Assessment of northern and southern rock sole (Lepidopsetta polyxstra and bilineata) stocks in the Gulf of Alaska

Introduction

Rock sole are demersal fish that can be found in shelf waters to 600 m depth (Allen and Smith, 1988). Two species of rock sole are known to occur in the north Pacific Ocean, northern rock sole (*Lepidopsetta polyxystra*) and southern rock sole (*L. bilineata*) (Orr and Matarese, 2000). Adult northern rock sole are found from Puget Sound through the Bering Sea and Aleutian Islands to the Kuril Islands, while the southern rock sole range from the southeast Bering Sea to Baja California (Stark and Somerton, 2002). These species have an overlapping distribution in the Gulf of Alaska (Wilderbuer and Nichol, 2009). Rock sole are most abundant in the Kodiak and Shumagin areas. The northern rock sole spawns in midwinter and spring, and the southern rock sole spawns in summer (Stark and Somerton, 2002). Northern rock sole spawning occurred in areas where bottom temperatures averaged 3°C in January, and southern rock sole spawned in areas where bottom temperatures averaged 6°C in June (Stark and Somerton, 2002). Rock soles grow to approximately 60 cm and can live in excess of 20 years (http://www.afsc.noaa.gov/race/behavioral/rocksole_fbe.htm).

Both rock sole species are managed as part of the shallow-water flatfish complex, which also includes yellowfin sole (*Pleuronectes asper*), starry flounder (*Platichthys stellatus*), butter sole (*Pleuronectes isolepis*), English sole (*Pleuronectes vetulus*), Alaska plaice (*Pleuronectes quadrituberculatus*), and sand sole (*Psettichthys melanostictus*), as these species are caught in the shallow-water flatfish fishery (Turnock et al., 2009).

Fishery

Rock sole are caught in the shallow-water flatfish fishery and are not targeted specifically, as they co-occur with several other species. The rock sole species were differentiated in survey data beginning in 1996, and were differentiated in the fishery observer data beginning in 1997. Data for more recent years have the species listed as northern (N), southern (S), or “undifferentiated” (U) rock sole as adult northern and southern rock sole are difficult to differentiate visually (Orr and Matarese, 2000). There is considerable uncertainty about the fraction of annual rock sole catch that is northern or southern rock sole.

Data

Fishery

Northern and southern rock sole in the Gulf of Alaska are part of the shallow water flatfish complex. Their catches are currently reported as rock sole by year and management area (Figure 1). The combined rock sole catch is primarily captured in NMFS area 630 followed by areas 620 and 610. Rock sole catch has ranged from 1765mt to 8112mt since 1993 and has average 4403mt (Table 1). Catch has been fairly stable since 2010 and averaged 3191mt.

Size composition data are available from the NMFS observer program from 1985 to present. Observations were recorded as rock sole until 1996. Northern and southern rock sole were differentiated after 1996. The sample sizes by species and sex are summarized in Table 2.

Survey

Survey data are available from the NMFS Gulf of Alaska groundfish survey conducted by the AFSC’s Resource Assessment and Conservation Engineering (RACE) division. Surveys were conducted triennially from 1984 until 1999 and then biennially from 2001 until present. These data include biomass estimates by area, length composition data, age composition data, and conditional age-at-length data. Northern and southern rock sole were not differentiated until 1996. After 1996, observed rock sole were classified as northern, southern, or unidentified rock sole.

The resulting estimates of total abundance are summarized in Table 3 and shown in Figure 2. The estimates do not include 2017, as these data are not available yet. Total biomass declined between 1996 and 1997 for both northern and southern rock sole. Biomass increased to a peak in 2007 and 2009 for northern rock sole and southern rock sole, respectively. Southern rock sole biomass declined in 2011 and has remained relatively stable. Northern rock sole biomass has generally declined since 2007.

Analytic approach
Model structure

All models were configured using Stock Synthesis (SS3). Several models are presented independently for northern and southern rock sole. These include the 2015 assessment models and modified versions using SS3 version 3.24ac (used in 2015) and SS3 version 3.30 (the newest version of SS3). Models 15.1 and 15.2a were run using SS3 version 3.24 and Model 15.2b was run using SS3 version 3.30. The models are summarized in Table 4.

The main difference between the 2015 model (15.1) and the others pertains to model fitting. Model 15.1 was fit to the survey age composition data (1996-2013) and fit to the survey conditional age-at-length data for this same time period and was not fit to the available survey length composition data. Hence, the same data were fit to twice and effectively gave higher weight to these age data. The alternative models to Model 15.1 were fit to the available survey length composition data and conditional age at length data.

The remaining model assumptions and estimated parameters were the same among the models. All model configurations covered ages 0 to 30, were sex-specific, and started in 1977. As mentioned in the data section, fishery catch (retained catch and discards) are reported as undifferentiated rock sole. Annual total catch was split evenly between northern and southern rock sole.

Growth was assumed to follow the von Bertalanffy growth relationship and was assumed constant over time. All growth parameters were estimated. Female natural mortality was fixed and equal to 0.2 and male natural mortality was estimated. Age based maturity was a fixed input vector and is shown in Figure 3.

The stock recruitment relationship was an average level of recruitment unrelated to stock size. Two of the stock-recruit parameters were fixed. Steepness was fixed equal to 1 in all model configurations, recruitment variability σ_R was fixed equal to 0.6. Unfished recruitment (R_0) and the R1_offset parameter, which adjusts the starting recruitment relative to R_0, were estimated within the model. Annual recruitment deviations were estimated for the full time period.

Sex-specific size-based selectivity functions were estimated for the fishery and survey. A double normal pattern was used for the fishery and survey. The selectivity parameters for the fishery were estimated and allowed for a dome-shape relationship. It was assumed that the survey selectivity was asymptotic. The parameters associated with the descending side of the double normal and the selectivity of the final size bin were fixed to accommodate this assumption. Male selectivity was estimated as an offset of female selectivity. When using a double normal pattern, five additional parameters are required to differentiate from the opposite sex. These parameters offset the female peak, ascending and descending limbs, and the selectivity at the final length bin. An additional parameter represents the apical selectivity for males.

Catchability was fixed equal to 1 in all model configurations. This assumes that the survey biomass estimates reflect absolute abundance.

Parameters estimated outside the assessment model

The initial values for the growth parameters used in the model are from Stark and Somerton, 2002.

Northern rock sole

- Males: L_∞=382 mm, k=0.261, t_0=0.160;
- Females: L_∞=429 mm, k=0.236, t_0=0.387.

Southern rock sole

- Males: L_∞=387 mm, k=0.182, t_0=-0.962;
- Females: L_∞=520 mm, k=0.120, t_0=-0.715.

