585	41606	41591
1-SPR	0.217	0.186	0.187	0.187	0.187

The re-weighting which moves from naïve use of sample sizes as effective sample sizes to an optimized and balanced variance (see methods) has a clear and marked effect on the estimates of B_0 and the depletion level. The de-emphasis of the age-composition data led to a shift from 30.4%B_0 to 33.9%B_0.

The first suggested adjustment from the original starting point (iteration 0) to iteration

1, made the largest and most significant change to the likelihoods and derived statistics, while the following changes made relatively minor changes in iteration three and four relative to that in iteration 1. When the relative fits to the age-composition data are examined for each year and sex (**Figure 8**) the most marked differences were in the years 1992 and 1995. In the other years there were minor changes primarily around the peak of observations.

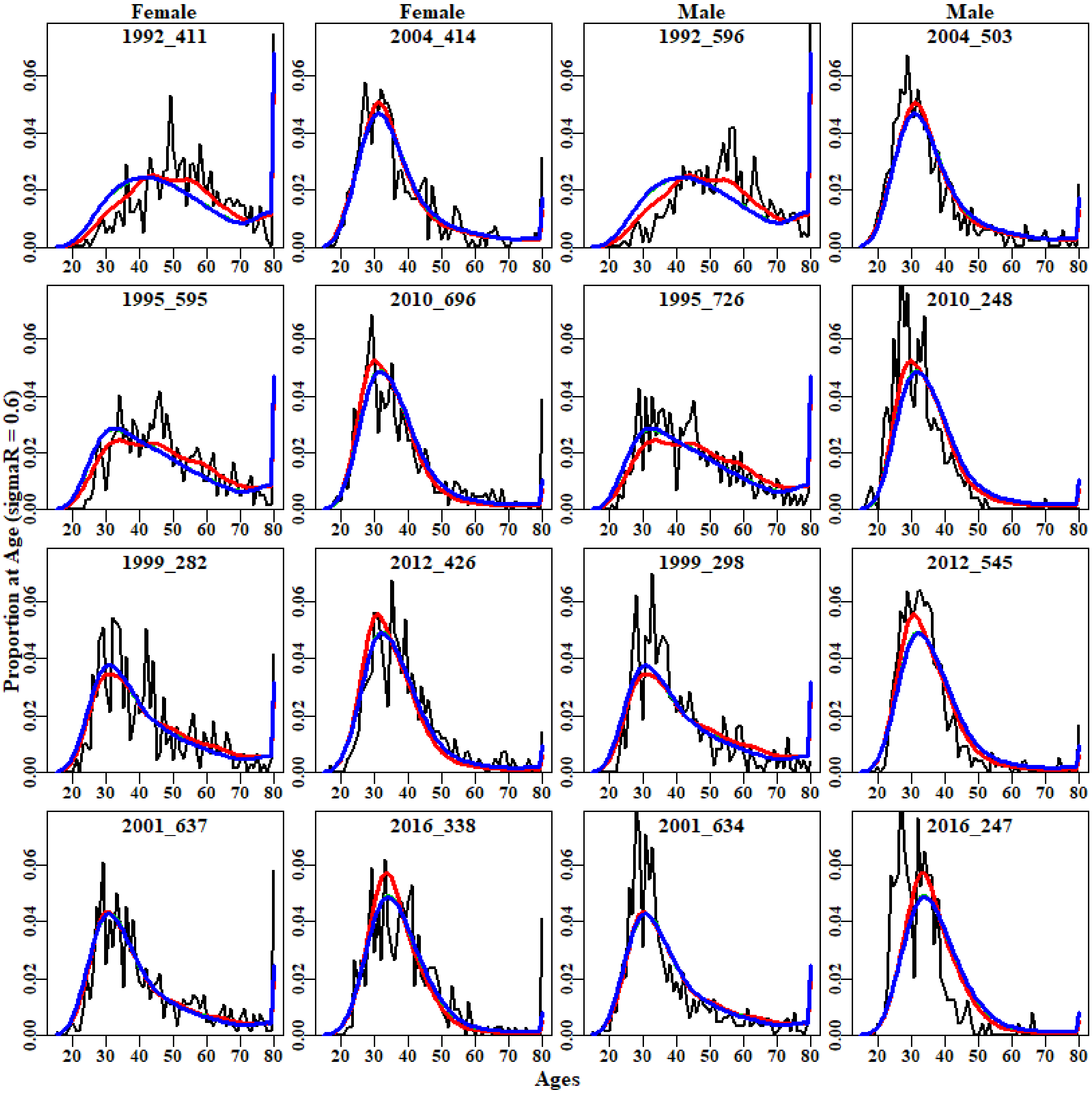

Figure 8. A comparison of the expected age-composition from the five stages of the iterative re-weighting process. The black lines are the observed data, the red line is the starting point for the re-weighting process and green and blue lines (essentially on top of each other) represent the third and fifth (final) iteration steps. The spikiness of the observed data derives from there being so many ages classes with sample numbers ranging from about 250 – 726. The legends include the year and original sample size.

In some years, however, for example in 1999 and 2001, only minor changes occur. In other years differences are more obvious although visually it is not always clear which is a better fit; the great noisiness of the data makes visual comparisons especially difficult. In 1995 males the revised predicted ages appear to find more of the observations but the original fits in 1992 and 1995 females are clearly closer to more data points than the later fits. The fit to the 2016 males mimics that to the 2012 males but ignores an apparent mode of fish from 25 – 30 cm. Whether this is a reflection of the relatively small sample size or some other aspect of un-representative sampling is unknown. The difference between males and females in 2016 is marked with females having many more fish older than 40 years, but given reports of Orange Roughy schools not being well mixed by sex such differences between males and females should not be unexpected.

3.2.2 RECRUITMENT DEVIATES

That the quality of fits to age-composition declines when the effective sample size is reduced is not surprising, what is surprising is that the fits in some of the years barely change. Unfortunately, the Orange Roughy East age-composition data is relatively noisy, which is a direct reflection of the sample sizes. Such sample sizes (**Table 6**) would usually provide a representative age-composition for many species but with 80 year classes such numbers will only ever provide noisy age distributions. This is also apparent in the variation visible in the plus-group (age 80) counts, as well as in the differences between the age distributions of the females and males (**Figure 4**). The predicted age-composition data will generally be a smoothed version of what is observed, but such noisy age-composition observations can still influence the predicted recruitment dynamics (**Figure 9**).

If the age-composition data are given a great deal of weight (which they are when their observed sample sizes are treated as their effective sample sizes) then anomalies such as the spike of recruits in 1937 can occur as well as the bumps up and down in the 1930s, the 1950s, and the 1970s. However, once the weighting on the age-composition is reduced then the recruitment deviates become less variable even though they retain the unusual pattern of a sequence of elevated recruitment followed by a sequence of reduced recruitment all before any fishing began.

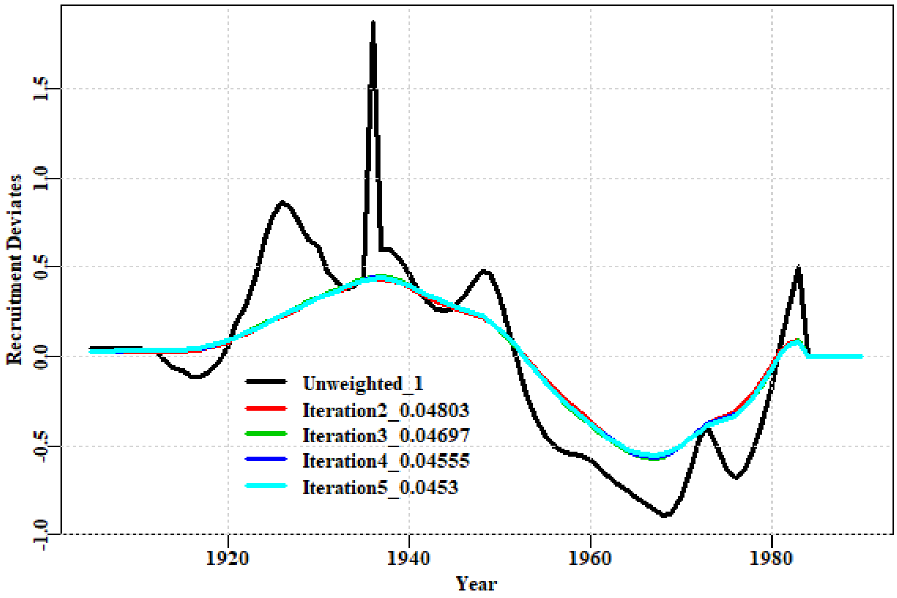

Figure 9. The recruitment residuals from each iteration of the re-weighting process. The black line is from the initial state where the age-composition data is given its maximum weight of 1.0.

3.2.3 INDICES OF ABUNDANCE

Within integrated assessments altering the relative weighting attributed to one data series, such as the age-composition data, influences the fits to other data series at the same time. In the case of the indices of abundance the relative fit to each series does indeed alter but not in a simple manner. The fit the egg-production estimate improves with down-weighting the age-composition data. Out of 10 towed body biomass estimates four were improved by changing the age-composition weighting while six became worse, whereas with the hull mounted estimates two improved while one became worse.

The relative model fits in the original base-case (and the final base-case) require relatively wide confidence intervals around the acoustic spawning biomass survey estimates to obtain an adequate model fit (**Figure 11**). These bounds encompass the differences in model fit exhibited following the application of variance re-weighting (**Figure 10**).

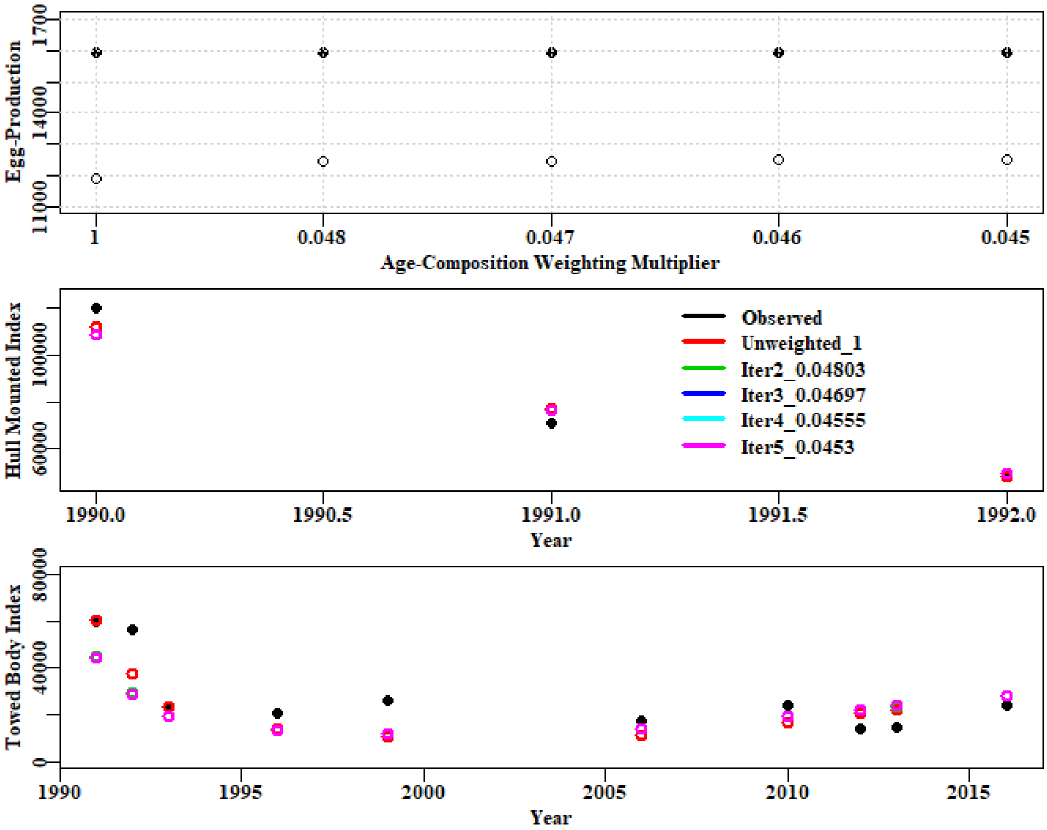

Figure 10. The effect of altering the weighting allocated to the age-composition data on the fits to the indices of abundance.

