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Orange Roughy (*Hoplostethus atlanticus*) Eastern Zone stock assessment incorporating data up to 2014

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Important disclaimer

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Contents

1 Summary

A workshop organised by AFMA (including New Zealand participants) was held at CSIRO Hobart in May 2014 to discuss the Eastern Zone orange roughy fishery and stock assessment, including the development of a base-case model specification. The base case model outlined in this document draws largely on the outcomes of that workshop, as well as the 'future work' outlined by Upston & Wayte (2012b). The aim of this document is to report on the Preliminary and Final Base-case assessment models that were considered by the Slope Resource Assessment Group (Slope RAG) at their meetings in September and October 2014, and to report on the additional work that was conducted during November 2014 (out of session).

The current assessment for Eastern Zone orange roughy (*Hoplostethus atlanticus* Collett 1889) uses an integrated stock assessment model implemented using the platform Stock Synthesis 3. It assumes a stock structure hypothesis that the Eastern Zone and Pedra Branca from the Southern Zone (all seasons) constitutes a single homogeneous stock. New data inputs since the 2011 preliminary assessment model (Upston & Wayte 2012a) include recent research catches; total spawning biomass estimates for 2012 and 2013 from acoustic towed surveys at St Helens Hill and St Patricks Head, and revised indices of spawning biomass from towed and hull surveys since 1990.

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. Informative prior distributions were developed for the catchability coefficient for the acoustic surveys, and the Francis (2011) data weighting method was applied to select the weights for the age composition data, which led to more weight being assigned to the acoustic survey indices when the model was fitted. The other new data inputs were a revised egg survey estimate, a catchability coefficient for that survey, and an updated ageing error matrix using data from a recent re-ageing experiment (by Fish Ageing Services). The re-ageing experiment, which was designed to investigate between-year bias in age reads, found no evidence of a major bias in the early age readings for Eastern Zone orange roughy.

A Preliminary Base-case model was presented at the Slope RAG meeting in September 2014, and the Final Base-case Model 0, which included minor updates to recent catches and the ageing error matrix, was presented at the Slope RAG meeting in October 2014. The model outcomes were similar; both models estimate a pattern of recruitment that oscillates from high to low prior to the start of the fishery, and imply a steep decline in female spawning biomass during the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline, and a recent increase to levels above 20% of the unfished female spawning biomass. The model estimates a recent increasing trend in spawning biomass, whereas the observed acoustic point estimates for 2012 and 2013 are less than the point estimates for the preceding years (Ryan et al. 2014 raise the possibility that the 2013 St Helens acoustic survey may have missed the spawning peak but they cannot be definitive).

The Final Base-case Model 0 estimated female spawning biomass in 2015 to be 26% of the unfished level (maximum posterior density MPD estimate). The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534 t. The outcome of Model 0 is consistent with those from the 2006 Eastern Zone orange roughy stock assessment, which forecasted that the biomass would reach the limit level of 20% of the unfished level in 2014 (if removals in each future year were based on the 48:48:20 harvest control rule).

The posterior median estimates from the MCMC simulation were close to the MPD estimates for most of the parameters of interest. The median estimate of female spawning depletion (SB_{2015}/ SB_0) was 0.25 with a 95% Bayesian CI of 0.23 to 0.28, and is close to the MPD estimate of 0.26. The 95% Bayesian CIs for the estimated parameters, notably female spawning biomass, are fairly narrow and may indicate that the model is constrained. In particular, the model assumption regarding the degree to which data inform estimates of recruitment in the recent and forecast years could have overly constrained the estimates of recruitment variability for these years, and this should be explored in future assessments.

The catchability coefficients for the towed and hull acoustic surveys were estimated by the Final Base-case model to be 1.32 and 1.78 respectively, and while substantially higher than 1, both were within the bounds of the priors. The selected priors may not have captured all of the uncertainty associated with the difference between estimates from the acoustic surveys and the underlying biomass. Assumptions regarding stock structure and the proportion spawning annually could also have a scaling effect on biomass estimates in the model.

Assumptions regarding stock structure are a key uncertainty in the assessment, as the model outcomes differed depending on this assumption. The base-case model was also sensitive to the inclusion of recruitment deviations, higher earlier catches and, to a lesser extent, the data weighting method for the age compositions.

2 Introduction

2.1 The fishery

The two 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 2006; Wayte 2007) and in 2011 (using data up to December 2010; Upston & Wayte 2012a, b). Hereafter, these models are referred to as “2006 assessment model” and the “2011 preliminary assessment model” respectively. Historically, the stock assessment has been referred to as the “Eastern Zone orange roughy stock assessment”, distinct from the “Southern Zone stock assessment” (Wayte 2002), and we continue with this naming convention. We describe the stock structure assumptions for the Eastern Zone stock assessment in Section 2.2.

A history of the fishery for orange roughy in the Australian Fishing Zone is provided by CSIRO & TDPIF (1996); Bax (2000); Wayte (2007), and in a series of articles in the journal, Australian Fisheries, since the early 1980’s (e.g. May 1989; December 1989; October 1990).

The fishery was closed to commercial fishing at end of 2006 (with the exception of the Cascade Plateau Zone), with orange roughy listed as conservation dependent. A 5-year conservation plan has been in place since 2007 and was due for review in 2011/12. It is currently in the process of review. There is a requirement under the Conservation Program, developed in response to the species being listed as conservation dependent, to collect information on how the stock status for the species is tracking over time. Consequently, recent estimates of biomass from acoustic surveys are available, and age data have also been collected. A research quota of less than 200 t has been allocated and fished in each year to collect this information. A workshop organised by AFMA (including NZ participants) was held at CSIRO Hobart in May 2014 to discuss the fishery and the Eastern Zone orange roughy stock assessment, including development of a base-case model specification. The base case model in this document draws largely on the outcomes of this workshop.

2.2 Stock structure

Information on stock structure and life history of orange roughy is included in Deriso & Hilborn (1994); CSIRO & TDPIF (1996); Bax (2000); Wayte (2007); and Prince & Hordyk (2011). In a review of Australian orange roughy stock assessments, Stokes (2009) recommended that a comprehensive or “forensic” review of all information relevant to stock structure (e.g. see Dunn & Devine, 2010, for orange roughy in New Zealand) be undertaken to explain and justify existing assumptions and/ or underpin model development for management strategy evaluation.

The stock structure of orange roughy remains uncertain. Stokes (2009) noted that modelling of biomass based on various plausible stock structure hypotheses, as was done in the 2006 assessment (Wayte, 2007), was a reasonable approach in the absence of information on stock structure. The stock structure hypotheses specified in the 2006 assessment are listed in Table 1 (from Wayte, 2007). The Australian orange roughy management zones and areas are shown in Figure 1.

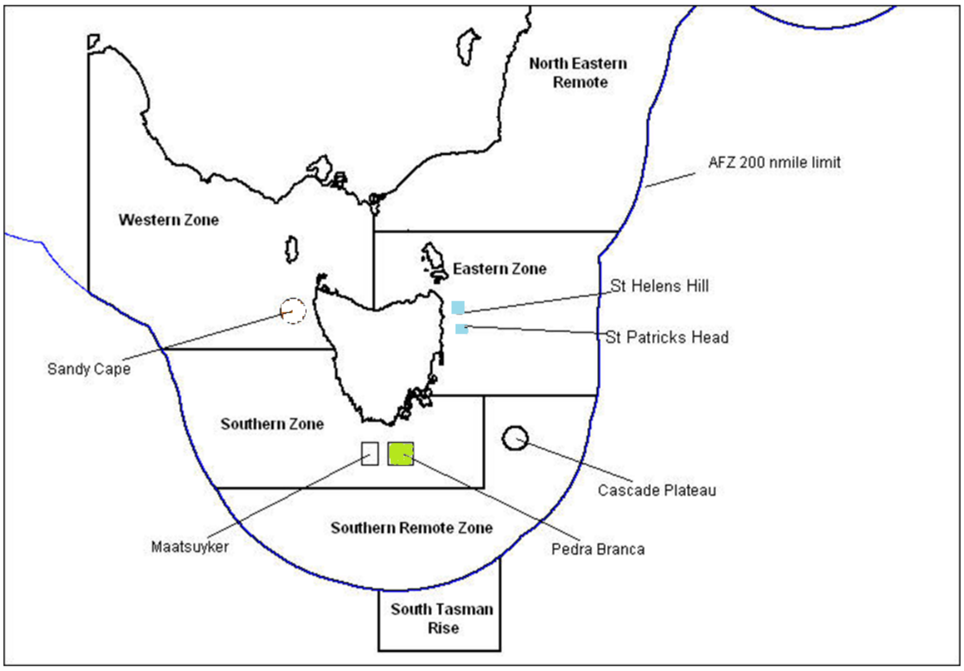


Figure 1. Map of Australian orange roughy management zones and areas (adapted from Wayte, 2007).

Table 1 The stock structure hypotheses used in the 2006 assessment (Wayte, 2007).

Stock hypothesis	Description	Corresponding catch data
East	All roughy in the Eastern zone (spawning and non-spawning)	Total Eastern zone catch (all months)
2002 Combined	Eastern zone spawning roughy and the Pedra Branca non-spawning roughy	Eastern zone winter catch (June, July, August) and Pedra Branca[1] non-winter catch (all months except June-Aug)
*Combined	Eastern zone roughy and the Pedra Branca roughy	Total Eastern zone catch (all months) and Pedra Branca catches (all months)
East + South	All roughy in the Eastern and Southern zones	Total Eastern zone catch and total Southern zone catch (all months)
East + South + West	All roughy in the Eastern, Southern and Western zones	Total Eastern zone catch, total Southern zone catch and total Western zone catch (all months)

[1] Pedra Branca area : -44.5S < latitude=<-44S; 146.5<=longitude<147.75

*Base-case in the 2006 assessment

The stock structure hypothesis used in the 2014 base-case model is the same as that specified for the 2006 and 2011 base-case models, i.e. the 'Combined' hypothesis in Table 1: Eastern Zone and Pedra Branca from the Southern Zone, for all seasons. For the 2014 assessment, we refer to this hypothesis as "East and South (Pedra Branca)". This stock structure hypothesis is partly based on the prevailing theory that a proportion of Southern Zone orange roughy migrate to the main spawning grounds in the Eastern Zone (St Helens Hill or the nearby St Particks Head) to spawn in winter. It excludes the possibility that orange roughy in other areas of the Southern Zone (e.g. Maatsuyker, near to Pedra Branca), and indeed other Zones, also migrate to spawn in the Eastern Zone. The base-case model includes all seasons so it implies a degree of mixing throughout the year.

The stock structure hypothesis used in the models will influence estimates of unfished biomass and current biomass, but not necessarily depletion estimates. Thus a potential "scaling" issue, stemming from an incorrect stock structure assumption (or some other factor), might become evident if the model consistently over- or under-estimates current spawning biomass when compared with a reliable time series of absolute biomass indices. We explore the sensitivity of the results to alternative stock structure in this assessment.

2.3 2014 Base-case and modifications to the 2011 Eastern Zone preliminary assessment

The 2014 base-case model was developed following discussions and outcomes of the May 2014 Australian Orange Roughy workshop, as well as reviews of the two most recent stock assessments (Wayte 2007; Upston &Wayte 2012a, b) by Stokes (2009), Cordue (2011) and a CSIRO internal review.

New data inputs since the 2011 preliminary assessment were: research catch for 2011- 2014; total spawning biomass estimates from acoustic towed surveys at St Helens Hill and St Patricks Head, for 2012 and 2013; and revised tow and hull acoustic biomass series - revised paired snapshots are used to calculate an average series (Section 3.1.5). Informative prior distributions have also been developed for the acoustic catchability parameter, for the towed and the hull surveys (Appendix A). The egg survey estimate of absolute female spawning biomass was revised, and historical assumptions regarding the survey were made explicit in the formulation of the catchability coefficient. The ageing error matrix was updated using data from a re-ageing experiment that was completed in October 2014 (Appendix B).

A Preliminary Base-case model was presented at the Slope RAG meeting in September 2014, and the Final Base-case Model 0, which included minor updates to recent catches and the ageing error matrix (when the data became available), was presented at the Slope RAG meeting in October 2014. The models were considered broadly similar by the RAG, and the sensitivity analyses for the Preliminary Base-case model were not repeated for the Final Base-case Model 0. We distinguish between the models in the relevant sections.

3 Methods

3.1 The data and model inputs

The parameters estimated by the model, priors, and pre-specified parameters are shown in Table 2.

This report uses the available data as they were known before 12 September 2014 (Preliminary Base-case model), and before 18 October 2014 (Final Base-case Model 0). We distinguish between the models only where relevant, given that they have the same parameters, stock assumptions, and data inputs (with only minor adjustments for recent catches and the ageing error matrix for the Final model (Table 3 and Appendix B)).

Table 2 Number of estimated parameters and values of pre-specified parameters of the model for the Eastern Zone orange roughy base-case assessment. F=female, M=male. N(μ,σ²) refers to a normal distribution with mean μ and variance σ².

Estimated parameters	Number of parameters	Prior	Source
Unexploited recruitment (ln (R_0))	1	N (9.3;10^2)	Chosen to be uninformative
Recruitment deviations 1905 - 1980*	76	N (0; σ_R^2)	See section 3.2.1 for rationale
Selectivity logistic inflection	1	N (35.0;99^2)	Chosen to be uninformative
Selectivity logistic width	1	N (3.0;99^2)	Chosen to be uninformative
Catchability coefficients			
q Acoustic towed	1	N (0.95;0.3^2)	Appendix B
q Hull	1	N (0.95;0.9^2)	Appendix B
Pre-specified 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		Est. selectivity of spawning aggregation.
Maturity logistic slope	-1.3 cm^{-1}		Smith et al. (1995)
Von Bertalanffy growth coefficient, k	0.06 yr^{-1}		
Length at 1 yr F	8.66 cm		
Length at 70 yrs F	38.6 cm		
Length-weight scale, *a*	3.51×10^{-5} (F) 3.83×10^{-5} (M)		Lyle et al. (1991)
Length-weight power, *b*	2.97, 2.942 (F,M)		Lyle et al. (1991)
Plus-group age	80 yr		
Length at age CV for young	0.07		Est. from data
Length at age CV for old	0.07		Exp. offset from young
Catchability coefficient (egg survey); *q*	0.90		Bell et al. (1992); Koslow et. al (1995) & Wayte (2007)

*for 1960 to 1973 the full bias-correction is applied, and for 1950 to 1959 and 1974 to 1980 the amount of bias-correction applied is linearly phased in and out.

3.1.1 BIOLOGICAL PARAMETERS

The sources for the pre-specified biological parameters used in the sex- and age- structured base-case model are given in previous assessment reports (CSIRO & TDPIF 1996; Bax 2000; Wayte 2007). The pre-specified parameter values (those for recruitment steepness, natural mortality) are broadly consistent with those used in New Zealand orange roughy stock assessments (e.g. Smith et al. 2001; MFSWG 2009; Cordue 2014). Other relevant references for biological parameters include Lyle et al. (1989).

Natural mortality (*M*) was set to 0.04yr^{-1}, which was a recommendation from the May 2014 Australian Orange Roughy workshop. The basis for this decision was the Stokes (2009) review of orange roughy stock assessments which recommended that “a consistent default assumption of *M*=0.04 should be made for all Australian orange roughy assessments. Departure from that default on a case by case basis should occur following careful analysis and re-examination of maximum age estimates”. Further, *M* was estimated to be 0.04yr^{-1} in the 2006 and 2011 base-case models; see Stokes (2009) for discussion of *M*.

Maturity was modelled as a logistic function of length, with 50% maturity at 35.8 cm. The model was fitted, and the parameters governing maturity as a function of length were set to match estimated selectivity of the spawning aggregations (i.e. ”maturity” is assumed to be the same as spawning). The approach of equating orange roughy being present on the spawning grounds with maturity (which will differ from functional maturity) is consistent with how recent assessments of orange roughy have been undertaken (Wayte 2007), including New Zealand assessments by Cordue (2014). Fecundity-at-length was assumed to be proportional to weight-at-length. The pre-specified parameters of the length-weight relationship are given in Table 2.

The selectivity of the fleet was assumed to be a length-based logistic function, with parameters for inflection and width for 95% selection estimated within the model. Selectivity of the acoustic surveys for male and female spawning roughy was set to mirror that of the trawl fleet. This allowed the selectivity of the spawning aggregations to be estimated, and maturity was fixed at the estimated values.

The “egg survey” (see Section 3.1.5) refers to the female spawning biomass estimate from St Helens Hill (main spawning ground), calculated using egg production methods (Koslow et al. 1995). Selectivity for the egg survey was set so that the expected survey abundance was equal to female spawning biomass (selectivity pattern 30 in Stock Synthesis; Methot & Wetzell, 2013).

Recruitment steepness was set to 0.75. However sensitivity of the assessment results to lower steepness (0.4), and a higher steepness (0.8) (Francis 1992) was also explored.

3.1.2 FLEETS

The assessment assumes a single trawl fleet, which is consistent with the 2006 and 2011 assessments. However, it differs from an earlier assessment that specified two Eastern fleets, St Helens Hill and St Patricks Head (Wayte & Bax, 2002). Wayte (2007) states the rationale for a one fleet model was the principal of parsimony.

The 2014 Australian Orange Roughy workshop resolved to model St Patricks Head and St Helen’s Hill together; given the available data there is no obvious way to resolve the apparent “switching” of spawning fish between the grounds in certain years (see Table 9.4 in Upston & Wayte 2012a).

Consistent with previous models, the current base-case model assumes a single fleet that fishes the East and South (Pedra Branca), throughout the year, and that the selectivity of the fleet can be estimated from the Eastern spawning aggregation. It may be prudent to test this in the future, if relevant data become available. However, the assumption of one fleet seems reasonable as historically the major component of the catch was taken from the Eastern spawning aggregations (during winter), with a lesser component from Pedra Branca (see Table 3; Bax 2000, Figure 2).

3.1.3 LANDED CATCHES

Commonwealth Commercial logbook data for the years 1985 to 1991 and landings for the years 1992 to 2014 provide information on orange roughy retained catch in the SESSF. The respective databases are administered by AFMA and a mirror copy of the databases (current at the date of extract by AFMA) is housed at CSIRO.

Table 3 lists reported and agreed catch histories for three of the Management Zones (Eastern, Southern, and Western Zones) and the area, East and PB, which encompasses the East and includes Pedra Branca (PB) in the South. The East and PB catch history is used in the base-case assessment. Wayte (2007) provides details on how catches have been adjusted from the originally reported values. Other key references for the rationale for adjustments to the catch history, including outcomes of the 1994 workshop that determined an "agreed" history are CSIRO & TDPIF 1996 (i.e. the 1994 orange roughy stock assessment report) and stock assessment reports by Bax (for years 1995, 1996 and 1997 – see Bax 1997, Bax 2000a and 2000b) for minor adjustments to the initial "agreed" history.

Table 6.1 (in section 6) lists catches for the sensitivity model I "Higher early catches", which places a nominal higher bound on agreed catches (see section 3.2.2).

Table 3. Total recorded logbook catches (t) 1985 - 1991, recorded landed catches (t) 1992 – 2014 (Reported), and agreed catch history* (Agreed) of orange roughy for East, South and West Management Zones and area Pedra Branca (PB) in the South. All seasons are included. The base-case model uses East and PB Agreed catches. * Agreed catch history (incorporates adjustments for proportion lost due to gear lost and burst bags/ panels etc, and misreporting (CSIRO & TDPIF 1996; Wayte 2007). Highlighted columns refer to catches included in the stock assessments used in the report. The catches for 2014 are estimates based on the landings as at October 2014. For the Preliminary Base-case model the EAST and PB catches for 2011 to 2013 inclusive were 160 t each year and the 2014 catch was not included.

	EAST		EAST and PB	PB only	SOUTH (including PB)		WEST
Year	Reported	Agreed	Agreed	Agreed	Reported	Agreed	Reported
1985	6	6	6	0	58	58	129
1986	33	33	60	27	631	631	3,970
1987	310	310	310	0	353	353	5,128
1988	1,949	1,949	1,949	0	469	469	4,765
1989*	18,365	26,236	28,575	2,339	7,620	10,886	1,386
1990*	16,240	23,200	34,502	11,302	24,801	35,430	802
1991*	9,727	12,159	20,436	8,277	11,541	14,426	628
1992*	7,484	15,119	24,265	9,146	7,947	16,054	1,141
1993*	1,971	5,151	8,798	3,647	7,602	5,486	1,031
1994*	1,682	1,869	4,140	2,271	4,345	4,828	927
1995	1,959	1,959	2,544	585	2,157	2,157	1,055
1996	1,998	1,998	2,231	233	802	802	1,320
1997	2,063	2,063	2,250	187	454	454	352
1998	1,968	1,968	2,087	119	250	250	360
1999	1,952	1,952	2,052	100	174	174	244
2000	1,996	1,996	2,109	113	311	311	192
2001	1,823	1,823	2,027	204	357	357	248
2002	1,584	1,584	1,674	90	167	167	294
2003	772	772	877	105	210	210	243
2004	767	767	797	30	80	80	321
2005	754	754	772	18	99	99	281
2006	614	614	615	1	5	5	159
2007	113	113	129	16	22	22	31
2008	98	98	98	0	0	0	5
2009	193	193	193	0	10	10	16
2010	113	113	113	0	18	18	27
2011	160	160	162	2	17	17	37
2012	163	163	163	0	22	22	20
2013	150	150	150	0	8	8	45
2014	20	20	20	0	20	20	20

3.1.4 DISCARD RATES

Discards are not included explicitly in the assessment, although they are included implicitly via adjustment to landed catches that are input into the model for “losses” at sea during the years 1989 to 1994 (Table 3). There are no implicit assumptions regarding discards for other years.

3.1.5 INDICES OF ABUNDANCE

The Eastern Zone orange roughy assessment uses relative indices of abundance (spawning biomass) from independent acoustic towed body (select years between 1991 to 2013) and hull (1990, 1991, 1992) surveys, and an absolute index from an egg survey (1992). The acoustic 38 kHz towed body and hull snapshot estimates of spawning biomass (and associated CVs) at St Helens Hill and St Patricks Head are listed in Tables 6.2, 6.3 and 6.4, with the paired area snapshots over 24 to 48 hrs denoted. The series was revised from that used in the 2011 preliminary assessment model, and the CVs were calculated to include an error estimate for the dead zone component (the dead zone refers to the area extending from the seafloor to the depth threshold for acoustics detection - where orange roughy are presumed to be distributed but not directly observed by acoustics). Based on expert judgement, the few observations of “zero” orange roughy were ignored. The interlaced towed survey used in 2013 was considered broadly comparable to the grid survey 1991 to 2012. Regarding the 2013 acoustic survey observations, Ryan et al. (2014) state that “given the apparent downward trend in biomass observed at St Helens Hill [over the survey period] it is possible that the 2013 surveys did not quantify the spawning stock at its peak”. We have included the 2013 estimates in the assessment because the survey was carried out in a manner that was consistent with the other years (see Table 6.2).

The average of the snapshots in each survey year was calculated (assuming a common variance, i.e. a simple average), to form a series that indexes relative male and female spawning biomass for the stock (an outcome from the May 2014 Australian Orange Roughy workshop). A series based on the maximum snapshot values was also calculated for a sensitivity analysis, as the maximum estimates were used in the previous stock assessments. The spawning biomass estimates from each area were combined for a given year by adding the area averages, and the ‘Combined areas CVs’ (St Helens and St Patricks areas combined) were calculated from the combined distributions. The ‘Between snapshots CV’=0.20 (a nominal value but based on the average between snapshot CVs for SH and SP) was a separate component of the total survey CV.

For early years, where there were observations from only one of the areas, the average catch ratio between the grounds over the years 1986 to 1996 (Table 9.4 in Upston & Wayte 2012a) was calculated and the ratio was applied to the observed St Helens acoustic estimates to derive the St Patricks biomass estimates (mean of the proportion StP/ (StH+StP) = 0.29, assuming a Beta distribution). The estimates were assigned a “wide” associated error (Orange Roughy May 2014 workshop) by adding in an additional CV=0.25 (termed “Survey one area CV”) as a separate component of the total survey CV. The total survey CV is calculated by combining the three component errors (considered independent) - Combined areas CV, Between snapshots CV, and Survey one area CV.

Priors were developed for the catchability (*q*) scalar for acoustic towed and hull surveys (Appendix A). The priors were developed using available acoustic data and expert judgement. In setting a prior for the acoustic catchability (*q* scalar) we essentially have made a statement about how well the acoustic towed or hull series is thought to provide an absolute estimate of biomass of the spawning roughy for the stock that we are assessing, East and South (Pedra Branca) for the base-case.