The parameters for weight-length relationship ($W = aL^b$, weight in kg and length in cm) for northern and southern rock sole males and females are $9.984\text{x}10_{-6}$ and 3.0468 for a and b, respectively (Turnock et al., 2011).

Results

Model evaluation

The resulting likelihoods, model fits to the data, and likelihood profiles for several key parameters are presented to evaluate the northern and southern rock sole models.

One result that does not need much belaboring is that SS3 version 3.24 and version 3.30 perform similarly. A comparison of the likelihoods and parameter estimates in Tables 5-8 for models N15.2a and N15.2b and S15.2a and S15.2b demonstrate this result. Given the similarities in the results from N15.2a and N15.2b and S15.2a and S15.2b, the results from these models will be referred to as model N15.2 and S15.2 throughout the results section.

Northern rock sole

Overall, the results are similar among the models. Figure 4 shows the results for the models considered and includes estimates of annual age-0 recruits, unfished recruitment, annual spawning biomass, and spawning biomass (SSB) in 2015. The age-0 recruits time-series is similar among the models where Model N15.2 has slightly larger estimates throughout time. The initial conditions of the model, estimated as R_0, from N15.2 are larger than N15.1, which helps to explain this subtle difference (Table 6, Figure 4). The SSB time-series are similar among the models, where model N15.2 has slightly higher SSB between 1977 and 1994 and between 2003 and 2015 than N15.1. The survey index covers the time period between 1996 and 2015 (Figure 5). The index biomass estimates from N15.2 are less than that from N15.1 between 1996 and 2005 and greater from N15.2 than N15.1 between 2009 and 2015 (Figure 5); a similar trend is seen in the SSB time series. At the end of the SSB time-series the median estimate of SSB in the terminal year (2015) from N15.2 is larger than the median estimate of N15.1; however, the distributions of the estimates overlap.

The model fits to the survey index are marginally different. The root mean square error statistic indicates that the N15.1 fit was better than N15.2 (Figure 5). The survey likelihood component was similar among the models (Table 5, Figure 5). Regardless, all models underestimate the biomass of the two peak years of the survey and overestimate biomass in the final year (Figure 5).

Table 6 compares key parameter estimates from the models under consideration. The stock recruitment parameters, male natural mortality, and the female and male growth parameters estimates are similar among the models. Male natural mortality is slightly higher from model N15.2 (0.26) than N15.1 (0.26) with similar CVs (~0.03). The female and male growth relationships resulting from the parameter estimates are shown in Figures 6 and 7 with and without uncertainty. The biggest departure between models N15.1 and N15.2 for the female growth relationship is the estimated asymptotic length, which is larger from N15.1 (49.61cm) than N15.2 (48.56 cm) (Figure 6). The male growth relationships are more similar than the female growth relationships. The estimated uncertainty at young and old ages is similar, but the estimates from N15.2 are larger than N15.1. Given the considerable uncertainty around the female and male growth relationships at older ages, many older age classes (i.e., ~11years and above) are associated with a wide range of similar length classes (Figure 7).

Figure 7 shows the model fits to the fishery and survey size composition data aggregated over year. The model fit to the female and male size composition data from the fishery are similar among the models. The overall survey size composition data used in N15.1 and N15.2 differed. The data in N15.1 was from 2015, whereas the full complement of data (1996-2015) was used in N15.2. One point of note is that the models do not fit the male size composition data particularly well. The model fits underestimate the frequency of 27cm – 31cm northern rock sole.

Figures 8, 9, and 10 show the model fits to the overall and annual fishery size composition data and Figure 11 shows the Pearson residuals from the resulting model fits. The residuals indicate that the models are underestimating a cohort between the years 2001 and 2011 (Figure 9). Figures 12 and 13 show the model fits to the annual survey size composition data and the resulting residuals. Model 15.1 was fit to the 2015 data. Figure 12 shows the expected fits to the years of data that were included in model N15.1 but not included in the likelihood calculation. The fits to the annual data from model N15.1 are similar to model N15.2. This is also true when comparing the residuals from 2015 for model N15.1 and N15.2 (Figure 13). The residual patterns from the model fits to the female size composition data indicate that the model underestimates an apparent cohort in 1996, 1999, and 2001 (Figure 13). The models consistently (9 out of 10 years) underestimate the peak (27cm-31cm) of the male size frequency data (Figures 12 and 13).

The fishery size composition data were fit using a double normal pattern to allow for dome-shape selectivity, whereas, the bottom trawl survey selectivity was modeled assuming selectivity was asymptotic (Figure 14). Fitting the model to survey size composition data in model N15.2 caused the estimated selectivity curves to shift to the right of the selectivity curve estimated from model N15.1. This reduced the survey selectivity on 20cm – 25 cm males and 20cm-30cm females and the fishery selectivity on 20cm – 35cm males and 20cm – 50cm females. The shift was more substantial for the fishery data. Additionally, the descending limb of the fishery selectivity curve was truncated so that the selectivity of the largest fish was higher from model N15.2 than model N15.1. This allowed the model to underestimate smaller individuals and overestimate larger individuals.

Many key parameters are fixed in the northern rock sole models and include female natural mortality, steepness, catchability, and some selectivity parameters to ensure the assumed selectivity curve shape. This and the fact that selectivity was the most sensitive, especially fishery selectivity, to the inclusion of the survey size composition data, likelihood profiling was conducted to determine how well the model parameters were specified or estimated and to identify data conflicts. The likelihood profiles are shown in Figure 15. There are some obvious conflicts between the age, length, and survey data. The catchability profile shows that the overall likelihood and the age likelihood component is minimized at the fixed value of Ln(0)=1. The survey and length likelihood components are minimized at higher values, Ln(1) and Ln(1.5). The steepness profile shows that the overall likelihood and the age likelihood component are minimized at the specified, fixed value of 1. The length and survey likelihood components are minimized at lower values, 0.2 and 0.4. The female natural mortality likelihood is minimized at a value higher than the fixed value of 0.2. The length and survey likelihood components are minimized at 0.375 and 0.25 and the age likelihood component is minimized at the fixed value of 0.2. The male natural mortality profile shows that the overall likelihood and the age and length likelihood components are minimized at the fixed value of 0.25. The survey likelihood component is minimized at a lower value, 0.0225.

Sensitivity analyses were conducted to try to address the residual pattern in fits to the male survey size composition data. These include estimating female natural mortality, steepness, catchability, and age-based survey selectivity. Given the wide range of age with similar length distributions, the hypothesis for using hypothesis for using an age-based selectivity for the survey was that it would lead to a better accounting of smaller fish being captured at older ages and reduce the residual pattern in the male size compositions. The results are not shown for any of the sensitivity runs because they are similar those from models N15.1 and 15.2. The sensitivity of the northern rock sole model to the assumed proportional split of total rock sole catch has not been explored yet, but should be considered and discussed.