Table 9. The predicted CPUE/indices relative to the observed indices from the daily egg production estimate, the hull mounted and towed body estimates. For each of the different relative weightings ascribed to the age-composition data. The optimum fit in each case is highlighted in yellow, although the differences between the predicted values for the different age-composition weightings that are < 1 is generally only a tiny proportional change.

Index	Year	Observed	1	0.04815	0.04296	0.04061	0.03996
egg	1992	15922	11867	12441	12470	12476	12477
towed	1991	59481	60258	45149	44398	44283	44263
towed	1992	56106	37298	29166	28764	28708	28701
towed	1993	22811	23336	19441	19248	19229	19229
towed	1996	20372	14060	13539	13504	13518	13522
towed	1999	25838	10740	11894	11935	11966	11974
towed	2006	17541	11062	13910	14064	14102	14117
towed	2010	24000	16753	19048	19202	19223	19231
towed	2012	13605	20314	22031	22155	22166	22168
towed	2013	14368	22197	23571	23674	23679	23678
towed	2016	24037	27866	28102	28110	28099	28090
hull	1990	120239	111953	108935	108720	108674	108658
hull	1991	71213	77245	76549	76506	76495	76492
hull	1992	48985	47812	49451	49566	49592	49600

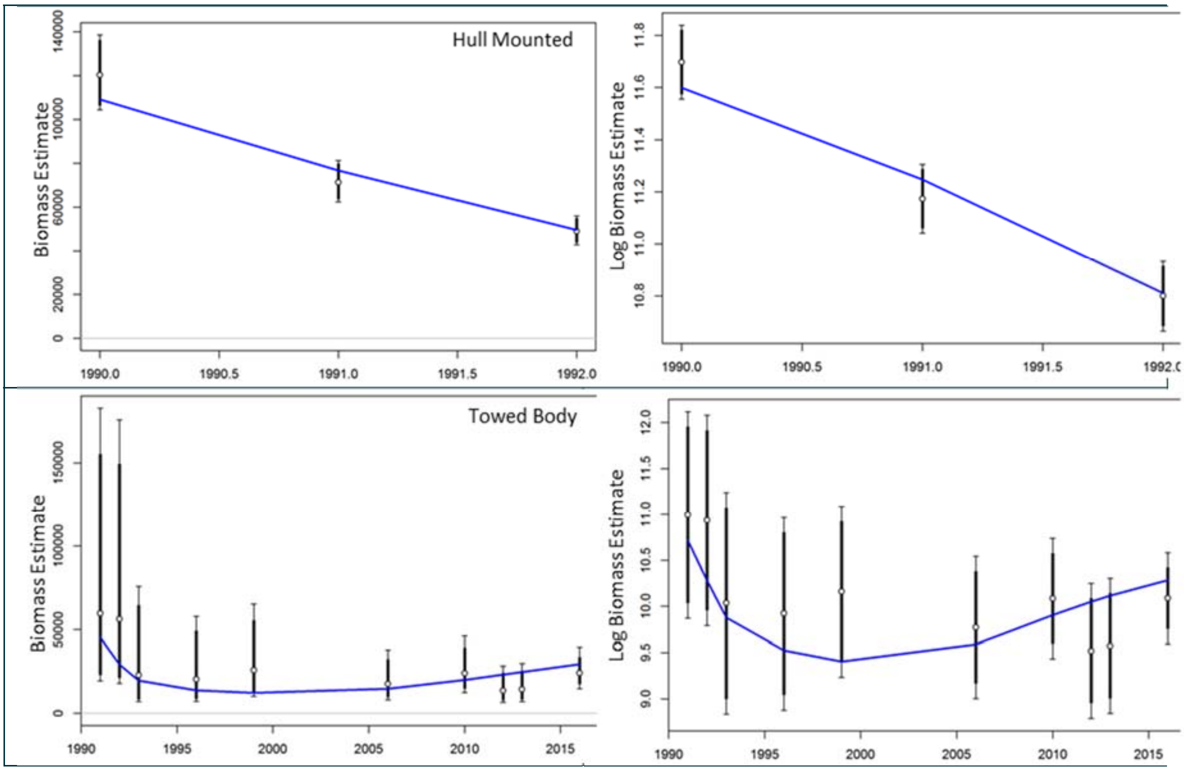

Figure 11. The balanced initial base-case model fit to the hull mounted acoustic survey indices (top panels) and the towed body acoustic surveys (bottom panels), each acts as an index of relative abundance. The plots on the right are of the natural-log Indices because log-normal residual errors were used to fit the model to the abundance index data. The thicker lines are the input variances and the thinner lines with the caps denote the additional variance required to optimize the model fit to the index data.

3.3 Likelihood Profiles

Rather than conduct sensitivity analyses on natural mortality, steepness, and selectivity characteristics, which are currently fixed parameters within the model, there are advantages to generating likelihood profiles for each so as to characterize how the model would perform across a given range of values for each parameter rather than just two or three. The basic idea behind generating a likelihood profile is to fix a given parameter at an array of different values and for each value repeat the model fitting so that all the other fitted parameters can be optimized under the constraint of the new value for the parameter that has been fixed. Such profiles were generated for natural mortality M, the stock recruitment relationship steepness value, h, and the size at 50% selectivity, $S50$.

3.3.1 NATURAL MORTALITY

Following Upston *et al.* (2015) natural mortality in the initial base-case assessment (Haddon, 2017) was fixed at 0.04. It is recognized that Orange Roughy is a long lived species with reports of fish living to ages between about 90 – 190 years (FAO workshop on Orange Roughy, Auckland, New Zealand, June 6 – 10, 2016; the original draft report Tingley, In Prep). In New Zealand, generally, a value for M of 0.045 is now used in stock assessments, but other estimates cited in Tingley (In Prep) include 0.045 (0.03 – 0.06), and 0.037 (0.025 – 0.062) from New Zealand, between 0.03 – 0.058 in Chile, and between 0.025 to 0.045 in the Northeast Atlantic. Values used for natural mortality have also varied in stock assessments of different areas within Australia with a minimum value of 0.02 being used for the Cascade Plateau (Wayte and Bax, 2007) and a maximum value of 0.042 being used by Wayte (2007) for the Eastern Zone Orange Roughy. Stokes (2009) recommended that 0.04 be used consistently across Australia, although made allowances for particular cases to be made.

A likelihood profile was generated across values of M from 0.023 up to 0.047 in steps of 0.001 (**Figure 12**). The total likelihood exhibits a minimum at 0.032 rather than closer to the assumed value of 0.04. This minimum is driven by the different trends expressed by the age-composition data likelihoods and those deriving from the index data and the recruitment deviates. The age-composition data likelihoods exhibit a minimum at M = 0.039 whereas both the index and the recruitment deviate likelihoods exhibit steady declines with minima at the smallest value of M used (0.023; **Table 10**).

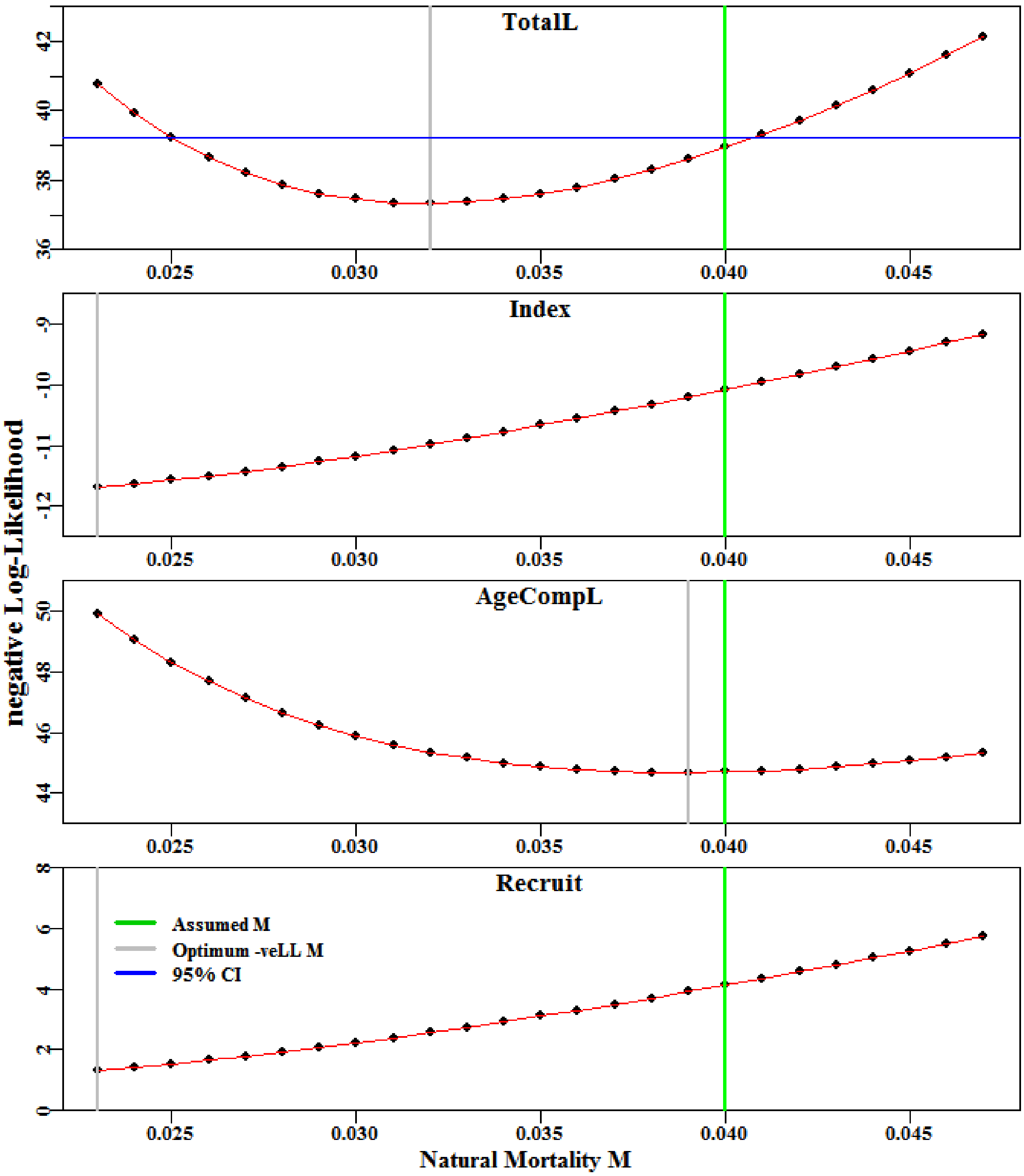

Figure 12. Likelihood profiles on natural mortality for values of *M* from 0.023 to 0.047 in steps of 0.001. The top plot illustrates the effect on the total likelihood (the sum of the three likelihoods below plus some other very minor contributions), and the three plots below that illustrate the three main components of that total likelihood. The blue horizontal line depicts a likelihood equal to the minimum + 1.92, which provides approximate 95% confidence intervals. The grey lines in each case denote the *M* value corresponding to the minimum likelihood for each series and the green lines depict the current assumed *M* value. The four plots all have different vertical scales.

The question arises whether the value assumed for natural mortality in the stock assessment should be changed. The value used (0.04) is very close to the approximate 95% confidence bounds (Venzon and Moolgavkar, 1988; Haddon, 2011) and the previous value assumed for *M* of 0.042 (Wayte, 2007) is above the 95% confidence limits. The shift to 0.04 from 0.042 in Upston et al (2015) would appear to have been a minimum reduction and a further reduction would appear to be appropriate given the fact that the confidence bounds in **Figure 12** only approximate those based on asymptotic standard errors and the true intervals are likely to be wider.

Moving the assumed value of *M* to that corresponding to the minimum of the Total Likelihood is an option especially since the analysis has other sources of uncertainty with the assessment outcomes and implications being significantly influenced by the stock recruitment steepness value, and the SigmaR value that constrains the variability of the recruitment residuals. Both the age-composition data and the indices of abundance are variable as illustrated by the spikiness of the age-composition values relative to the predicted age-composition values (**Figure 8**), and the broad 95% confidence intervals of the difference abundance indices (Haddon, 2017).

Table 10. The outputs from conducting a likelihood profile on natural mortality, *M*. Depletion, B_0, and 1-SPR are all derived statistics while the other four columns are the total likelihood and the three main components. The minimum likelihood value in each case is highlighted in yellow.

