A 2016 updated assessment of the squid resource, *Loligo reynaudii*

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Summary

The squid stock assessment model was last implemented in 2013 and at that time included data to 2012. An additional 3 years of data are now available and these have been included in an updated assessment. Sensitivity to incorporating additional survey data as well as a revised trawl catch series has been investigated. A Bayesian analysis has also been conducted and projections 10 years into the future suggest that effort in this fishery be maintained at 250 000 man-days.

Introduction

The squid stock assessment model is based upon Baranov catch equations. Results reported in 2013 (Glazer and Butterworth, 2013) indicated that any effort exceeding around 250 000 man-days would likely result in a probability exceeding 5% of the biomass falling below 20% of pristine in any future year. In addition, the average projected CPUE was shown to fall below the historic average for effort levels in excess of 250 000 man-days. The subsequent scientific TAE advice arising from those results was that effort in this fishery be limited to 250 000 man-days and, assuming that 210 fishing days per vessel during a season is achievable, to no more than 1190 fishers[1].

Data and sensitivity tests

Additional data that have become available since the assessment conducted in 2013 are as follows:

- 2013 - 2015 catches for both trawl and jig fisheries, and
- 2013 - 2015 nominal jig CPUE for the core set of vessels, and some minor changes to the jig CPUE for the period 2007-2012 as a result of corrections to and verifications of the jig database that have been undertaken since 2013.

In addition to updating the assessment to include the additional catch and CPUE data, two sensitivity tests were conducted relating to (i) additional survey abundance indices and (ii) a revised series of trawl catches based on a reconciliation carried out by Glazer (2016).

In past analyses the survey abundance indices included in the assessment model have been restricted to surveys conducted on the Research Vessel *Africana* utilizing “old” gear. Abundance indices are also available, however, from surveys conducted *by RV Africana* utilizing “new” gear, as well as from a commercial vessel, *FV Andromeda*, which conducted surveys during the time that the *RV Africana* was unavailable. For the sensitivity test which includes all survey indices of abundance it is assumed that there is no difference in catchability across gear types or vessels (i.e. the model fits to a single autumn

[1] The final allocation of crew to this fishery (after appeals) amounts to 2451 fishers (T. Tanci, DAFF, pers. commn). Prior to FRAP the fishery comprised 2422 fishers.

index and a single spring index respectively, both of which comprise abundance indices from all sources so that a single catachability coefficient is estimated for each series).

All the data included in the 2016 assessment and associated sensitivity tests are reported in Tables 1-5.

The assessment model

The Baranov catch equations are provided in Appendix A together with the likelihood equations and prior distributions assumed for the estimable parameters.

Joint posterior mode estimates

Table 6 reports model estimates at the joint posterior mode across the various assessments conducted:

- Model 1: 2013 assessment utilizing Roel (1998) catches for the period 1971-1996,
- Model 1a: 2013 assessment utilizing revised trawl catches for the period 1971-1996,
- Model 2: 2016 assessment utilizing Roel (1998) trawl catches for the period 1971-1996,
- Model 2a: 2016 assessment utilizing revised trawl catches for the period 1971-1996, and
- Model 3: 2016 assessment utilizing revised trawl catches for the period 1971-1996 and additional survey abundance indices obtained from *RV Africana* utilizing "new" gear and from *FV Andromeda*.

Replacing the current 1971-1996 trawl catches with the revised catches of Glazer (2016) results in a higher estimate of initial recruitment (R_0), and hence pristine biomass (B_{1971}). Recent biomasses relative to pristine, however, are at similar levels as those for the Roel (1998) *vs* revised catch series and this is illustrated by comparing Models 1 and 1a (2013 assessment) and Models 2 and 2a (2016 assessment) in Table 6. Also of note is that η (the parameter which reflects the degree to which recruitment is impacted by jigging) increases when incorporating the revised trawl catches. There is little difference between results for Model 2a and Model 3 (with extra abundance indices), except that the latter shows somewhat greater recruitment and biomass around 2009.

Figures 1-7 compare the estimated recruitment series, the recruitment residuals, begin-year biomass series and fits to the indices of abundance (the latter restricted to those assessments that include data to 2015) across the models considered.

Bayesian analyses and projections

For the Bayesian posterior computations the Markov chain Monte Carlo (MCMC) method was applied to Model 2a which included the following set of data:

1. Jig catches for the period 1995-2015 – Table 1
2. Trawl catches for the period 1971-2015, with the 1971-1996 catches comprised of the revised catches of Glazer (2016) – Table 5

3. Jig CPUE for the period 1995-2015 – Table 2
4. Trawl CPUE for the period 1978-1999 – Table 3
5. Survey abundance indices for Africana "old" gear only – Table 4 – since it is unlikely that the catchability coefficients across gear types and vessels will be the same and currently no calibration exercises have been undertaken to determine this.

A chain of200 million samples was run, saving every 2000 which resulted in 100 000 samples, 20 000 of which were discarded as burn-in, leaving 80 000 samples for analysis purposes. Despite the length of the chain the model failed to converge. Time constraints have precluded further analyses of longer chains (which can take days to run), and the 80000 samples from the current chain were analysed to determine whether the lack of convergence would bias the statistic of importance, namely the biomass at the end of the projection period relative to pristine biomass, $\frac{B^*_{2025}}{K}$.

Analysis of the chain

The chain of 80 000 samples was broken into four parts, each containing 20 000 samples and the model was projected forward using each of the four sets of samples. The assumptions made relating to effort in the projections are as follows:

- The proportion of annual jig effort expended in each period is equivalent to the average observed over the last 3 years for which data are available (2013-2015), and is 0.28:0.72 for Jan-Mar:Apr-Dec.

- Future trawl effort is constant and is equivalent to the average standardized effort in the trawl fishery over the last 5 years for which data are available (1995-1999).

- The proportion of annual trawl effort expended in each period is equivalent to the average observed over the last 5 years for which data are available (1995-1999), and is 0.19:0.81 for Jan-Mar:Apr-Dec.

The resulting $\frac{B^*_{2025}}{K}$ statistics and associated probability intervals are plotted in Figure 8 for fixed effort levels ranging from 200 000 – 400 000 man-days in intervals of 50 000. It is evident from Figure 8 that the 5^{th} percentile across samples within a given effort level are at similar levels, suggesting that non-convergence of the MCMC chain is not of major concern for the key result. This was further investigated by plotting both the median and lower 5^{th} percentile values within each effort level relative to their means and these are shown in Figure 9. On the whole trends with effort are generally linear for each case, except perhaps for the 400 000 man-days scenario.