<u>*Southern rock sole*</u>

The results from the models being considered for southern rock sole are more similar to each other than the northern rock sole models. Figure 15 shows the time series of age-0 recruits and spawning biomass, unfished recruitment, and spawning biomass in the terminal year (2015). The initial conditions in terms of unfished recruitment and unfished spawning biomass were almost identical for models S15.1 and S15.2 (Figure 16). The median estimates of R_0 were similar with considerable distribution overlap. The age-0 recruit time series for models S15.1 and S15.2 track each other closely. The spawning biomass time series are almost identical at the beginning and end of the time series. Spawning biomass from model S15.2 is less than model S15.1 from the late 1980s until 2000. This is somewhat consistent with the fits to the survey index (Figure 17).

The model fits to the survey index are almost identical except for the 1996 and 1999 estimates, where the model S15.1 estimates are larger than the model S15.2 estimates (Figure 17). All models underestimated the increase to the peak of the index (2005, 2007, and 2009) and overestimated the 2011 biomass. The root mean square error statistics indicate that fit to the index was improved by model S15.2. The survey likelihood component was also improved (Table 7). This is due to an improvement in fit to the first three years of the index.

Table 8 compares key parameter estimates from the models under consideration. All parameter estimates and CVs are similar among the models. The female and male growth relationships resulting from the parameter estimates are shown in Figures 18 and 19 with and without uncertainty. The estimated uncertainty at young and old ages was similar between the models. Given the considerable uncertainty in the female and male growth relationships at older ages, many older age classes (i.e., ~15years and above) are associated with similar length classes (Figure 19).

The overall model fits to the fishery and survey size composition data are similar for models S15.1 and S15.2 (Figure 20). The model adequately fits the fishery size composition data, whereas the fit to the male survey size composition is adequate and underestimates the overall peak of the female size composition data.

Figures 21 and 22 show the model fits to the annual fishery size composition data and Figure 23 shows the Pearson residuals from the resulting model fits. Although the fits to the fishery data are adequate, the residuals indicate that the models are underestimating a cohort between the years 2004 and 2008 (Figure 23). Figures 24 and 25 show the model fits to the annual survey size composition data and the resulting residuals. Model 15.1 was fit to the 2015 data. Figure 23 shows the expected fits to the years of data that were included in the model but not included in the likelihood calculation. The fits to the annual data from model S15.1 are similar to model S15.2. The residual patterns from the model fits to the female size composition data indicate that the model consistently underestimates the peak of the size distribution, but especially in 1996, 1999, 2001, and 2015 (Figure 25).

The fishery size composition data were fit using a double normal pattern to allow for dome-shape selectivity, however, the estimated female and male selectivity curves are more asymptotic (Figure 26). The bottom trawl survey size composition data were fit assuming selectivity was asymptotic (Figure 26). The use of the survey size composition data rather than the direct age composition data led to shifts in two of the selectivity curves. The female fishery selectivity curve from model S15.2 shifted to the right of the curve from model S15.2. The shift mainly influenced the selectivity of the lengths between 20cm and 45cm, where selectivity was reduced. The male fishery selectivity curved from model S15.2 shifted to the left of the model S15.1 curve. This shift increased the selectivity on male southern rock sole between 30cm and 40cm. The female survey selectivity curve and the male fishery selectivity curve were almost identical from models S15.1 and S15.2.

Similar to the northern rock sole evaluation likelihood profiling was conducted to determine how well some of the key model parameters were specified or estimated and to identify data conflicts. Profiles were conducted for catchability, steepness, and female and male natural mortality. The results are shown in Figure 27. The total likelihood is minimized at the specified catchability value, Ln(0)=1. The survey and age likelihood components are minimized at a catchability vale lower than the specified value and the length composition likelihood is minimized at a higher value than specified. All likelihood components are in agreement about the steepness and are minimized at the specified value of one. The total likelihood and age likelihood component are minimized at 0.25 for male natural mortality. The survey and length likelihood components are minimized at higher natural mortality (0.275). Female natural mortality is fixed at 0.2 in the model. The total likelihood is minimized at 0.175, the survey and length likelihood components was minimized at 0.225, and the age likelihood component is minimized at 0.275. Addressing some of these data conflicts through data weighting within the model may help to better estimate the index or size composition data. The current data weighting includes the specified annual index standard error and the number of hauls is used as the multinomial weight for the size composition data.

Table 1. Total rock sole catch from Alaska Fisheries Information Network (AKFIN) as of 2017-08.

Year	Catch (mt)
1993	8112.12
1994	3008.11
1995	3923.91
1996	6595.32
1997	5466.78
1998	2532.34
1999	1765.35
2000	5386.69
2001	4771.73
2002	5564.29
2003	3554.642
2004	2216.745
2005	4130.501
2006	5763.282
2007	6727.395
2008	7269.088
2009	6538.692
2010	3285.281
2011	3094.423
2012	2828.570
2013	4058.255
2014	3440.340
2015	2622.197
2016	3008.461

Table 2. Number of lengths by year, species, and sex sampled by the NMFS fisheries observer program.

	NRS		SRS		U/NRS/SRS	
Year	Female	Male	Female	Male	Female	Male
1989	-	-	-	-	184	211
1990	-	-	-	-	2319	2585
1991	-	-	-	-	4915	3323
1992	-	-	-	-	11995	10988
1993	-	-	-	-	12093	9306
1994	-	-	-	-	3171	2872
1995	-	-	-	-	6326	4909
1996	-	-	-	-	15756	11890
1997	542	334	1020	587	14864	11826
1998	1807	1148	3168	2081	8171	5276
1999	394	242	197	197	955	713
2000	1818	1482	1404	1121	3756	3146
2001	1913	1545	1828	1332	3983	3049
2002	3256	1929	1643	1162	5205	3461
2003	1293	1192	1041	779	2616	2173
2004	520	314	1242	719	1944	1205
2005	977	803	1120	681	2457	1896
2006	1979	1177	1113	634	3233	1930
2007	1978	1713	1731	1197	4598	3697
2008	1717	1087	1999	1455	4353	3005
2009	2273	1679	2218	1459	4569	3223
2010	1064	1093	1087	742	2216	1914
2011	314	327	479	275	818	622
2012	1036	657	1733	1202	2769	1859
2013	851	1154	669	498	1520	1652
2014	746	779	338	249	1084	1028
2015	520	547	104	90	624	637
2016	1172	1504	379	203	1551	1707

Table 3. NMFS GOA bottom trawl survey total biomass estimates (in metric tons) and standard deviation.