M	Depletion	B_0	1-SPR	TotalL	Index	AgeCompL	Recruit
0.023	0.189	44540	0.2713	40.7829	-11.6812	49.8850	1.34092
0.024	0.198	44197	0.2648	39.9365	-11.6316	49.0409	1.42943
0.025	0.207	43880	0.2586	39.2385	-11.5726	48.3062	1.53304
0.026	0.216	43587	0.2526	38.6716	-11.5056	47.6681	1.6498
0.027	0.225	43318	0.2469	38.2213	-11.4314	47.1157	1.7781
0.028	0.233	43071	0.2413	37.8748	-11.3510	46.6396	1.91665
0.029	0.242	42847	0.236	37.6214	-11.2652	46.2315	2.06439
0.03	0.251	42644	0.2309	37.4515	-11.1744	45.8845	2.22043
0.031	0.26	42461	0.2259	37.3569	-11.0793	45.5921	2.38408
0.032	0.269	42298	0.2211	37.3305	-10.9802	45.3490	2.55473
0.033	0.278	42154	0.2164	37.3659	-10.8774	45.1502	2.73188
0.034	0.287	42029	0.2119	37.4576	-10.7714	44.9915	2.91513
0.035	0.295	41921	0.2075	37.6006	-10.6623	44.8691	3.10412
0.036	0.304	41831	0.2032	37.7906	-10.5504	44.7797	3.29854
0.037	0.313	41758	0.199	38.0238	-10.4358	44.7204	3.49815
0.038	0.322	41701	0.1949	38.2967	-10.3187	44.6884	3.70271
0.039	0.33	41660	0.1909	38.6062	-10.1993	44.6815	3.91201
0.04	0.339	41634	0.187	38.9495	-10.0778	44.6976	4.12586
0.041	0.347	41623	0.1832	39.3242	-9.95409	44.7347	4.3441
0.042	0.356	41627	0.1795	39.7279	-9.82844	44.7913	4.56655
0.043	0.364	41645	0.1759	40.1588	-9.7009	44.8658	4.79304
0.044	0.373	41677	0.1723	40.6148	-9.57154	44.9570	5.02343
0.045	0.381	41723	0.1689	41.0945	-9.44045	45.0635	5.25755
0.046	0.389	41782	0.1654	41.5961	-9.30769	45.1845	5.49524
0.047	0.397	41855	0.1621	42.1184	-9.17333	45.3189	5.73634

With a maximum observed age of 162 in the Eastern zone stock (**Figure 13**) it may be that the current assumed value of 0.04 may be implying too high a productivity. Rather than reduce it all the way down to the apparent optimum of 0.032, in the face of the many sources of uncertainty in this assessment a compromise of *M* = 0.036 was adopted for further analysis.

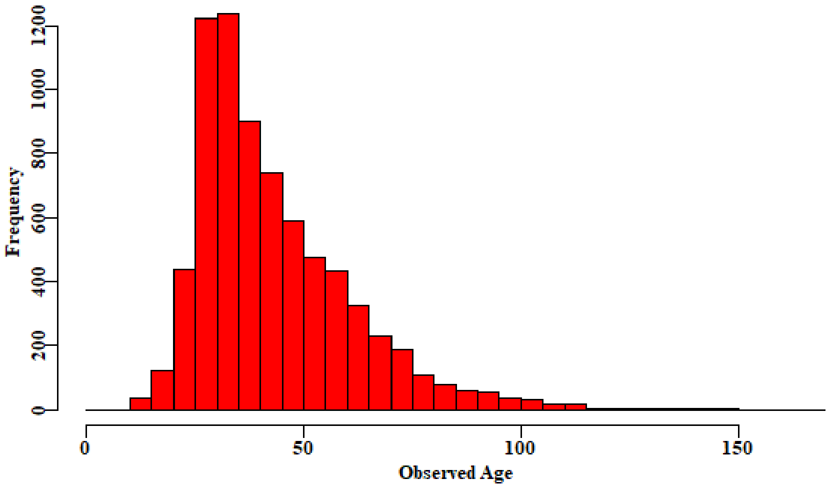

Figure 13. The combined Orange Roughy age data available for the Eastern Zone across years 1992 - 2010, presented in age-classes of 5 years. Approximately 10% are 65 years or older and 5% 75 years and older, with a maximum observed age of 162.

3.3.2 STEEPNESS

With most species the steepness assumed for the stock recruitment relationship has important implications for a species' productivity and hence for any stock assessment. In the previous assessment (Upston et al., 2015) and the initial base-case (Haddon, 2017), a value of $h = 0.75$ was adopted. Consistent with the sensitivities conducted in the last assessment (Upston et al, 2015) the likelihood profile on steepness has little influence on the fit of the current assessment to the available data (**Figure 14**). This would appear to be because the recruitment into the fishery currently occurring would still be about at unfished levels. If they continue to recruit at about the age of 30 – 35 then the depressing effects of the fishery on subsequent recruitment (see **Figure 9**) should start to influence recruitment within the next few years.

However, even though the current stock assessment is barely altered by changing the steepness value currently set at 0.75, the influence on the implied productivity of the stock is very great (**Figure 15**; it must be remembered this is also using a natural mortality of 0.04). The implied *MSY* for a steepness of 0.55 is more than doubled by increasing steepness to 0.95. Even a steepness of 0.75 suggest that B_{MSY} would occur around 20%B_0 with an *MSY* about 150% that with a steepness of 0.55.

The steepness of the stock recruitment relationship is an important influence on stock dynamics that needs further discussion. Intuitively, the large aggregations needed in Orange Roughy for effective spawning suggests that depletion should impose large impacts on recruitment dynamics. If that really is the case then a steepness of 0.75 may suggest a biologically implausible productivity. In a manner similar to natural mortality a steepness of 0.6 will be adopted for this assessment, which is more in line with a relatively low productivity stock. However, steepness in Orange Roughy also needs to be reviewed as 0.6 may not be low enough for a species with such low productivity.

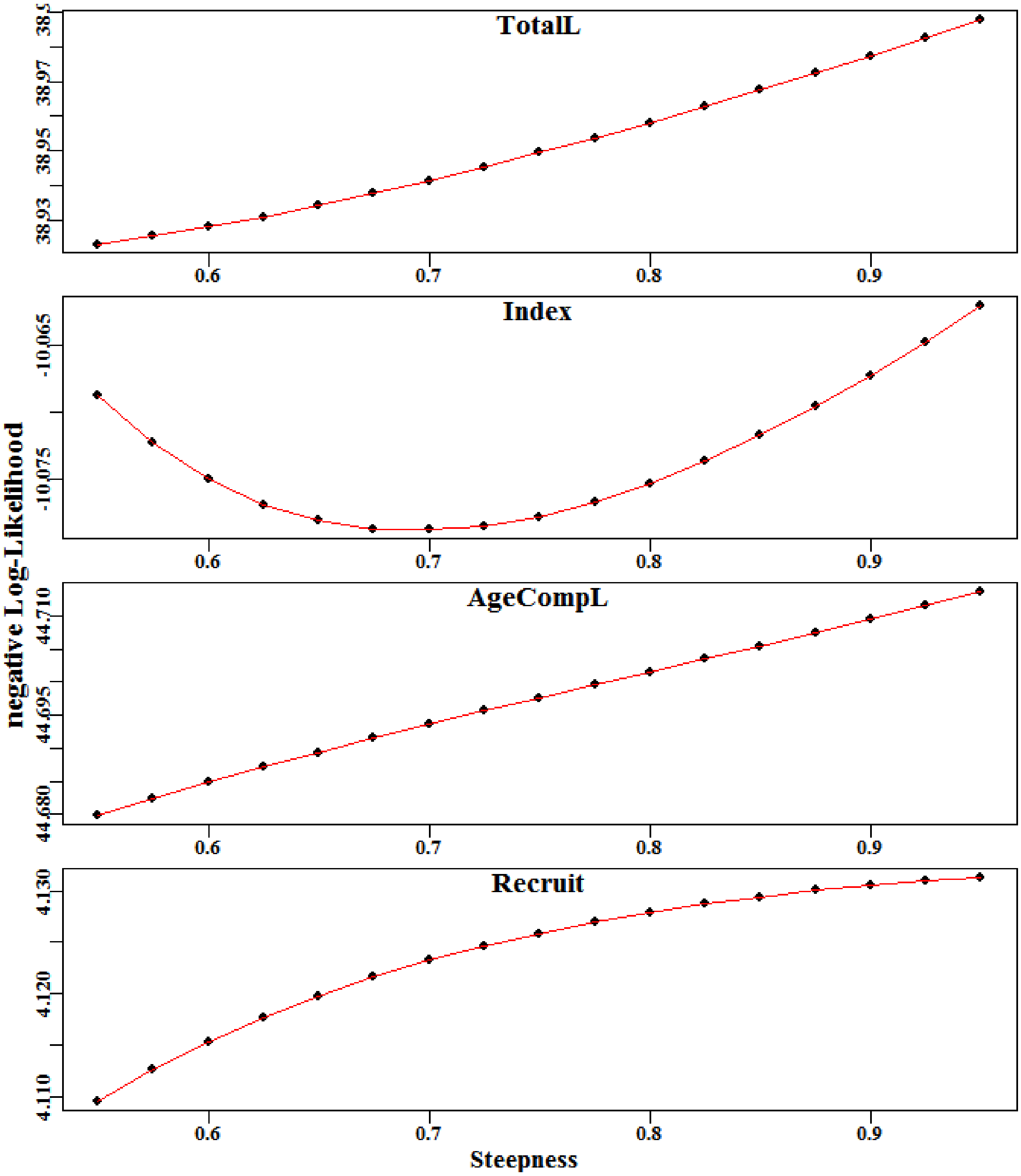

Figure 14. The likelihood profile derived for the Beverton-Holt stock recruitment relationships steepness, which ranged from values of 0.55 – 0.95. The strong trends apparent in the plots are misleading because the vertical scales in each case are very small only varying at the second decimal place. The maximum difference generates in the total likelihood was from about 38.925 – 38.99.

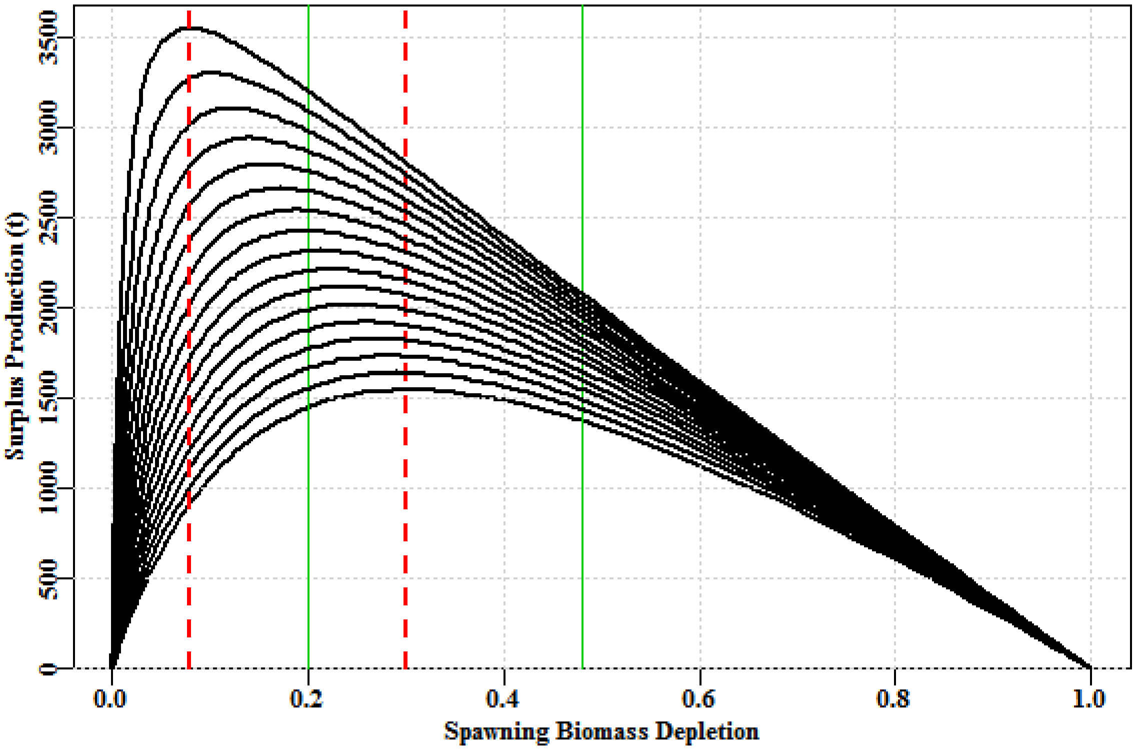

Figure 15. The influence of changing the steepness in the likelihood profile. The green lines are the current Harvest Strategy Policy biomass depletion reference points. The right hand red line at about 30% is the implied B_{MSY} with a steepness of 0.55, where the red line on the left is that for a steepness of 0.95, with the lines in between representing steepness values of 0.575 – 0.925.