Final projections

Since the four parts of the chain yield similar results (as shown in Figures 8 and 9) all 80 000 samples were used to perform stochastic projections 10 years into the future under various constant effort scenarios and the following performance statistics are reported:

- average annual catches by the jig fishery
- average annual variation (AAV) in catch by the jig fishery from one year to the next, where:

$$AAV = \frac{1}{10}\sum_{y=2016}^{y=2025} \left|C_y - C_{y-1}\right| / C_{y-1}$$

- $\frac{B^*_{2025}}{K}$
- $\frac{B^*_{lowest}}{K}$

These results are presented in Figure 10 and indicate that any effort exceeding around 250 000 man-days will result in a probability exceeding 5% of the biomass falling below 20% of pristine in any future year.

Also of interest to the jig fishery would be the projected CPUE and this is shown in Figure 11. The average jig CPUE by the fishery over the period 2011-2015 is also indicated and it is evident that the average projected CPUE would fall below the historic average for effort levels exceeding 250 000 man-days.

References

Anon. 2014. Recommendations of the Squid Scientific Working Group for the sustainable management of the Chokka Squid resource (*Loligo reynaudii*) for the 2015 fishing season. 5pp.

Glazer, JP. 2016. A reconciliation of the trawl catches of *Loligo reynaudii* as used in the stock assessment model. Unpublished working group document: FISHERIES/2013/SEP/SWG-SQ/54. 6pp.

Glazer, JP and Butterworth, DS. 2013. Further Squid Assessment and Projection Results for a Bayesian Approach to Take Account of Uncertainty in Parameter Values. Unpublished working group document: FISHERIES/OCT/2016/SWG-SQ/25. 14pp.

Roel, B.A. 1998. Stock Assessment of the Chokka squid *Loligo vulgaris reynaudii*. PhD thesis. 217 pp.

Table 1: Trawl and jig squid catches (tons). Shaded values represent additional data that have become available since the 2013 assessment was conducted. Trawl catch source: Roel (1998) and Demersal FAO 47A report. Jig catch sources: SABS (1985-2007), NCRS (2008+). The catches in brackets indicate those that were included in the 2013 assessment and which have subsequently been updated for inclusion in the 2016 assessment.

	Trawl			Jig	
Year	**Jan-Mar**	**Apr-Dec**		**Jan-Mar**	**Apr-Dec**
1971	26.64	46.36			
1972	186.88	325.12			
1973	342.00	595.00			
1974	1322.00	2300.00			
1975	1331.86	2317.14			
1976	769.77	339.23			
1977	1025.21	2096.79			
1978	1021.20	3967.80			
1979	2080.57	3035.43			
1980	1006.84	2047.16			
1981	1719.16	2036.84			
1982	1536.75	2067.25			
1983	2304.69	1810.31			
1984	586.70	1528.30			
1985	1633.12	2053.88		117	2487
1986	222.88	715.12		248	3151
1987	238.30	413.70		170	2627
1988	169.36	651.64		213	4614
1989	413.20	749.80		2044	7534
1990	290.36	454.64		459	1728
1991	141.72	351.28		149	4330
1992	90.22	196.78		218	1752
1993	50.62	227.38		309	6402
1994	220.10	266.90		2493	4356
1995	125.43	213.57		1735	5578
1996	155.23	205.77		1828	4996
1997	75.60	161.40		945	2829
1998	128.37	187.62		1644	4919
1999	90.94	183.72		1662	4973
2000	81.66	272.30		1217	4844
2001	119.41	124.85		719	2228
2002	62.73	142.43		1819	7795
2003	76.14	261.67		2166	9654
2004	123.38	267.91		5028	8233
2005	94.60	279.25		2758	6389
2006	134.22	223.97		3583	5708
2007	126.77	369.32		2044	7394
2008	169.43	353.76		3034	5987
2009	395.80	363.63		3242	7099
2010	221.55	339.02		3665	7112
2011	256.86	202.70		3154	4642
2012	71.55	155.78		2018 (2032)	4374 (4246)
2013	15.67	45.32		521	2143
2014	77.40	135.29		1192	5715
2015	85.60	247.24		2734	3745

Table 2: Jig CPUE indices (the nominal CPUE for a core set of vessels, measured as catch per man-day). Note that the model fits to the April-December index only. New data since the 2013 assessment are shaded yellow. The CPUE values in brackets indicate those that were used in the 2013 assessment, and which have subsequently been updated for inclusion in the 2016 assessment.

	CPUE	
Year	**Jan-Mar**	**Apr-Dec**
1995	30.48	31.24
1996	29.49	25.36
1997	15.88	16.24
1998	18.21	26.11
1999	29.66	25.83
2000	19.68	28.16
2001	21.36	19.42
2002	22.40	30.58
2003	28.44	37.03
2004	45.00	26.74
2005	22.85	21.97
2006	30.48	22.49
2007	21.66	27.20 (27.23)
2008	29.84 (29.05)	37.90 (36.75)
2009	37.98 (37.59)	32.84 (32.32)
2010	31.24 (31.33)	25.89 (25.86)
2011	25.57 (25.52)	17.86 (17.88)
2012	16.26 (16.46)	21.31 (21.27)
2013	8.86	12.25
2014	23.53	33.30
2015	31.68	23.73

Table 3: Trawl CPUE indices (kg/minute) (Roel, 1998).

	CPUE	
Year	**Jan-Mar**	**Apr-Dec**
1978	13.77	7.46
1979	19.97	7.92
1980	14.52	4.31
1981	17.78	8.12
1982	16.50	4.94
1983	24.10	3.22
1984	8.90	4.02
1985	12.69	3.17
1986	6.20	2.80
1987	5.79	2.11
1988	5.60	3.15
1989	8.81	3.43
1990	6.25	2.07
1991	5.28	2.34
1992	3.84	1.72
1993	3.53	2.09
1994	6.58	2.14
1995	5.20	2.08
1996	5.25	2.10
1997	4.34	1.79
1998	4.83	2.21
1999	5.17	1.84

Table 4 – Abundance estimates obtained from research surveys conducted by *RV Africana* between 1986 and 2015 (bold values indicate estimates obtained utilizing the new gear), and from research surveys conducted aboard the commercial vessel *FV Andromeda* since 2014 (bold underlined estimates). The shaded areas indicate surveys that extended to depths of 200m only.