Year	Species	Total biomass	SD
1984	Unidentified	137623.3	12208.20
1987	Unidentified	123393	20328.94
1990	Unidentified	156032.4	19472.26
1993	Unidentified	173043.6	14569.99
1996	northern rock sole	78845	9929.87
1999	northern rock sole	61543.4	15133.87
2001	northern rock sole	64808.8	9887.32
2003	northern rock sole	79648.2	9513.65
2005	northern rock sole	91452.8	10123.21
2007	northern rock sole	102640.7	12063.82
2009	northern rock sole	95845.8	16067.68
2011	northern rock sole	72875	12426.75
2013	northern rock sole	74587	13586.89
2015	northern rock sole	52068.9	7612.96
1996	southern rock sole	127390	12580.04
1999	southern rock sole	106234.5	10580.32
2001	southern rock sole	122491.6	14643.07
2003	southern rock sole	126819.3	12479.76
2005	southern rock sole	147580.1	15092.81
2007	southern rock sole	162357.7	11810.29
2009	southern rock sole	191764.5	22591.33
2011	southern rock sole	120572.9	10318.33
2013	southern rock sole	131427.5	13993.24
2015	southern rock sole	125234.2	9530.97

Table 4. Summary of data and model assumptions for the northern and southern rock sole model alternatives. In the text the model number is preceded by a N or S to denote the species.

Model	**15.1**	**15.2a**	**15.2b**
SS version	SS3v3.24ac	SS3v3.24ac	SS3v3.30
Model dimensions			
Start and end year	1977, 2015	1977, 2015	1977, 2015
Data			
Fishery catch	1977-2015	1977-2015	1977-2015
Survey biomass estimates	1996-2011 (triennial), 2003-2015 (biennial)	1996-2011 (triennial), 2003-2015 (biennial)	1996-2011 (triennial), 2003-2015 (biennial)
Fishery length comp	1997-2015	1997-2015	1997-2015
Survey length comp	2015	1996-2011 (triennial), 2003-2015 (biennial)	1996-2011 (triennial), 2003-2015 (biennial)
Survey age composition	1996-2011 (triennial), 2003-2013 (biennial)	-	-
Survey conditional age at length	1996-2011 (triennial), 2003-2013 (biennial)	1996-2011 (triennial), 2003-2013 (biennial)	1996-2011 (triennial), 2003-2013 (biennial)
Growth	Von Bertalannfy	Von Bertalannfy	Von Bertalannfy
L_at_Amin (Fem & Mal)	Estimated	Estimated	Estimated
L_at_Amax (Fem & Mal)	Estimated	Estimated	Estimated
K (Fem & Mal)	Estimated	Estimated	Estimated
CV_young (Fem & Mal)	Estimated	Estimated	Estimated
CV_old (Fem & Mal)	Estimated	Estimated	Estimated
Natural mortality	0.2 (Female), Estimated (Male)	0.2 (Female), Estimated (Male)	0.2 (Female), Estimated (Male)
Maturity	Fixed input vector	Fixed input vector	Fixed input vector
Stock recruitment			
Ln(R0)	Estimated	Estimated	Estimated
Steepness	Fixed = 1	Fixed = 1	Fixed = 1
σ_R	Fixed = 0.6	Fixed = 0.6	Fixed = 0.6
R1_offset	Estimated	Estimated	Estimated
Recruitment devs	Estimated (1977-2015	Estimated (1977-2015	Estimated (1977-2015
Catchability	Fixed =1	Fixed =1	Fixed =1
Selectivity – length	Double normal	Double normal	Double normal
Fishery			
P1: Peak (Fem)	Estimated	Estimated	Estimated
P2: top (Fem)	Estimated	Estimated	Estimated
P3:Ascend width (Fem)	Estimated	Estimated	Estimated
P4: Descend width (Fem)	Estimated	Estimated	Estimated
P5:Selex first bin (Fem)	Fixed	Fixed	Fixed
P6: Selex last bin (Fem)	Estimated	Estimated	Estimated
P1: Peak (Male)	Estimated	Estimated	Estimated
P2: Ascend width (Male)	Estimated	Estimated	Estimated
P3: Descend width (Male)	Fixed	Fixed	Fixed
P4: Selex last bin (Male)	Fixed	Fixed	Fixed
P5: Scale (Male)	Fixed	Fixed	Fixed

*In SS3v3.30 R1_offset parameter no longer exists. It is estimated as a SR regime parameter

Table 4. Continued

Model	**15.1**	**15.2a**	**15.2b**
Selectivity – length	Double normal	Double normal	Double normal
Survey			
P1: Peak (Fem)	Estimated	Estimated	Estimated
P2: top (Fem)	Fixed	Fixed	Fixed
P3:Ascend width (Fem)	Estimated	Estimated	Estimated
P4: Descend width (Fem)	Fixed	Fixed	Fixed
P5:Selex first bin (Fem)	Fixed	Fixed	Fixed
P6: Selex last bin (Fem)	Fixed	Fixed	Fixed
P1: Peak (Male)	Estimated	Estimated	Estimated
P2: Ascend width (Male)	Estimated	Estimated	Estimated
P3: Descend width (Male)	Fixed	Fixed	Fixed
P4: Selex last bin (Male)	Fixed	Fixed	Fixed
P5: Scale (Male)	Fixed	Fixed	Fixed

Table 5. Total likelihood and likelihood components for the three northern rock sole models.

Model	N15.1			N15.2a			N15.2b		
	All	Fsh	Surv	All	Fsh	Surv	All	Fsh	Surv
Total	1018.4			910.98			911.0		
Catch_like:	1.2E-14	1.2E-14	0	1.1E-14	1.1E-14	0	1.1E-14	1.1E-14	0
Surv_like:	-11.4	0	-11.4	-11.9	0	-11.9	-11.9	0	-11.9
Length_like:	304.0	255.6	48.4	262.2	207.9	54.2	262.3	207.9	54.3
Age_like:	732.7	0	732.7	667.8	0	667.8	667.8	0	667.8

Table 6. Parameter estimates/values and CVs for key parameters from the northern rock sole model.