There is also an absolute estimate of female spawning biomass (15,922 t, CV=0.5) for 1992, based on the egg production method (Bell et al. 1992; Koslow et al. 1995), which includes an adjustment to account for 5% loss of eggs due to advection from the survey area (the Koslow et al. 1995 estimate of 13,785 t was increased to 15,922 t); a recommendation in Deriso & Hilborn 1994. The catchability coefficient (*q*) for the egg production survey was set to 0.90 (Table 2) to account for an estimated 10% of spawning females that did not migrate from the Southern zone to St Helens in 1992 (this assumption was also incorporated into the acoustic survey priors, Appendix A). This is consistent with the assumptions in historical assessments, but is made explicit in the specification of catchability (*q*) for the absolute index (Bell et al. 1992; Deriso & Hilborn, 1994).

A distinction is made between the (i) percentage of spawning fish that are on the spawning grounds in the East and therefore can be "seen" by the acoustics surveys (recall the base-case stock structure assumption is East and South (Pedra Branca) i.e. it includes migration of fish from Pedra Branca), and (ii) the proportion of mature fish that are spawning in a given year. Historically, the implicit assumption for (i) has been 100%, except for 1992 when it was estimated that there were only 90% of spawning fish available to the surveys, i.e. a small percentage of spawners remained in the South in that year (and the egg survey was adjusted; Deriso & Hilborn 1994; Bell et al. 1992; Koslow et al. 1995). The assumption for (i) (the percentage of spawning fish on the grounds) in the current base-case is approximately 95% (the prior distribution is defined as a Beta(95, 5)). The current assessment models the spawning population and therefore explicitly references (i).

The current assessment does not explicitly include (ii) the proportion of mature fish that are spawning in a given year (this was agreed at the Orange Roughy workshop in May 2014), but assumes that it is constant on average (i.e. we assume that relative abundance of the spawning stock that is indexed by the acoustic surveys is not confounded with the proportion of mature fish that are spawning in a given year). Historically the implicit assumption for (ii) was 70% based on Bell et al. (1992) and the Koslow et al. (1995) proportion spawning surveys. An exception to the assumption of a constant proportion spawning is the acoustic hull series. In previous assessments the proportion spawning was not assumed to be constant over the early years of the fishery, as it developed (an historical assumption - see Deriso & Hilborn 1994). The 1990 hull acoustic estimate was increased by 30%, to account for a lower observed proportion spawning estimate in that year compared to 1991 and 1992 (proportion spawning 54% in 1990, 71% in 1991 and 72% in 1992 (Bell et al. 1992; Koslow et al. 1995)).

A non-constant proportion spawning for the hull index over the early years of the fishery (1990, 1991, and 1992) has also been assumed in this assessment. However no proportion spawning adjustment was made to the towed index as it begins in 1991 (proportion spawning was estimated to be 71% in that year).

3.1.6 AGE COMPOSITION DATA

Male and female age-compositions for years when spawning aggregations were sampled: 1992, 1995, 1999, 2001, 2004, 2010 are included in the assessment and are assumed to be simple random samples of the catch (see Table 6.5 for sample sizes). The age-compositions for St Helens Hill and St Patricks Head have been weighted based on either the relative abundance implied by the acoustic estimates or the relative catch (see method outlined in Wayte, 2007). The age samples for 1992 and 1995 are from St Helens only (but see Appendix C regarding 1995), where the major proportion of the catch was taken (Table 9.4 Upston & Wayte 2012a).

The issue of potential ageing bias, that is, the between-year bias for a given reader(s) - the drift hypothesis (Francis, 2006), was investigated by re-ageing approximately 350 Eastern Zone orange roughy otoliths from each of four years used in the stock assessment (1992, 1995, 2001, 2004; Appendix B). The latest ageing protocols (Tracey et. al 2007) were used for re-ageing (using the same method as for the 2010 ageing in the stock assessment). If notable bias was detected in the early age reads, the age reading bias could be modelled using the outputs of a program developed by Andre Punt (unpublished data).

A recommendation by Francis & Hilborn (2002) was to include an estimate of ageing error as model input so the ageing imprecision is dealt with within the model by including a correction to the likelihood. An estimate of the standard deviation of age reading error was calculated from data supplied by Kyne Krusic-Golub of Fish Ageing Services (Table 6.6). The estimate was updated from that used in the 2011 preliminary assessment, to include data from the re-ageing experiment (the difference between the age error matrices was minor).

Further details of the age samples used in the stock assessment are reported in Appendix C, including the current state of knowledge on provenance of the historical age samples, the sample coverage (Table C1), and the raw age frequencies (Figure C1). We also include information on sampling methods, and a note on the 2012 and 2013 age samples (otoliths are as yet unread) in Appendix C.

3.2 Stock assessment method

3.2.1 POPULATION DYNAMICS MODEL AND PARAMETER ESTIMATION

The current assessment is based on a two-sex age-structured model incorporating growth and stochastic recruitment to provide a series of annual stock biomasses given the catch history.

The integrated model analysis was conducted using the software package Stock Synthesis (SS, version 3.24Q; Methot & Wetzel, 2013). 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 technical description (Methot & Wetzel, 2013). Some key assumptions of the base-case analysis of Eastern Zone orange roughy are:

1. The Eastern Zone and Pedra Branca (from the Southern Zone) constitute a single stock within the area of the fishery;
2. As in previous assessments, the population is assumed to have been at its unfished biomass with the corresponding equilibrium unfished age-structure at the start of 1904. The fishery start year was 1980 (with zero catches for 1980 to 1984, to avoid an unrealistic recruitment spike being estimated by the model (S. Wayte pers. comm. 2014));
3. One trawl fishing fleet is modelled;
4. The natural mortality rate, *M*, is assumed to be independent of age and time, and not to differ between sexes (*M* is set to $0.04yr^{-1}$ in the model);
5. Recruitment is assumed to be distributed about a Beverton-Holt stock-recruitment relationship, with parameters being the average recruitment at unfished equilibrium, R_0, and steepness, *h*. The standard deviation of the variation about the stock-recruitment relationship (quantified by σ_R) is pre-specified (fixed in the model), along with the extent of how bias-correction changes over time. Recruitment deviations were estimated for 1905 to 1980 (1980 is the fishery start year). For 1960 to 1973 the full bias-correction is applied, and for 1950 to 1959 and 1974 to 1980 the amount of bias-correction to be applied is linearly phased in and out. Recruitment deviations were estimated from 1905, as there are catch data in 1985 and orange roughy aged 80+ years (born in 1905 or earlier) were caught in the early years of the fishery (80+ observed in the age compositions for 1992). The recruitment deviations were estimated to 1980, since orange roughy recruit to the fishery at approximately 35 yrs, thus few of the fish born in 1980 would have recruited to the fishery in 2014 or 2015;
6. The plus- age group was set at 80 years;
7. The Francis (2011) approach is used for weighting the age compositions.

The estimated and pre-specified parameters of the model are shown in Table 2 (Section 3.1).

3.2.2 SENSITIVITY TESTS AND ALTERNATIVE MODELS

Key sensitivities to the base-case model were identified at the May 2014 Australian Orange Roughy workshop and by Slope RAG. Five of the sensitivities that were defined *a priori* (A to E) were considered for the Preliminary Base-case model at the September 2014 Slope RAG (final recent catches and age error data were unavailable at the time), and these provided information on the effects of some of the main changes between the current assessment model, and previous assessment models (e.g. informative priors for the catchability coefficient (*q*) for the acoustic biomass estimates, a new weighting method for age compositions, acoustic indices as the average of snapshots rather than the maximum).

The five additional key sensitivities (F to J) that were considered for the Final Base-case Model 0 at the October 2014 Slope RAG included three alternative stock structure assumptions identified in Wayte (2007), sensitivity to a higher agreed catch for the early years, and sensitivity to include a minor age bias for early age compositions. Sequential models for the preliminary and final base-case models were also completed to show the effects of main changes to the data and model settings on the model outcomes. Standard sensitivities to natural mortality, steepness and data weighting for the Final Base-case are also considered.

Model outputs and sensitivity analyses presented for the Preliminary Base-case model and associated sequential models (September RAG) are listed in Table 6.7. The model outputs and sensitivity analyses for the Final Base-case Model 0 and the associated sequential model (October RAG) are listed in Table 4 (Results section 4.2.3).

The sensitivity tests and their rationale are:

A. weight the age-composition data using the McAllister and Ianelli (1997) method used in past assessments. This weighting approach was used in the previous assessment (2011 preliminary base-case models) and is compared to the current base-case model that uses the Francis (2011) approach to weighting the age compositions;
B. set the CV for the priors for *q* for the towed acoustic survey index to a larger value (i.e. diffuse priors CV=99);
C. do not estimate recruitment deviations. A scenario similar was included in the 2006 assessment (the 'no age' model) and the 2011 preliminary assessment (the "No Recruitment Devs" model). This sensitivity test sets recruitment to expected recruitment, determined by the stock-recruitment function;
D. use the maximum acoustic spawning biomass estimates in the model instead of the average estimates. The maxima have been used in the previous stock assessments;
E. assume a lower steepness (h=0.4; Francis, 1992). Sensitivity of the model to an alternative stock-recruitment relationship to the Beverton and Holt was not tested (but see Upston & Wayte (2012a) - similar depletion estimates for the 2011 preliminary model assuming a B-H or Ricker stock-recruitment relationship were reported);
F. assume an alternative stock structure (East + South; Stokes 2009). The catches from the Eastern Zone and all of the Southern Zone (all seasons) are included in the model, whereas the base-case includes catches from only Pedra Branca in the Southern Zone. The same indices of relative abundance apply to all the alternative stock structure models, so the assumption is that the observed spawning aggregations in a given year comprise most of the spawning population from the respective Zones/ areas that are included in the stock structure (i.e. the assumption is that the orange roughy from the other Zones/ areas migrate to the Eastern Zone during winter to spawn);
G. assume an alternative stock structure (East + South + West; Stokes 2009). The catches from the Eastern, Southern and Western Zones (all seasons) are included ;
H. assume an alternative stock structure (East; Stokes 2009). The catches from the Eastern Zone only (all seasons) are included;
I. use higher earlier catches. This scenario was suggested as a nominal upper bound on the Agreed catch history (Table 6.1). A lower bound was not tested. However, the scenario "Unadjusted catches" was included in Upston & Wayte (2012a) - estimated a less depleted spawning stock than for Base-case Model A;
J. allow for a minor ageing bias (Appendix B, Table B1). The re-ageing experiment did not find evidence of major bias in the early age readings of Eastern Zone orange roughy; nevertheless we

tested the effect of correcting for the minor bias (~1 year) that was detected in the early age readings in some years (see Appendix B).

Additional diagnostic models were completed for the Final Base-case Model 0 (post-October RAG) and are listed in Table 4. The diagnostic models tested sensitivity of the Final Base-case model to alternative data weightings, natural mortality, steepness, and a lower bound for the fleet selectivity width (the base-case model lower bound was set at 1.0 based on previous models; Wayte 2007 and Upston & Wayte 2012a).

The following four metrics were used to examine the sensitivity of the results of the base-case models to some of the assumptions and data inputs:

- the average unexploited female spawning biomass, SB_0;
- SB_{2015} - the female spawning biomass at the start of 2015 (SB_{2014} for Preliminary Base-case model);
- SB_{2015}/SB_0 - the depletion level at the start of 2015, i.e. the 2015 spawning biomass expressed as a fraction of the unexploited spawning biomass (SB_{2014}/SB_0 for Preliminary Base-case model);
- *–lnL* - the overall negative of the logarithm of the likelihood function (this is the value minimised when fitting the model, thus a lower value implies a better fit to the data, although this value is not comparable among all of the sensitivity tests);

A qualitative assessment of the model fit to the expected values for each data source was completed and the relative contribution to the likelihood from each source of data fitted in the assessment was considered when gauging model performance.

The 20:35:48 harvest rule is used to calculate the RBC.

3.2.3 MCMC ANALYSIS FOR FINAL BASE-CASE MODEL 0

The Markov chain Monte Carlo (MCMC) is a method for approximating the posterior distribution for parameters of interest in the Bayesian framework (Gelman et al. 2003). The MCMC simulation should be run long enough so that the model converges in the sense that the parameter vectors are random independent samples from the posterior (i.e. the distribution of draws is close enough to the target posterior distribution $p(\theta \mid y)$) (Gelman et al. 2003).

MCMC simulations of the parameter space were completed for the Final Base-case Model 0 (during November 2014). Diagnostics from an initial run revealed a high correlation for the selectivity parameters (which will degrade the efficiency of MCMC implementation) and the estimate for the selectivity width was drifting towards low values (approaching zero; implying knife-edged selectivity). Therefore the selectivity inflection and width parameters were set at the maximum posterior density (MPD) estimates. Note that maturity was fixed in the base-case model at the estimated values for the selectivity of the spawning aggregations (i.e. selectivity of trawl fleet).

The final MCMC simulation ran for 24 million cycles, every 40,000th iteration was saved (run time for the final model was ~ 6 days using a standard scientific personal computer). This gave 600 samples from the posterior distribution. The first sample was omitted from the chain, which resulted in 599 posterior samples. Model convergence was assessed using the statistics: (i) the extent of batch auto-correlation (examined using trace plots), (ii) whether the posterior distribution was approximately multivariate normal (we examined the plot of the posterior distribution), and whether the distribution of the chain is stationary, as judged by the *p*-value computed from the Geweke statistic (which should be close to 1) and (iii) whether the Heidelberger and Welch test is passed or not (Gelman et al. 2003). The R package, r4ss (Taylor et al., 2014), was used to produce the plots and statistics.

Alternative chains with different starting values for the MCMC simulation can also be used to assess model convergence. The MCMC simulations from alternative chains were not completed at the time of writing. However, they should be possible to do in the future (J. Upston following up on the implementation of this in Stock Synthesis).

4 Results and Discussion

4.1 Preliminary Base-case Model

The Preliminary Base-case model (September 2014 RAG) results are included in Table 6.7 (section 6). The parameter estimates, fits to the data, and the assessment outcomes are very similar to those for Final Base-case Model 0 (see Table 4; female spawning depletion in 2015 is 0.26 for both models), and are therefore not presented in this section. The similarity in model outcomes is not unexpected given the minor differences between the two base-case models. The Final Base-case Model 0 included minor adjustments to recent catches (2011, 2012 and 2013; the 2014 estimated catch was added) and to the age error matrix. (Tables 3 and 6.6), otherwise the models are the same. We consider the results from the sensitivity tests and transition models for the Preliminary Base-case model in Section 4.3, as the analyses provide information on the effects of some of the main changes to the current assessment model, when compared to the previous Eastern Zone orange roughy assessment models.

4.2 Final Base-case Model 0

The Final Base-case model 0 assumed a stock hypothesis: East and South (Pedra Branca), all seasons; and included relative spawning biomass indices from towed (1991 – 2013, selected years) and hull (1990-1993) acoustic surveys, with priors imposed on catchability (*q*); and an absolute female spawning biomass index for 1992, derived from egg production methods. The ending year expected growth is pre-specified in the model (Figure 1).

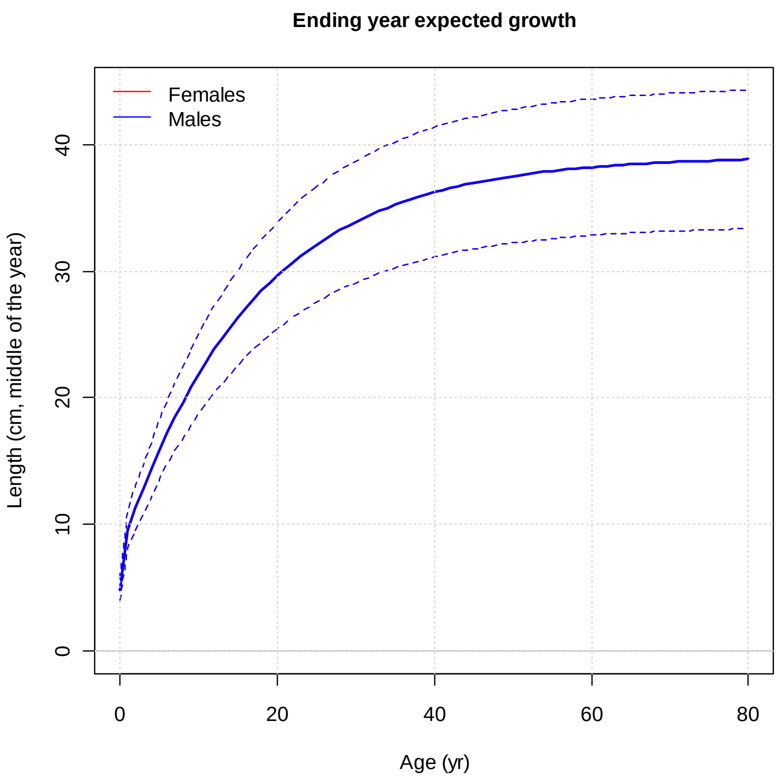


Figure 2. The ending year expected growth (one curve for males and females), which is pre-specified in the model.

4.2.1 PARAMETER ESTIMATES

The parameter estimates for unexploited recruitment (SR_LN(R0)), selectivity and the catchability coefficients (*q*) are shown in Table 4. The Final Base-case model estimate of selectivity inflection was 35.8 cm, and selectivity width was 1.0 cm (Table 4). The selectivity width was estimated to be at the lower bound set for this parameter, so we have considered sensitivity where the bound is set lower (see Section 4.3).

The Final Base-case model estimate of the catchability scalar (*q*) for the acoustic towed survey was 1.32 (Table 4). The estimate of *q* implies that the acoustic towed survey is on average observing more spawning orange roughy (~ 1.3 times) than the available spawning biomass (estimated in the model). For the recent four years of towed surveys we note that the observed point estimates are above the model estimates for 2006 and 2010, however they are below the model estimates for 2012 and 2013 (Figure 3). A *q* estimate of 1.32 is within the bounds of the prior, which had approximately 95% of its density between 0.40 to 1.50 (Table 6.2 and Appendix A, Figure A2), thus *q* could moderately deviate from 1, and in either direction. It is noteworthy that the estimates of *q* ranged between 2.6 and 3.3, depending on the model in the 2011 preliminary base-case assessment (Upston & Wayte 2012a). In the 2011 model, the surveys indexed total mature biomass, and the greater *q* is at least in part explained by the multiplying up of the acoustic observations of spawning biomass to total mature biomass. We do not directly compare outcomes from the 2011 model and the base-case model in this document, given the different data inputs and model structure.

The estimate of *q* for the hull survey in the Final Base-case model was 1.78 (Table 4). This estimate is within the bounds of the prior, which has a wide CV (0.92) to reflect the greater uncertainty associated with the hull biomass estimates than for those from the towed body acoustic surveys.

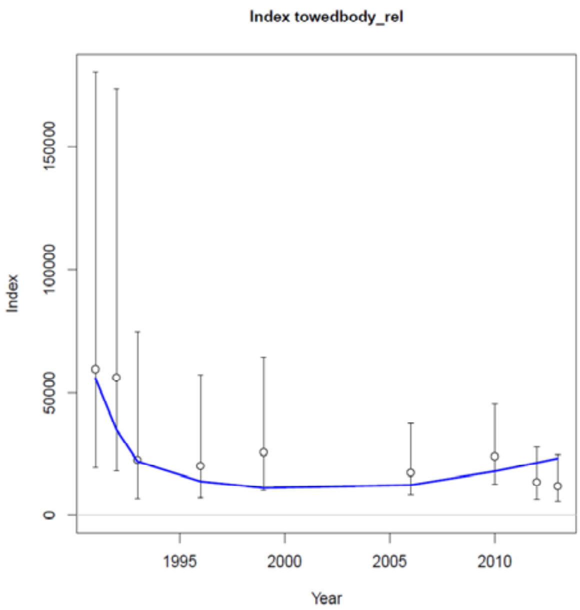
The acoustic indices are considered to be relative indices in the model in the sense that there are several factors that can influence the acoustic biomass estimates (e.g. see the note in Table 6.2 on 2013 survey timing). If we have not captured all of the uncertainty in our prior definitions (e.g. the random error component could be much larger than assumed), then the imposed *q* scaling in the model may be too “tight”. Further, there are assumptions regarding stock structure and constant proportion spawning that are embedded in the model, which could have also have a scaling effect on biomass estimates. Hence ongoing review of the prior definitions of *q* for the acoustic surveys based on the latest data and understanding of the system, is suggested.

4.2.2 FITS TO THE DATA

There were good fits to the abundance indices and the age data for the Final Base-case Model 0 (Figures 3 and 4). The model estimates of spawning biomass for 2012 and 2013 are above the observed point estimates for the towed body survey, and below the survey estimates in 2006 and 2010 (Figure 3). However, the trajectories of spawning biomass intercept all the 95% confidence intervals for the abundance indices. Plots of the Pearson residuals for the age data showed no notable trend in the residuals (Figure 5).

The model estimate for the 1992 egg survey absolute index of female spawning biomass was 15,922 t (i.e. the same as the observed estimate). The *q* for the survey was set at 0.9.

Acoustic towed body (1991-2013)



Acoustic hull (1990-1993)

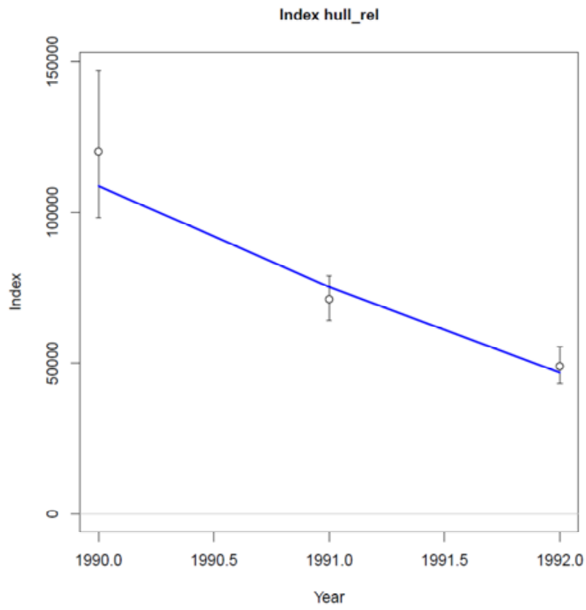


Figure 3 Final Base-case Model 0 Observed (circles) and model-estimated (lines) of relative indices of total spawning biomass - Acoustic towed (left plot) and hull (right plot). The vertical lines indicate approximate 95% confidence intervals for the data.