	South Coast - Autumn Index		South Coast - Spring Index	
Year	**Abundance (t)**	**SE (t)**	**Abundance (t)**	**SE (t)**
1986			8638	1880
1987			12111	1733
1988	9075	1336		
1989	19025	4191		
1990	9222	1832	13434	1849
1991	14695	3503	23595	4021
1992	13145	1476	10034	1448
1993	22361	3938	14409	2437
1994	22377	5331	15255	2383
1995	23511	3021	13616	1549
1996	27968	2673		
1997	10026	1049		
1998				
1999	19495	2230		
2000				
2001			10558	1532
2002				
2003	22448	2937	**13789**	**1587**
2004	**15670**	**2403**	**17412**	**3550**
2005	**17209**	**2490**		
2006	20118	2187	12763	1295
2007	**21516**	**2472**	**23029**	**3090**
2008	**31328**	**3478**	**20108**	**2847**
2009	**32060**	**2772**		
2010	16938	2363		
2011	**27738**	**3815**		
2012				
2013				
2014	**<u>16052</u>**	**<u>1622</u>**		
2015	**<u>15831</u>**	**<u>2732</u>**		

Table 5: Alternative trawl catches for the period 1971-1996 (Glazer, 2016)

Year	Jan-Mar	Apr-Dec
1971	96.31	183.69
1972	176.12	335.88
1973	322.31	614.69
1974	1245.89	2376.11
1975	1255.18	2393.82
1976	724.76	1382.24
1977	1128.94	2153.06
1978	1085.99	3903.01
1979	2128.42	2987.58
1980	971.16	2082.84
1981	1373.42	2382.58
1982	1450.72	2153.28
1983	2292.13	1822.87
1984	574.08	1540.92
1985	769.71	917.29
1986	211.91	633.09
1987	240.40	411.60
1988	159.40	661.60
1989	391.01	771.99
1990	249.78	495.22
1991	161.00	335.00
1992	92.05	194.95
1993	50.66	227.34
1994	224.71	275.29
1995	123.10	215.90
1996	167.69	216.31

Table 6: Parameter estimates at the joint posterior mode for the various assessments conducted. (Note that B*2013 is a projected value in the 2013 assessment, and B*2016 is a projected value in the 2016 assessment.)

	Model 1 (Data to 2012)	Model 1a (Data to 2012)	Model 2 (Data to 2015)	Model 2a (Data to 2015)	Model 3 (Data to 2015)
Model parameters	2013 assessment (Roel (1998) trawl catches, Africana old gear surveys only) [baranov2013a.tpl]	2013 assessment (Updated trawl catches, Africana old gear surveys only) [baranov2013revtrcat.tpl]	2016 assessment (Roel (1998) trawl catches, Africana old gear surveys only) [baranov2016.tpl]	2016 assessment (revised trawl catches 1971-1996 based on catch reconciliation, Africana old gear only) [baranov2016revrecat.tpl]	2016 assessment (revised trawl catches based on catch reconciliation, Africana old gear, new gear and Andromeda survey estimates) [baranov2016survey.tpl]
Parameter estimates					
ℓnX	10.744	11.011	10.724	11.025	11.063
R0 (initial recruitment)	46351.8	60505.5	45415.7	61384.5	63793.7
h	0.300	0.292	0.354	0.345	0.326
η	0.530	0.896	1.208	1.891	1.702
g	1.263	1.266	1.272	1.276	1.279
B*1971	64633.7	84253.3	63090.4	85146.4	88390.2
B*2012	18110.9	24394.6	17468.3	24464.7	30360.3
B*2013	18718.8	25049	16996.7	23764.1	27224.3
B*2014	n/a	n/a	15776.7	21769.2	24130.5
B*2015	n/a	n/a	24363.9	33669.9	35546.2
B*2016	n/a	n/a	22783.6	31424.2	33392.3
B*2012/B*1971	0.280	0.290	0.277	0.287	0.343
B*2013/B*1971	0.290	0.297	0.269	0.279	0.308
B*2014/B*1971	n/a	n/a	0.250	0.256	0.273
B*2015/B*1971	n/a	n/a	0.386	0.395	0.402
B*2016/B*1971	n/a	n/a	0.361	0.369	0.378
Stock recruit residuals					
σ_R(input)	0.3	0.3	0.3	0.3	0.3
σ_R(estimated)	0.19	0.19	0.205289	0.20	0.21
CPUE Jig Apr-Dec					
q	0.000642004	0.000487384	0.000635407	0.000465386	0.000425874
σ*	0.2	0.2	0.2	0.2	0.2
CPUE Trawl Jan-Mar					
q	0.000274239	0.000204492	0.000272964	0.000196053	0.000191648
σ*	0.2	0.2	0.2	0.2	0.2
CPUE Trawl Apr-Dec					
q	5.49E-05	4.15E-05	4.15E-05	3.96E-05	3.87E-05
σ*	0.2	0.2	0.2	0.2	0.2
Autumn index					
q	0.273954	0.210069	0.270524	0.200327	0.202328
σ*	0.346413	0.347691	0.346023	0.347331	0.312252
Spring index					
q	0.369809	0.279461	0.366957	0.267432	0.266119
σ*	0.26198	0.262953	0.26106	0.262048	0.243804
-ℓnL values					
jig A-D	-9.86	-9.80	-9.99	-9.92	-9.06
trawl J-M	-6.90	-6.82	-7.08	-6.98	-6.72
trawl A-D	-9.76	-9.80	-9.86	-9.92	-9.56
autumn	5.02	5.07	5.01	5.06	5.61
spring	0.79	0.83	0.76	0.80	0.11
S/R residuals	-3.21	-3.26	-2.29	-2.35	-2.07
$F_{jig\ J\text{-}M}$	-83.81	-83.81	-92.79	-92.79	-92.79
$F_{jig\ A\text{-}D}$	-83.81	-83.81	-92.78	-92.78	-92.78
$F_{trawl\ J\text{-}M}$	-125.71	-125.71	-134.69	-134.69	-134.69
$F_{trawl\ A\text{-}D}$	-125.71	-125.71	-134.69	-134.69	-134.69
penalties (g)	-1.19	-1.16	-1.12	-1.09	-1.07
Total	-444.13	-443.96	-479.52	-479.35	-477.71

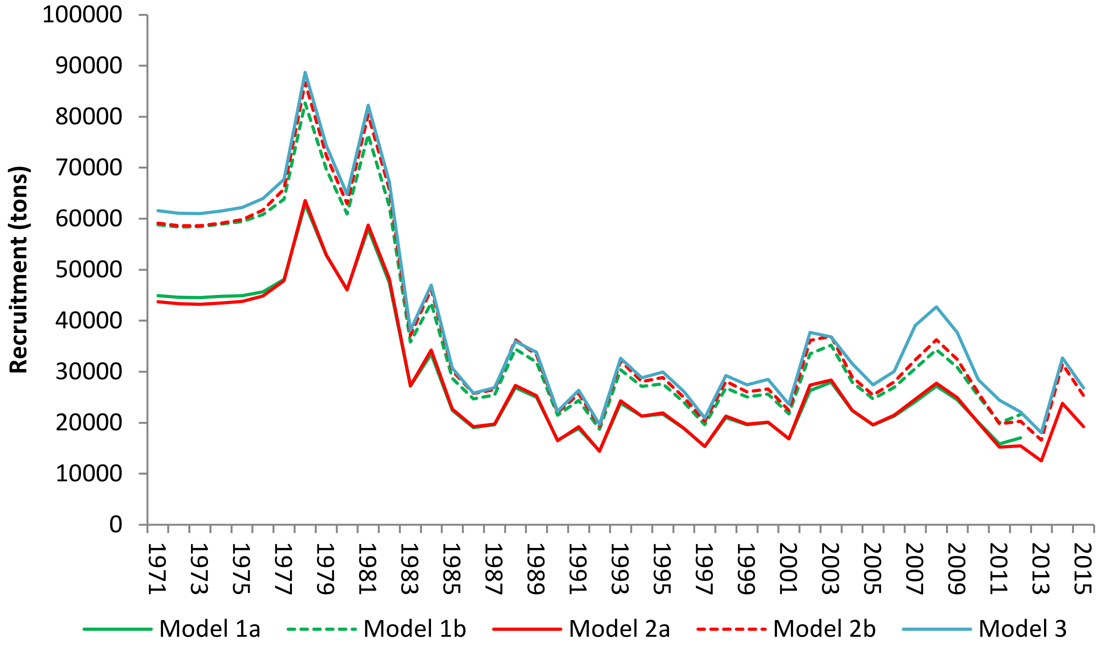

Figure 1: Recruitment series for the respective models[1].