	N15.1		N15.2a		N15.2b	
Parameter	Mean	CV	Mean	CV	Mean	CV
SR_LN(R0)	11.67	0.01	11.82	0.01	11.83	0.01
SR_BH_steep	1.00	-	1.00	-	1.00	-
SR_R1_offset	-0.09	1.43	-0.08	1.57	-0.08	1.57
NatM_p_1_Fem_GP_1	0.20	-	0.20	-	0.20	-
NatM_p_1_Mal_GP_1	0.25	0.03	0.25	0.03	0.25	0.03
L_at_Amin_Fem_GP_1	10.05	0.07	10.41	0.06	10.41	0.06
L_at_Amax_Fem_GP_1	45.54	0.02	42.88	0.02	42.85	0.02
VonBert_K_Fem_GP_1	0.21	0.07	0.23	0.06	0.23	0.06
CV_young_Fem_GP_1	2.40	0.14	2.26	0.13	2.26	0.13
CV_old_Fem_GP_1	7.83	0.05	7.58	0.04	7.58	0.04
L_at_Amin_Mal_GP_1	9.80	0.07	10.67	0.06	10.68	0.06
L_at_Amax_Mal_GP_1	39.21	0.02	37.44	0.02	37.43	0.02
VonBert_K_Mal_GP_1	0.26	0.07	0.26	0.08	0.26	0.08
CV_young_Mal_GP_1	2.49	0.13	2.17	0.13	2.17	0.13
CV_old_Mal_GP_1	5.37	0.05	5.67	0.05	5.67	0.05
SizeSel_1P_1_Fishery	46.06	0.04	52.13	0.02	52.26	0.02
SizeSel_1P_2_Fishery	0.37	0.25	-0.02	8.36	-0.04	2.84
SizeSel_1P_3_Fishery	5.40	0.02	5.69	0.01	5.70	0.01
SizeSel_1P_4_Fishery	-3.25	2.07	-7.36	3.03	-7.07	2.96
SizeSel_1P_5_Fishery	-10	-	-10	-	-10	-
SizeSel_1P_6_Fishery	-0.35	2.81	1.15	2.37	1.08	2.24
SzSel_1Male_Peak_Fishery	-8.91	0.18	-11.50	0.09	-11.60	0.08
SzSel_1Male_Ascend_Fishery	-0.78	0.21	-0.86	0.14	-0.86	0.13
SzSel_1Male_Descend_Fishery	0	-	0	-	0	-
SzSel_1Male_Final_Fishery	0	-	0	-	0	-
SzSel_1Male_Scale_Fishery	1	-	1	-	1	-
SizeSel_2P_1_Survey	34.45	0.08	36.46	0.05	36.50	0.05
SizeSel_2P_2_Survey	0	-	0	-	0	-
SizeSel_2P_3_Survey	4.89	0.07	5.03	0.04	5.04	0.04
SizeSel_2P_4_Survey	0	-	0	-	0	-
SizeSel_2P_5_Survey	-10	-	-10	-	-10	-
SizeSel_2P_6_Survey	10	-	10	-	10	-
SzSel_2Male_Peak_Survey	-5.95	0.51	-6.22	0.33	-6.25	0.31
SzSel_2Male_Ascend_Survey	-0.78	0.64	-0.73	0.41	-0.73	0.40
SzSel_2Male_Descend_Survey	0	-	0	-	0	-
SzSel_2Male_Final_Survey	0	-	0	-	0	-
SzSel_2Male_Scale_Survey	1	-	1	-	1	-

Table 7. Total likelihood and likelihood components for the three southern rock sole models.

Model	S15.1			S15.2a			S15.2b		
	All	Fsh	Surv	All	Fsh	Surv	All	Fsh	Surv
Total	934.54			906.27			906.27		
Catch_like:	1.8E-15	1.8E-15	0	2.5E-15	2.5E-15	0	2.5E-15	2.5E-15	0
Surv_like:	-15.3	0	-15.3	-16.5	0	-16.5	-16.5	0	-16.5
Length_like:	164.0	158.4	5.6	201.8	161.8	40.0	201.8	161.8	40.0
Age_like:	787.2	0	787.2	725.3	0	725.3	725.3	0	725.3

Table 8. Parameter estimates and CVs for key parameters from the southern rock sole model.

	S15.1		S15.2a		S15.2b	
Parameter	Mean	CV	Mean	CV	Mean	CV
SR_LN(R0)	12.35	0.01	12.40	0.01	12.40	0.01
SR_BH_steep	1	-	1	-	1	-
SR_R1_offset	-0.11	1.14	-0.10	1.31	-0.10	1.31
NatM_p_1_Fem_GP_1	0.2	-	0.2	-	0.20	-
NatM_p_1_Mal_GP_1	0.25	0.03	0.26	0.03	0.26	0.03
L_at_Amin_Fem_GP_1	11.84	0.06	12.14	0.05	12.14	0.05
L_at_Amax_Fem_GP_1	49.61	0.01	48.56	0.01	48.56	0.01
VonBert_K_Fem_GP_1	0.19	0.05	0.20	0.05	0.20	0.05
CV_young_Fem_GP_1	3.27	0.09	3.17	0.09	3.17	0.09
CV_old_Fem_GP_1	4.94	0.05	4.93	0.04	4.93	0.04
L_at_Amin_Mal_GP_1	13.11	0.04	13.65	0.04	13.65	0.04
L_at_Amax_Mal_GP_1	40.40	0.02	40.58	0.02	40.58	0.02
VonBert_K_Mal_GP_1	0.23	0.07	0.21	0.07	0.21	0.07
CV_young_Mal_GP_1	2.33	0.11	2.32	0.11	2.32	0.11
CV_old_Mal_GP_1	4.59	0.06	4.67	0.06	4.67	0.06
SizeSel_1P_1_Fishery	47.60	0.03	52.77	0.04	52.77	0.04
SizeSel_1P_2_Fishery	2.46	4.15	2.04	13.88	2.04	13.92
SizeSel_1P_3_Fishery	5.43	0.02	5.72	0.02	5.72	0.02
SizeSel_1P_4_Fishery	-1.33	78.10	-0.06	3829.24	-0.05	4593.15
SizeSel_1P_5_Fishery	-10	-	-10	-	-10	-
SizeSel_1P_6_Fishery	2.10	33.43	3.67	25.76	3.67	25.76
SzSel_1Male_Peak_Fishery	-9.85	0.16	-13.85	0.14	-13.85	0.14
SzSel_1Male_Ascend_Fishery	-0.85	0.18	-1.10	0.14	-1.10	0.14
SzSel_1Male_Descend_Fishery	0	-	0	-	0	-
SzSel_1Male_Final_Fishery	0	-	0	-	0	-
SzSel_1Male_Scale_Fishery	1	-	1	-	1	-
SizeSel_2P_1_Survey	42.39	0.07	43.33	0.04	43.33	0.04
SizeSel_2P_2_Survey	0	-	0	-	0	-
SizeSel_2P_3_Survey	5.34	0.05	5.40	0.03	5.40	0.03
SizeSel_2P_4_Survey	0	-	0	-	0	-
SizeSel_2P_5_Survey	-10	-	-10	-	-10	-
SizeSel_2P_6_Survey	10	-	10	-	10	-
SzSel_2Male_Peak_Survey	2.91	1.46	-5.65	0.42	-5.65	0.42
SzSel_2Male_Ascend_Survey	0.36	1.10	-0.48	0.57	-0.48	0.57
SzSel_2Male_Descend_Survey	0	-	0	-	0	-
SzSel_2Male_Final_Survey	0	-	0	-	0	-
SzSel_2Male_Scale_Survey	1	-	1	-	1	-