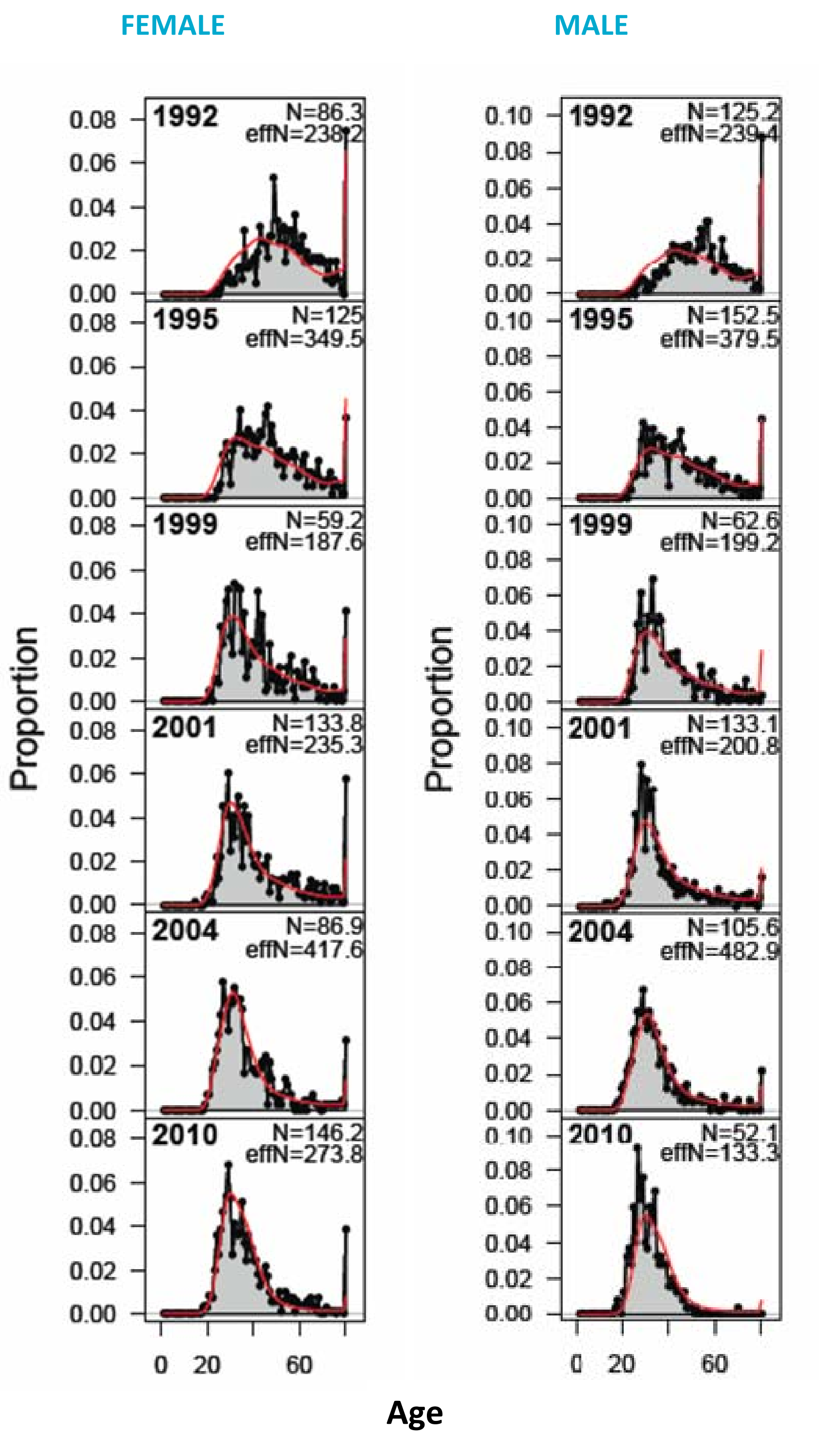
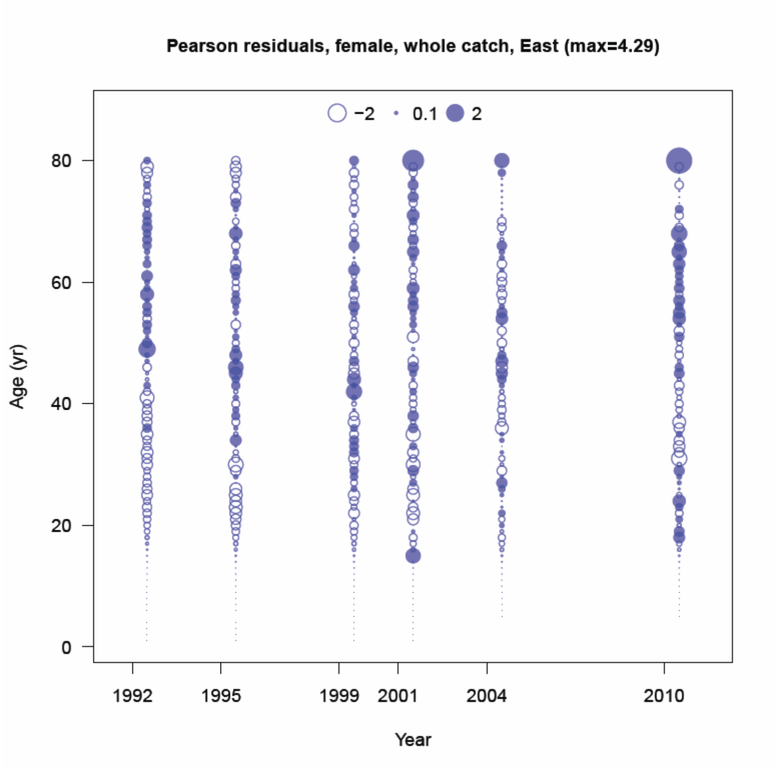


Figure 4 Fits to age compositions for the Final Base-case Model 0.



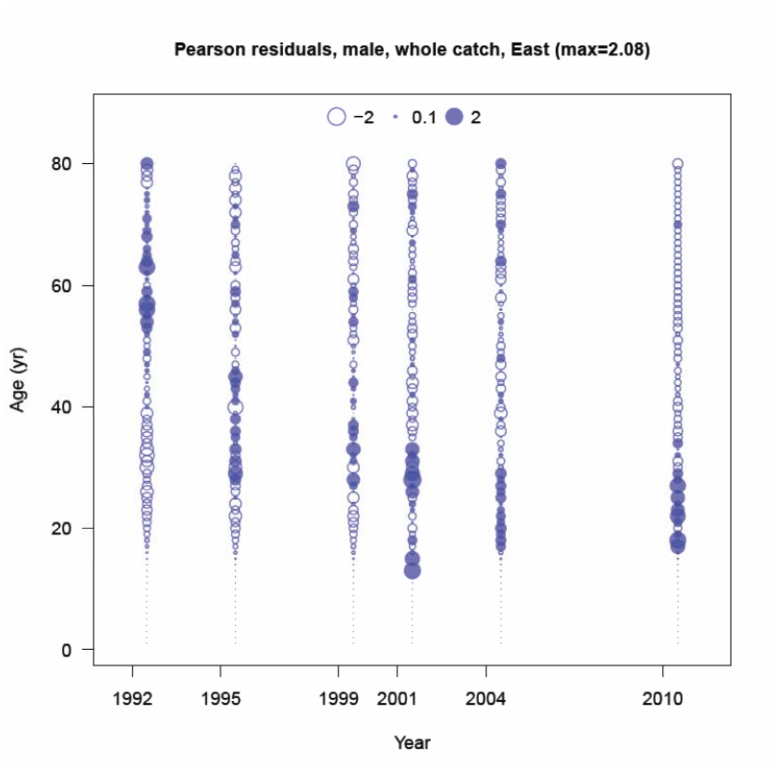


Figure 5 Standardized residual plots - age compositions for the Final Base-case Model 0.

4.2.3 ASSESSMENT OUTCOMES

The Final Base-case Model 0 estimated stock status in 2015 (female spawning biomass at the start of 2015 relative to the unfished female spawning biomass) at 26% (MPD estimate). The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534t (Table 4). The outcome was consistent with the 2006 Eastern Zone orange roughy stock assessment model, which forecasted that the biomass would rebuild to the limit level of 20% of the unfished spawning biomass in 2014 (if catches equalled those from the 48:48:20 harvest control rule each year) (Table 6.8, Wayte 2007).

The trajectory of female spawning biomass relative to unfished levels implies a pattern of steep decline in the spawning biomass in the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline between approximately 1995 and 2005, and a recent increase to levels above 20% (Figure 6). The forecast over the next 55 years implies a continued increase in the female spawning biomass, at a slower rate beyond 2020 and over the next five decades (estimated mean generation time from the model was ~56 years) (Figure 7).

The model estimates a pattern of recruitments that oscillates from high to low prior to the start of the fishery (Figure 8). The recruitment deviations are not estimated after 1980 for the base-case model, instead expected recruitment from the spawner recruitment curve is assumed.

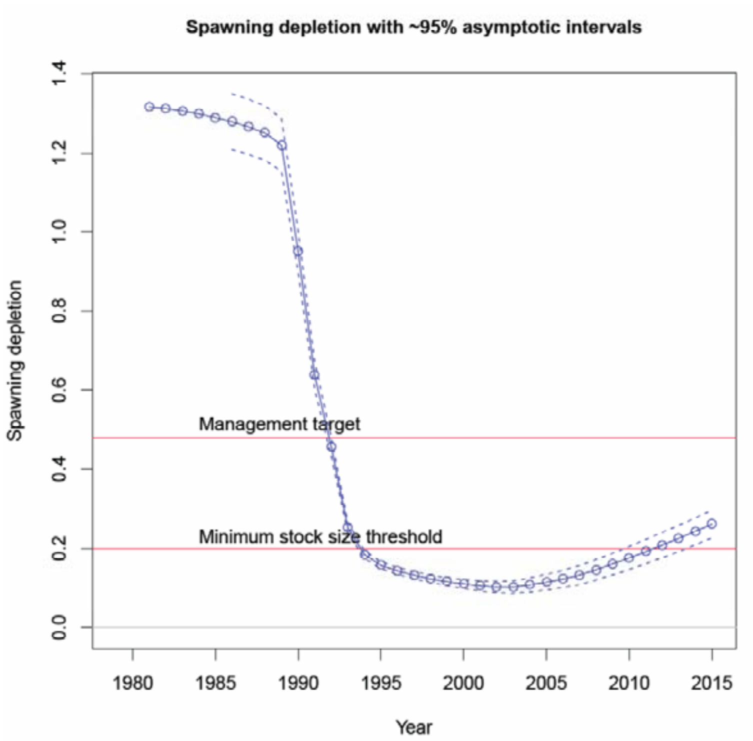


Figure 6. Time-trajectory of spawning biomass depletion (with 95% asymptotic confidence intervals) corresponding to the MPD estimates for the Final Base-case model 0.

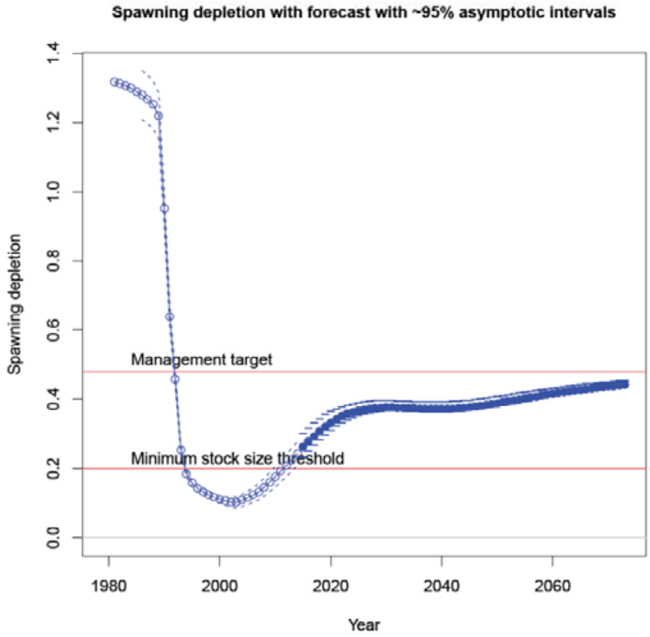


Figure 7 Time-trajectory of spawning biomass depletion (with 95% asymptotic confidence intervals) corresponding to the MPD estimates for the Final Base-case Model 0, and including a forecast period (assuming constant recruitment for the forecast period).

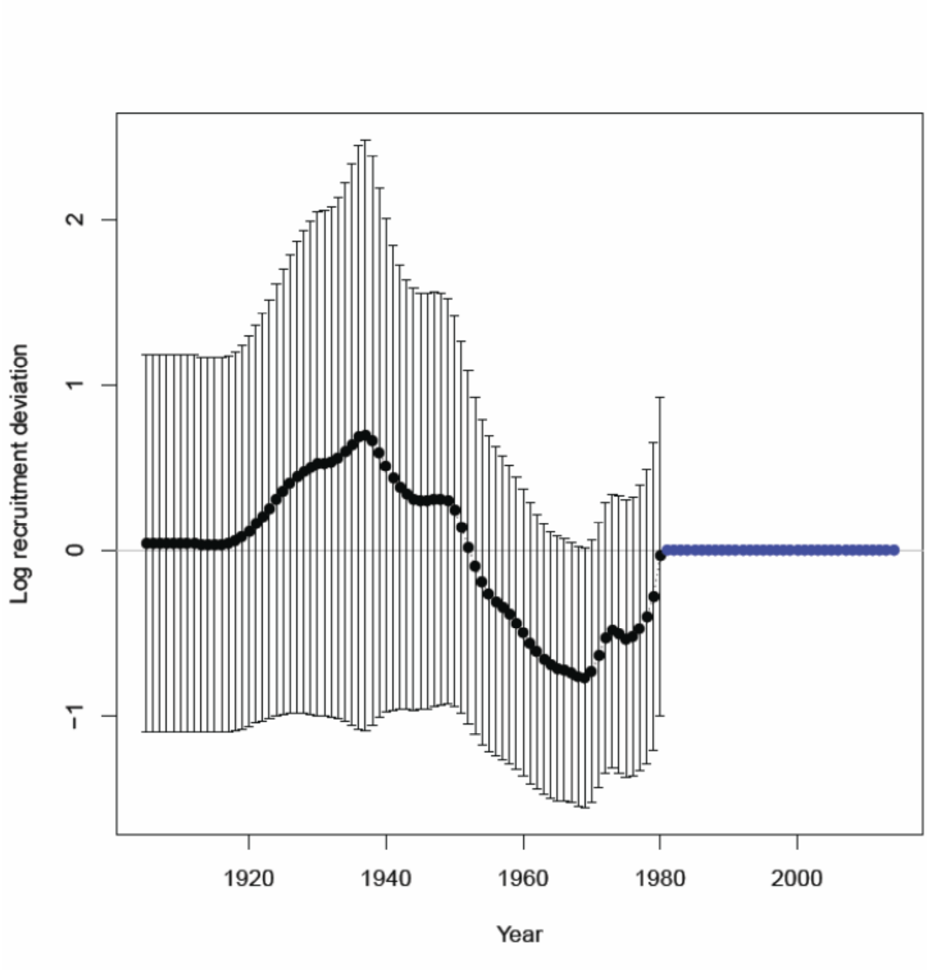


Figure 8 Final Base-case Model 0 – Recruitment estimates for the Eastern Zone base case analysis - time trajectory of estimated recruitment deviations. Recruitment deviations are not estimated after 1980, instead expected recruitment (from the spawner recruitment curve) is assumed.

Table 4. Summary of results for Final Base-case Model 0 (tuned model) and the associated sensitivity tests (same tuning as Final Base-case), including sequential models to construct the final base model, and additional diagnostic models. Lower total NLL (negative log-likelihood) values indicate a better fit to the data for comparable models. Models with different weighting and data are not comparable (C indicates models that are comparable to Final Base-case). *q* prior for towed: N(0.95, 0.3), hull: N(0.95, 0.92).

Model	FEMALE SPAWN BIOMASS							NLL	NLL Main components			Estimated Parms				
	SB0	SB2014	SB2014/B0	SB2015	SB2015/B0	RBC_{2015}	RBC_{2070}	Total	Survey	Age_comp	Recruit	SR_LN(R0)	Selectivity_Infl.	Selectivity_Width	Q3_Towed_rel	Q4_Hull_rel
Final Base-case Model 0	38,931	9,470	0.24	10,185	0.26	381	1,534	210.32	-17.61	134.89	12.67	9.05	35.77	1.00	1.32	1.78
Sensitivity Model F: Stock Structure E + S	47,295	9,398	0.20	10,225	0.22			347.98	-15.67	274.37	9.10	9.25	35.37	1.00	1.27	1.65
Sensitivity Model G: Stock Structure E + S + W	51,325	9,954	0.19	10,832	0.21			434.95	-16.70	364.08	7.78	9.33	34.99	1.00	1.10	1.53
Sensitivity Model H: Stock Structure E	37,560	17,483	0.47	18,200	0.48			249.90	-12.38	180.77	1.23	9.02	35.10	1.00	0.69	1.62
Sensitivity Model I: Higher early catches	43,061	8,937	0.21	9,652	0.22			619.73	-14.49	536.59	18.03	9.15	33.80	1.00	0.91	1.28
Sensitivity Model J: Minor Age bias	38,842	9,528	0.25	10,244	0.26			212.12	-17.65	136.40	12.88	9.05	35.90	1.00	1.36	1.82
Sequential Models associated with Final Base-case Model 0																
Model: Preliminary Base-case model September RAG	38,727	9,223	0.24	9,887	0.26			210.88	-17.70	135.18	13.05	9.05	35.70	1.01	1.32	1.76
Final Base-case Model 0: Update age error & recent catches (as above)	38,931	9,470	0.24	10,185	0.26			210.32	-17.61	134.89	12.67	9.05	35.77	1.00	1.32	1.78

Additional Models (post October RAG)	FEMALE SPAWN BIOMASS							NLL	NLL Main components		
	SB0	SB2014	SB2014/B0	SB2015	SB2015/B0			Total	Survey	Age_comp	Recruit
Diagnostic Model i: *h* 0.4 [C]	38,965	9,817	0.25	10,540	0.27			209.67	-17.42	134.29	12.46
Diagnostic Model ii: *h* 0.7 [C]	38,934	9,494	0.24	10,209	0.26			210.27	-17.60	134.84	12.66
Diagnostic Model iii: *h* 0.8 [C]	38,929	9,449	0.24	10,165	0.26			210.37	-17.63	134.94	12.69
Diagnostic Model iv: M 0.035 [C]	39,313	8,436	0.21	9,087	0.23			208.36	-17.88	135.52	10.21
Diagnostic Model v: M 0.045 [C]	38,776	10,440	0.27	11,216	0.29			215.65	-17.32	136.51	16.16
Diagnostic Model vi: selectivity width low bound 0.1 [C]	38,863	9,389	0.24	10,103	0.26			210.21	-17.60	134.75	12.76
Diagnostic Model vii: Double weight on age data	37,515	8,352	0.22	9,036	0.24			341.97	-17.59	259.38	19.37
Diagnostic Model viii: Half weight on age data	40,512	10,818	0.27	11,561	0.29			140.82	-17.52	72.65	5.70
Diagnostic Model ix: Double weight on biomass indices	38,721	9,269	0.24	9,975	0.26			192.59	-35.64	134.84	12.87
Diagnostic Model x: Half weight on biomass indices	39,034	9,574	0.25	10,294	0.26			219.07	-8.65	134.89	12.64

4.3 Sensitivity analysis

Sensitivity analyses were completed for the Preliminary Base-case model (Table 6.7) and the Final Base-case Model 0 (Table 4). The outcomes of the base-case models were similar, and we consider the key sensitivities to each of the models here to investigate various questions. The sensitivity analyses for the Preliminary Base-case model provide information on the effects of some of the main changes in the current assessment model, when compared to the previous Eastern Zone orange roughy assessment models (2006 and 2011). The sensitivity analyses for the Final Base-case model provide information on the effects of different stock structures, a higher agreed catch for the early years, and the effect of a minor age bias for the early age compositions (Appendix B). We also include additional sensitivity tests (post-October RAG) as a diagnostic tool to examine sensitivity of the results from the Final Base-case model to alternative data weightings, natural mortality, steepness, and a lower bound for the fleet selectivity width.

4.3.1 SENSITIVITY ANALYSIS FOR PRELIMINARY BASE-CASE MODEL

Sensitivity of the Preliminary Base-case model to alternative assumptions and different data was investigated (Sensitivity Models A to E and Sequential Models; Table 6.7). The fits for Sensitivity Model C, No Recruitment Deviations, are included below because, of the models tested, this scenario had the greatest impact on the assessment outcomes. The Preliminary Base-case model outcomes were also influenced (to a lesser extent) by the weighting method used for the age compositions. Sensitivity Model A, which used the McAllister and Ianelli (2007) weighting method for age compositions (the method used in the previous stock assessment) was compared to the Preliminary Base-case model, which used the Francis (2011) weighting approach , as was agreed by the Australian Orange Roughy workshop in May 2014. The Preliminary Base-case estimated a less depleted female spawning stock in 2014 than the Sensitivity Model A (Table 6.7).

The Preliminary Base-case model was not overly sensitive to using the maximum acoustic spawning biomass estimates instead of the average estimates (Sensitivity Model D), or to using a broader CV around the priors for q for the towed acoustic survey index (i.e. diffuse priors CV=99) (Sensitivity Model B; Table 6.7).

The effect on the Preliminary Base-case model of adding in recent data since 2010 (i.e. the 2012, 2013 towed acoustic estimates and the catches for 2011, 2012 and 2013) was a slightly lower estimate of B_0 and 2014 spawning biomass, and hence a greater depletion in 2014 (Model #1: Data to end of 2010; Table 6.7). This shows that the base-case model is at least partially sensitive to the recent data.

FITS TO THE DATA - SENSITIVITY MODEL C (NO RECRUITMENT DEVIATIONS)

Fits to relative abundance (biomass) towed body index (Figure 9) and age compositions (Figure 10) for sensitivity Model C: No Recruitment Deviations show an obviously degraded fit to the early age data (Figure 10). There are fewer older-age fish in 1992 and 1995 implied by the model, and a different implied trend for spawning biomass, which is considered implausible given the large early catches and the population dynamics (Figure 9; Table 3). The total negative log-likelihood for the Preliminary Base-case model was substantially lower than that for sensitivity Model C (Table 6.7), indicating a better overall fit to the data for the Preliminary Base-case model, which estimated recruitment deviations.

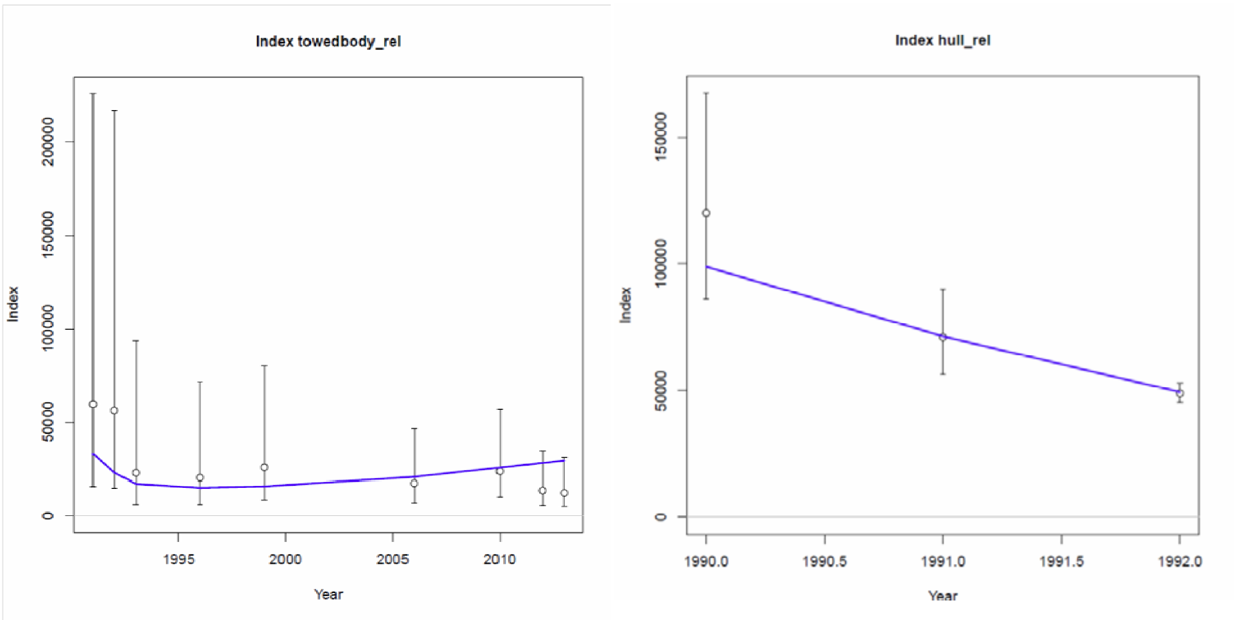
The fits for the acoustic towed and hull relative index do not improve on that of the Preliminary Base-case Model as both model fits go through the confidence intervals for the data (the variance for the sensitivity model has been re-tuned; however, the estimates for 1990, 1991 and 1992 have a wide associated CV in both models).

The Preliminary Base-case model sensitivity C provides insight into the dynamics in the model (demonstrates the influence of assuming constant recruitment, described by the spawner-recruitment curve, on the model survey biomass estimates). If we consider the 1999, 2006 and 2010 model point estimates for the towed body index in Figure 9(a), they are closer to the observed point estimates than that of the Preliminary Base-case model in Figure 9(b) and are coincident with lower model biomass estimates for the early years in the no recruitment deviations model.

Following from above, other inputs into the model that will influence how rapidly a stock can recover include the biology of orange roughy – the species are long-lived and have low fecundity; one generation time for orange roughy is estimated to be around 56 years (model estimate).