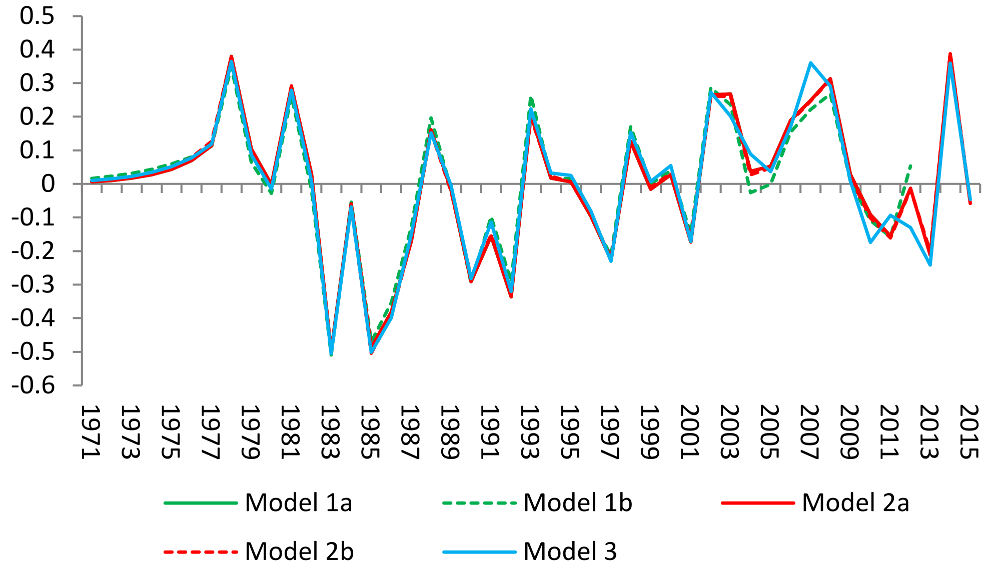

Figure 2: Recruitment residuals for the respective models[1].

[1] Model 1a – 2013 assessment, Roel (1998) trawl catches
Model 1b – 2013 assessment, revised trawl catches
Model 2a - 2016 assessment, Roel (1998) trawl catches
Model 2b: - 2016 assessment, revised trawl catches
Model 3: 2016 assessment, revised trawl catches, all survey estimates

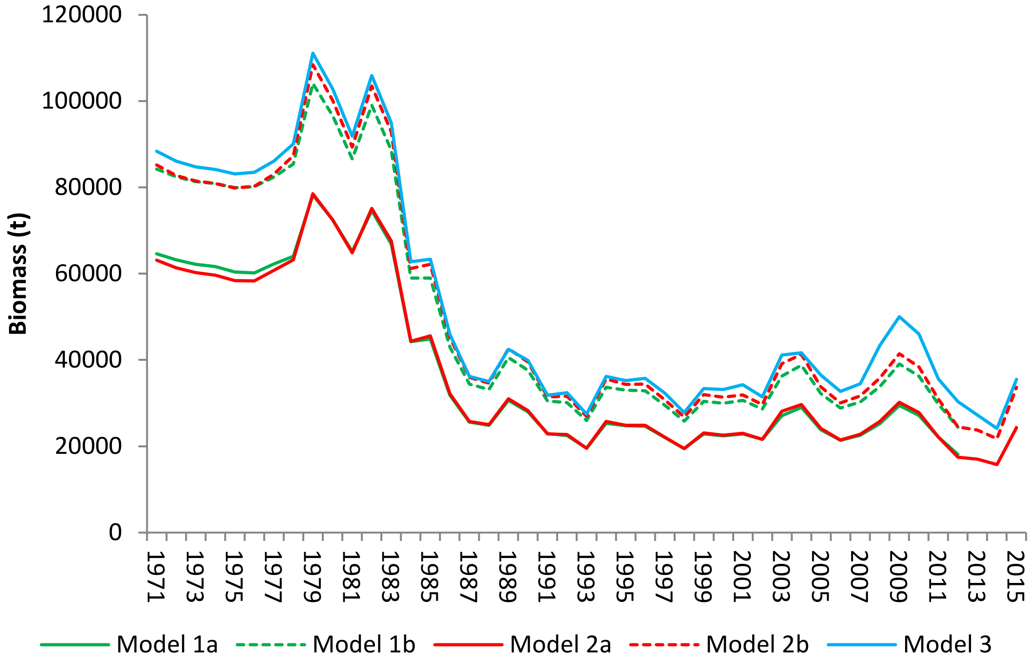

Figure 3: Begin-year biomass[1].

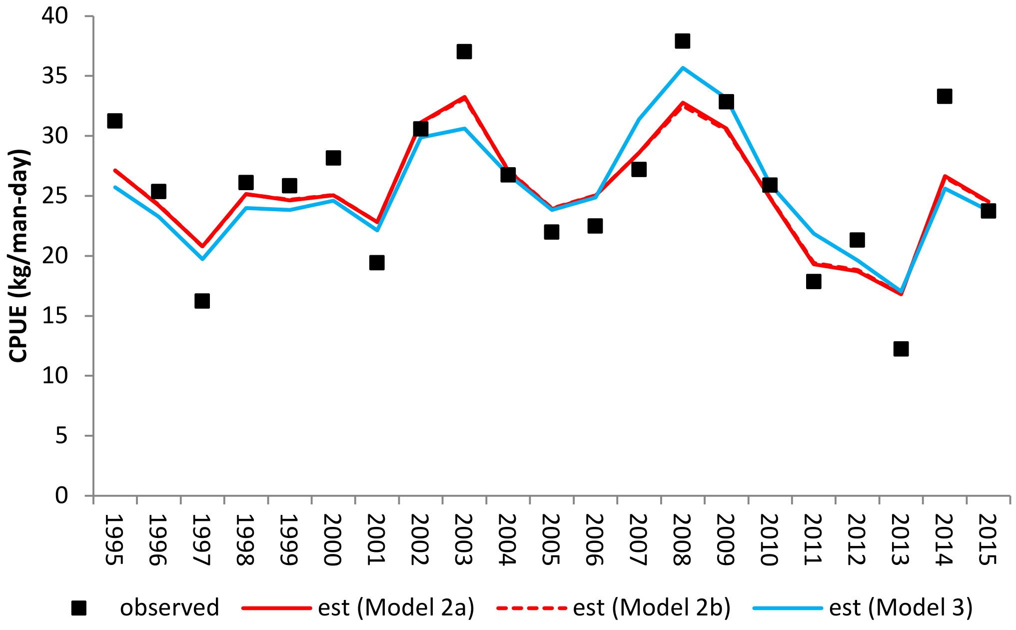

Figure 4: Fits to the April-December jig CPUE index[1].