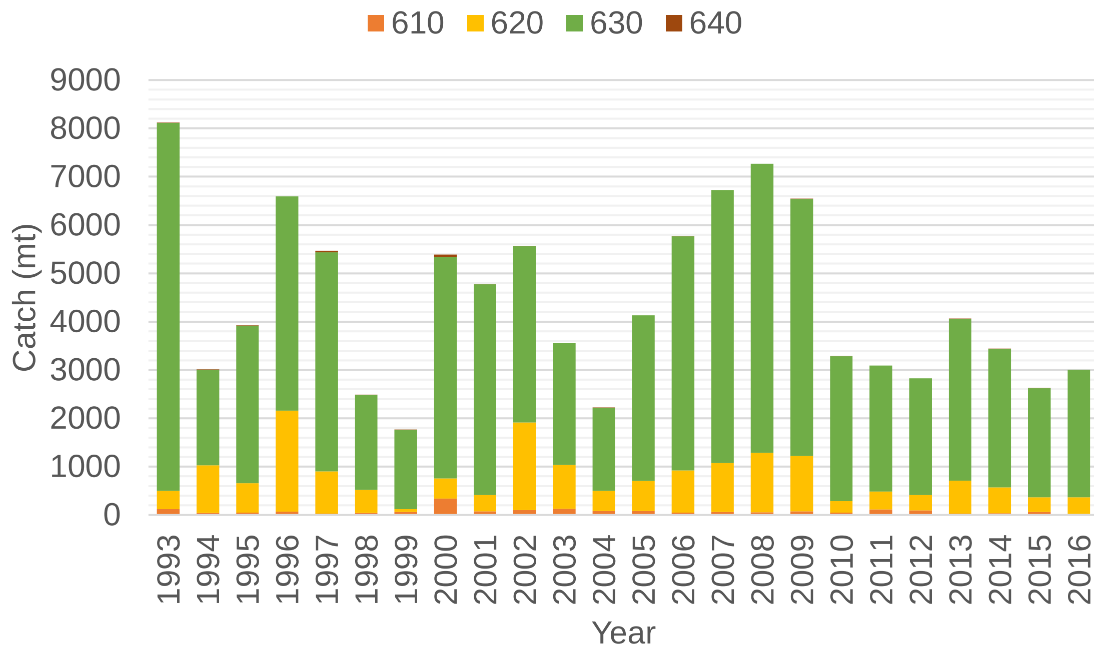


Figure 1. Total rock sole catch (retained + discards) by area (as of 2017-08).

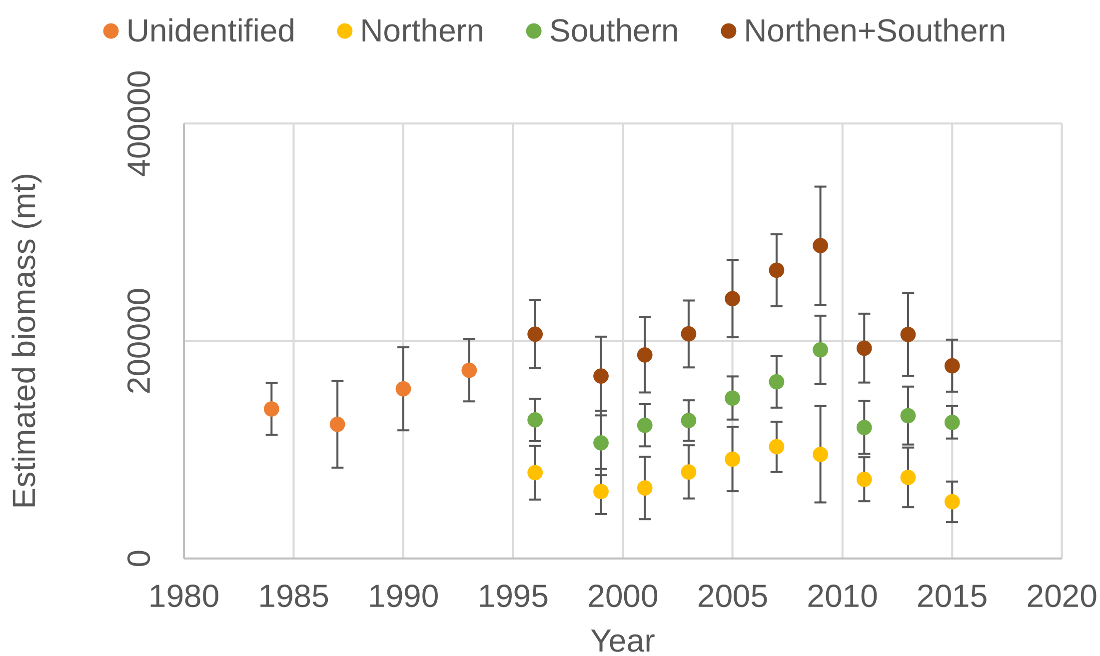


Figure 2. Total biomass estimates from the NMFS GOA bottom trawl survey for unidentified, northern, southern rock sole.