(a) Sensitivity Model C (No Recruitment Deviations)

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)



(b) Preliminary Base Model – Acoustic towed body and hull (for reference)

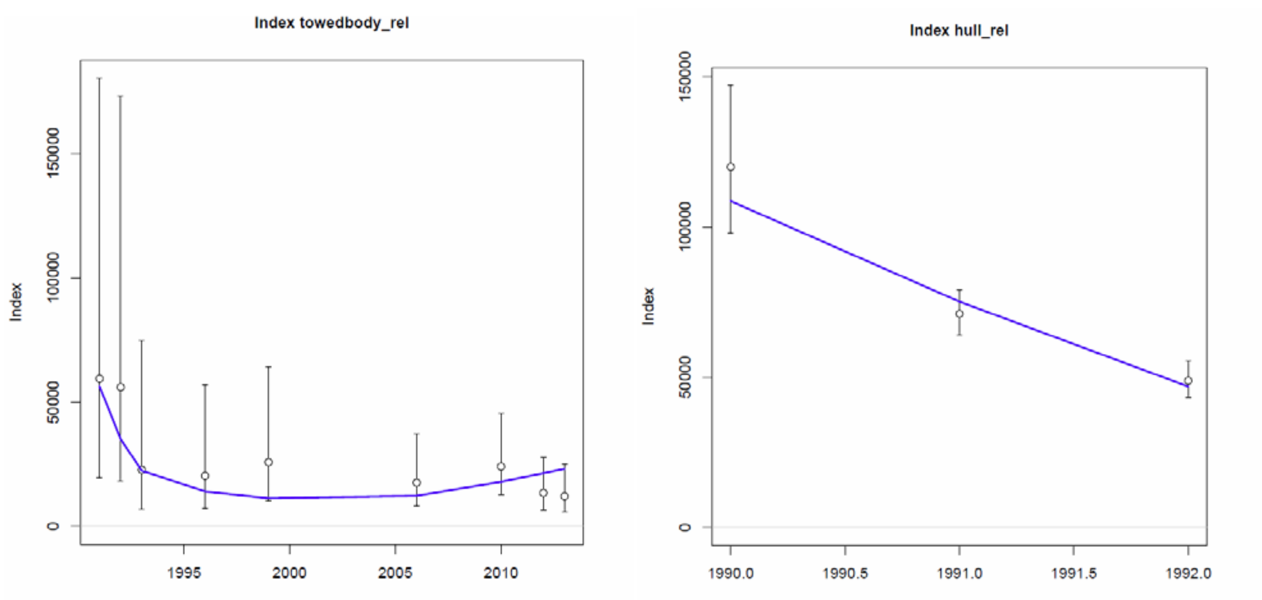


Figure 9 (a) Sensitivity Model C Observed (circles) and model-estimates (lines) of relative indices of total spawning biomass - Acoustic towed and hull, against year. (b) Preliminary Base Model - towed survey towed and hull survey fits (left and right plots respectively) for reference. The vertical lines indicate approximate 95% confidence intervals for the data.

FEMALE   MALE

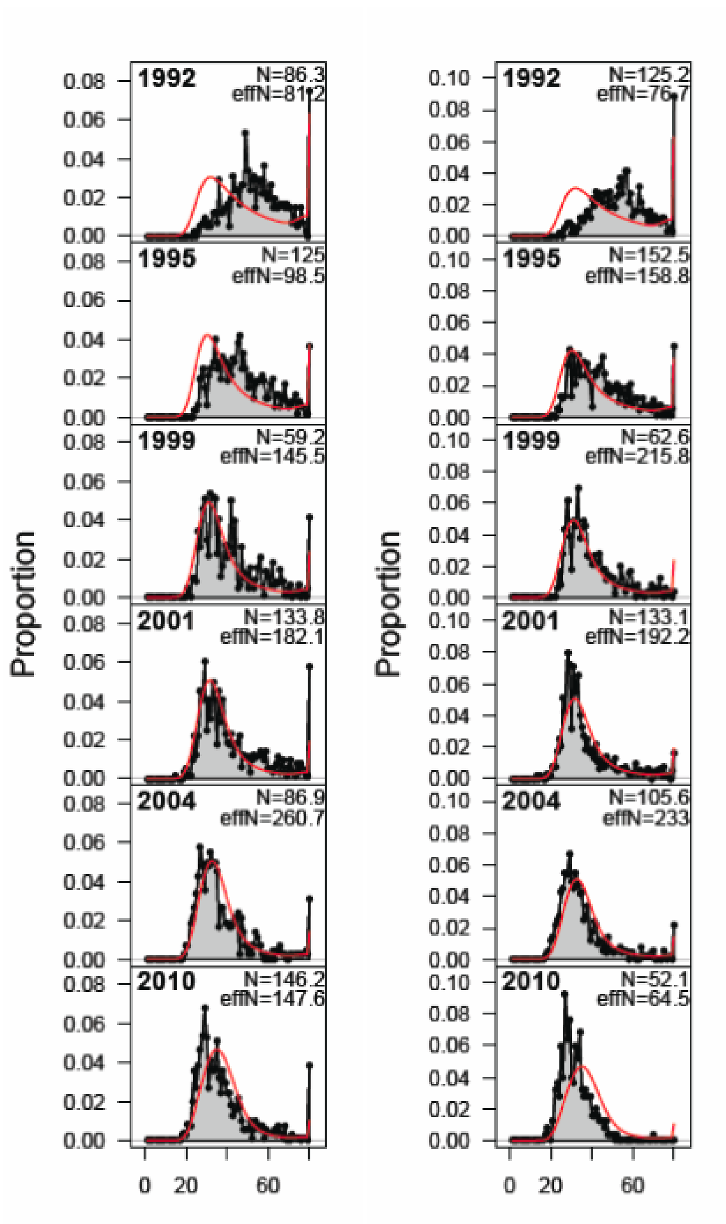


Figure 10 Fits to age compositions for Sensitivity Model C.

FITS TO THE DATA - SENSITIVITY MODEL A (MCALLISTER & IANELLI WEIGHTING)

Fits to relative abundance (biomass) index (Figure 11) and age compositions (Figure 12) for sensitivity Model A: McAllister and Ianelli (2007) weighting are comparable with those of the Preliminary Base-case model, with only minor differences for the early years.

Acoustic towed body (1991-2013)

Sensitivity Model A

Preliminary Base Model

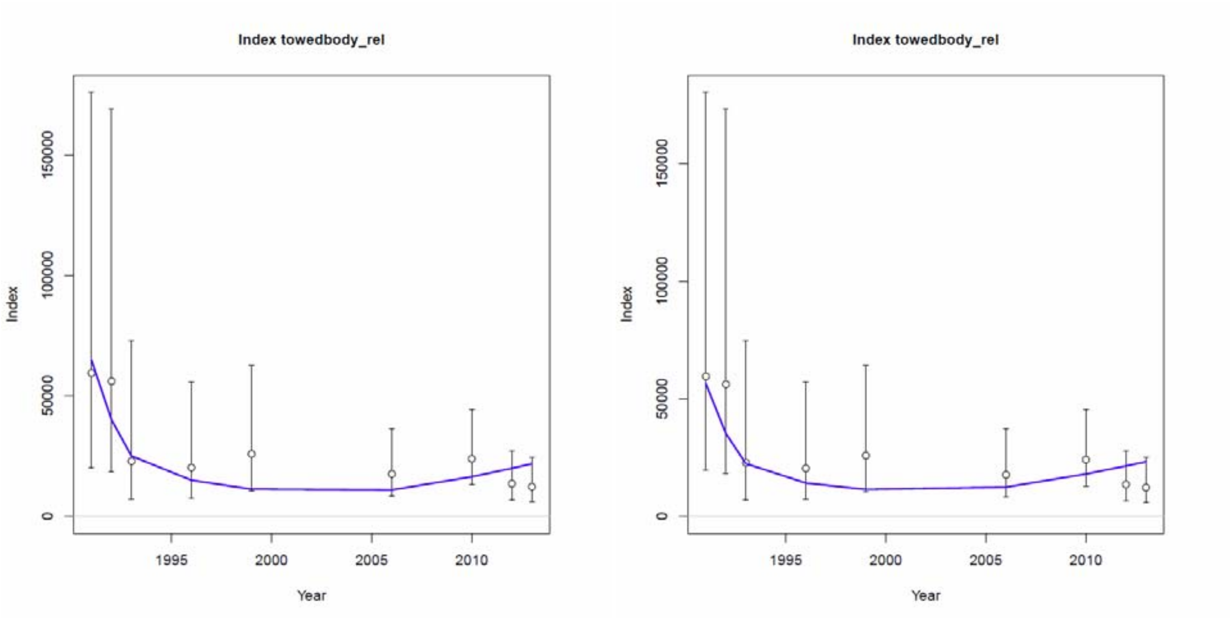


Figure 11 Comparison of fits to acoustic towed surveys for Sensitivity Model A (M&I weighting; left plot) and Preliminary Base Model (Francis weighting; right plot). Observed (circles) and model-estimates (lines) of relative indices of total spawning biomass, against year. The vertical lines indicate approximate 95% confidence intervals for the data.

Sensitivity Model A **Preliminary Base Model**

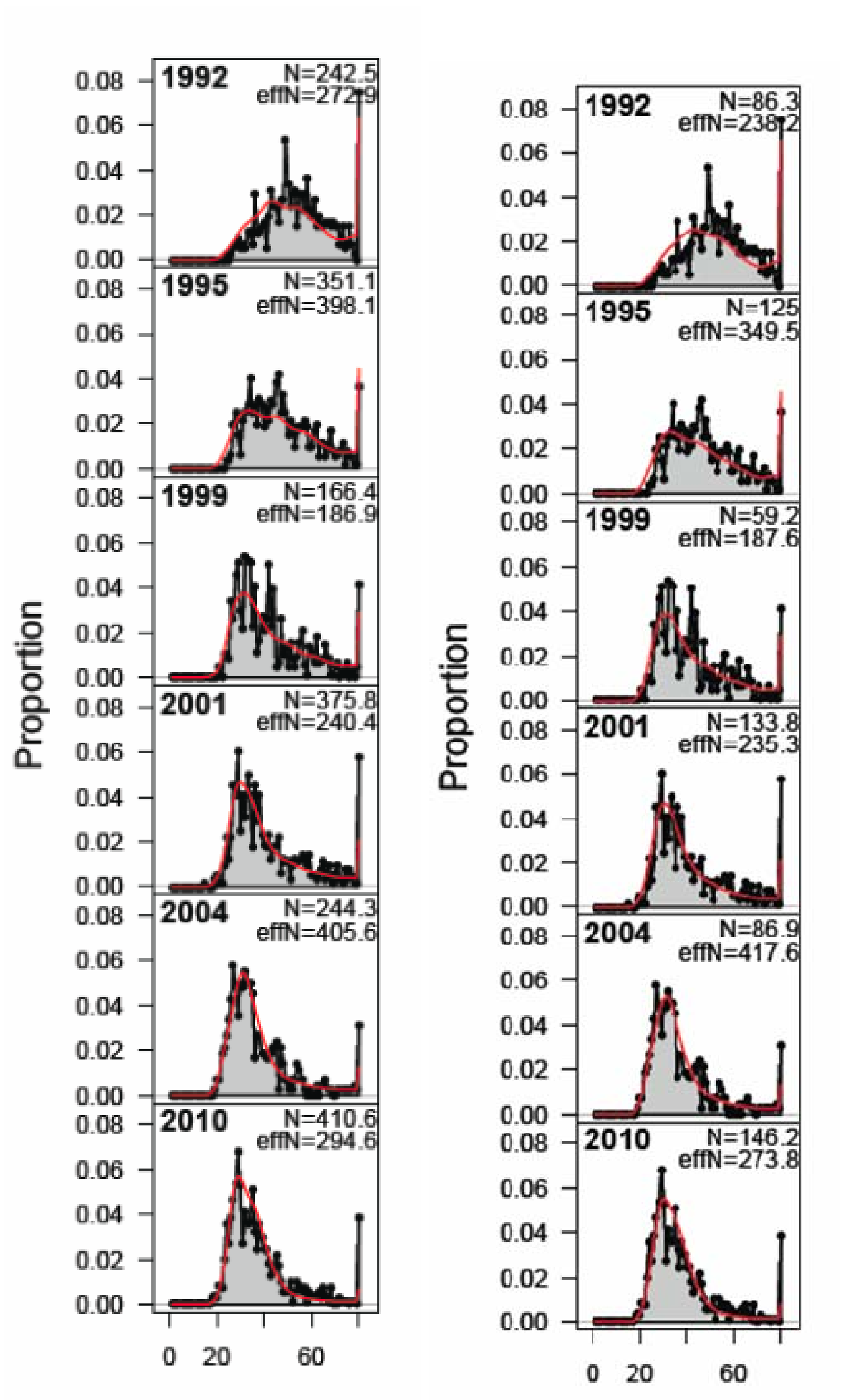


Figure 12 Comparison of fits to FEMALE age compositions for Sensitivity Model A -M&I weighting (left plot) and Preliminary Base Model -Francis weighting (right plot).

4.3.2 SENSITIVITY ANALYSIS FOR FINAL BASE-CASE MODEL 0

Sensitivity of the results of the base-case model to alternative assumptions and different data was tested (Sensitivity Models F to I and additional Diagnostic Models (i) to (x); Table 4). The fits for Sensitivity Model G: Alternative stock structure East + South + West, and for Sensitivity Model H: Alternative stock structure: East, are provided below (Figures 13 to 16).

Apart from Sensitivity Model J, which examined the effect on the model outcomes of a minor age bias in the early age compositions, the results of the Final Base-case Model 0 outcomes differed notably from those of the key sensitivity tests (Table 4). The base-case model was sensitive to the Stock Structure assumption (Sensitivity Models F, G, and H) and to the Higher earlier catches (Sensitivity Model I) (Table 4). The scenario that had the greatest impact on the assessment outcomes was the assumption of a stock structure comprising only the Eastern Zone (Sensitivity Model H). Assuming this stock structure, the model estimated a much greater female spawning biomass in 2015 and a lower level of spawning depletion relative to unfished (Table 4; Figure 15). Sensitivity Model G assumed a broader stock structure, East + South + West, and estimated a larger initial female spawning biomass and a greater level of spawning depletion relative to unfished compared to the Final Base-case model (Table 4). The catch history provides some insights (Table 3); total catch between 1985 and 2014 for the E+S+W is approximately twice that of East only, and 68% of the agreed catch in one of the peak years, 1989, comes from East only. Further, the model estimates an increase in recruitment for the period since approximately 1965 to 1980 for the East only model, whereas for the E+S+W model estimated recruitment decreases over that period (Figure 16).

Examining the estimated q for the acoustic towed and hull surveys for each of the stock structure sensitivity models, and the model fits to the surveys and age compositions, provides some insight into the underlying dynamics in the model. For example, for the towed survey, the estimate of q is 0.69 for the stock structure East, compared with 1.32 for the base-case model and 1.10 for East, South and West (E+S+W) stock structure (Table 4). The lower towed survey q for the East stock structure is coincident with an implied biomass trend from the model that is “flat” across the series, with less of a decline in the early years (Figure 15), however the fit to the age compositions was not degraded. Whilst for the broader E+S+W stock structure, with q estimated at 1.10, the fit to the early age compositions was notably degraded, and there were only subtle differences in the fit to the towed survey for the early and the recent years (Figures 13, 14 and 15).

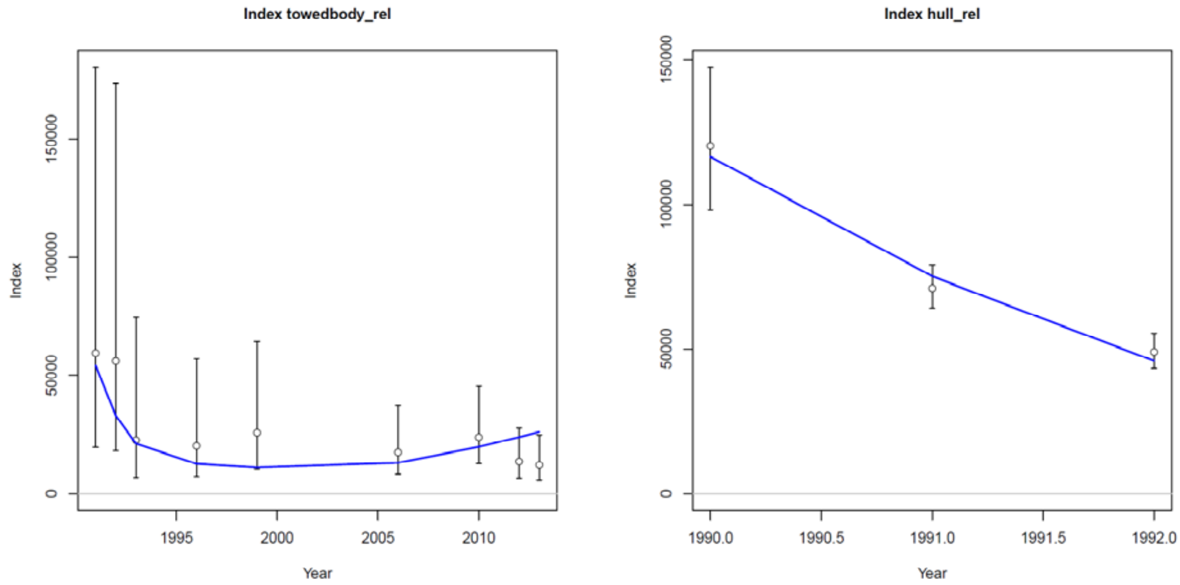
The additional diagnostic models showed that the Final Base-case model was not overly sensitive to the values for steepness tested (including a low steepness of 0.4), or a lower bound on the selectivity width (0.1 instead of 1.0 in the base-case) (Table 4). However the Final Base-case model was moderately sensitive to alternative data weightings, and natural mortality (Table 4).

FITS TO THE DATA - SENSITIVITY MODEL G (EAST+SOUTH+WEST)

Fits to the relative abundance (biomass) indices (Figure 13) and age compositions (Figure 14) for Sensitivity Model G: Stock structure E+S+W are compared to the Final Base-case Model 0. There is a subtle difference in the fits for the acoustic towed body – the sensitivity model estimate for the first year (1991) is less than that for the Final Base-case model, and for recent years since 2006 the implied biomass upwards trajectory in marginally steeper (Figure 13). However the fits to the early age compositions are notably degraded in the sensitivity model (Figure 14).

(a) Sensitivity Model G (Stock structure EAST+SOUTH+WEST)

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)



(b) Final Base Model 0 – Acoustic towed body and hull (for reference)

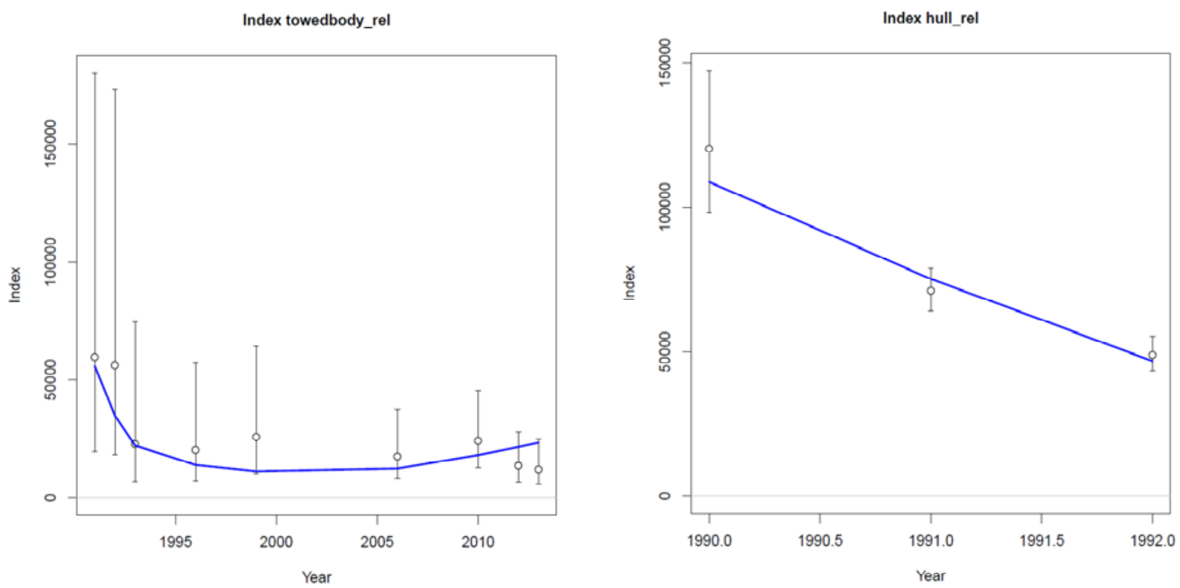


Figure 13 (a) Sensitivity Model G Observed (circles) and model-estimated (lines) of relative indices of total spawning biomass - Acoustic towed and hull, against year. (b) Final Base Model 0 towed and hull survey fits (left and right plots respectively) for reference. The vertical lines indicate approximate 95% confidence intervals for the data.

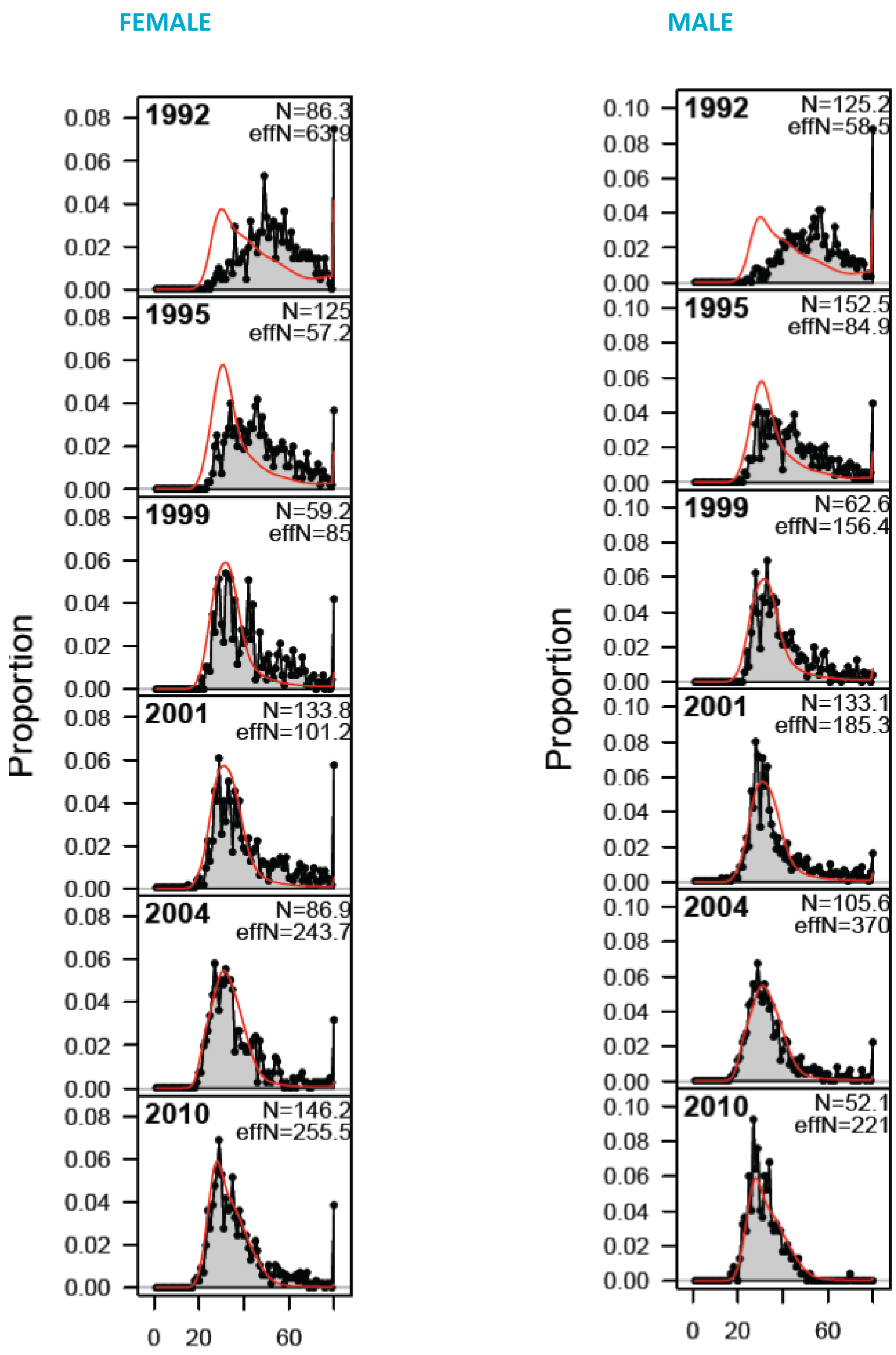


Figure 14 Fits to age compositions for Sensitivity Model G.