3.3.3 SELECTIVITY

The selectivity for the fishery is estimated (that for the acoustic surveys is fixed), with the optimum value for S50%, the size at which 50% of fish are selected, was 35.456 cm. This value closely matches the optimum when a profile was generated for values between 34.0 to 37.0 in steps of 0.25. after about 35.75 the likelihood profiles for the indices and the recruitment contribution do not follow a typical smooth trajectory (**Figure 16**). The selectivity is highly influential on the model outcomes and the relative weighting of the different data streams becomes unbalanced as the size of 50% selectivity increases. This appears to be why the right-hand limb of the total likelihood curve is not as steep as the left-hand limb. It would be possible to rebalance the variances at each step in the likelihood profile, although this is not generally done in sensitivities but it could be added to the list of options to explore in the future.

Whatever the case, the likelihood profile suggests that the estimated value appropriately reflects the available data and at least the left-hand limb suggests that the selectivity would not need to change much to have a large effect on the outcome.

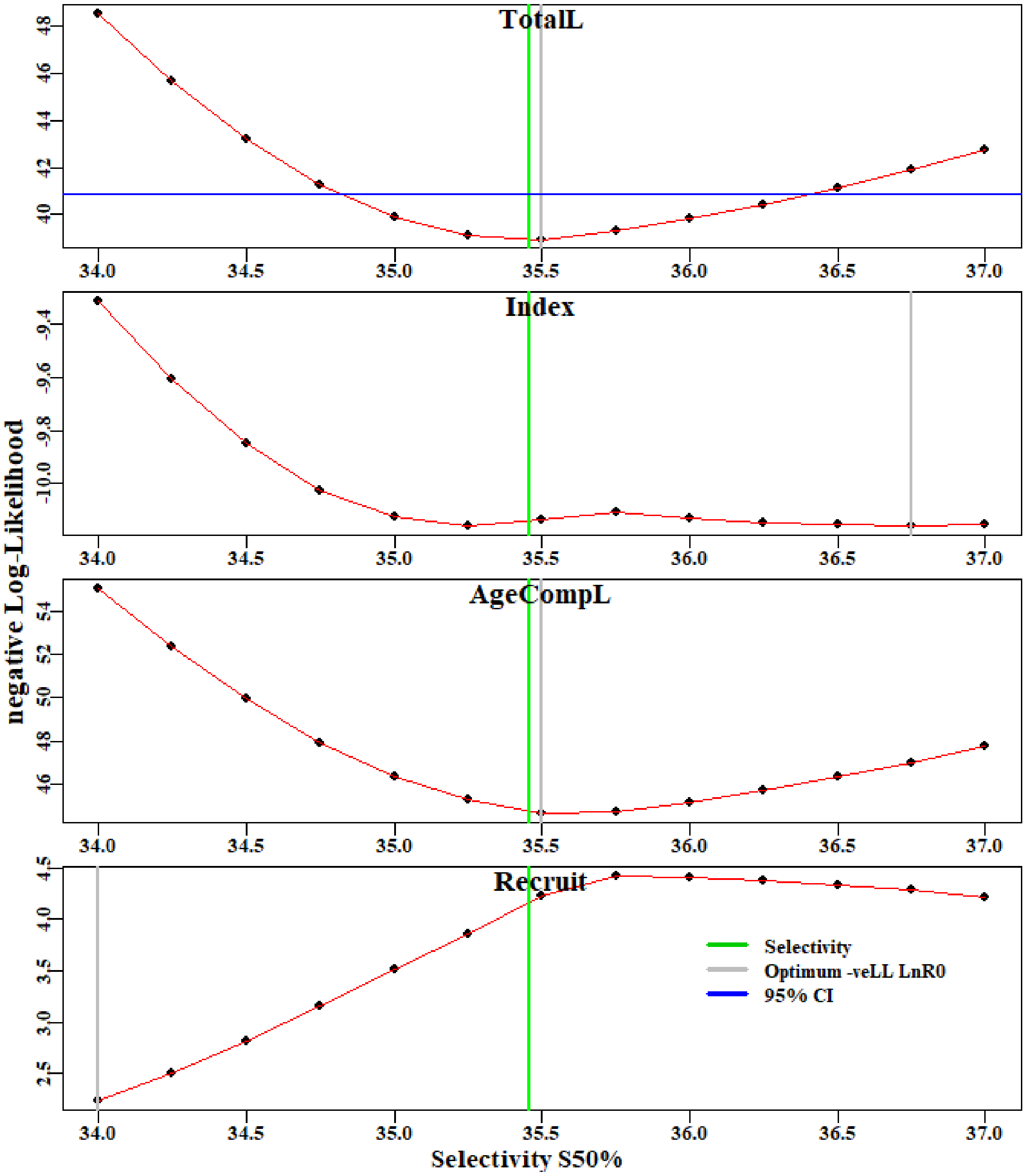

Figure 16. Likelihood profiles varying the selectivity parameter for the size at 50% selection between 34.0 and 37.0 in steps of 0.25. Likelihoods for the total, the combined indices of abundance, and age-composition data, and the contribution from the recruitment deviates are plotted. The green line is the optimum estimated value while the grey lines are the optimum for each likelihood.

3.4 Final Base-Case

3.4.1 SPR PHASE PLOT

So as to characterize the current stock status with respect to the current harvest strategy policy limit and target reference points the complement of the Spawning Potential Ratio (1 - SPR) was plotted against the expected SPR at the respective biomass and fishing mortality targets (**Figure 17**). Fortunately, the current status indicates both that the stock is not over-fished nor is over-fishing occurring, although the stock is still below the target of $B_{48\%}$. It was only when catches dropped below 200 t that over-fishing stopped and stock recovery made serious increases.

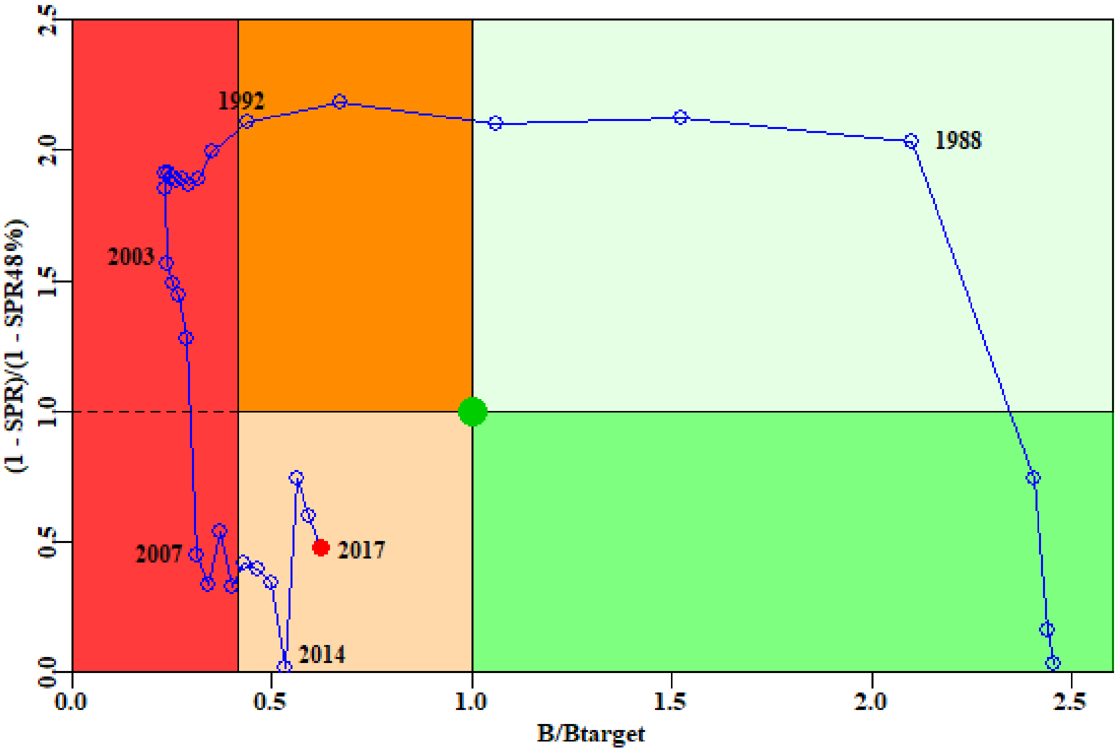

Figure 17. A phase plot of the female spawning biomass as a ratio with the proxy for $B_{MEY} = B_{48\%}$, against $(1 - SPR)/(1 - SPR_{48\%})$, which is used as a proxy for fishing mortality. The blue line and dots represent the status trajectory through the history of the fishery. The red dot represents the current status and the large green dot the ideal target. The red block constitutes a state of being overfished and if above the 1.0 on the y-axis also over-fishing. The light-green area is above the biomass target but over-fishing is occurring, although if that is part of a planned fish-down this is not a bad outcome. The years 1989 – 1992 bracket the highest catches (**Table 4**).

3.4.2 COMPARISON WITH THE INITIAL BASE-CASE

The final base-case for Orange Roughy East uses a natural mortality of 0.036, a steepness of 0.6, and the iterative re-weighting of sample variances (effective sample sizes) led to a recruitment variability of 0.7. These are the only parameters that changed from the initial base-case (**Table 11**; and see **Table 3**). The changes to the fitted parameters were relatively minor.

A comparison of the initial base-case with the final base-case illustrates the effect of the change in productivity implied by the changes to natural mortality and steepness. The female spawning biomass trajectory is lower in the final base-case, although the 95%

confidence intervals strongly overlap (**Figure 18**). The asymptotic confidence intervals invariably underestimate the full variability and uncertainty, so they also serve to illustrate the uncertainty behind the median assessment outcomes.

Table 11. The estimated and changed pre-specified model parameters for the Eastern Zone Orange Roughy initial and final base-case stock assessment (Haddon 2017, and current document).

Parameter	Initial Base-Case	Final Base-Case
Unexploited recruitment; log(R0)	9.0773	8.8286
Selectivity logistic inflection	35.456	35.502
Selectivity logistic width	1.0021	1.0023
q Acoustic towed catchability	0.97659	1.15853
q Hull catchability	1.68159	1.74029
B_0	41591	41348
Depletion	0.337	0.298
Fixed parameters	Values	Values
Recruitment steepness, *h*	0.75	0.6
Recruitment variability , σ_R	0.59	0.7
Rate of natural mortality, *M*	0.04	0.036

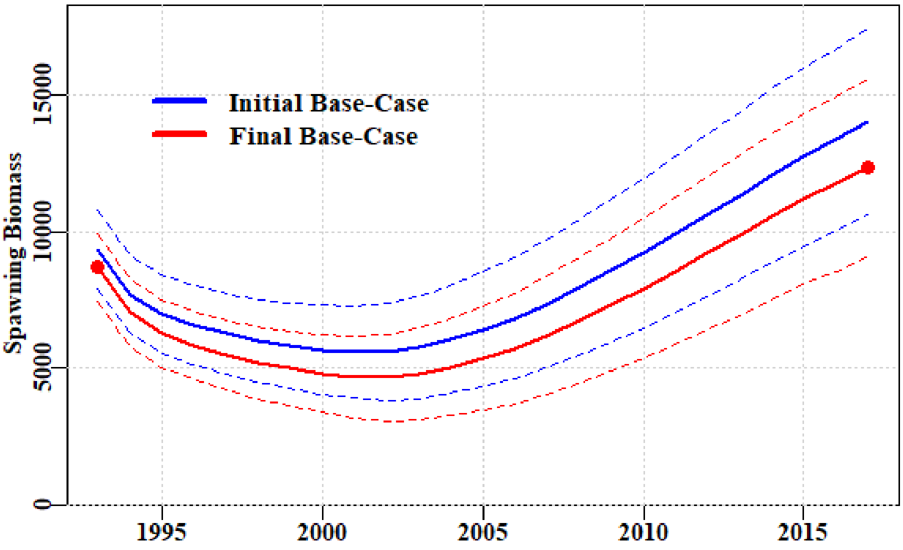

Figure 18. A comparison of the female spawning biomass trajectories from the initial and final base-cases over the years 1993 – 2017, along with the asymptotic 95% confidence intervals (the dashed lines). The intervals for the final base-case were from 21.9% - 37.7%B_0 and for the initial base-case from 25.6% - 41.9%B_0.