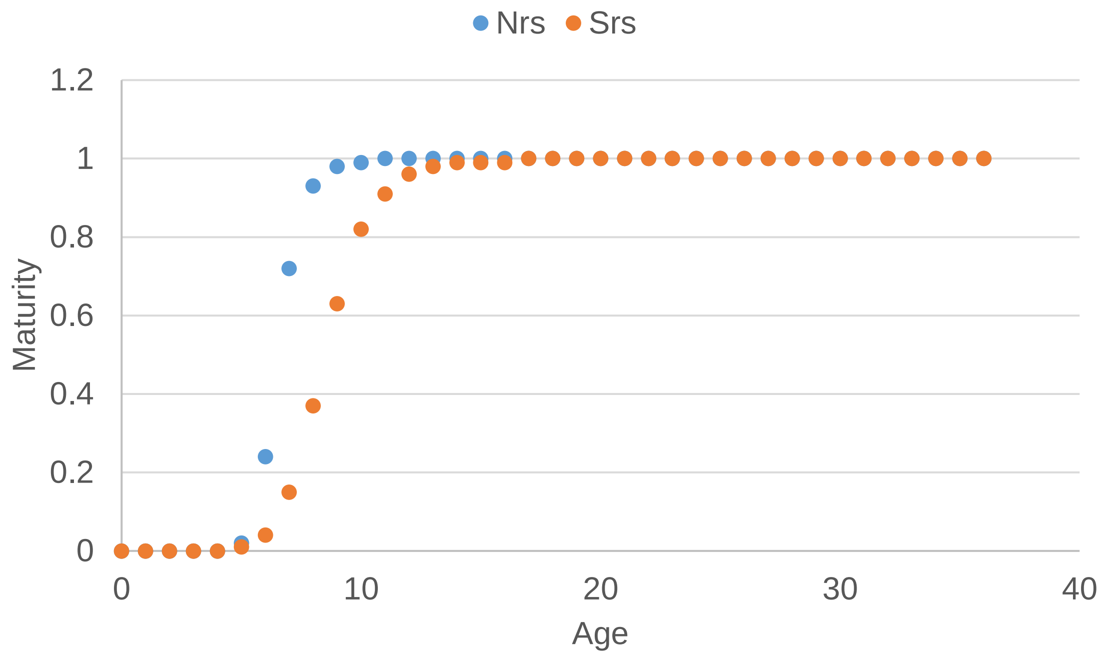


Figure 3. Northern and southern rock sole maturity curves.

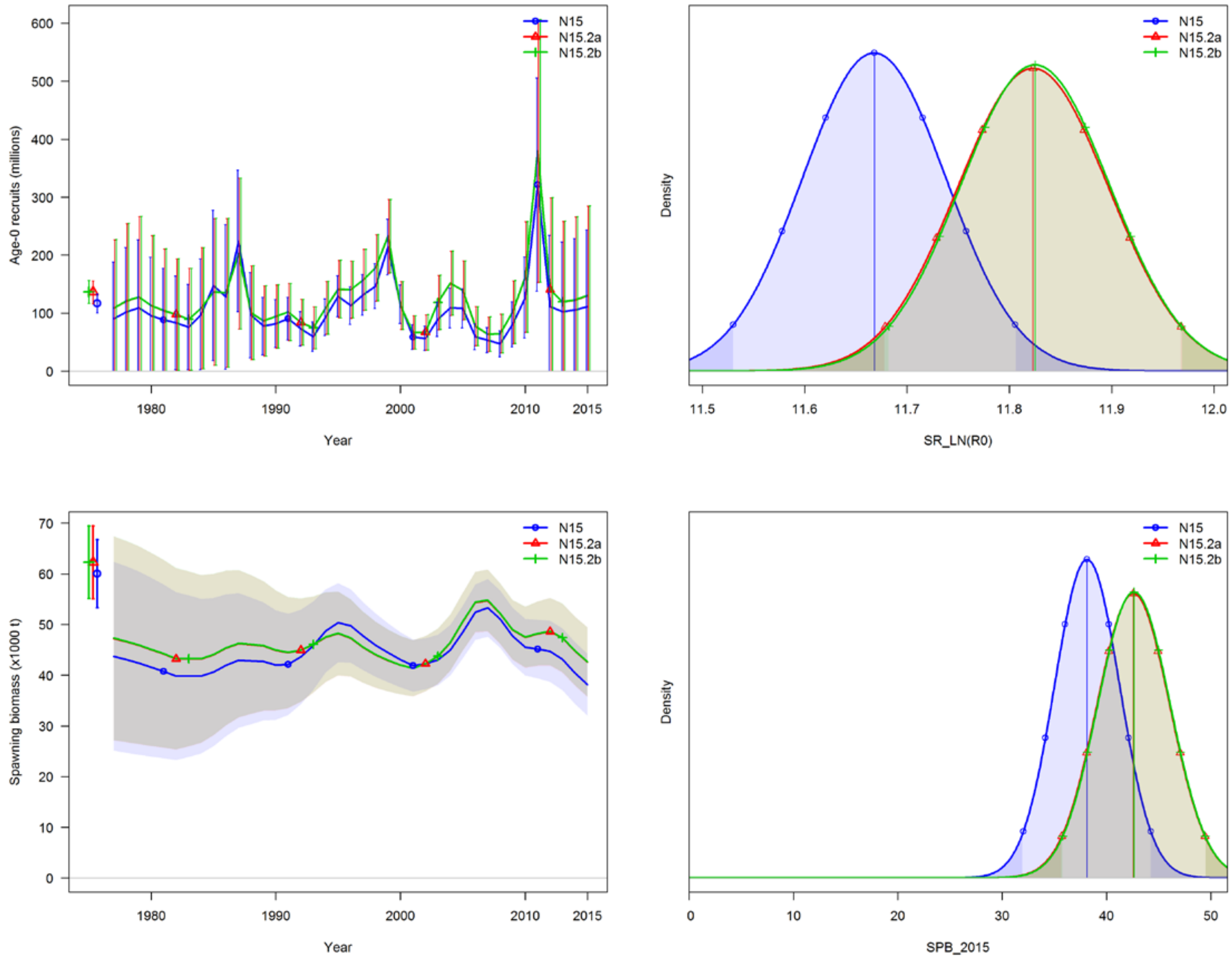
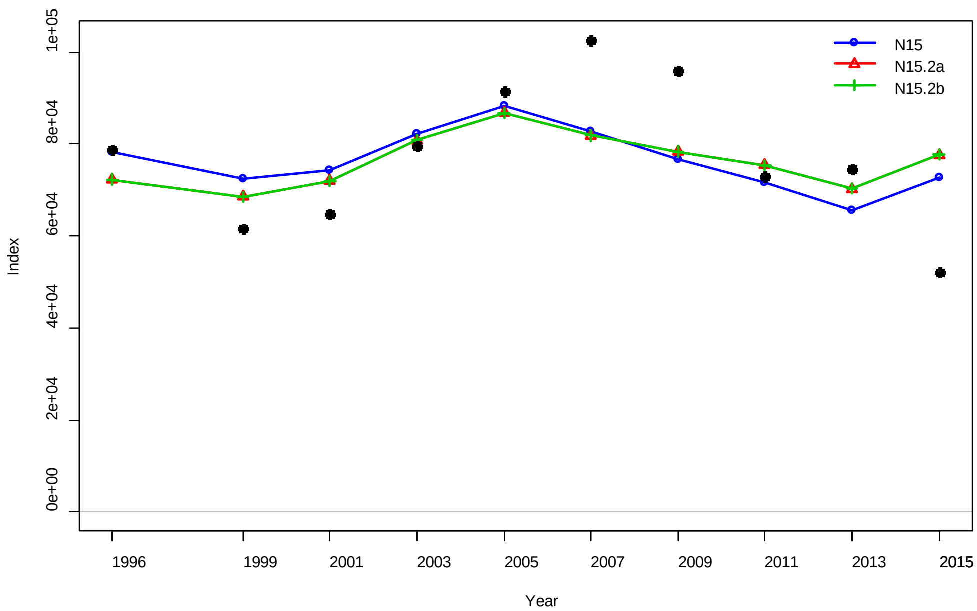


Figure 4. Northern rock sole age-0 recruits, Ln(R_0) density, spawning stock biomass with uncertainty, and spawning biomass density in 2015.