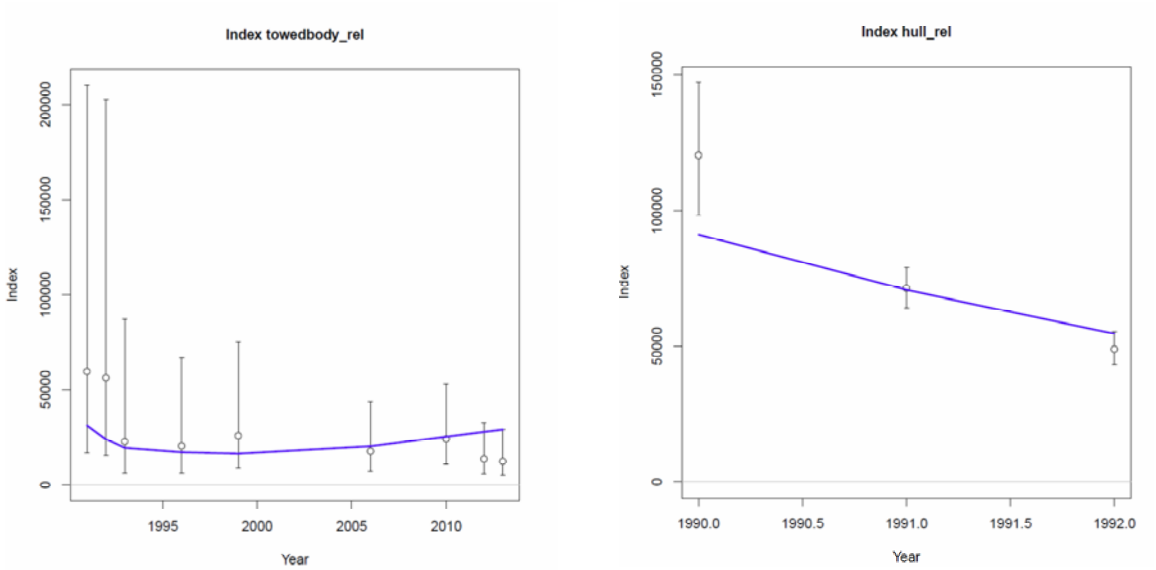
FITS TO THE DATA - SENSITIVITY MODEL H (EAST ONLY)

Fits to relative abundance (biomass) indices (Figure 15) for Sensitivity Model H: Stock structure: EAST are compared to the Final Base-case Model 0. The fits to the age compositions were comparable with those for the Final Base-case model and are not shown here. However, similar to Sensitivity Model C, with No Recruitment Deviations, there is a different implied trend for spawning biomass for the towed body, the trend being “flat” across the series (Figure 15).

The fits for the acoustic towed relative index do not improve on that of the Preliminary Base-case Model as both model fits go through the confidence intervals for the data. The fits for the acoustic hull relative index are degraded in Sensitivity Model H compared to the Final Base-case model (Figure 15).

(a) Sensitivity Model H (Stock structure EAST)

Acoustic towed body (1991-2013) Acoustic hull (1990-1993)



(b) Final Base Model 0 – Acoustic towed body and hull (for reference)

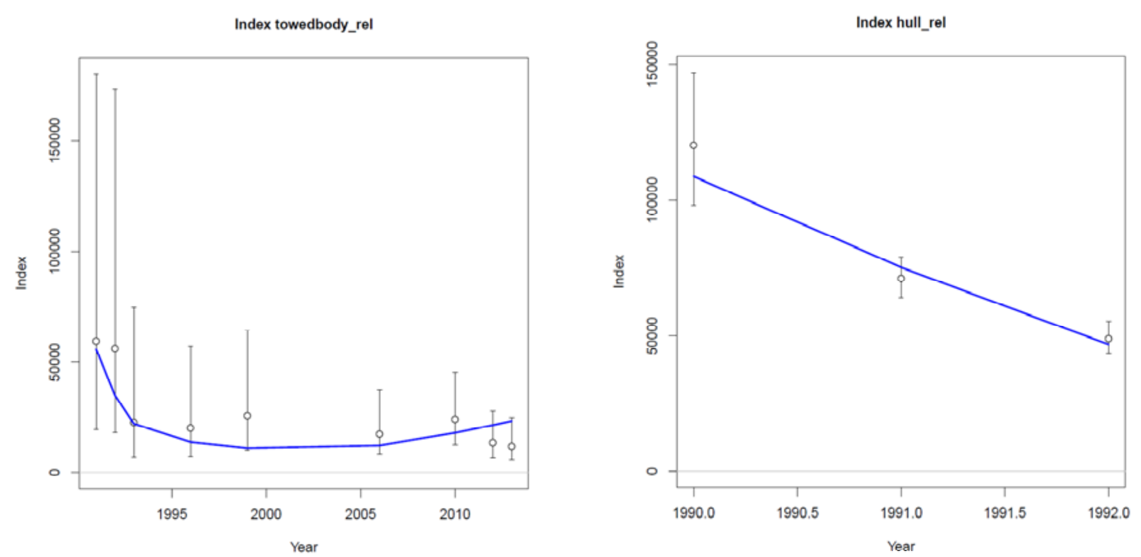
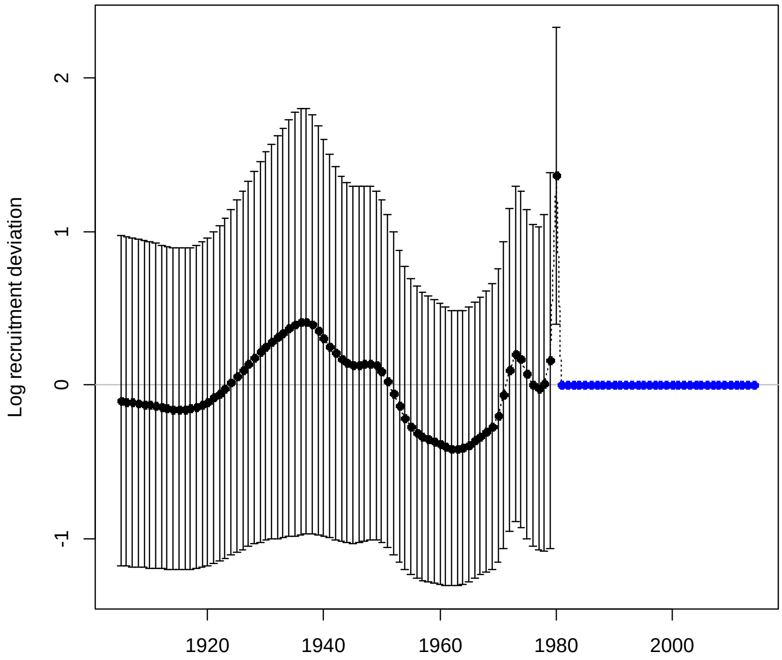


Figure 15 (a) Sensitivity Model H Observed (circles) and model-estimated (lines) of relative indices of total spawning biomass - Acoustic towed and hull, against year. (b) Final Base Model 0 towed and hull survey fits (left and right plots respectively) for reference. The vertical lines indicate approximate 95% confidence intervals for the data.

The model estimates an increase in recruitment for the period since approximately 1965 to 1980 for the East only model, whereas for the E+S+W model estimated recruitment decreases over that period (Figure 16).

(a) Sensitivity Model H (Stock structure EAST)



(b) Sensitivity Model G (Stock structure EAST+SOUTH+WEST)

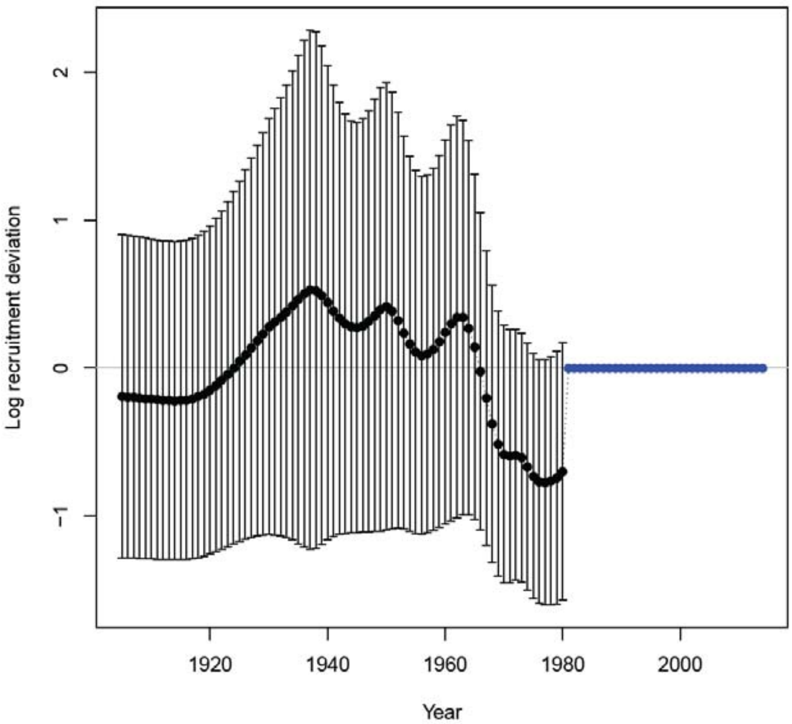


Figure 16 Time trajectory of estimated recruitment deviations for Sensitivity Model H (a) and Sensitivity Model G (b). Recruitment deviations are not estimated after 1980, instead expected recruitment (from the spawner recruitment curve) is assumed.

4.4 MCMC simulations for the Final Base-case Model 0

The MCMC simulation approached convergence. However, the chain was not yet fully converged even with 24 million cycles and a thinning interval of 40,000 (see Appendix D – diagnostic plots). Nevertheless, we consider the results of the MCMC analysis as adequate for the purposes of this report, i.e. to draw broad inferences about the variability in the parameter estimates from the base-case model.

The female spawning biomass trajectory with 95% Bayesian credible intervals are given in Figure 17, the posterior distribution for estimated female spawning depletion is given in Figure 18, and the estimated probability density function for the RBC is shown in Figure 19.

The posterior median estimates from the MCMC simulations were close to the maximum posterior density (MPD) estimates for most of the parameters of interest (Table 5). The MPD estimates for initial female spawning biomass (B_0) and initial recruitment (SR_LN(R0)) are outside of the 95% Bayesian CIs (Table 5). This is in part explained by recruitment for the era ~ 1930 to 1950, which is estimated by the MCMC to be greater than that estimated by MPD, and with more precision (Figure 20). However, the median estimate of female spawning depletion (SB_{2015}/ SB_0) was 0.25 with a 95% Bayesian CI of 0.23 to 0.28, which is similar to the MPD estimate of 0.26 (Table 5). The median estimates for the catchability parameter *q* for the towed body and the hull were close to the MPD estimates (Table 5).

The 95% Bayesian CIs for the estimated parameters, notably female spawning biomass (Figure 17), are fairly narrow and may indicate that the model parameter space is constrained. Further work should consider this in more detail. In particular, there are assumptions embedded in the model regarding the degree to which the data inform estimates of recruitment in the recent (1981 to 2013) and forecast years that should be explored in future assessments. Briefly, the issue is that for the base-case model MPD estimate of SB_{2015} the recruitment deviations are not estimated beyond 1980 (given orange roughy do not recruit until ~35 years, very few fish post-1980 will have recruited in 2015), instead average recruitment (from the spawner recruitment curve) is assumed. However, for the MCMC simulations for the Final Base-case model we enable stochastic recruitment and this extends into the recent and forecast periods (beyond 1980), but we apply a penalty function for the recent and forecast years when there is sparse, noisy data. It is possible that recruitment variability has been overly constrained for these recent years.

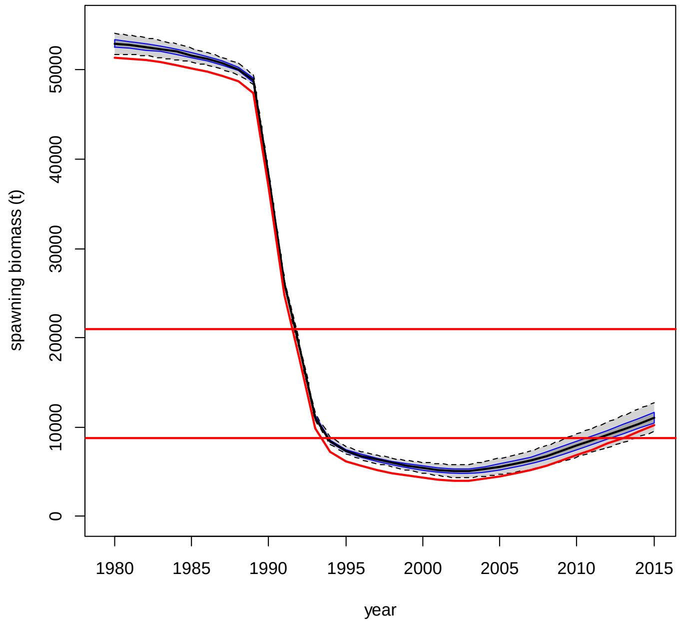


Figure 17. Female spawning biomass trajectory to 2015 (50% and 95% Bayesian credible intervals: blue and dotted black lines respectively). The horizontal red lines denote the 20% minimum stock size threshold and the 48% management target. The estimate of initial spawning biomass (not shown) is less than the 1980 estimate. The MPD female spawning biomass trajectory is shown by the red line.

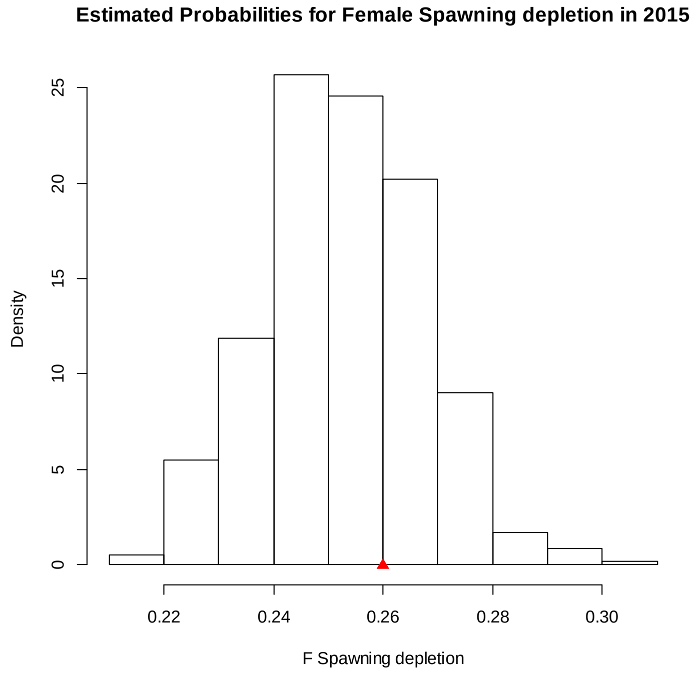


Figure 18. Estimated probabilities for female spawning depletion in 2015 for Final Base-case Model 0. The MPD estimate is shown by the red point on the x-axis.

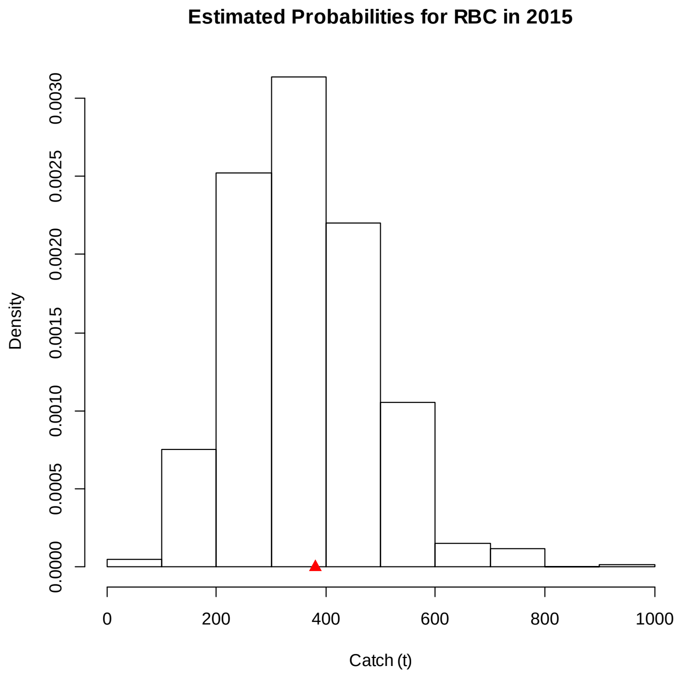


Figure 19. Estimated probabilities for RBC in 2015 for Final Base-case Model 0. The MPD estimate is shown by the red point on the x-axis.

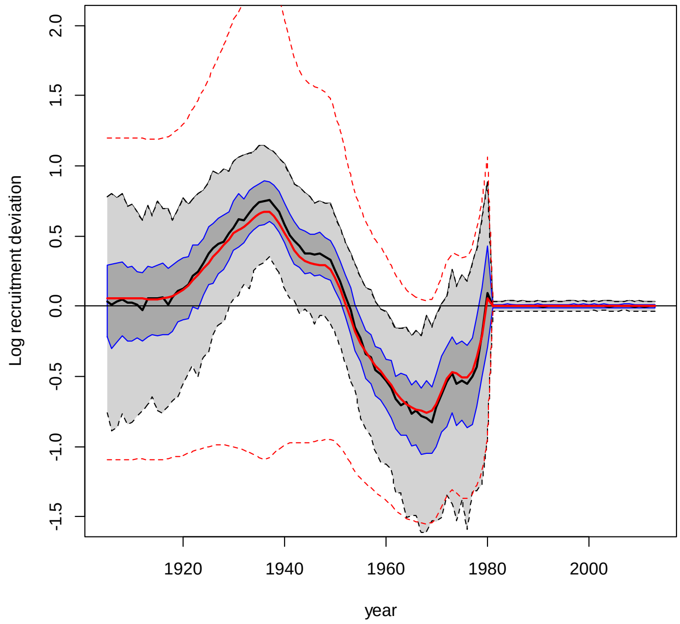


Figure 20. Time trajectory of estimated recruitment deviations for Final Base-case Model 0 (50% and 95% Bayesian credible intervals: blue and dotted black lines respectively). The MPD estimate is shown by the red line (with 95% asymptotic confidence intervals: red dotted line).

SUMMARY OF MCMC RESULTS FOR FINAL BASE CASE MODEL 0

Table 5. Summary statistics for key parameters estimated from MCMC simulations of the Final Base-case Model 0.

Key parameters	MPD esimtate	MCMC Median	(95% Bayesian CI)	1%	99%
SR_LN(RO)	9.05	9.16	(9.13 - 9.20)	9.12	9.21
Q3_Towed_rel	1.32	1.31	(1.03 - 1.66)	0.92	1.80
Q4_Hull_rel	1.78	1.79	(1.65 - 1.93)	1.62	1.95
SB0	38,931	43,591	(41,863 - 45,282)	41,641	45,707
SB2015	10,185	11,020	(9,586 - 12,620)	9,320	13,165
SB2015/B0	0.26	0.25	(0.23 - 0.28)	0.22	0.29
RBC2015	381	351	(151 - 622)	120	718

4.5 Summary

The Final Base-case Model 0 maximum posterior density (MPD) estimate of female spawning biomass in 2015 was 26% of unfished female spawning biomass, which was close to the median Bayesian estimate of 25% with 95% Bayesian CI of 23% to 28%. The estimated RBC under the 20:35:48 harvest control rule is 381t, with a long-term RBC of approximately 1,534 t.

The model estimates a steep decline in female spawning biomass in the early 1990's (as the commercial fishery developed), followed by a period of gradual further decline, and a recent increase to levels above 20% of unfished level. The forecast over the next 55 years implies a continued increase in the female spawning biomass, at a slower rate beyond 2020 and over the next five decades if catches equal RBCs (estimated mean generation time from model was ~56 years).

The model estimates a spawning biomass trend that is recently increasing, whereas the observed acoustic point estimates for 2012 and 2013 are less than estimates for preceding years (but see Ryan et al. 2014). In this assessment we have adopted a weighting scheme for the data that places more importance on fitting the acoustic indices as a direct measure of spawning biomass. Hence, the acoustic indices are influential in the model. Thus, a continued series for the acoustic towed index (that uses a consistent survey design) could be particularly important. Given the observed year-to-year variability in recent acoustic estimates, making observations over a few consecutive years would provide some context for the observations.

The catchability coefficients for the towed and hull acoustic surveys were estimated by the Final Base-case model to be 1.32 and 1.78 respectively, and these were within the bounds of the priors.

The stock structure assumption is a key uncertainty in the assessment, as the model outcomes differed depending on this assumption. The base-case model was also sensitive to the inclusion of recruitment deviations (which concurs with Cordue's 2014 finding for NZ orange roughy model), higher earlier catches and, to a lesser extent, the data weighting method for the age compositions (Francis 2011 or McAllister and Ianelli 2007).

4.6 Future work

In addition to the any remaining future work outlined in Upston & Wayte (2012b), further work to investigate some of the uncertainty and improve on the base-case model could include:

- Stock structure is a key uncertainty in the assessment, as the model outcomes differed depending on the assumption regarding stock structure. The next step for modelling could be management strategy evaluation (MSE) testing of the assessment outcomes when different stock structures are assumed (see Stokes 2009);
- Continue to investigate uncertainty in the stock assessment. The MCMC simulations would benefit from further work in terms of running the chain for longer (and get closer to model convergence), and running alternative chains (another check for model convergence). Also, the model has embedded assumptions regarding how well the observed data inform estimates of recruitment in the recent and forecast years (1981 onwards), and testing of the model sensitivity to those assumptions would be useful;
- Further investigation of the data weighting method used in the assessment could be important, since the base-case model is sensitive to the method used. Whilst the Francis (2011) method for weighting the age compositions is the currently accepted method, this is an evolving field of study;
- Some minor technical issues were identified during internal review and these should be reviewed for the next assessment: source the data for the young length at age CV; revise the years for which recruitment deviations are estimated (this becomes increasingly important beyond 2015, as the fishery moves into an era where recruitment is estimated from the spawning stock that was fished (commencing in the mid-1980's).

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6 Tables

Table 6.1. Catches (t) for Sensitivity Model I “Higher earlier catches” for the Eastern Zone (East) and the area Pedra Branca (PB). The “Higher agreed catch” values were suggested by AFMA (May 2014) as a nominal higher bound on the agreed catches in the base-case model.

	BASE CASE		HIGHER AGREED CATCH	
Year	**EAST and PB MX1**	**Catch_EAST and PB Agreed MX1*Reported catch**	**EAST and PB_HigherCatch MX2**	**EAST and PB _HigherCatch MX2*Catch_EAST and PB Agreed**
1988		1949	1.5	2924
1989	1.3	28575	1.5	42863
1990	1.3	34502	1.5	51753
1991	1.2	20436	1.5	30654
1992	1.55+	24265	2	48530
1993	2.1*	8798	1.5	13197
1994	1.1			
TOTAL Catch (t) 1988-1993		118525		189920

"MX" is multipler
MX1 rationale is outlined below:
1989, 1990: 30% losses assumed; 1991: 20% losses assumed
1992+ reported catches increased by 45% for est. misreporting + 10% losses assumed
1993*: 2665 t transferred from South zone reported catch to East zone catch for est. misreporting + 10% losses assumed
1994: 10% losses assumed
Sources: Wayte (2007) Eastern Roughy Assessment (description of adjustments);
Upston & Wayte (2012a) Table 9.6 catches used in the 2011 prelim assessment for base-case (highlighted column 2)
Note: A "low catch" scenario (at the extreme end) is given by Sensitivity Model A - Unadjusted catch in Table 9.9 of Upston & Wayte (2012a), which includes the reported catch with no upwards adjustments

Table 6.2. Acoustic TOWED spawning biomass estimates and associated CVs by snapshot, area and year. Snapshot refers to one observation for an acoustic survey. The average survey estimates, associated CVs and priors are tabulated. The "Bias" column is a flag to check that the calculated total survey CV for early years is not too "narrow" – expert judgement was that in early years the acoustic estimates were generally less precise than for recent years. Key: Area SH =St Helens, SP=St Patricks; Pair –flag for snapshot pair within 24-48 h; Max Biomass –maximum snapshot biomass; snapshot CVs were obtained from acoustic reports (for acoustics CV2 e.g. see Table 3.10 in Ryan et al. 2013); Bias-flag to impose a "wide" CV. Total survey CV is calculated by adding the three component errors (considered independent) - Combined areas CV, Between snapshots CV, Survey one area CV.