The recruitment residuals describe very similar trajectories although the bias-adjustment in the initial base-case is greater in the earlier years than in the final base-case and the extra recruitment residual added to the assessment (in 1981) rises further above the zero line in the final base-case (**Figure 19**).

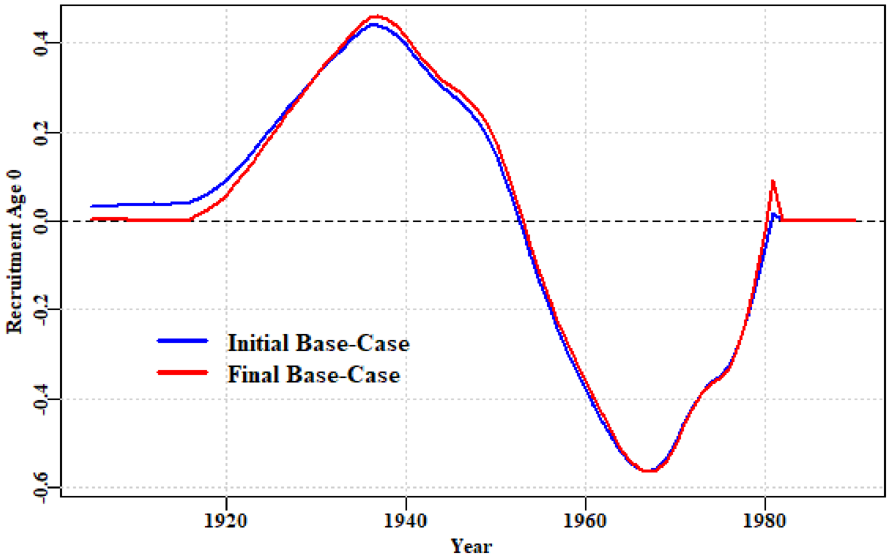

Figure 19. A comparison of the initial and final base-case recruit deviates from 1905 – 1990.

Finally, the depletion levels also exhibit almost parallel trajectories with a gradual deviation during the stock recovery phase (**Figure 20**).

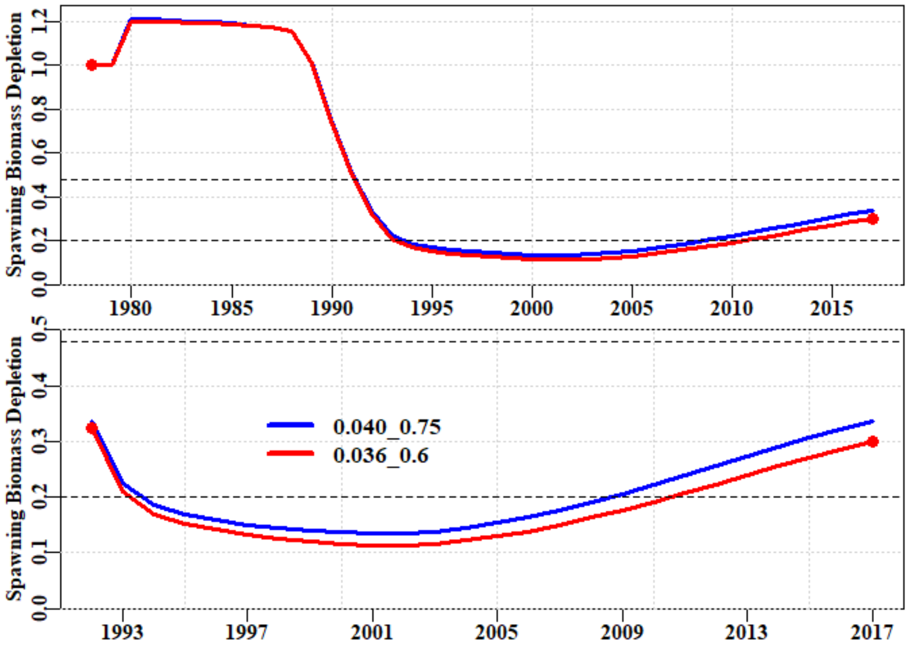

Figure 20. A comparison of the complete trajectory of the female spawning biomass depletion along with a magnified version focussed on the years 1992 – 2017. The dashed black lines are the limit and target reference points. The 0.040_0.75 refer to the initial base-case *M*=0.04 and *h*=0.75, while the final base-case has *M*=0.036 and *h*=0.6.

Likelihood profiles remain essentially the same as before except, of course, that the fixed values of *M* and *h* are in different locations closer to the total likelihood optimum (though still not identical to it). Further examination of the assumptions behind fixing these parameters is required. The information available in the stock assessment is insufficient for the assessment to converge when attempts are made to estimate *M*. Only assessments with many years of data and contrasting periods of depletion and recruitment are capable of generating an estimate of steepness, *h*, so no attempt was made with Orange Roughy.

3.5 Forecasts and Cross-Catch Risk Assessment

To obtain the RBCs it is necessary to project the optimum fitting model forwards into the future. As there was debate in the RAG as to which of the two base-cases should be accepted both were projected forward and results presented. The dynamics are projected forwards 55 years under the standard 20:35:48 harvest control rule for SESSF tier 1 species (Day, 2009), and then the predicted catches taken in the years 2018 onwards are detailed (Figure 21). In addition, to the standard projections the predicted catches for each series, from 2018 – 2040, were transferred to a projection of the alternative base-case to provide for a cross projected-catch risk assessment. Thus, the predicted catches from the initial base-case (*M*=0.04 and *h*=0.75) for years 2018 – 2040 are used in a projection of the final base-case (*M*=0.036 and *h*=0.6) and vice-versa. In this way the implications of applying the different catches if the model specification is incorrect can be determined. This is only done so as to facilitate the choices to be made by fishery managers over which base-case to adopt.

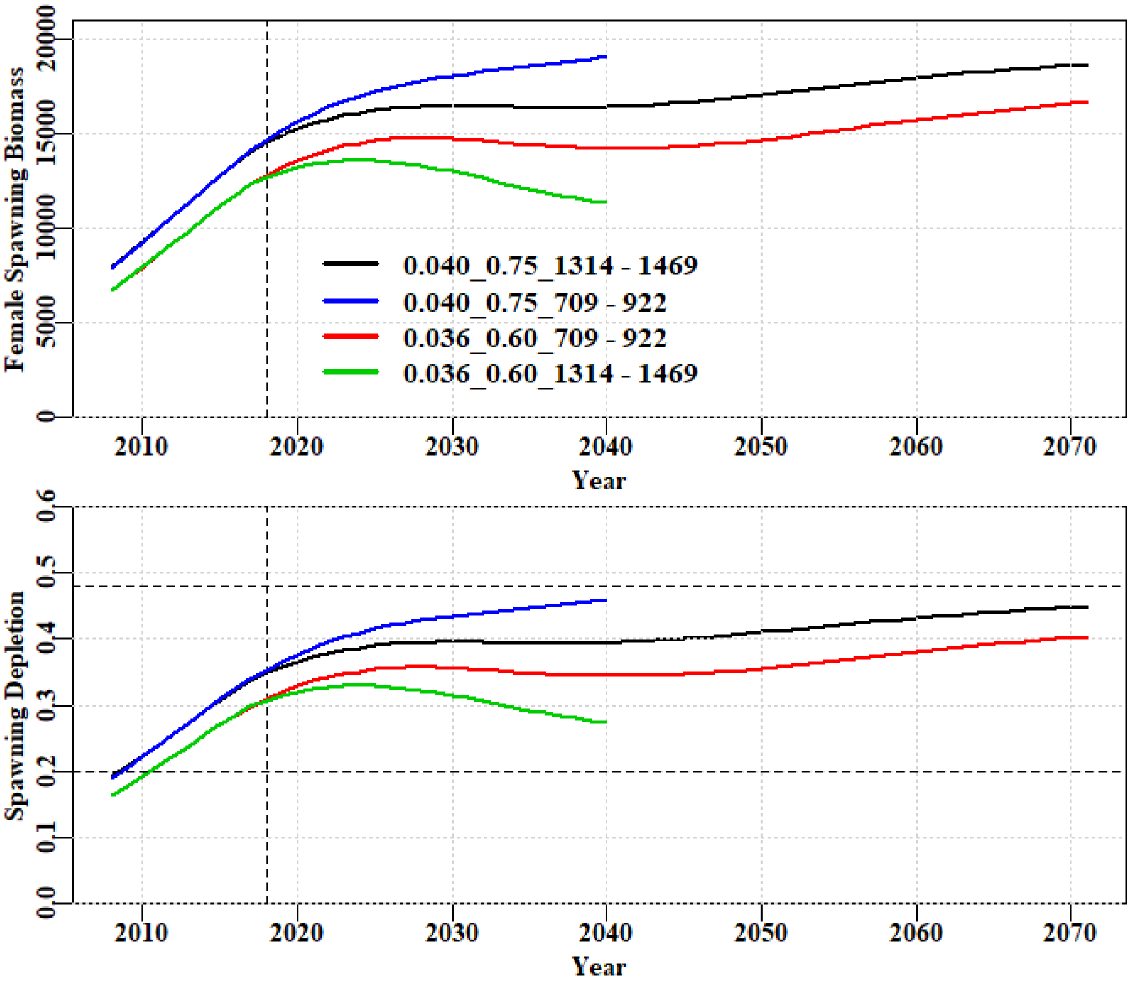

Figure 21. The predicted spawning biomass of Orange Roughy East projected for 55 years for the initial base-case (black line) and the final base-case (red line), using the standard 20:35:48 HCR. In addition, there is a projection to 2040 (24 years) of the initial base-case using he predicted catches from the final base-case (blue line) and of the final base-case using the predicted catches from the initial base-case (green line).

There is an unexpected dip in the recovery of both primary trajectories from about 2030 – 2050, after which they both continue on almost parallel upward trajectories (**Figure 21**), although neither achieves the target reference point by the end of 55 years (in

2071). This reduction in recovery has been brought about by the forward projection of age-0 recruitment expectations off the stock recruitment relationship for the years 1982 onwards (**Figure 22**). While the two recruitment trajectories are effectively parallel the higher intrinsic productivity implied by the initial base-case's *M* and *h* values leads directly to the higher numbers of recruits at age-0. The depletion of the spawning stock that occurred from the beginning of the 1990s leads in turn to an immediate drop in the expected recruitment in both base-cases which lasts through to the 2010s. If these low recruitment levels of age-0 fish are projected forwards for 30 or 40 years this accounts for the dip in female spawning biomass from the 2030s – 2050s.

While the predicted dip in recovery could be viewed as contrary to any strict rebuilding strategy, the projected dip is only predicted to begin after about 2027 onwards and continue until about 2051 (**Figure 21**; **Table 12**). Given the relatively high level of uncertainty in the current assessment (e.g. **Figure 11**), management would only need to become concerned after about 2025 should the predicted dip still occur in any projections.

The predicted RBCs from the final base-case for the next three years 2018 – 2020 are 709, 776, and 834, which have a mean of 773 tonnes for the 20:35:48 HCR (**Table 13**). The average yield from 2068 – 2071 is about 1,100 t, and is generated by an instantaneous fishing mortality rate of 0.0315 (equivalent to an annual harvest of 3.1%). For the initial base-case the RBCs are 1314, 1347, and 1375 t, with an average of 1345 t (**Table 14**), and the average yield in the later years is about 1665 t at an *F* of 0.042. Even after 55 years the Eastern Orange Roughy stock is not predicted to have achieved the biomass target reference point of $B_{48\%}$ in either base-case version.