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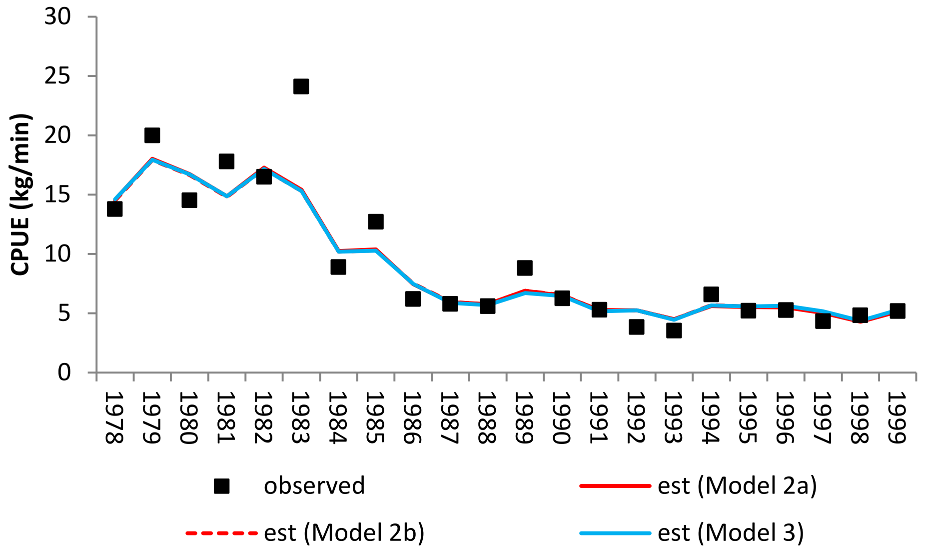
[1] Model 1a – 2013 assessment, Roel (1998) trawl catches
Model 1b – 2013 assessment, revised trawl catches
Model 2a - 2016 assessment, Roel (1998) trawl catches
Model 2b: - 2016 assessment, revised trawl catches
Model 3: 2016 assessment, revised trawl catches, all survey estimates



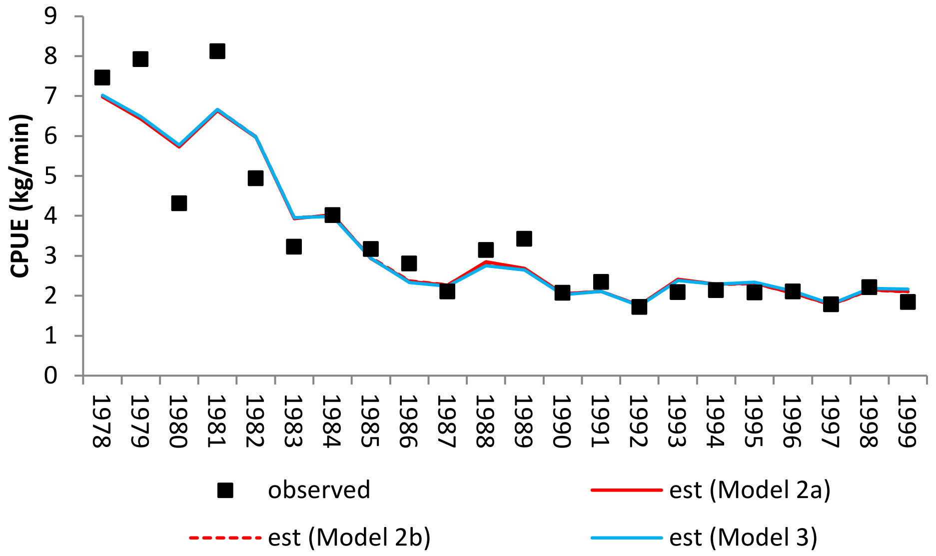


Figure 5: Fits to the January-March (top panel) and April-December (bottom panel) trawl CPUE indices[1].

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[1] Model 1a – 2013 assessment, Roel (1998) trawl catches
Model 1b – 2013 assessment, revised trawl catches
Model 2a - 2016 assessment, Roel (1998) trawl catches
Model 2b: - 2016 assessment, revised trawl catches
Model 3: 2016 assessment, revised trawl catches, all survey estimates

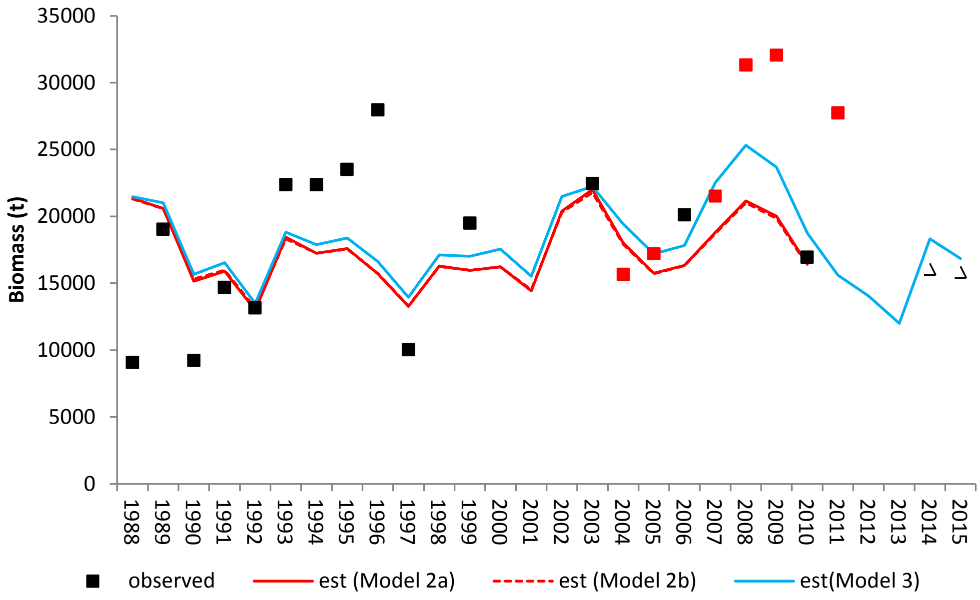

Figure 6: Fits to the autumn survey biomass indices. Black squares represent *RV Africana* "old" gear indices, red squares represent *RV Africana* "new" gear indices and open triangles represent *FV Andromeda* indices[1].