											SNAPSHOT BIOMASS				SNAPSHOT CV					AVERAGE BIOMASS				SURVEY CV						PRIORS			
Year	System	Fleet	Date	Op	Transects	Area	Pair	Target strength (original)	Target strength (revised)	Simrad TVG error factor	Biomass above DZ (t)	Deadzone %	**Biomass total (t)**	Max Biomass	snapshot CV	snapshot CV1 incl. deadzone	acoustics CV2	**total snapshot CV (CV1 & CV2)**	Bias	Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
1991	S	3	30/07/1991	SS291	?	SH		-50.0	-51.8	1.10	34,526	25.1	46,109	1	0.28	0.31	0.2	0.37	1	1991	46,109	-	59,481	0.37	-	0.37	0.20	0.25	0.49	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1991	S	3	-	-	-	SP		-	-		-	-	-																				
1992	S	3	19/07/1992	SS392	?	SH		-50.0	-51.8	0.93	27,394	37	43,493	1	0.28	0.33	0.2	0.39	1	1992	43,493	-	56,106	0.39	-	0.39	0.20	0.25	0.5	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1992	S	3	-	-	-	SP		-	-		-	-	-																				
1993	S	3	25/07/1993	SS593	?	SH		-50.0	-51.8	1.12	13,851	21.7	17,683	1	0.35	0.37	0.2	0.42	1	1993	17,683	-	22,811	0.42	-	0.42	0.20	0.25	0.53	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1993	S	3	-	-	-	SP		-	-		-	-	-																				
1996	M1	3	17/07/1996	SS496_1	?	SH		-50.0	-51.8	1.12	12,320	14.6	14,429		0.28	0.29	0.2	0.35		1996	15,793	-	20,372	0.31	-	0.31	0.20	0.25	0.45	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1996	M1	3	20/07/1996	SS496_2	?	SH		-50.0	-51.8	1.12	13,733	20	17,156	1	0.28	0.30	0.2	0.36															
1996	M1	3	-	-	-	SP		-	-		-	-	-																				
1999	M1	3	18/07/1999	SP6	6	SP	1	-50.3	-52.0	1	-	-	21,366		0.63	-	0.2	-	1	1999	4,955	20,883	25,838	0.36	0.67	0.33	0.20		0.39	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1999	M1	3	19/07/1999	SH6	5	SH	1	-50.0	-51.7	1	0	0	0		-	-	-	-	1														
1999	M1	3	30/07/1999	SP18	3	SP	2	-50.3	-52.0	1	17,178	15.8	20,399	1	0.63	0.64	0.2	0.67	1														
1999	M1	3	31/07/1999	SH22	5	SH	2	-50.0	-51.7	1	3,815	23	4,955	1	0.28	0.3	0.2	0.36															
2006	M2	3	15/07/2006	1_2	10	SH		-50.3	-52.2	1	10,723	23.8	14,065		0.12	0.17	0.23	0.29		2006	14,668	2,873	17,541	0.28	0.29	0.24	0.20		0.31	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2006	M2	3	16/07/2006	6_7	10	SH	1	-50.3	-52.2	1	12,464	23.6	16,307		0.14	0.18	0.23	0.29															
2006	M2	3	18/07/2006	10	12	SP	1	-50.1	-52.1	1	1,659	23	2,156		0.15	0.19	0.23	0.30															
2006	M2	3	18/07/2006	11_12	10	SH	1	-50.3	-52.2	1	10,581	31.5	15,438		0.09	0.18	0.23	0.29															
2006	M2	3	19/07/2006	13_14	10	SH	1	-50.3	-52.2	1	9,699	24.8	12,895		0.1	0.16	0.23	0.28															
2006	M2	3	20/07/2006	15	12	SP	2	-50.1	-52.1	1	1,973	13.7	2,286	1	0.15	0.16	0.23	0.28															
2006	M2	3	20/07/2006	16_17	10	SH	2	-50.3	-52.2	1	12,586	21.5	16,037	1	0.11	0.15	0.23	0.28															
2006	M2	3	22/07/2006	26_27	10	SH	3	-50.3	-52.2	1	11,656	15.8	13,847		0.13	0.15	0.23	0.28															
2006	M2	3	23/07/2006	30	12	SP	3	-50.1	-52.1	1	2,162	6.9	2,322		0.15	0.16	0.23	0.28															
2006	M2	3	25/07/2006	40	12	SP	4	-50.1	-52.1	1	4,507	4.6	4,727		0.17	0.17	0.23	0.29															
2006	M2	3	25/07/2006	42_43	10	SH	4	-50.3	-52.2	1	10,575	21.6	13,486		0.09	0.14	0.23	0.27															

Table 6.2. continued. Acoustic TOWED spawning biomass estimates and associated CVs. Regarding the 2013 acoustic survey observations, Ryan et al. (2014) state that "given the apparent downward trend in biomass observed at St Helens Hill [over the survey period] it is possible that the 2013 surveys did not quantify the spawning stock at its peak". We have included the 2013 estimates in the assessment because the survey was carried out in a manner that was consistent with the other years (despite vessel equipment issues the AOS survey was conducted within the historical time-frame), and there was no *a priori* reason to exclude the observations (given the potential for large shot-to-shot variability in spawning condition of orange roughy a single trawl observation was not definitive enough to conclude that the survey had missed the main spawning event).

											SNAPSHOT BIOMASS				SNAPSHOT CV						AVERAGE BIOMASS			SURVEY CV						PRIORS			
Year	System	Fleet	Date	Op	Transects	Area	Pair	Target strength (original)	Target strength (revised)	Simrad TVG error factor	Biomass above DZ (t)	Deadzone %	**Biomass total (t)**	Max Biomass	snapshot CV	snapshot CV1 incl. deadzone	acoustics CV2	**total snapshot CV (CV1 & CV2)**	Bias	Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
2010	AOS	3	18/07/2010	18	10	SH	1	-52.0	-52.0	1	14,200	26	19,200	1	0.08	0.15	0.1	0.18		2010	19,350	4,650	24,000	0.18	0.18	0.15	0.20		0.25	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2010	AOS	3	19/07/2010	21	12	SP	1	-52.0	-52.0	1	6,000	3.2	6,200	1	0.13	0.13	0.1	0.16															
2010	AOS	3	22/07/2010	27	12	SP	2	-52.0	-52.0	1	2,600	16.1	3,100		0.17	0.19	0.1	0.21															
2010	AOS	3	22/07/2010	30	10	SH	2	-52.0	-52.0	1	14,600	25.1	19,500		0.08	0.15	0.1	0.18															
2012	AOS	3	16/07/2012	2	10	SH	1	-52.0	-52.0	1	7,085	41.2	12,058	1	0.18	0.26	0.1	0.28		2012	9,237	4,368	13,605	0.29	0.24	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2012	AOS	3	17/07/2012	5	6	SP	1	-52.0	-52.0	1	2,328	34.7	3,564	1	0.16	0.23	0.1	0.25															
2012	AOS	3	18/07/2012	11	10	SH	2	-52.0	-52.0	1	4,582	25	6,107		0.26	0.29	0.1	0.31															
2012	AOS	3	19/07/2012	15	6	SP	2	-52.0	-52.0	1	6,973	2.3	7,136		0.17	0.17	0.1	0.20															
2012	AOS	3	21/07/2012	24	6	SP	3	-52.0	-52.0	1	2,152	10.5	2,405		0.22	0.23	0.1	0.25															
2012	AOS	3	20/07/2013	12_13	9	SH	3	-52.0	-52.0	1	7,707	19.3	9,547		0.23	0.25	0.1	0.27															
2013	AOS	3	21/07/2013	14	9	SP	1	-52.0	-52.0	1	4,863	11.9	5,519	1	0.37	0.37	0.1	0.38		2013	6,284	5,892	12,176	0.30	0.28	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2013	AOS	3	21/07/2013	17_18	9	SH	1	-52.0	-52.0	1	6,560	23.5	8,572	1	0.23	0.26	0.1	0.28															
2013	AOS	3	22/07/2013	19_20	9	SP	1	-52.0	-52.0	1	4,932	13.5	5,700		0.13	0.15	0.1	0.18															
2013	AOS	3	24/07/2013	23_24	9	SH	2	-52.0	-52.0	1	2,887	27.7	3,995		0.24	0.27	0.1	0.29															
2013	AOS	3	25/07/2013	27a	9	SP	2	-52.0	-52.0	1	6,025	6.7	6,458		0.24	0.24	0.1	0.26															

Table 6.3. Acoustic TOWED spawning biomass estimates and associated CVs - average survey estimates, associated CVs and priors. Regarding the 2013 acoustic survey observations, Ryan et al. (2014) state that "given the apparent downward trend in biomass observed at St Helens Hill [over the survey period] it is possible that the 2013 surveys did not quantify the spawning stock at its peak". We have included the 2013 estimates here because the survey was carried out in a manner that was consistent with the other years.

	AVERAGE BIOMASS			SURVEY CV						PRIORS			
Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
1991	46,109	-	59,481	0.00	-	0.37	0.20	0.25	0.49	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1992	43,493	-	56,106	0.00	-	0.39	0.20	0.25	0.5	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1993	17,683	-	22,811	0.00	-	0.42	0.20	0.25	0.53	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1996	15,793	-	20,372	0.31	-	0.31	0.20	0.25	0.45	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
1999	4,955	20,883	25,838	0.36	0.67	0.33	0.20		0.39	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2006	14,668	2,873	17,541	0.28	0.29	0.24	0.20		0.31	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2010	19,350	4,650	24,000	0.18	0.18	0.15	0.20		0.25	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2012	9,237	4,368	13,605	0.29	0.24	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)
2013	6,284	5,892	12,176	0.30	0.28	0.21	0.20		0.29	LN(1,0.15)	Beta(95,5)	LN(1, 0.25)	N(0.95, 0.30)

Table 6.4. Acoustic HULL spawning biomass estimates and associated CVs by snapshot, area and year. A snapshot refers to one observation for an acoustic survey. The average survey estimates, associated CVs and priors are tabulated. Key: Area SH =St Helens, SP=St Patricks; Max Biomass –maximum snapshot biomass; snapshot CVs were obtained from acoustic reports (for acoustics CV2 e.g. see Table 3.10 in Ryan et al. 2013). Total survey CV is calculated by adding the three component errors (considered independent) - Combined areas CV, Between snapshots CV, Survey one area CV.

											SNAPSHOT BIOMASS				SNAPSHOT CV				
Year	System	Fleet	Date	Op	Transects	Area	Pair	Target strength (original)	Target strength (revised)	Simrad TVG error factor	Biomass above DZ (t)	Deadzone %	**Biomass total (t)**	Max Biomass	snapshot CV	snapshot CV1 incl. deadzone	acoustics CV2	**total snapshot CV (CV1 & CV2)**	Bias
1990	Hull	4	16/07/1990	SH190	5	SH		-50.0	-51.8	1.23	48,227	33	71,699	1	0.49	0.51	0.2	0.55	
1990	Hull	4	-	-	-	SP		-	-		-	-	-						
1991	Hull	4	26/07/1991	SS291	5	SH		-50.0	-51.8	1.24	36,680	34	55,204	1	0.41	0.44	0.2	0.48	
1991	Hull	4	-	-	-	SP		-	-		-	-	-						
1992	Hull	4	17/07/1992	SS392	5	SH		-50.0	-51.8	1.25	23,405	38	37,973	1	0.41	0.45	0.2	0.49	
1992	Hull	4	-	-	-	SP		-	-		-	-	-						

	AVERAGE BIOMASS			SURVEY CV						PRIORS			
Year	SH Biomass_average (t)	SP Biomass_average (t)	**SH+SP Biomass_average (t)**	SH average total snapshot CV	SP average total snapshot CV	Combined areas CV	Between snapshots CV	survey one area CV	**total survey CV_average**	target strength ratio (ts_ true/ts) A	%SB popn surveyed (prop) B	Random error C	**Catchability Q (A*B*C)**
1990	71,699	-	120,239	0.55	-	0.55	0.20	0.25	0.63	LN(1,0.15)	Beta(95,5)	LN(1, 0.8)	N(0.95, 0.92)
1991	55,204	-	71,213	0.48	-	0.48	0.20	0.25	0.58	LN(1,0.15)	Beta(95,5)	LN(1, 0.8)	N(0.95, 0.92)
1992	37,973	-	48,985	0.49	-	0.49	0.20	0.25	0.59	LN(1,0.15)	Beta(95,5)	LN(1, 0.8)	N(0.95, 0.92)

Table 6.5. Number of age samples by sex and area, used to construct age compositions that are input into the stock assessment model (areas combined). Note that the model is subsequently tuned to account for variance in the age compositions relative to the quality of the fit to these data (i.e. tuned to down-weight the importance of variable age-composition samples). The weighting factors applied when combining the areas SP and SH are given, and we outline the rationale. *For 1992 SP was not sampled - most of the catch was taken from SH (~90%; Table 9.4 Upston & Wayte 2012a) and it was assumed that most of the spawning fish were at SH in these years (Wayte 2007). Similarly, the 1995 catch was mostly taken from SH (84%) where the sampling occurred. The logbook data indicate that some of the 1995 samples may have been taken be from SP, and if so, we consider whether a 'combined' age distribution (with area sample weighting = 1) is appropriate, since this is the 'weighting' in the current assessment with all samples designated as SH (see also Appendix C).

Year	St Helens (SH)			St Patricks (SP)			Combined area		Combined area sample weighting	
	F	M	Tot	F	M	Tot	F	M	SP : SH	Rationale
1992*	410	596	1006	-	-		410	596	-	
1995*	595	726	1321	?	?		595	726	-	? some of the SH samples could be from SP. If so, age compositions by logbook area SP SH were broadly similar (Appendix C); an unweighted 'combined' distribution seems appropriate
1999	117	94	211	165	204	369	282	298	1.08	sample ratio SP: SH = 1.75 (Wayte 2007) & estimate 85% of spawning fish at SP (towed body acoustics; Kloser et al 2008)
2001	305	175	480	332	460	792	637	635	1	sample ratio SP: SH = 1.65, in proportion to commercial catches (no towed body acoustic estimates; Wayte 2007)
2004	228	234	462	186	270	456	414	504	1	age compositionns for SP SH were similar (Wayte 2007)
2010	474	121	595	218	130	348	692	251	1	age compositionns for SP SH were broadly similar (Appendix C); combined areas age frequency without sample weighting was similar to that with a combined area weighting SP: SH of 0.4 (sample ratio SP: SH=0.59 & estimate 24% of spawning fish at SP (towed body acoustics; Kloser et al 2011)

Table 6.6. Standard deviations of age reading error, based on 1,856 otolith readings by CAF, FAS & affiliates.

Age	StDev	Age	StDev
1	0.001	41	3.242
2	0.173	42	3.312
3	0.259	43	3.383
4	0.345	44	3.453
5	0.430	45	3.523
6	0.515	46	3.592
7	0.600	47	3.661
8	0.684	48	3.730
9	0.767	49	3.798
10	0.851	50	3.866
11	0.934	51	3.933
12	1.016	52	4.000
13	1.098	53	4.067
14	1.180	54	4.133
15	1.262	55	4.199
16	1.343	56	4.264
17	1.423	57	4.330
18	1.503	58	4.394
19	1.583	59	4.459
20	1.663	60	4.523
21	1.742	61	4.586
22	1.821	62	4.649
23	1.899	63	4.712
24	1.977	64	4.774
25	2.054	65	4.836
26	2.131	66	4.898
27	2.208	67	4.959
28	2.284	68	5.020
29	2.360	69	5.080
30	2.436	70	5.140
31	2.511	71	5.200
32	2.586	72	5.259
33	2.660	73	5.318
34	2.734	74	5.377
35	2.808	75	5.435
36	2.881	76	5.493
37	2.954	77	5.550
38	3.027	78	5.607
39	3.099	79	5.663
40	3.170	80	5.719

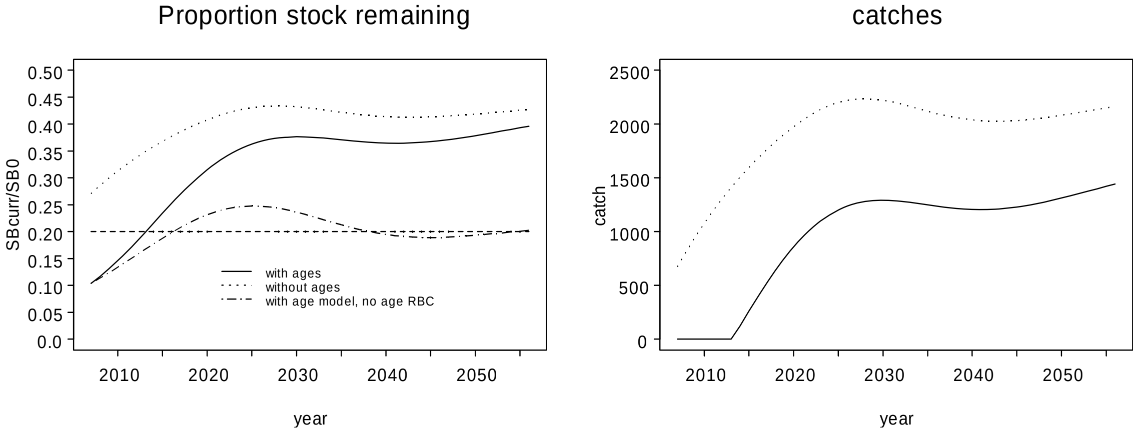
Table 6.7. Summary of results for Preliminary Base-case model and sensitivity tests (tuned models), including sequential models for the base case model specification and data inputs. Lower total NLL (negative log-likelihood) values indicate a better fit to the data for comparable models. Models with different weighting and data are not comparable (C indicate models comparable to Preliminary Base-case). *q* prior for towed: N(0.95, 0.3), Hull: N(0.95, 0.92). Sequential Models #1 and #2 have acoustic survey (towed and hull), age and catch data to 2010 (Tables 3, 6.3, 6.4 and 6.5). Preliminary Base-case model with data to end of 2013 has the same data inputs, model structure and data weighting approach as Model #1 but includes the acoustic towed survey data for 2012 and 2013 (Table 6.3), and thus shows the influence of the new data on the model outcomes. *2011 Preliminary Base-case A model used the same weighting approach as Model #2 but the data inputs and model structure are different (e.g. the 2011 model used a maximum acoustic index without priors for *q*; acoustic survey observations of spawning biomass were multiplied up to index total mature biomass). In a broad sense, comparison of outcomes for the latter two models shows the impact of revising the data inputs and model structure.

Model	**FEMALE SPAWN BIOMASS**			**NLL**	**NLL Main components**			**Estimated Parms**				
	SB0	**SB2014**	**SB2014/B0**	Total	Survey	Age_comp	Recruit	SR_LN(R0)	Selectivity_Infl.	Selectivity_Width	Q3_Towed_rel	Q4_Hull_rel
Preliminary Base-case model	38,727	9,223	0.24	210.88	-17.70	135.18	13.05	9.05	35.70	1.01	1.32	1.76
Sensitivity Model A: M&I Weighting	36,693	7,726	0.21	448.08	-17.57	361.19	22.89	8.99	35.76	1.00	1.53	1.77
Sensitivity Model B: Diffuse priors	38,579	9,095	0.24	206.16	-21.60	134.48	13.75	9.04	35.76	1.13	1.46	1.86
Sensitivity Model C: No Recruitment Devs (degrade age fit)	44,479	18,237	0.41	328.49	-15.95	264.51	0.00	9.18	35.58	2.17	0.79	1.69
Sensitivity Model D: Maximum acoustic SB estimate	38,767	9,269	0.24	206.39	-22.49	135.56	12.71	9.05	35.69	1.01	1.40	1.83
Sensitivity Model E: Steepness 0.40 [C]	38,770	9,587	0.25	206.39	-21.40	134.71	12.73	9.05	35.73	1.01	1.31	1.85
Sequential Models associated with Preliminary Base-case model												
Model #1: Data to end of 2010 (Francis weighting)	39,012	9,562	0.25	203.79	-26.35	136.63	11.77	9.05	35.67	1.00	1.72	1.83
Model #2: Data to end of 2010 (McAllister & Ianelli weighting)*	36,973	8,055	0.22	441.88	-25.50	362.76	21.45	9.00	35.75	1.00	2.07	1.86
Model: 2011 Preliminary Base-case A (Upston & Wayte 2012a)*	41,128	9,326	0.23	347.28	-3.96	346.67	4.56	9.28	36.23	2.06	3.26	n/a
Preliminary Base-case model: Data to end of 2013 (as above)	38,727	9,223	0.24	210.88	-17.70	135.18	13.05	9.05	35.7	1.01	1.32	1.76

Table 6.8. Excerpt from Wayte(2007; p 445). The future projection, applying the 48:48:20 harvest control rule each year, indicates that the biomass will reach the limit level of 20% unfished in 2014 (bottom panel – left).

Proportion of stock remaining in ten years and catch over ten years using different future catch regimes.

Model	Future catches	Prop. remaining in 2016	Total catch 2007-2016
One fleet with age	RBC 48:48:20	0.25	777
One fleet with age	RBC 48:48:20 from no age model	0.19	12,199
One fleet, no age data	RBC 48:48:20	0.38	12,199



RBC calculations for the 48:48:20 HCR for the scenarios with and without fitting to age, and the estimates of proportion of stock remaining if the ‘no age’ RBCs are applied to the ‘with age’ scenario.

7 Appendices

Appendix A – Priors for acoustic surveys

The priors for catchability coefficients (*q*) for the acoustic towed and hull biomass estimates used in the base-case assessment are listed in Tables 6.2, 6.3 and 6.4. The priors were developed using the methods of Cordue (presentation to the Australian Orange Roughy workshop, 15 -16 May 2014; Cordue 2014) for the NZ orange roughy assessments as a starting point, and modified for the Australian Eastern orange roughy situation using the available acoustic data (see below) and expert judgement (informal orange roughy acoustics working group in Hobart included J. Upston, T. Ryan, R. Kloser, and A. Punt). An outline of the methods is provided here.

In brief, the methods for calculating acoustic priors were:

Determine the sampling distribution, mean and CV associated with each of three components that we considered for the acoustic priors: (i) uncertainty in acoustic target strength (TS), i.e. the ratio of true target strength to assumed target strength – lognormal distribution centred at 1 with CV=0.15 (after Cordue presentation 2014: a) calculate the mean and standard deviation of two independent mean estimates of acoustic TS, -52.0 and -51.1 dB (ignores sampling variability), and assume TS ~ N(-51.6, sd=0.64), b) convert TS from log scale to linear scale via $\log_e(10^{ts/10})$ where ts is random normal TS, to get $\log_e(10^{ts/10})$ ~ N(-11.88, 0.1476), c) calculate mean and standard deviation of lognormal distribution centred on 1 (including bias correction); (ii) percentage of the spawning stock on the Eastern grounds that acoustics is “seeing” – historically the assessment has assumed 100% and the current assessment assumes “most” (Beta distribution centred on 95%) but allows for the possibility that some spawning stock do not migrate to the Eastern grounds in some years (e.g. an estimated 10% of spawning fish from the South did not migrate to the East in 1992; Bell et al. 1992). Thus a Beta(95, 5) distribution, centred on 95% and with reasonably high values of α and β for an approximately normal shape, was chosen for this prior component. The distribution shape, with less probability mass towards the left-hand tail of the distribution (less probability of only 90% or fewer spawning fish migrating to the spawning grounds and being observed), seemed appropriate based on expert judgement, however other Beta distributions could also have been used (e.g. Beta(950, 50); (iii) random error component capturing other uncertainty (e.g. estimated density of fish in an area; species ID issues; sampling variability in target strength since (i) is an average of the mean estimates). The random error has a lognormal distribution centred on 1, with a nominal “low” CV for towed body surveys, and a wider CV for the hull surveys, given the uncertainty with species ID and other issues (Kloser & Ryan et al. 2001).

The next step was to combine the independent component distributions to get an overall distribution. The CVs associated with each of the three components (and hence the overall prior) were determined by data and expert judgement – in combining the three components and setting a prior on acoustic catchability (*q* scalar) we essentially have made a statement about how well the acoustic towed or hull series is thought to provide an absolute estimate of biomass of the spawning roughy for the stock East and South (Pedra Branca). i.e. the stock we are assessing. We have assumed on average a constant percentage of fish migrating to the eastern grounds and spawning each year. The priors will undoubtedly be further developed as more information becomes available, thus the random error component (lognormal with CV=0.25 for the towed body and 0.8 for the hull) was explicitly included to accommodate this.

Distributions for each of the independent components, and the combined overall distribution for the acoustic *q* prior- are shown below (Figures A1 to A3). The series of acoustics reports are also listed immediately below.