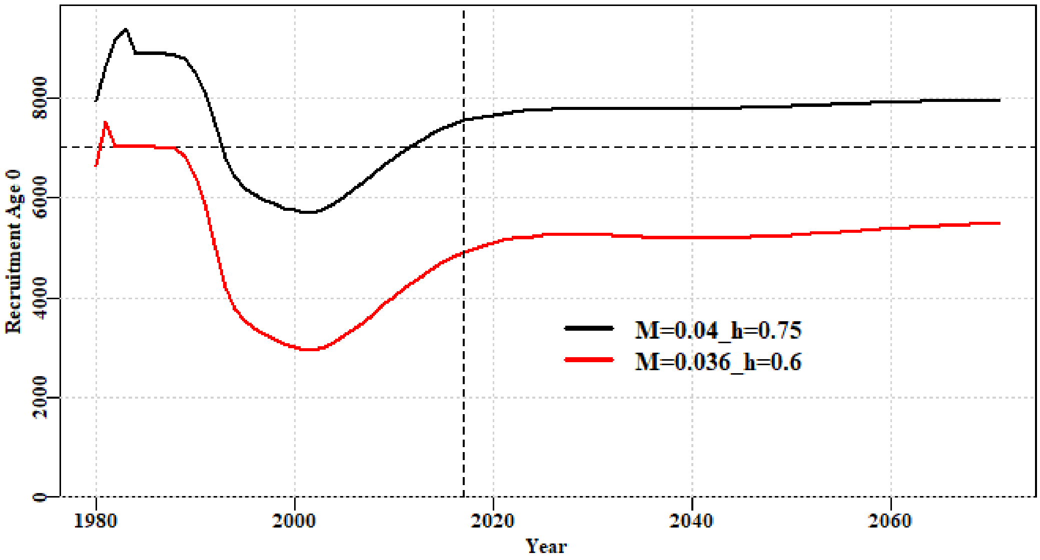

Figure 22. The predicted recruitment estimated from the stock recruitment relationship projected forward out for 55 years after 2017. The marked dip in expected recruitment between the early 1990s and about 2010 reflects the high degree of depletion in the spawning stock starting back in the 1990s.

While it would be possible to project the model much further than 2071, the uncertainty of such projections makes them unreliable, especially in the face of a directionally changing marine environment. Instead it is possible to revert to equilibrium methods that determine the expected production curve when the fishery is allowed to achieve equilibrium at each level of depletion (**Figure 23**).

Table 12. The projected female spawning biomass from the final base-case out to 2071, including the spawning biomass and the related depletion level. The highlighted years denote the period where the rebuilding stalls and even reverses until 2051.

Year	SpB	Depl	Year	SpB	Depl	Year	SpB	Depl
2015	11176	0.270	2034	14494	0.351	2053	14996	0.363
2016	11759	0.284	2035	14428	0.349	2054	15103	0.365
2017	12320	0.298	2036	14368	0.347	2055	15211	0.368
2018	12812	0.310	2037	14317	0.346	2056	15320	0.371
2019	13232	0.320	2038	14276	0.345	2057	15430	0.373
2020	13599	0.329	2039	14246	0.345	2058	15538	0.376
2021	13911	0.336	2040	14230	0.344	2059	15645	0.378
2022	14168	0.343	2041	14226	0.344	2060	15750	0.381
2023	14374	0.348	2042	14235	0.344	2061	15852	0.383
2024	14532	0.351	2043	14257	0.345	2062	15951	0.386
2025	14647	0.354	2044	14290	0.346	2063	16047	0.388
2026	14723	0.356	2045	14335	0.347	2064	16140	0.390
2027	14765	0.357	2046	14391	0.348	2065	16229	0.392
2028	14778	0.357	2047	14455	0.350	2066	16314	0.395
2029	14765	0.357	2048	14528	0.351	2067	16396	0.397
2030	14733	0.356	2049	14609	0.353	2068	16474	0.398
2031	14685	0.355	2050	14698	0.355	2069	16548	0.400
2032	14626	0.354	2051	14792	0.358	2070	16619	0.402
2033	14561	0.352	2052	14892	0.360	2071	16687	0.404

The equilibrium yield curve identifies MSY values of about 1472 and 2314 t but of more interest to the Commonwealth harvest strategy is the potential yield at 48% B_0. The equilibrium calculations that give rise to the production curve estimate the equilibrium surplus production at $B_{48\%}$ to be 1276 and 1784 t respectively (**Figure 23**).

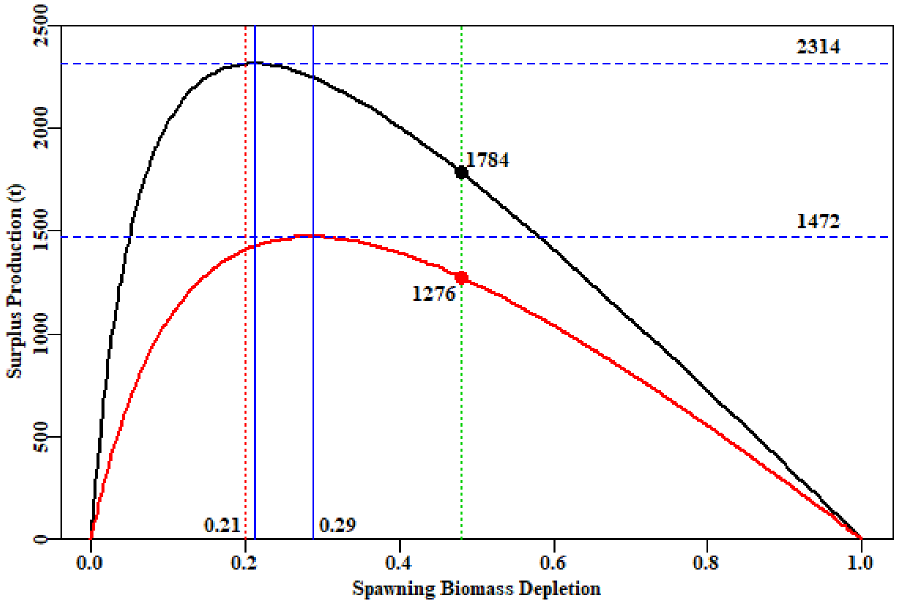

Figure 23. The surplus production plot for the initial (black line) and final base-cases (red line) indicating equilibrium maximum sustainable yields of 2314 t and 1472 t respectively. The long term equilibrium yield at $B_{48\%}$ was 1784 t and 1276 t in the final base-case. B_{MSY} occurred at 0.21B_0 and 0.29B_0 respectively.

Table 13. Predicted female spawning biomass, age-0 recruits, fishing mortality, and depletion across the years of projection of the final base-case (M=0.036, h=0.6).

Year	FemSpB	Recruit_0	Catch (t)	F	Depletion
Unfished	41349	0	0	0.0000	1.000
2011	8562	4009	162	0.0090	0.207
2012	9206	4167	163	0.0084	0.223
2013	9862	4315	150	0.0072	0.239
2014	10539	4456	7	0.0003	0.255
2015	11176	4590	460	0.0194	0.270
2016	11759	4708	360	0.0144	0.284
2017	12320	4809	465	0.0178	0.298
2018	12812	4902	709	0.0260	0.310
2019	13232	4978	776	0.0276	0.320
2020	13599	5041	834	0.0288	0.329
2021	13911	5094	883	0.0298	0.336
2022	14168	5137	924	0.0306	0.343
2023	14374	5173	956	0.0313	0.348
2024	14532	5200	975	0.0315	0.351
2025	14647	5221	982	0.0315	0.354
2067	16396	5436	1091	0.0315	0.397
2068	16474	5445	1096	0.0315	0.398
2069	16548	5454	1101	0.0315	0.400
2070	16619	5462	1106	0.0315	0.402
2071	16687	5470	1110	0.0315	0.404

Table 14. Predicted female spawning biomass, age-0 recruits, fishing mortality, and depletion across the years of projection of the Initial base-case (M=0.04, h=0.75).

Year	FemSpB	Recruit_0	Catch (t)	F	Depletion
Unfished	41634	0	0	0.0000	1.000
2011	9960	6789	162	0.0076	0.239
2012	10659	6928	163	0.0072	0.256
2013	11371	7055	150	0.0062	0.273
2014	12107	7173	7	0.0003	0.291
2015	12805	7283	460	0.0168	0.308
2016	13454	7379	360	0.0125	0.323
2017	14086	7461	465	0.0154	0.338
2018	14582	7535	1314	0.0420	0.350
2019	14941	7590	1347	0.0420	0.359
2020	15259	7628	1375	0.0420	0.367
2021	15535	7660	1400	0.0420	0.373
2022	15770	7687	1421	0.0420	0.379
2023	15965	7710	1438	0.0420	0.383
2024	16122	7728	1451	0.0420	0.387
2025	16244	7742	1461	0.0420	0.390
2067	18459	7929	1651	0.0420	0.443
2068	18516	7933	1656	0.0420	0.445
2069	18569	7938	1661	0.0420	0.446
2070	18619	7941	1665	0.0420	0.447
2071	18668	7945	1669	0.0420	0.448

3.5.1 CROSS-CATCH PROJECTION RISK ANALYSIS

Two assessments were generated for Orange Roughy East, the initial base-case, with $M = 0.04$ and $h = 0.75$ and the final base-case with $M = 0.036$ and $h = 0.6$. While the likelihood profile on M, the natural mortality (**Figure 12**), was sufficient to justify a reduction in the assumed natural mortality rate. How far to reduce it was less clear. The change from a minimum total log-likelihood occurring at 0.031 in the initial base-case to a minima at 0.032 in the final base-case indicates there is an interaction between M and the steepness, h, which is not surprising as both are related to stock productivity. Many more such analyses would be required however, to appropriately characterize this interaction.

Changing the steepness value for the stock recruitment relationship was less simple. Some RAG members felt that despite Orange Roughy being well recognized as a low productivity species this would not necessarily require a reduction in the steepness used. The argument was made that as a species that forms dense spawning aggregations Orange Roughy would not suffer greatly from density dependent reductions in recruitment success as stock size declined and so a reduction in steepness from 0.75 to 0.6 was not warranted. On the other hand, the steepness of Orange Roughy stock recruitment relationships has never been estimated well and so the h=0.75 used in the initial base-case is merely a repeat of the assumptions used in many stock assessments conducted on shallower water, more productive species; this does not mean 0.75 is correct for Orange Roughy. Agreement over the issue of the contribution of steepness to Orange Roughy stock productivity was not reached in the November SE RAG and so two base-cases with their projections are presented.

One way of determining the relative risk of the management implications derived from the different base-cases is to transfer the predicted catches from each base-case to the other base-case's projections (**Figure 21**).

This was done for both base-cases and the implied trajectories included with the spawning biomass and depletion trajectories for the full projections of the two base-cases. When the predicted future catches from the initial base-case (M=0.04, h=0.75) are used to project forward the dynamics of the final base-case (M=0.036, h=0.6), the spawning biomass and depletion both began to decline reaching $0.274B_0$ by 2040 after a peak of about $0.329B_0$ in 2024 (**Figure 21**). When the predicted catches from the final base-case are used in the initial base-case projections the stock is predicted to recover at a faster rate achieving approximately $0.46B_0$ by 2040 and avoiding the 2030 - 2050 dip in stock biomass (Figure 21).

If only the first three years are taken account of (to reflect the impact of a three year TAC) then irrespective of which set of catches are applied to which base-case stock recovery is predicted to continue, fastest with the lower catches and more productive base-case, the two base-cases recover at about the same rate, and the higher catches in the least productive base-case still improve in terms of depletion only not so much as with the lower catches.

The lower RBC values are therefore of lower risk than the higher values, although even with a multi-year TAC from 2018 – 2020 the impact of applying the wrong catches to the wrong model is predicted to be minor (**Figure 21**).

4 Discussion

It was possible to extend the integrated stock assessment for Eastern zone Orange Roughy implemented using the software Stock Synthesis (Methot and Wetzel, 2013) conducted in 2014 to generate a new final base-case for the stock in 2017. In the previous assessment multiple stock structure hypotheses were examined but here only the single assumption is made of a stock encompassing the Eastern zone (Orange Roughy zone 10) and the Eastern side of the Southern zone (Orange Roughy zone 21; Pedra Branca). This reflects the previous three year TAC set for this management unit/stock.

The stock has continued to rebuild along a trajectory very similar to that predicted in the 2014 stock assessment (Upston et al, 2015). This entailed the inclusion of catches from 2014 – 2016, new age composition data from 2012 and 2016, a revised estimate of the 2013 towed-body acoustic biomass survey from 2013, and a new acoustic biomass survey estimate from 2016.