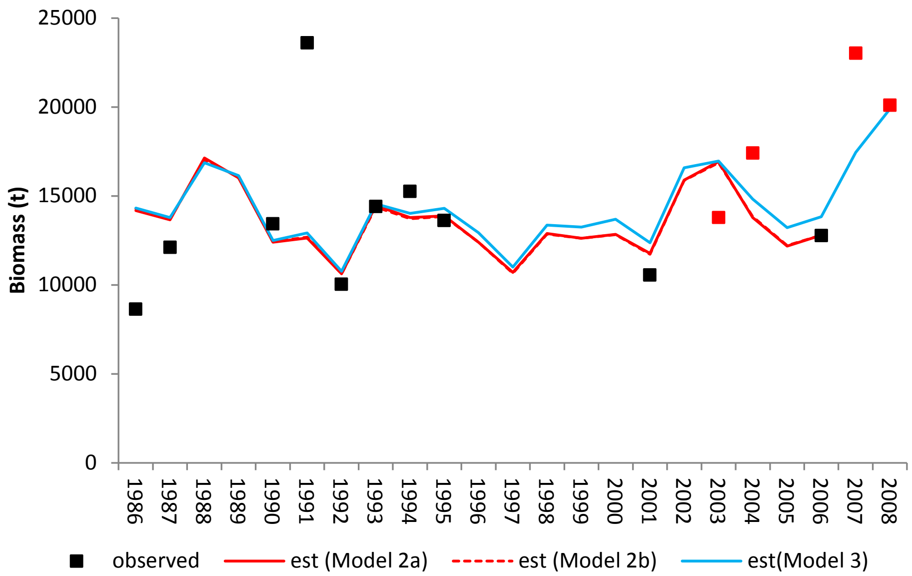

Figure 7: Fits to the spring survey biomass indices. Black squares represent *RV Africana* "old" gear indices, red squares represent *RV Africana* "new" gear indices[1].

[1] Model 1a – 2013 assessment, Roel (1998) trawl catches
Model 1b – 2013 assessment, revised trawl catches
Model 2a - 2016 assessment, Roel (1998) trawl catches
Model 2b: - 2016 assessment, revised trawl catches
Model 3: 2016 assessment, revised trawl catches, all survey estimates

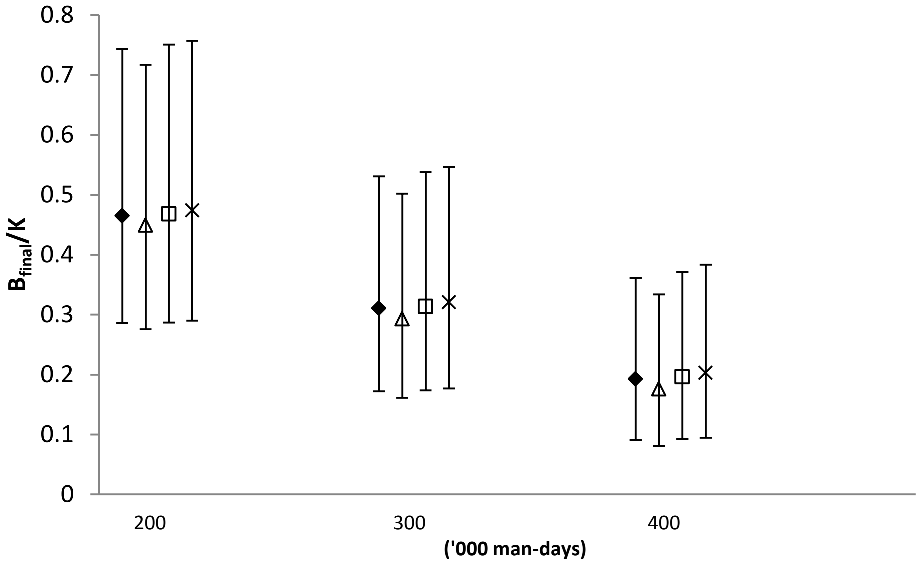

Figure 8: Median B_{2025}/K for various effort levels obtained from projecting forward from four parts of the chain where each part contains 20000 samples. The 5^{th} and 95^{th} percentiles are also shown.