Years	Index	Reference
1990	Hull	Kloser & Ryan (2002)
1991	Hull /Towed	Kloser & Ryan (2002)
1992	Hull /Towed	Kloser & Ryan (2002)
1993	Towed	Kloser & Ryan (2002)
1996	Towed	Kloser & Ryan (2002)
1999	Towed	Kloser, R. J., T. E. Ryan, et al. (2001)
2006	Towed	Kloser, R. J., T. E. Ryan, et al. (2008)
2010	Towed	Kloser, R. J., I. A. Knuckey, et al. (2011); Kloser et al 2012
2012	Towed	Ryan.T.E, Sutton.C, et al. (2013)
2013	Towed	Ryan, T. E., C. Sutton, et al. (2014)

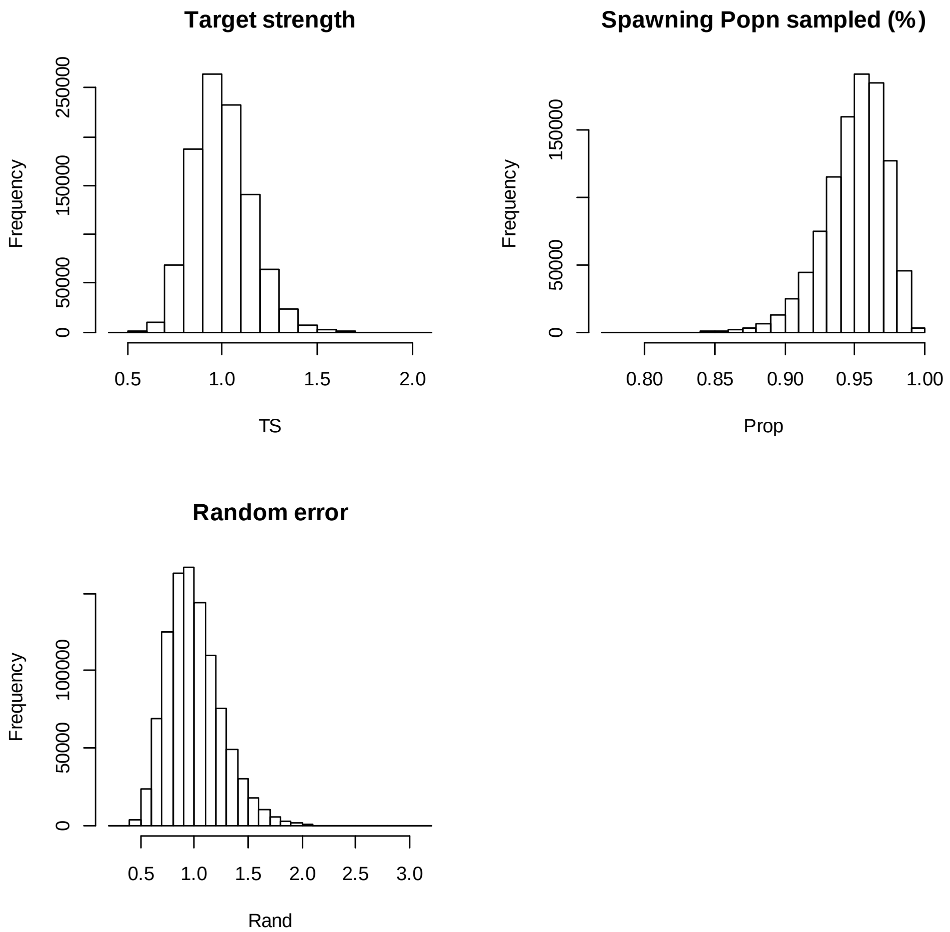


Figure A1. Prior component distributions for target strength, spawning population sampled, and random error for acoustics towed.

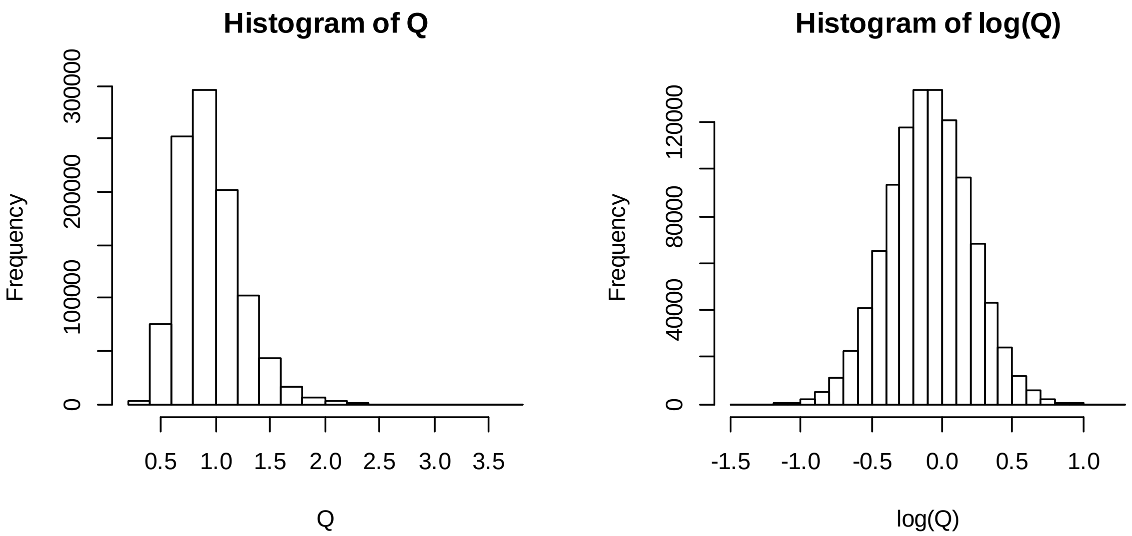


Figure A2. Priors for q and $\log_e(q)$ for acoustics towed

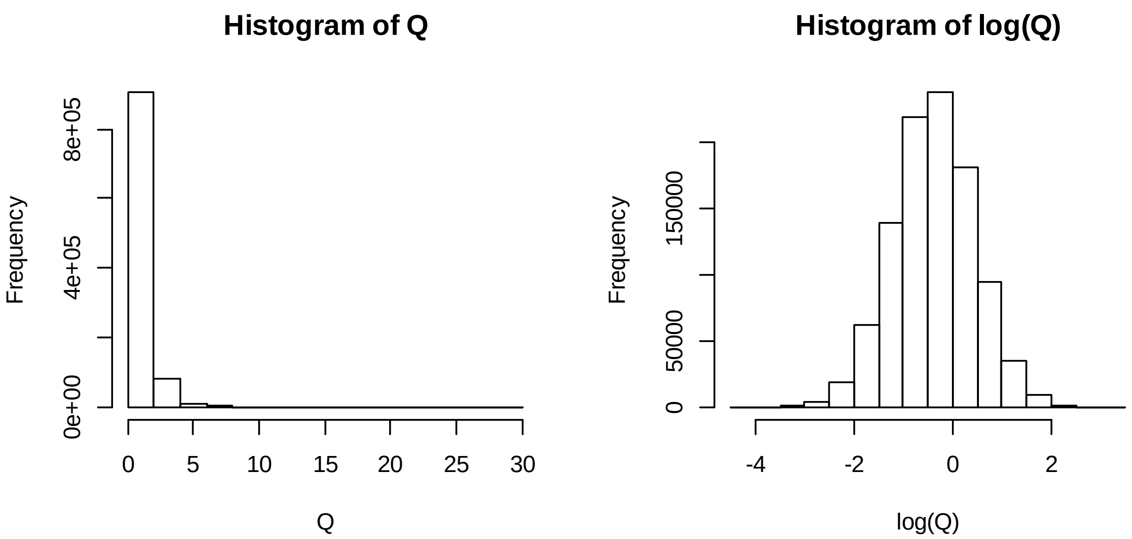


Figure A3. Priors for q and $\log_e(q)$ hull. The random error component is greater than that for towed body.

Appendix B – Re-ageing of Eastern roughy otoliths to test for bias in age reads (J. Upston, K. Krusic Golub & A.E. Punt)

Re- ageing of Eastern Zone orange roughy samples used in the stock assessment was completed by Kyne Krusic Golub (KKG, Fish Ageing Services). Approximately 350 otoliths from each of four years were re-aged: 1992, 1995, 2001, and 2004. Simulations by Punt (pers comm) indicated that a 10% linear bias in age reads could be detected in a sample size of 350.

The otolith samples from each year were selected at random within batches (proxy for vessel) and spread across dates/areas approximately in proportion to sampling, and including the range of ages in the sample. Approximately even numbers of females and males were selected randomly (as per the assessment – separate sex model). J. Upston did the random sample selections from the CSIRO historical data files for the stock assessment (with reference to 2011 version of FAS database), and KKG cross matched the selections with the current FAS database and the otolith slides. The re-ageing was done “blind” i.e. KKG did not have reference to the original ages when re-reading the otoliths, and the ageing methods followed those described by Tracey et al. (2007). For each sample the number of zones from the primordia to the transition zone (TZ) and the number of zones from the TZ to the edge of the otolith was counted and recorded. The final age was the sum of these two counts. The TZ age was also recorded along with readability scores for pre TZ and post TZ counts. For the purpose of this assessment, only the total ages were compared.

The age error program AGEMAT by Punt (2014) was used to model ageing error and bias, to estimate ageing error/bias matrices for each year, which can be incorporated into the stock assessment model. There was no evidence of major bias from the results of the re-reads of the otoliths (QQ plots in Figure B1, noting that the plus age group in the model is 80), and therefore no imperative to include ageing bias in the ageing error matrix for the base-case model. However a minor bias (~1 yr) was evident in the 60-80 age range for some years (e.g. 1995, 2001), and therefore the inclusion of a minor ageing bias (matrix in Table B1) in the model was explored as a sensitivity test. The model estimates of female spawning biomass and depletion were similar to those of the base-case model (a more parsimonious model). The result was as expected given the minor age bias (in the context of the estimated ageing error) and the down-weighting of the age-data in the current assessment (Francis 2011 weighting approach for age compositions).

The results of the re-ageing experiment are included below (Figure B1 and Table B1).

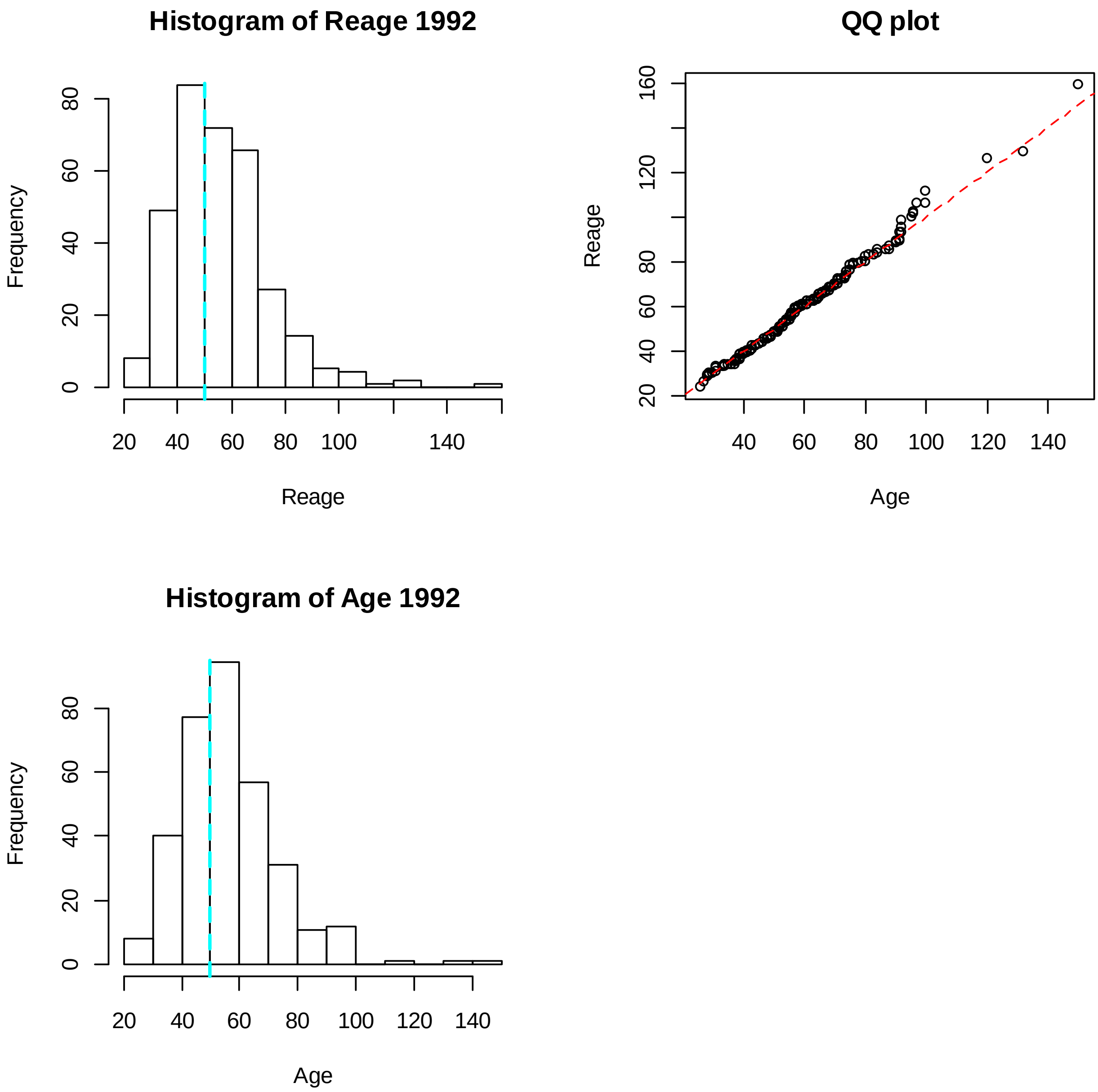


Figure B1. Histograms and QQ plots for re-ageing experiment for 1992; n = 330.

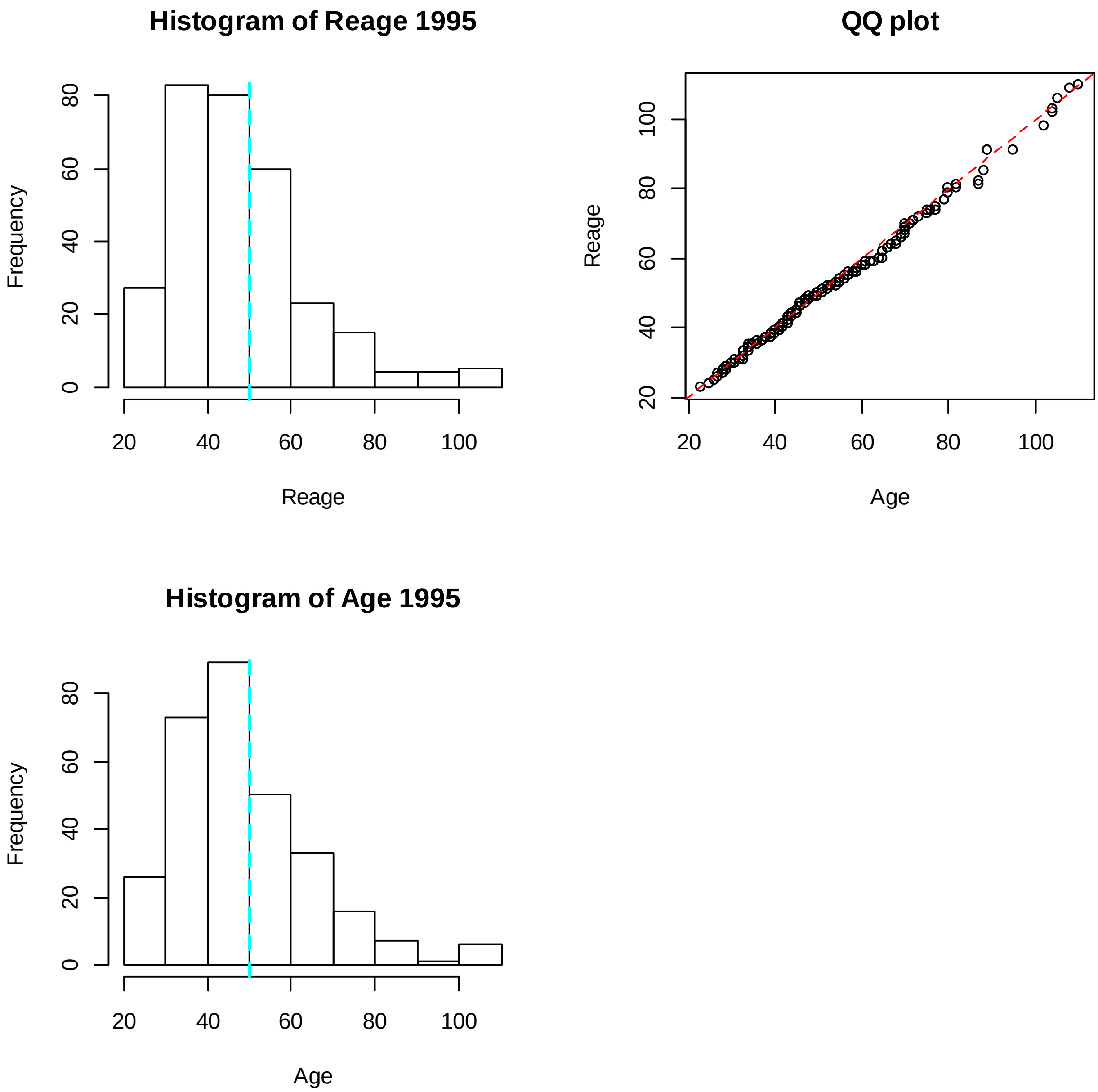
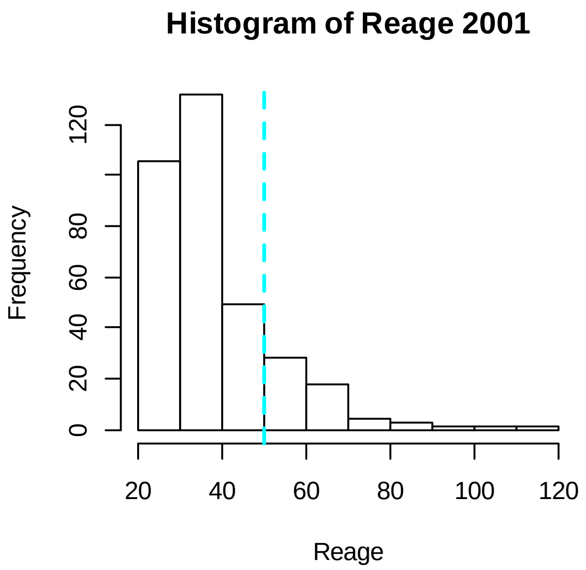


Figure B1. Histograms and QQ plots for re-ageing experiment for 1995; n = 304.



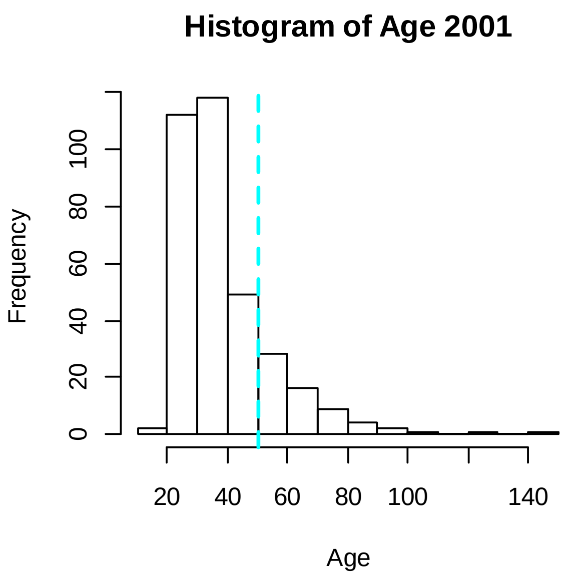


Figure B1. Histograms and QQ plots for re-ageing experiment for 2001; n = 343.

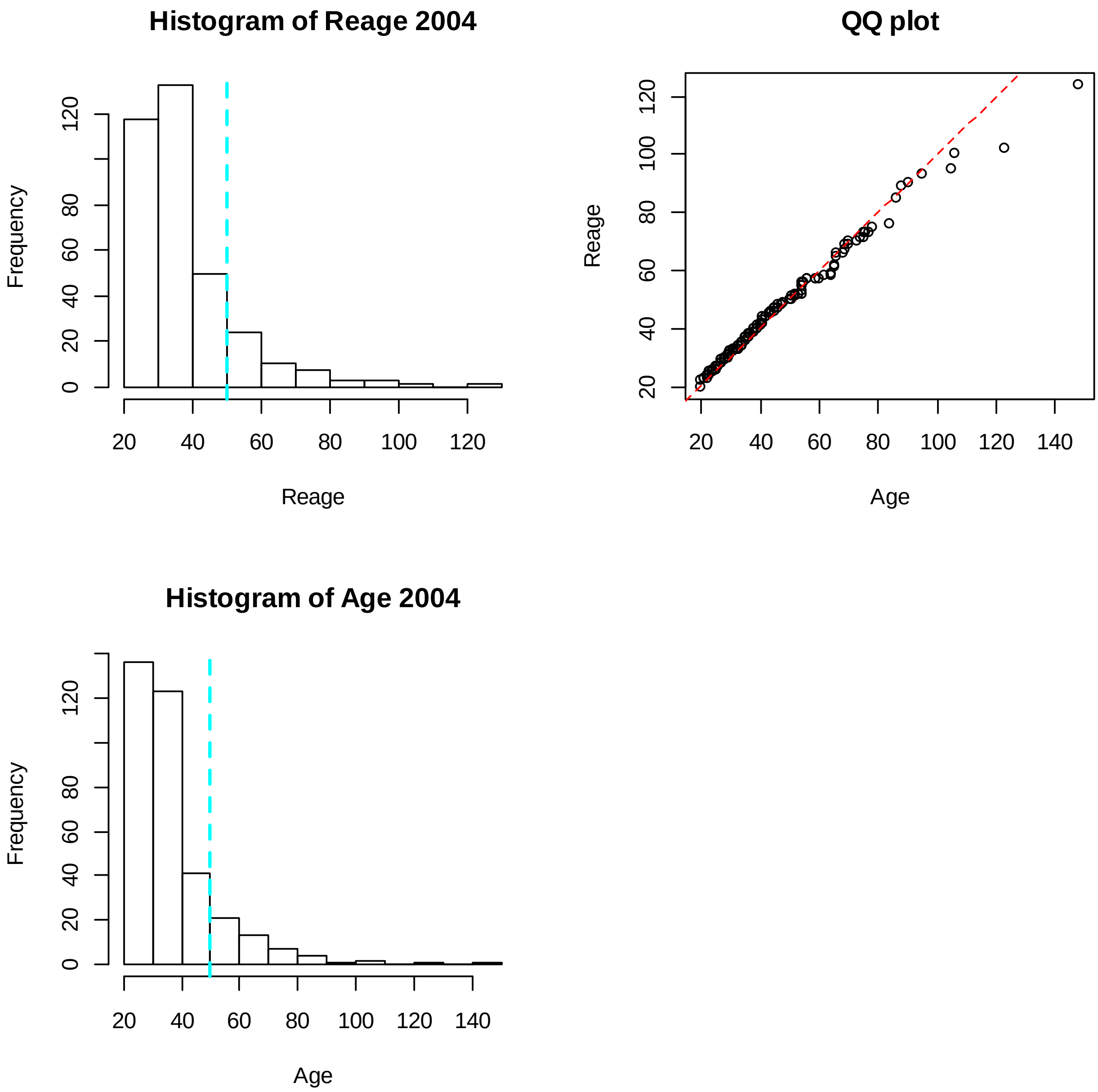


Figure B1. Histograms and QQ plots for re-ageing experiment for 2004; n = 350.

Table B1. Estimated age error and minor age reading bias for “old” age reading method, applied to 1995, 1999, 2001 and 2004 (sensitivity “Minor age reading bias”; note that for 1992 there no evidence of a minor bias (Figure B1), hence it was not included for this analysis). E.g. Expected Age would be 60.5 for Age 60 if the reader was unbiased (ignoring error).