Once an initial base-case had been fitted the production of a series of likelihood profiles on some of the more important fixed parameters within the model relating to stock productivity along with the plot of stock status against catches shed doubt on the validity or plausibility of the assumed values for natural mortality, M, and of the steepness of the stock recruitment relationship, h. When the stock was depleted down to about 12%B_0 catches of 600 – 700 tonnes were enough to for over-fishing to be occurring and it was only once catches dropped down to about 160 t (during the acoustic surveys) that serious rebuilding occurred. This suggested the stock was not as resilient as suggested by an M=0.04 and a steepness of h=0.75. Similarly, the likelihood profile on natural mortality suggested a significant improvement in model fit given a lower value for M and the distribution of ages found in the Eastern zone also suggest a lower value would be more appropriate (**Figure 12**, **Figure 13**). In a similar manner the profile on steepness indicated an overall model inclination towards a much lower value than 0.75, even the Index data were slightly improved by a steepness of 0.7 (**Figure 14**). While changing the steepness had very little effect on the model fitting it had a large effect on the relative productivity (**Figure 15**).

An alternative base-case, termed the final base-case, was produced by implementing lower but plausible values of M=0.036 and h=0.06. While this improved the model fit slightly it also leads to lower levels of productivity. However, at the November SE RAG some members were not convinced that there was sufficient justification for such reductions so both base-cases are presented with their forecasts and with cross-catch risk projections. Whatever the outcome of management, the values selected for M and h need a more thorough review than was possible here before the next stock assessment. Many stock assessments in the southern hemisphere have origins from the 1990s when the growth and maximum age of Orange Roughy was still under intense debate. Given the maximum ages observed, and the occasional large plus group at 80 years the changes made in the current assessment may require further adjustment.

The stock is predicted to have reached a depletion level of about 29.8%B_0 or 33.8%B_0 in 2017. Catches and implied fishing mortality rates currently remain low enough that stock rebuilding should continue relatively rapidly over at least the next three years given the predicted RBCs from either base-case (**Figure 21**; **Table 13**, **Table 14**).

Neither base-cases predicted that the stock would recover to the biomass target reference point of $0.48B_0$ within 55 years (out to 2071; the approximate generation time is estimated at about 57 years). Recovery progress was slowed in both cases by a pronounced dip in predicted recruitment produced by the rapid decline in spawning biomass that occurred in the very early 1990s (**Figure 7**, **Figure 17**, and **Figure 22**).

A cross-catch risk assessment was conducted on both base-cases indicating that in the long term allocating the higher catches to the wrong model structure could lead to a failure to recover (**Figure 21**). However, while, not surprisingly, the lower predicted RBCs (average 773 t relative to 1314 t) have a lower risk, the outcome that the application of either time series (or average) over the next three years would be difficult to distinguish according to the predictions made by the current assessment model and the precision of the estimates possible from the stock assessment model.

Using (1 – SPR), the spawning potential ratio, it was possible to assert that with either base-case the stock is neither over-fished nor is over-fishing occurring (**Figure 7**, **Figure 17**).

4.1.1 FUTURE DEVELOPMENTS

Further investigations using the likelihood profile approach may have value in identifying the parameters to which the assessment is most sensitive. By generating multiple likelihood profiles with each re-weighted to a different base-line value, a comparison of these curves would indicate the variability induced by the iterative re-weighting process. If it were large it would mean that the optimum values of parameters in any one likelihood profile may depend upon what constituted the starting point within the stock assessment. Whatever the case, it is clear that the assumptions used in any assessment where there is limited data available (as in the Orange Roughy assessment) can be very influential on the final outcomes of the stock assessments and could contribute to inter-annual variations between stock assessments for the same stocks (Punt et al, 2017).

With regard to future data collection, when further age-composition data are collected consideration should be given to increasing the sample sizes in an effort to reduce the noisiness (spikiness) of the age-compositions obtained. Some consideration to obtaining relatively balanced samples between the sexes might also be made. A continuation of the acoustic surveys will also always have value.

Appendix A

Table 15. The observed age frequency in samples of Eastern zone Orange Roughy. ‘F’ is female and ‘M’ is male. There were no observations of fish younger than 8 years old.

	F	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
N	**411**	**595**	**282**	**637**	**414**	**696**	**426**	**338**	**596**	**726**	**298**	**634**	**503**	**248**	**545**	**247**
Age	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
14	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0
17	0	0	0	0	0	2	0	0	0	0	0	2	2	2	0	0
18	0	0	0	2	1	3	0	0	0	0	0	1	3	1	0	0
19	0	0	0	3	3	2	0	0	0	0	0	1	6	0	1	1
20	0	0	1	1	3	6	0	0	0	1	0	5	7	3	0	1
21	0	0	0	1	8	5	2	1	0	0	0	5	11	8	1	2
22	0	0	3	6	9	14	3	1	0	4	2	11	13	9	5	4
23	1	2	3	14	11	25	4	9	1	3	5	16	14	7	14	14
24	0	2	2	8	14	19	6	6	1	10	3	13	22	15	18	13
25	1	4	10	14	18	27	12	9	0	9	8	33	23	10	23	14
26	2	12	7	29	24	33	13	6	3	10	13	27	28	23	31	22
27	3	15	13	26	20	38	14	12	5	24	19	51	27	16	29	16
28	4	9	14	39	15	48	15	20	5	31	12	46	34	19	35	14
29	2	4	8	16	21	37	24	10	1	10	6	20	25	10	30	12
30	3	13	6	26	20	19	23	15	4	29	14	45	23	9	31	5
31	2	15	15	20	23	29	20	9	1	15	14	35	28	15	35	19
32	5	17	15	32	21	25	14	21	3	29	21	42	24	13	35	13
33	5	24	14	26	21	26	10	13	7	19	11	26	21	17	32	16
34	3	15	6	11	19	36	29	10	6	25	13	21	22	8	33	14
35	12	17	12	29	7	23	21	9	6	26	14	17	13	7	31	14
36	5	12	3	19	11	17	19	14	8	19	14	12	14	8	21	8
37	5	19	5	26	11	25	15	16	10	25	8	16	17	7	20	12
38	6	17	8	15	8	21	23	14	7	17	8	10	6	7	21	5
39	7	11	6	12	8	17	12	16	14	5	6	12	9	4	12	4
40	2	16	7	11	7	17	15	18	12	21	8	8	12	4	8	3
41	8	13	14	15	7	13	13	6	17	19	6	14	11	5	10	3
42	13	18	6	8	8	9	8	12	14	22	7	7	5	4	12	3
43	10	17	11	11	9	11	13	7	16	23	8	4	6	3	3	1
44	10	23	1	12	10	15	9	6	13	28	6	8	3	3	5	1
45	7	25	2	14	1	12	11	8	16	20	6	5	6	2	5	2
46	11	15	7	4	9	7	7	8	16	13	3	9	2	3	5	3
47	11	20	3	8	6	4	6	8	11	15	4	7	7	1	1	1
48	22	15	4	7	3	4	6	6	17	11	4	6	3	1	3	0
49	14	9	1	7	1	4	5	3	12	14	4	5	2	1	2	0
50	10	13	5	2	3	7	5	2	11	13	1	8	3	0	2	1
51	12	11	2	6	1	1	4	1	15	15	3	3	3	1	1	0
52	13	6	1	8	3	4	2	6	19	7	2	3	3	0	0	1
53	6	10	3	7	6	7	5	3	22	14	6	4	4	0	4	0
54	12	11	5	7	5	6	2	3	16	11	4	4	2	0	1	0
55	12	11	6	9	3	4	1	2	25	6	1	5	3	0	3	0

cont. The observed age frequency in samples of Eastern zone Orange Roughy. ‘F’ is female and ‘M’ is male. There were no observations of fish younger than 8 years old.

	F	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Age	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**	**1992**	**1995**	**1999**	**2001**	**2004**	**2010**	**2012**	**2016**
56	9	13	2	8	1	5	3	0	25	14	2	3	2	0	1	0
57	15	11	0	6	0	1	3	4	13	7	5	2	0	0	1	0
58	9	6	4	9	1	4	1	1	16	15	5	2	2	0	1	0
59	8	6	3	3	0	3	1	0	8	6	2	2	2	0	0	0
60	11	10	2	3	0	3	2	1	10	9	0	6	0	0	1	0
61	6	12	5	2	2	3	1	0	10	9	3	2	0	0	0	1
62	8	3	2	4	0	4	0	1	19	3	1	3	0	0	2	0
63	6	7	2	5	2	2	0	1	13	4	0	3	4	0	2	0
64	6	7	2	7	2	5	1	0	10	9	1	2	1	0	0	0
65	7	3	4	2	3	3	2	1	9	5	0	2	1	0	0	2
66	7	6	2	6	1	1	1	1	6	4	1	4	1	0	0	0
67	6	10	0	2	1	5	3	1	10	6	1	3	1	0	0	0
68	7	5	0	1	0	0	3	0	8	3	2	0	2	0	1	0
69	6	3	1	4	0	1	0	1	6	8	0	1	3	1	0	0
70	6	4	2	6	1	0	2	0	8	6	2	2	0	0	0	0
71	3	5	0	2	1	2	1	1	6	1	0	3	0	0	0	0
72	6	7	1	1	1	1	0	0	5	6	4	4	0	0	0	0
73	2	1	0	5	1	1	0	0	7	1	0	1	0	0	3	0
74	3	5	2	2	1	1	1	1	7	4	0	5	3	0	0	0
75	6	3	0	5	1	0	2	0	6	1	2	1	1	0	0	0
76	3	3	1	3	1	1	0	0	2	4	0	1	0	0	0	0
77	1	1	0	1	2	1	0	0	3	1	1	0	1	0	0	0
78	0	1	1	1	1	0	0	0	2	4	0	3	0	0	0	0
79	31	22	12	37	13	27	6	14	53	33	1	10	11	0	9	1

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5 Appendix -Alternative ORE Forecasts

5.1 Introduction

The most recent integrated stock assessment for Orange Roughy East (*Hoplostethus atlanticus*) has uncertainties in the model fitting. This is indicated by the broad confidence intervals around the indices of relative abundance and the difficulty the model has in fitting the spikiness of the age-composition data. There is also the unusual patterns exhibited in the estimates of recruitment through time, which appear to reflect the difficulty that the model used has in fitting to the extremely rapid increase in fishing mortality experienced by Orange Roughy (all stock assessment models that include recruitment residuals are likely to suffer the same issue). In addition, there remains uncertainty as the most appropriate parameter values for variables such as natural mortality and the stock recruitment steepness, both of which are very influential on productivity. In the current assessment (the document in which this is an appendix),

In an attempt to characterize the uncertainty intrinsic to the assessment likelihood profiles were estimated for both steepness and natural mortality. Both of these likelihood profiles suggested that the values assumed for natural mortality and for steepness were too large and indicated that the model would have fitted the data a little better had those values been smaller.
To explore this issue further two alternative base-case scenarios of relative productivity have been examined. The first most productive scenario was the original basecase, which had a fixed natural mortality value of 0.04 and a steepness of 0.75. The second less productive scenario was termed the final base-case and assumed a natural mortality of 0.036 and a steepness of 0.6. The two scenarios gave similar outcomes to the assessment with the least productive model, **0.036-0.6**, suggesting the 2017 depletion was about 30%B_0 while the more productive scenario, **0.04-0.75**, estimated the 2017 depletion as about 34%B_0. The bigger differences occurred with respect to the predicted RBCs obtained by projecting the standard SESSF Tier 1 harvest control rule forward (Day, 2009). The average over the next three years was 773 t for the **0.036-0.6** scenario but was 1345 t for the **0.04-0.75** scenario, with long term yields predicted to be 1276 t and 1784 t respectively.

While it can be argued that orange roughy are notoriously un-productive and that a natural mortality of 0.04 should not permit fish of some of the ages observed in the eastern zone it remains very difficult to decide, in a fully defensible manner, which values for these parameters are most appropriate. To determine the potential risk of adopting the wrong values a cross-catch risk assessment was used where the predicted future catches (RBCs) from each scenario are implemented within the forecasts of the opposite scenario and the outcomes compared with the non-crossed outcomes. However, the predicted RBCs are generated by the Stock Synthesis software but it is unaware of the extra meta-rules that the SESSF harvest strategy has in place. In particular there is a 50% change rule that determines that any changes to a TAC cannot be more than 50% of its current value. Given the current total TAC is 500t (465 t off St Helens and St Patricks plus 35t in the Southern Zone part of the eastern zone stock - see Upston et al, 2015) that means the maximum it can increase to would be 775 t. Thus, the predicted values from the **0.036-0.6** scenario would not be influenced by the 50% change meta-rule, but those from the **0.04-0.75** scenario would be affected. To ensure that decisions will be made using the most up-to-date information some extra forecasts were requested that compared the predicted depletion states of the two base-case scenarios, but applying the average forward catches while also applying the 50% change meta-rule.