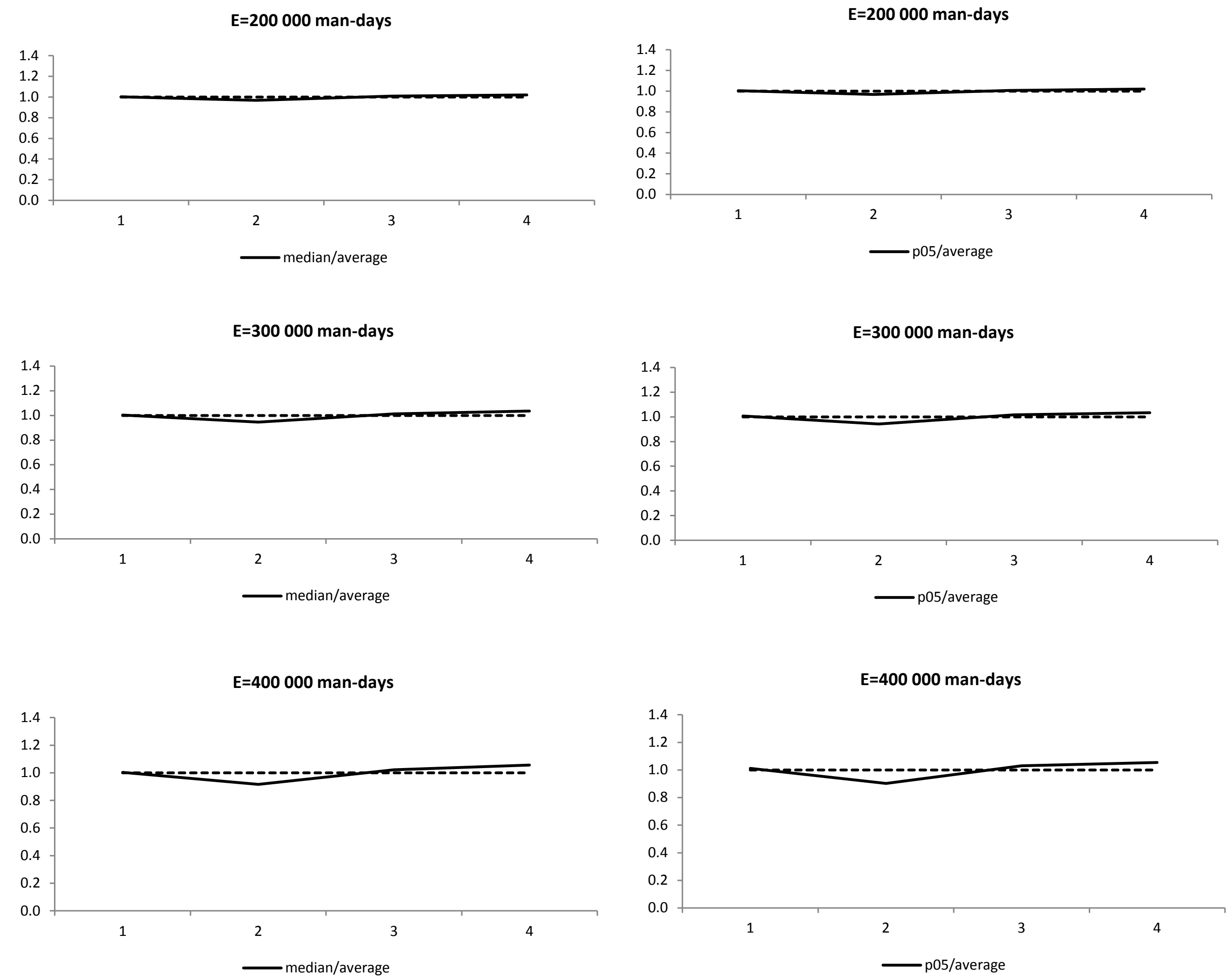

Figure 9: Median B_{2025}/K (left panel) and 5^{th} percentile (right panel) values for four parts of the chain where each part contains 20000 samples, normalised by their average.

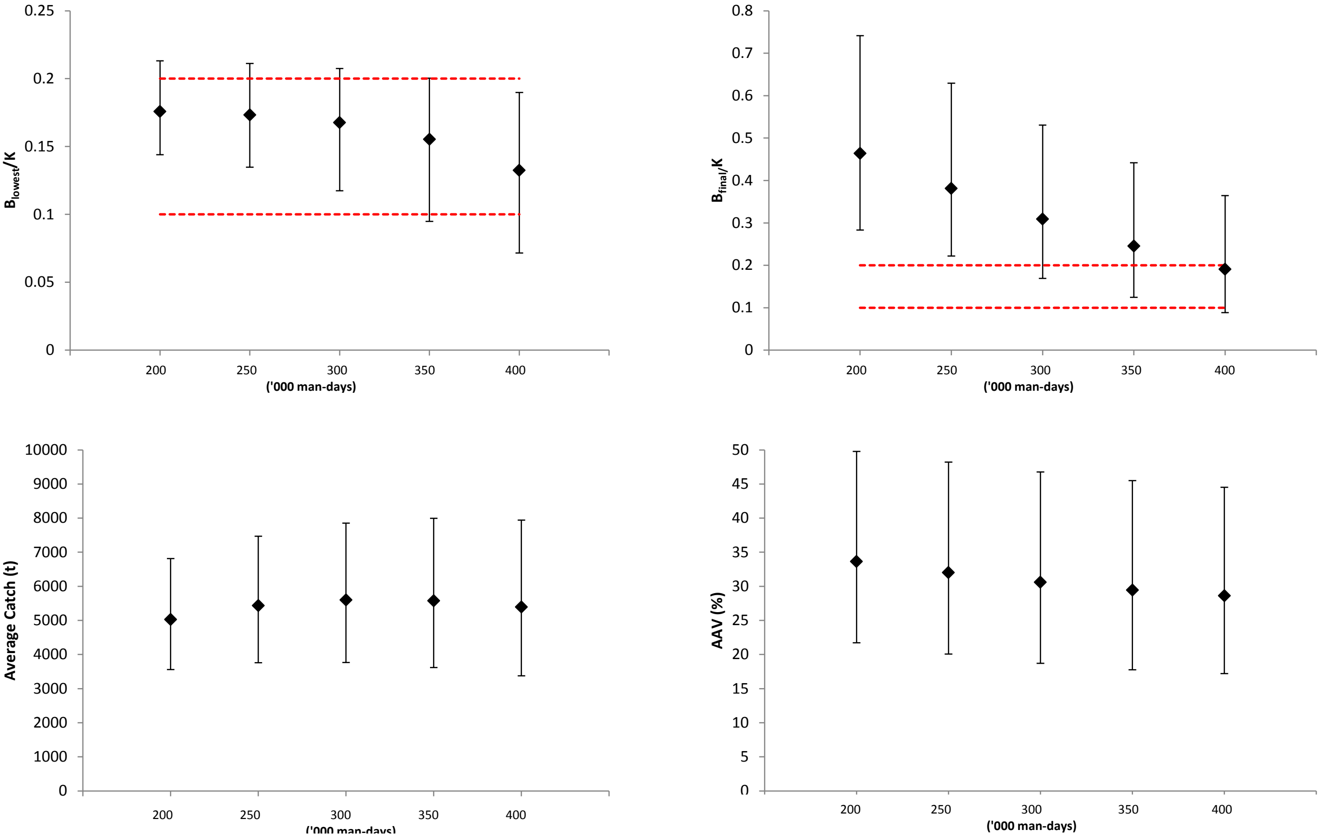

Figure 10: Performance statistics obtained from projecting the resource forward utilizing 80 000 samples. Catches refer to those by the jig fishery. To aid interpretation, dashed horizontal lines at depletions of 0.1 and 0.2 are included in the top two plots.

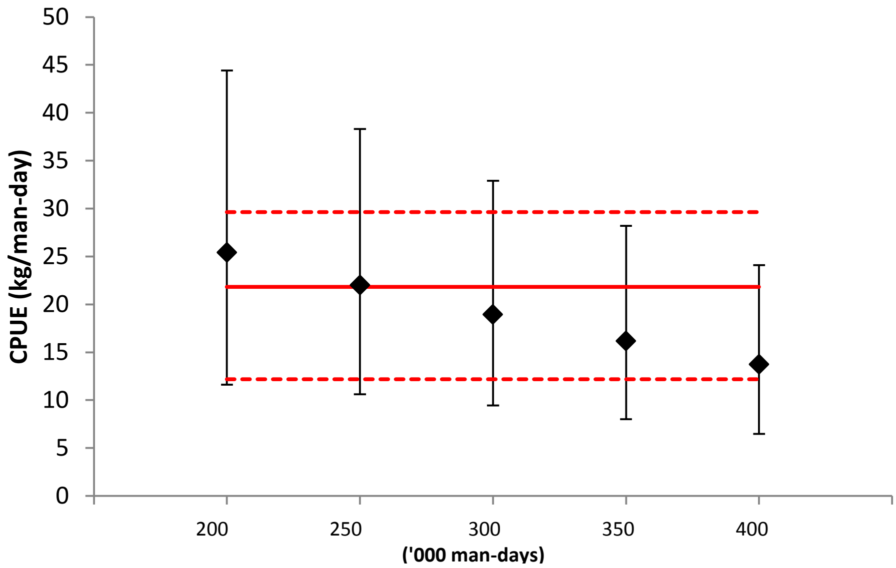

Figure 11: Average jig CPUE over the projection period for various fixed levels of effort. The 5th and 95th percentiles are also shown. The horizontal lines represent the average annual nominal jig CPUE as taken by the fishery over the period 2011 – 2015 (all vessels, restricted to 3≤crew≤20) together with the 5th and 95th percentiles.