Age	StDev	Expected Age	Age	StDev	Expected Age
1	0.001	0.5	41	3.242	41.4
2	0.173	1.5	42	3.312	42.5
3	0.259	2.5	43	3.383	43.5
4	0.345	3.6	44	3.453	44.5
5	0.430	4.6	45	3.523	45.5
6	0.515	5.6	46	3.592	46.6
7	0.600	6.6	47	3.661	47.6
8	0.684	7.7	48	3.730	48.6
9	0.767	8.7	49	3.798	49.6
10	0.851	9.7	50	3.866	50.7
11	0.934	10.7	51	3.933	51.7
12	1.016	11.8	52	4.000	52.7
13	1.098	12.8	53	4.067	53.7
14	1.180	13.8	54	4.133	54.7
15	1.262	14.8	55	4.199	55.8
16	1.343	15.9	56	4.264	56.8
17	1.423	16.9	57	4.330	57.8
18	1.503	17.9	58	4.394	58.8
19	1.583	18.9	59	4.459	59.9
20	1.663	19.9	60	4.523	60.9
21	1.742	21.0	61	4.586	61.9
22	1.821	22.0	62	4.649	62.9
23	1.899	23.0	63	4.712	64.0
24	1.977	24.0	64	4.774	65.0
25	2.054	25.1	65	4.836	66.0
26	2.131	26.1	66	4.898	67.0
27	2.208	27.1	67	4.959	68.1
28	2.284	28.1	68	5.020	69.1
29	2.360	29.2	69	5.080	70.1
30	2.436	30.2	70	5.140	71.1
31	2.511	31.2	71	5.200	72.2
32	2.586	32.2	72	5.259	73.2
33	2.660	33.3	73	5.318	74.2
34	2.734	34.3	74	5.377	75.2
35	2.808	35.3	75	5.435	76.2
36	2.881	36.3	76	5.493	77.3
37	2.954	37.3	77	5.550	78.3
38	3.027	38.4	78	5.607	79.3
39	3.099	39.4	79	5.663	80.3
40	3.170	40.4	80	5.719	81.4

Appendix C – Eastern Zone orange roughy age samples from winter spawning aggregations

Further details of the historical age samples in the stock assessment – from Eastern spawning aggregations (exception 1999 St Patricks also included non-aggregated fish; Bax 2000 and references therein; Wayte 2007) - were annotated (future work that was identified in Upston & Wayte 2012b). Kloser et al. (2012) list sources for Eastern Zone orange roughy age samples. However these samples were for July only and spawning aggregations were presumed (there was no identifier in the FAS database for an aggregation). The Eastern Zone stock assessment includes historical age samples selected from spawning aggregations in July, and in other months during the spawning season (the data were kept in an historical data base held by CSIRO). Table C1 includes the current state of knowledge on the provenance of the historical age samples used in the stock assessment. It was not possible to directly match the historical age samples to individual shots for the early years; however from the commercial logbook data we were able to derive the total number of possible shots that were sampled for a given date, area of operation and vessel (Table C1).

During the 1999 spawning season, otoliths from orange roughy at St Helens and St Patricks in 'aggregated' and 'backscatter' samples were collected and aged (see Table C1 Comments). According to Kloser et al. (2001) 'aggregation' samples were taken from regions where distinct and large fish marks were seen with the deep towed acoustic body and the resulting catch was large enough (> 1 tonne) to confirm that the mark was sampled. 'Backscatter' samples were taken from diffuse fish marks on areas of flat bottom adjacent to the seamount and canyon, and adjacent deep areas. The age profiles for St Helens orange roughy differed between the 'aggregated' and 'backscatter' samples and only the aggregated age samples were included in the stock assessment (Bax 2000; Figure C1). The age profiles for St Patricks did not differ between the sample types and all of the samples were included in the stock assessment (Bax 2000; Figure C1).

The age data in the stock assessment are assumed to be simple random samples from orange roughy spawning aggregations at St Helens Hill or St Patricks Head, taken from survey shots (surveys utilised commercial vessels) or from commercial fishing operations (Table C1). The assumption of random sampling from shots is broadly consistent with the findings of Kloser et al. (2012; Figure 4.5) who found the CAF (now FAS) dataset to be a random sub-set of the CSIRO length dataset for most years (exception 2004, St Patricks females were on average 1 cm smaller in the age sub-set c.f. csiro dataset). For 1992, there was no direct test (the sampling periods differed), although we know that age samples in the early years were taken from unsorted large commercial catches (J. Lyle 2014 pers. comm.), either at port or onboard.

As a gauge of sample coverage (whether the coverage is sufficient for a representative sample), we report the number of vessels, days and shots from which age samples were collected in Table C1. We also report the average KG per shot in July, as a proxy for orange roughy aggregations (catches > ~ 1 tonne) at the time of sampling, although it can only be a broad indicator as it is inferred from logbook records for most years. Regarding sample coverage, there is a tendency to sample ages over fewer days and shots in recent years. Given the potential for large shot-to-shot and day-to-day variability in ages of orange roughy on the spawning grounds (Kloser et al. 2012) it could be important to revise the strategy for future age sampling.

We note that there are age samples, as yet unread, for 2012 and 2013 (sampling was coincident with acoustic surveys), and the 2012 age sample may provide some important insights given that the observed spawning biomass point estimate at St Helens approximately half of the 2010 estimate (Table 6.3). The 2013 age sampling method was different from that for other years – smaller shot weights were sampled, possibly around edges of the spawning aggregation (see Ryan et al. 2014) – thus the 2013 age samples may not be representative of the spawning aggregation or comparable with previous years (e.g. different selectivity of trawl shots), and if so, are therefore unlikely to be useful for stock assessment purposes.

In addition to Table C1, histograms of the Eastern orange roughy raw age frequency data from the historical assessment files (now crossed-referenced with the FAS data), and for 2010, are included below. The graphs were produced using Stata Vers 10.1.

Table C1. Sample coverage and provenance of the age samples used in the Eastern Zone orange roughy stock assessment. All Vessels were commercial fishing vessels, and for select years research surveys (see Comments - "survey" or "commercial fishing"). Key: Area "SH" St Helens Hill; "SP" St Patricks Head. The age data in the latest Fish Ageing Services (FAS) database were available at the shot level for 1999, 2001, and 2010 but catch per shot was not available. The latter data were sourced from reports for 2004 and 2010 and from the logbook data for the other years (see Reference). *from logbook records and based on all possible July shots spanning the sampling period for a given vessel(s) and area. The number of shots for 1992 and 1995 are the total shots from logbooks based on the otolith sample dates (sampling period for 1995). [L] The minimum for SH 1999 is an under-estimate as the age samples are only from the fish aggregations that were identified during the survey. [SP?] Possibly includes samples from St Patricks. A note that the 1987 Eastern Zone age samples were from non-aggregated fish and are not included in the assessment (Bax 2000).

Year, sampling period	Area	JulyAvKG.shot^{-1}	Vessels	Days	Shots	FAS Batch no.	Comments	Reference
1992 21 June to 06 July	SH	25750* (25,000 - 26,500)	3	5	21*	91, 92, 94, 95, 98	commercial fishing	Anon (1995) cited in Smith et al (1998); Bax (2000); no shot info in FAS dbase
1995 06 to 13 July	SH (& SP?)	7459* (775 - 20,000)	5	15	55*	24[SP?],26[SP?],27,28,30,31	commercial fishing logbooks indicate also SP area?	Smith et al (1998); Bax (2000); Fig C1 this report no shot info in FAS dbase
1999 11 to 26 July	SH	4490* (10[L] - 36,000)	1	4	5	78, 82, 83, 85	survey; incl. only aggreg. fish	Kloser et al (2001) see Fig. 3.1; Bax 2000; shot info in FAS database
1999 09 July to 10 Aug	SP	9483* (5 - 55,000)	1	7	10	77, 80, 81, 84, 86, 88, 89	survey; incl. aggreg. & non-aggreg. fish	as above for 1999
2001 05 July to 02 Aug	SH	2873* (50 - 7,000)	2	11	22	115	commercial fishing	Kloser et al (2001) see Fig. 8.8; shot info in FAS database
2001 06 to 29 July	SP	5260* (301 - 26,500)	2	15	26	114	commercial fishing	as above for 2001
2004 19 to 22 July	SH	4,750 1,500 - 7,000)	1	4	6	166	industry survey; assume age sample was random across shots	Diver (2004) Tables 2 & 5 no shot info in FAS dbase
2004 20 to 23 July	SP	12,333 (4,000 - 28,000)	1	3	3	167	industry survey; assume age sample was random across shots	as above for 2004
2010 15 to 22 July	SH	7,677 (60 - 14,000)	1	5	6	233, 234, 238, 239, 242 to 247 inclusive	survey; revised 2010 data	Kloser et al (2011) Table A-2 shot info in FAS database
2010 17 to 22 July	SP	1,500 (1,500 - 1,500)	1	2	2	231, 232, 235, 236, 237, 240, 241	survey; revised 2010 data	as above for 2010

Figure C1 Histograms of raw age frequency data (prior to weighting) in the assessment model for historical years – 1992 to 2004 inclusive - and for 2010.

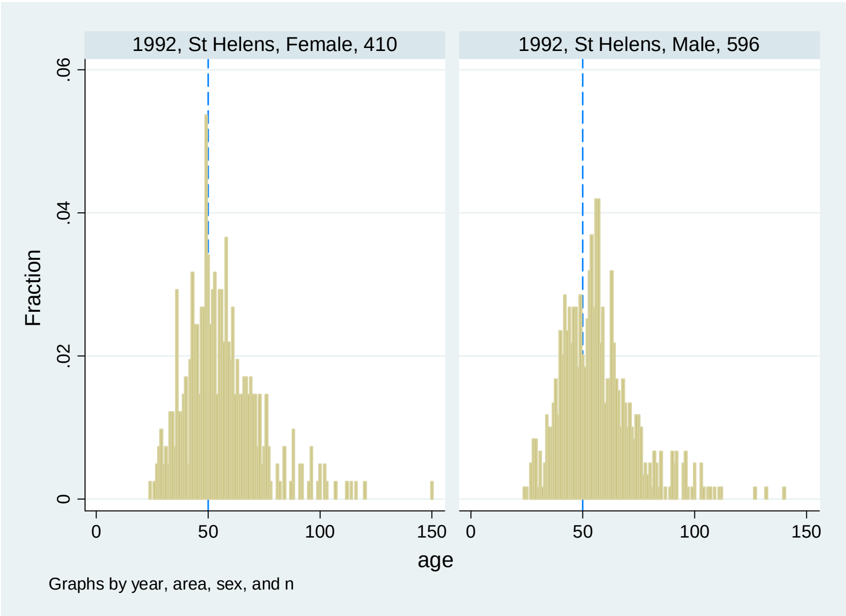


Figure C1 continued – raw age frequencies

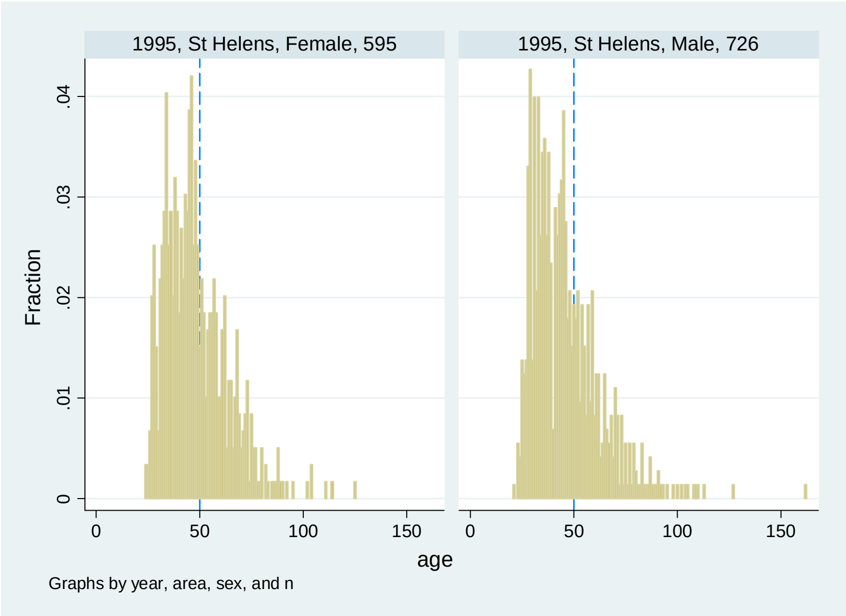
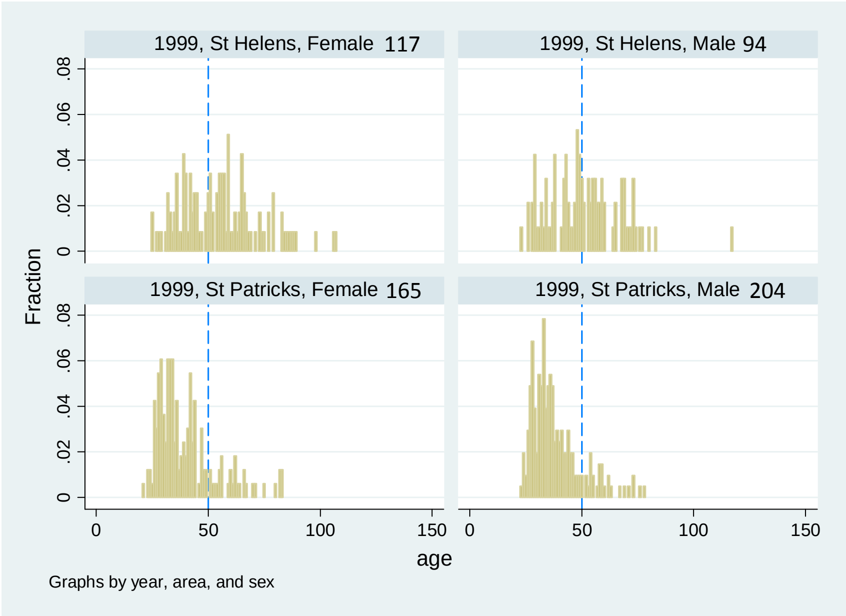
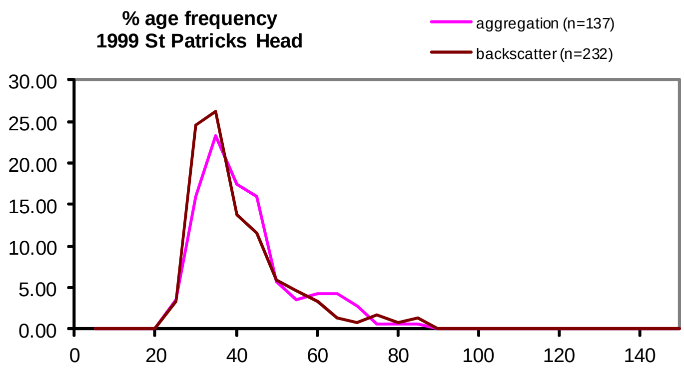


Figure bottom panel 1995 - age frequency by area from logbook records (derived from the latitude). The age frequencies for logbook areas are broadly similar, therefore a 'combined' distribution without weighting by area (top panel - historically denoted as St Helens area) seems appropriate. However, if it is necessary to follow-up further then the area for age samples would need to be verified with reference to the original raw data sheets (not held by CSIRO; see Table C1), given that both Bax (2000) and Wayte & Bax (2002) refer to the 1995 age samples as from St Helens spawning aggregations and the historical CAF data (held by FAS) lists the samples as East Coast - St Helens, Tasmania area. Note - the difference in total sample sizes for the top and bottom plots is explained by the former samples being sourced from historical files and the latter from the recent FAS database, which seems to be missing some of the age samples. This was not considered an issue as the age frequencies derived from the different sources were similar (investigated by J. Upston).

Figure C1 continued – raw age frequencies





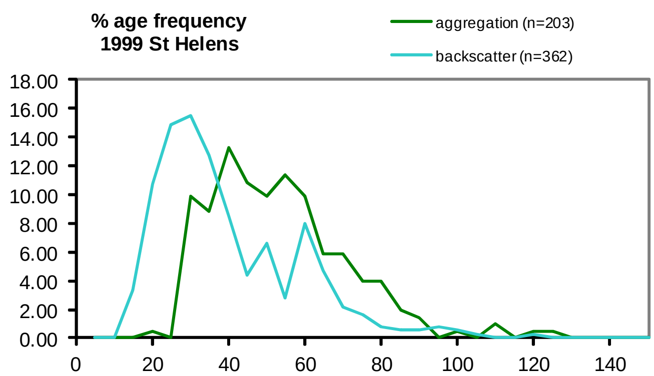


Figure bottom panels 1999 - Bax (2000) Figure 6 adapted. The plots show similar age frequency distributions for 'aggregation' and 'backscatter' samples for St Patricks in 1999, and different age frequency distributions for corresponding samples from St Helens. Hence the rationale, in addition to presumably boosting the otherwise low sample size, for historically including St Patricks 'backscatter' age samples in the stock assessment (which has a focus on spawning aggregations).

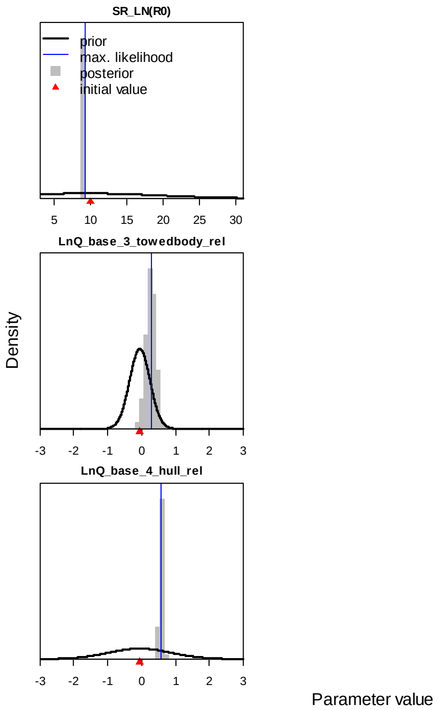
Figure C1 continued – raw age frequencies

Figure C1 continued – raw age frequencies

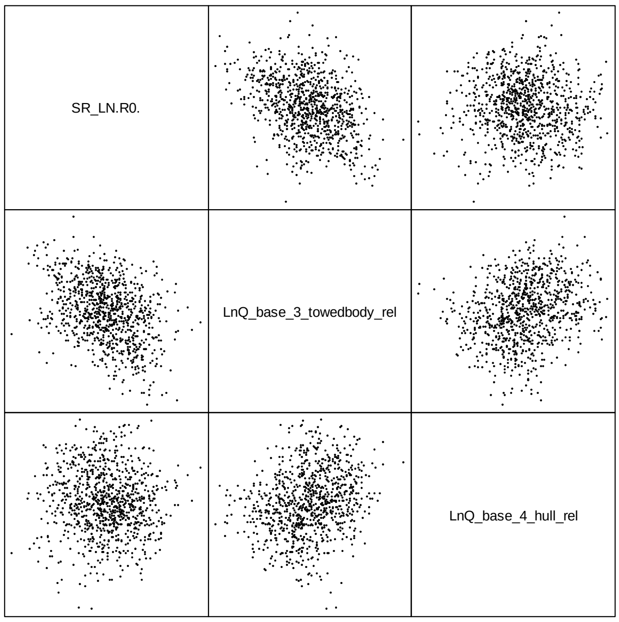
Appendix D – MCMC Diagnostics for Final Base-case Model 0

The diagnostic plots from the MCMC simulations for the Final Base-case Model 0 -24 million cycles, a 40,000 thinning interval, and omitting the first sample in the chain - are included below. Note that the final MCMC sample did not pass the convergence statistics (Geweke statistic and the Heidelberger and Welch test). With a heavy thinning interval the sample size was only 599, so there was less power to detect violations of convergence, however the trace plots suggested that the model was near convergence.

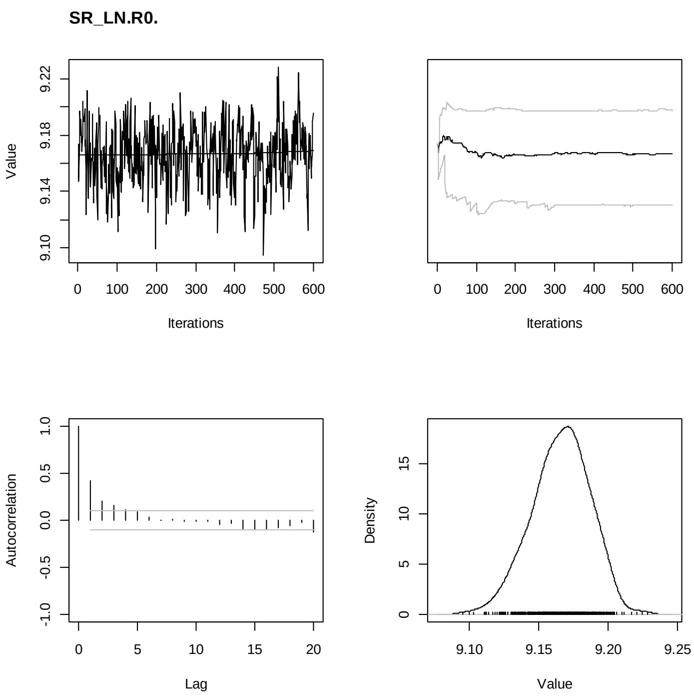
(a) Plot of prior and posterior distributions



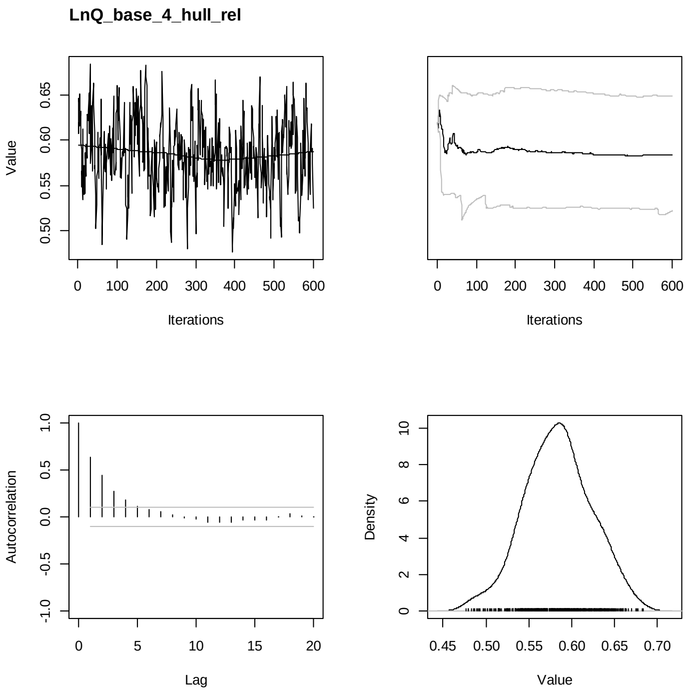
(b) Pairwise correlation plot for main parameters

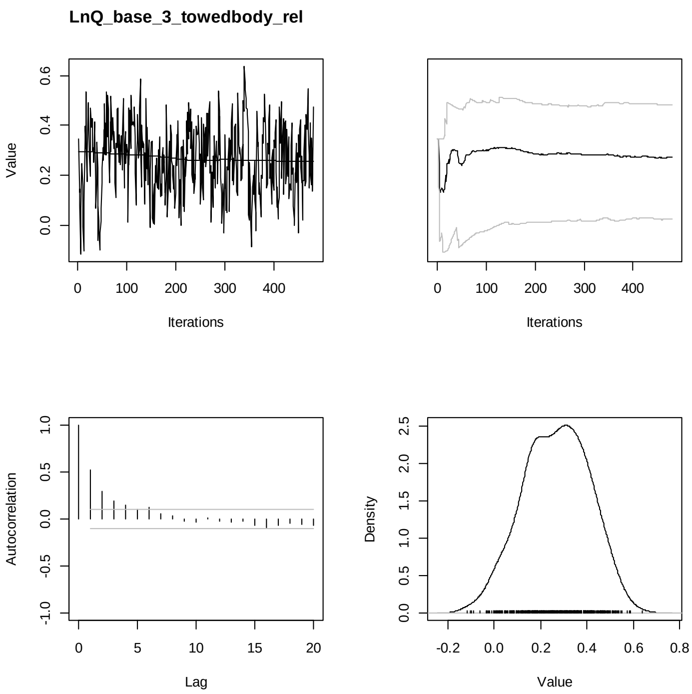


(c) Four panel plot for unexploited recruitment (SR_LN(R0)): trace plot and moving average (top panel), autocorrelation plot (bottom panel – left), and probability density plot for parameter (a check for approximate multivariate normal shape; bottom panel - right)



(d) Four panel plot for the log of the catchability parameter, *q*, for acoustic hull and towed body surveys : trace plot and moving average (top panel), autocorrelation plot (bottom panel – left), and probability density plot for parameter (a check for approximate multivariate normal shape; bottom panel - right)





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