Table 1: The catches imposed and compared on the two productivity scenarios. Catches from 2022 onwards were constant at 1345 t.

	Year	M=0.036, h=0.6	M=0.036, h=0.6	M=0.04, h=0.75	M=0.04, h=0.75
2017	2017	500	500	500	500
2018	2018	1345	750	1345	750
2019	2019	1345	1125	1345	1125
2020	2020	1345	1345	1345	1345
2021	2021	1345	1345	1345	1345

5.2 Results and Discussion

When these comparisons were made the effects of these changes were only minor.

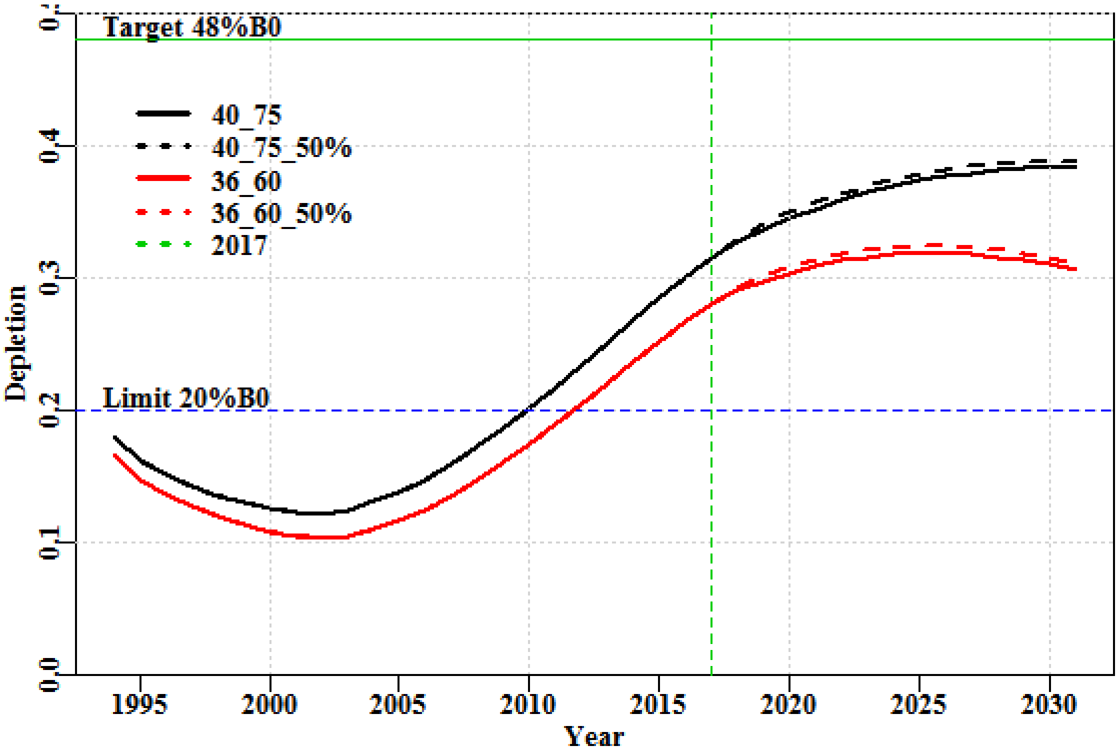

Figure 1: A comparison of the average catches predicted by the more highly productive scenario as modified by the 50% maximum change meta-rule.

More details are apparent in a tabulation of the results. In particular in the highlighted sections of table 2 and table 3, especially the predicted depletion levels in 2031 where the 50%change rule has led to a 0.005% change in the depletion level in each case.

Table 2: The predicted spawning biomass and recruitment levels for the different treatments

Era	Yr	SpB	SpB4050	SpB36	SpB3650	Recr40	Recr4050	Recr36	Recr3650
VIRG	1978	4056	40560	40584	40584	0	0	0	0
INIT	1979	4056	40560	40584	40584	0	0	0	0
TIME	1980	4906	49069	48385	48385	0	0	0	0
TIME	1981	4906	49069	48446	48446	7936	7936	6630	6630
TIME	1982	4902	49020	48462	48462	8581	8581	7411	7411
TIME	1983	4892	48921	48433	48433	9057	9057	7143	7143
TIME	1984	4877	48773	48358	48358	9256	9256	7142	7142
TIME	1985	4857	48574	48236	48236	9016	9016	7140	7140
TIME	1986	4831	48319	48059	48059	9013	9013	7138	7138
TIME	1987	4796	47965	47786	47786	9010	9010	7134	7134
TIME	1988	4724	47243	47142	47142	9005	9005	7128	7128
TIME	1989	4133	41332	41227	41227	8995	8995	7114	7114
TIME	1990	3006	30064	29843	29843	8903	8903	6967	6967
TIME	1991	2108	21085	20760	20760	8638	8638	6556	6556
TIME	1992	1357	13570	13112	13112	8254	8254	5995	5995
TIME	1993	8981	8981	8458	8458	7625	7625	5150	5150
TIME	1994	7311	7311	6753	6753	6875	6875	4255	4255
TIME	1995	6577	6577	5994	5994	6446	6446	3787	3787
TIME	1996	6149	6149	5541	5541	6214	6214	3542	3542
TIME	1997	5802	5802	5168	5168	6062	6062	3383	3383
TIME	1998	5518	5518	4856	4856	5929	5929	3244	3244
TIME	1999	5302	5302	4611	4611	5813	5813	3122	3122
TIME	2000	5124	5124	4404	4404	5720	5720	3021	3021
TIME	2001	4993	4993	4242	4242	5640	5640	2933	2933
TIME	2002	4954	4954	4172	4172	5578	5578	2862	2862
TIME	2003	5080	5080	4265	4265	5560	5560	2831	2831
TIME	2004	5336	5336	4486	4486	5619	5619	2872	2872
TIME	2005	5640	5640	4753	4753	5735	5735	2968	2968
TIME	2006	5999	5999	5073	5073	5864	5864	3080	3080
TIME	2007	6459	6459	5494	5494	6006	6006	3207	3207
TIME	2008	7010	7010	6003	6003	6173	6173	3366	3366
TIME	2009	7589	7589	6539	6539	6355	6355	3545	3545
TIME	2010	8198	8198	7105	7105	6526	6526	3721	3721
TIME	2011	8837	8837	7701	7701	6689	6689	3892	3892
TIME	2012	9494	9494	8314	8314	6842	6842	4060	4060
TIME	2013	1017	10171	8945	8945	6985	6985	4219	4219
TIME	2014	1087	10876	9602	9602	7117	7117	4372	4372
TIME	2015	1155	11553	10229	10229	7242	7242	4519	4519
TIME	2016	1218	12189	10811	10811	7351	7351	4650	4650
FOR	2017	1281	12811	11374	11374	7445	7445	4763	4763
FOR	2018	1330	13372	11799	11870	7530	7530	4866	4866
FOR	2019	1366	13837	12091	12262	7593	7601	4940	4952
FOR	2020	1400	14201	12343	12543	7637	7657	4989	5017
FOR	2021	1430	14505	12553	12756	7676	7699	5031	5063
FOR	2022	1457	14774	12718	12923	7710	7732	5064	5096
FOR	2023	1480	15007	12839	13044	7739	7761	5090	5122
FOR	2024	1500	15204	12916	13122	7764	7785	5109	5140
FOR	2025	1516	15368	12951	13157	7784	7805	5121	5152
FOR	2026	1530	15499	12946	13152	7801	7821	5126	5157
FOR	2027	1540	15601	12906	13109	7814	7834	5125	5156
FOR	2028	1548	15676	12832	13034	7825	7844	5119	5150
FOR	2029	1553	15728	12731	12930	7832	7851	5108	5139
FOR	2030	1557	15761	12605	12802	7837	7856	5092	5123
FOR	2031	1559	15778	12461	12655	7841	7859	5073	5103

Table 3: The predicted TACs and depletion levels for each scenario.

Era	Yr	TAC40	TAC405	TAC36	TAC3650	depl40	depl4050	depl36	depl3650
VIRG	1978	0	0	0	0	1.000	1.000	1.000	1.000
INIT	1979	0	0	0	0	1.000	1.000	1.000	1.000
TIME	1980	0	0	0	0	1.210	1.210	1.192	1.192
TIME	1981	0	0	0	0	1.210	1.210	1.194	1.194
TIME	1982	0	0	0	0	1.209	1.209	1.194	1.194
TIME	1983	0	0	0	0	1.206	1.206	1.193	1.193
TIME	1984	0	0	0	0	1.202	1.202	1.192	1.192
TIME	1985	6	6	6	6	1.198	1.198	1.189	1.189
TIME	1986	60	60	60	60	1.191	1.191	1.184	1.184
TIME	1987	310	310	310	310	1.183	1.183	1.177	1.177
TIME	1988	1949	1949	1949	1949	1.165	1.165	1.162	1.162
TIME	1989	28575	28575	28575	28575	1.019	1.019	1.016	1.016
TIME	1990	34502	34502	34502	34502	0.741	0.741	0.735	0.735
TIME	1991	20436	20436	20436	20436	0.520	0.520	0.512	0.512
TIME	1992	24265	24265	24265	24265	0.335	0.335	0.323	0.323
TIME	1993	8798	8798	8798	8798	0.221	0.221	0.208	0.208
TIME	1994	4140	4140	4140	4140	0.180	0.180	0.166	0.166
TIME	1995	2544	2544	2544	2544	0.162	0.162	0.148	0.148
TIME	1996	2231	2231	2231	2231	0.152	0.152	0.137	0.137
TIME	1997	2250	2250	2250	2250	0.143	0.143	0.127	0.127
TIME	1998	2087	2087	2087	2087	0.136	0.136	0.120	0.120
TIME	1999	2052	2052	2052	2052	0.131	0.131	0.114	0.114
TIME	2000	2109	2109	2109	2109	0.126	0.126	0.109	0.109
TIME	2001	2027	2027	2027	2027	0.123	0.123	0.105	0.105
TIME	2002	1674	1674	1674	1674	0.122	0.122	0.103	0.103
TIME	2003	877	877	877	877	0.125	0.125	0.105	0.105
TIME	2004	797	797	797	797	0.132	0.132	0.111	0.111
TIME	2005	772	772	772	772	0.139	0.139	0.117	0.117
TIME	2006	615	615	615	615	0.148	0.148	0.125	0.125
TIME	2007	129	129	129	129	0.159	0.159	0.135	0.135
TIME	2008	98	98	98	98	0.173	0.173	0.148	0.148
TIME	2009	193	193	193	193	0.187	0.187	0.161	0.161
TIME	2010	113	113	113	113	0.202	0.202	0.175	0.175
TIME	2011	162	162	162	162	0.218	0.218	0.190	0.190
TIME	2012	163	163	163	163	0.234	0.234	0.205	0.205
TIME	2013	150	150	150	150	0.251	0.251	0.220	0.220
TIME	2014	7	7	7	7	0.268	0.268	0.237	0.237
TIME	2015	460	460	460	460	0.285	0.285	0.252	0.252
TIME	2016	360	360	360	360	0.301	0.301	0.266	0.266
FOR	2017	500	500	500	500	0.316	0.316	0.280	0.280
FOR	2018	1345	750	1345	750	0.328	0.330	0.291	0.292
FOR	2019	1345	1125	1345	1125	0.337	0.341	0.298	0.302
FOR	2020	1345	1345	1345	1345	0.345	0.350	0.304	0.309
FOR	2021	1345	1345	1345	1345	0.353	0.358	0.309	0.314
FOR	2022	1345	1345	1345	1345	0.359	0.364	0.313	0.318
FOR	2023	1345	1345	1345	1345	0.365	0.370	0.316	0.321
FOR	2024	1345	1345	1345	1345	0.370	0.375	0.318	0.323
FOR	2025	1345	1345	1345	1345	0.374	0.379	0.319	0.324
FOR	2026	1345	1345	1345	1345	0.377	0.382	0.319	0.324
FOR	2027	1345	1345	1345	1345	0.380	0.385	0.318	0.323
FOR	2028	1345	1345	1345	1345	0.382	0.386	0.316	0.321
FOR	2029	1345	1345	1345	1345	0.383	0.388	0.314	0.319
FOR	2030	1345	1345	1345	1345	0.384	0.389	0.311	0.315
FOR	2031	1345	1345	1345	1345	0.384	0.389	0.307	0.312

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