Appendix A

Table A.1: Baranov model formulations.

Description	Baranov equations
2nd period biomass	$B_y = B_y^* e^{-0.25(g+F_y^{jig,J-M}+F_y^{trawl,J-M})}$
begin-year biomass	$B_{y+1}^* = (B_y + e^{0.75g} R_y) e^{-0.75(g+F_y^{jig\ A-D}+F_y^{trawl\ A-D})}$
Recruitment	$R_y = \frac{\alpha B_y^* e^{-\eta F_{y-1}^{jig\ A-D}}}{\beta + B_y^*} e^{(\xi_y - \frac{\sigma_R^2}{2})}$
Average biomass: Jan-Mar trawl/jig CPUE	$\overline{B}_y = B_y^* e^{-\frac{1.5}{12}(g+F_y^{jig,J-M}+F_y^{trawl,J-M})}$
Average biomass Apr-Dec trawl/jig CPUE	$\bar{B}_y = (B_y + e^{0.75g} R_y) e^{-\frac{4.5}{12}(g+F_y^{jig,A-D}+F_y^{trawl,A-D})}$
Average biomass: spring index	$\bar{B}_y = (B_y + e^{0.75g} R_y) e^{-\frac{5.5}{12}(g+F_y^{jig,A-D}+F_y^{trawl,A-D})}$
Average biomass: autumn index	$\bar{B}_y = (B_y + e^{0.75g} R_y) e^{-\frac{1}{12}(g+F_y^{jig,A-D}+F_y^{trawl,A-D})}$
Fits to catches (to determine Fs)	
jig Jan-Mar	$\hat{C}_y^{jig,J-M} = 0.25 F_y^{jig,J-M} B_y^* (1 - e^{-0.25\left(g+F_y^{jig,J-M}+F_y^{trawl,J-M}\right)})/[0.25(g + F_y^{jig,J-M} + F_y^{trawl,J-M})]$
jig Apr-Dec	$\hat{C}_y^{jig,A-D} = 0.75 F_y^{jig,A-D} (B_y + e^{0.75g} R_y)(1 - e^{-0.75\left(g+F_y^{jig,A-D}+F_y^{trawl,A-D}\right)})/[0.75(g + F_y^{jig,A-D} + F_y^{trawl,A-D})]$
Trawl Jan-Mar	$\hat{C}_y^{tr,J-M} = 0.25 F_y^{trawl,J-M} B_y^* (1 - e^{-0.25\left(g+F_y^{jig,J-M}+F_y^{trawl,J-M}\right)})/[0.25(g + F_y^{jig,J-M} + F_y^{trawl,J-M})]$
trawl Apr-Dec	$\hat{C}_y^{tr,A-D} = 0.75 F_y^{trawl,A-D} (B_y + e^{0.75g} R_y)(1 - e^{-0.75\left(g+F_y^{jig,A-D}+F_y^{trawl,A-D}\right)})/[0.75(g + F_y^{jig,A-D} + F_y^{trawl,A-D})]$

Table A.2: Fits to indices (- *ℓn*L)

Apr-Dec jig	$n\ell n\sqrt{2\pi}\sigma^*_{jAD} + \frac{1}{2\sigma^{*2}_{jAD}}\sum_{y=1}^{n}(\ell n(CPUE^{jAD}_y - \ell n(q_{jAD}) - \ell n(\bar{B}^{jAD}_y))^2$
Jan-Mar trawl	$n\ell n\sqrt{2\pi}\sigma^*_{tJM} + \frac{1}{2\sigma^{*2}_{tJM}}\sum_{y=1}^{n}(\ell n(CPUE^{tJM}_y - \ell n(q_{tJM}) - \ell n(\bar{B}^{tJM}_y))^2$
Apr-Dec trawl	$n\ell n\sqrt{2\pi}\sigma^*_{tAD} + \frac{1}{2\sigma^{*2}_{tAD}}\sum_{y=1}^{n}(\ell n(CPUE^{tAD}_y - \ell n(q_{tAD}) - \ell n(\bar{B}^{tAD}_y))^2$
Autumn index	$n\ell n\sqrt{2\pi}\sigma^*_{aut} + \frac{1}{2\sigma^{*2}_{aut}}\sum_{y=1}^{n}(\ell n(B^{aut}_y - \ell n(q_{aut}) - \ell n(\bar{B}^{aut}_y))^2$
Spring index	$n\ell n\sqrt{2\pi}\sigma^*_{spr} + \frac{1}{2\sigma^{*2}_{spr}}\sum_{y=1}^{n}(\ell n(B^{spr}_y - \ell n(q_{spr}) - \ell n(\bar{B}^{spr}_y))^2$
recruitment residuals	$\sum_{y=1}^{n}\ell n(\sqrt{2\pi}) + \ell n(\sigma_r) + \frac{1}{2\sigma^2_R}\xi^2_y)$
g penalty	$\ell n(\sqrt{2\pi}\sigma + \frac{1}{2\sigma^2}(g - 1.2)^2$
Jan-Mar jig catches	$n\ell n\sqrt{2\pi CV^2} + \frac{1}{2CV^2}\sum_{y=1}^{n}(\ell nC^{jig,J-M}_y - \ell n\hat{C}^{jig,J-M}_y)^2$
Apr-Dec jig catches	$n\ell n\sqrt{2\pi CV^2} + \frac{1}{2CV^2}\sum_{y=1}^{n}(\ell nC^{jig,A-D}_y - \ell n\hat{C}^{jig,A-D}_y)^2$
Jan-Mar trawl catches	$n\ell n\sqrt{2\pi CV^2} + \frac{1}{2CV^2}\sum_{y=1}^{n}(\ell nC^{trawl,J-M}_y - \ell n\hat{C}^{trawl,J-M}_y)^2$
Apr-Dec trawl catches	$n\ell n\sqrt{2\pi CV^2} + \frac{1}{2CV^2}\sum_{y=1}^{n}(\ell nC^{trawl,A-D}_y - \ell n\hat{C}^{trawl,A-D}_y)^2$

Table A.3: Assumed priors for the estimable parameters

Parameter	**Prior Distribution**
ℓnX (where R_0 = $e^{\ell nX}$)	~U$(-\infty, \infty)$
$\ell n\eta$ (where η=$e^{\ell n\eta}$)	~U$(-\infty, \infty)$
h	~U(0.25,1)
g	~N(1.2,0.1^2)
Stock recruitment residuals, ξ_y	~N(0,σ_R^2) where σ_R is assumed to be 0.3 on input
$F_y^{jig,Jan-Mar}$	~U(0,3.0)
$F_y^{jig,Apr-Dec}$	~U(0,3.0)
$F_y^{trawl,Jan-Mar}$	~U(0,3.0)
$F_y^{trawl,Apr-Dec}$	~U(0,3.0)