Model	RMSE
15.1	0.165
15.2a	0.170
15.2b	0.170

Figure 5. NMFS GOA bottom trawl survey northern rock sole index and model fit comparison.

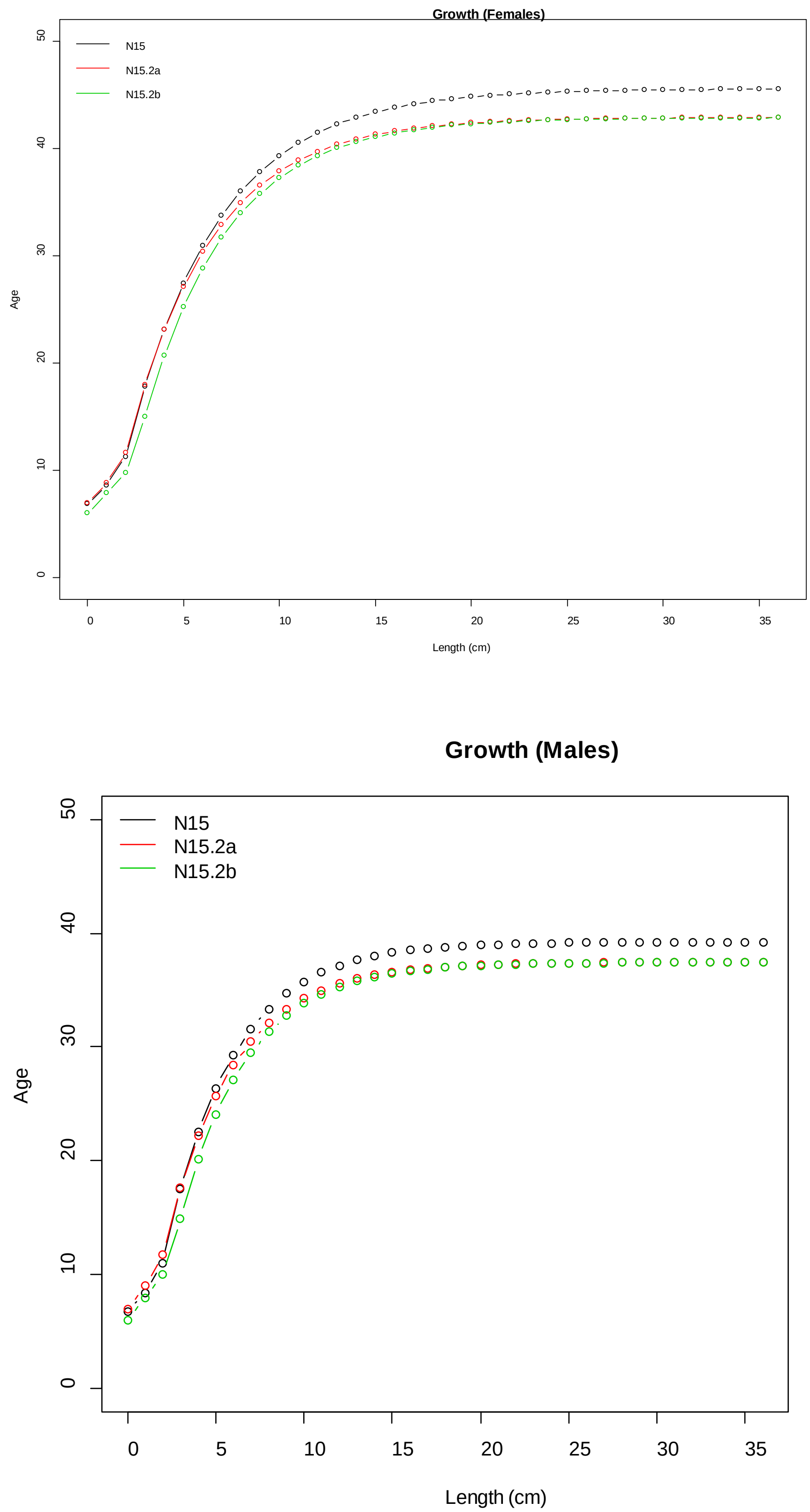
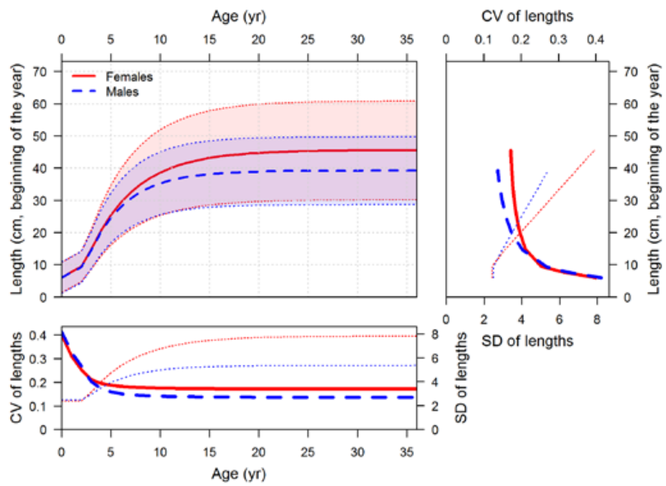
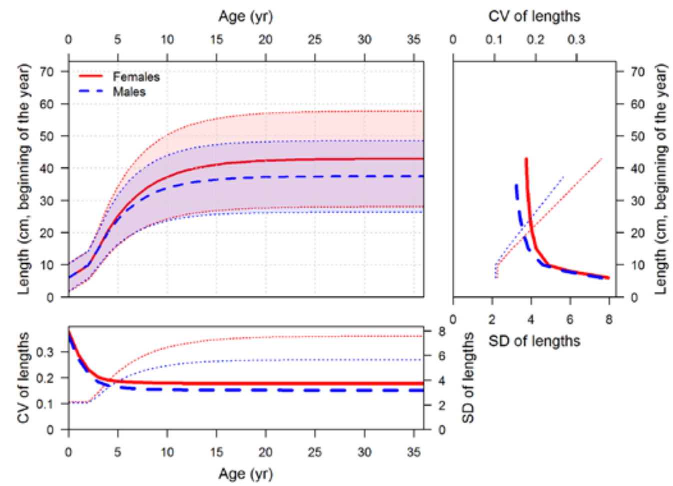


Figure 6. Northern rock sole growth, female (top) and male (bottom).

Model N15.1



Model N15.2a



Model N15.2b

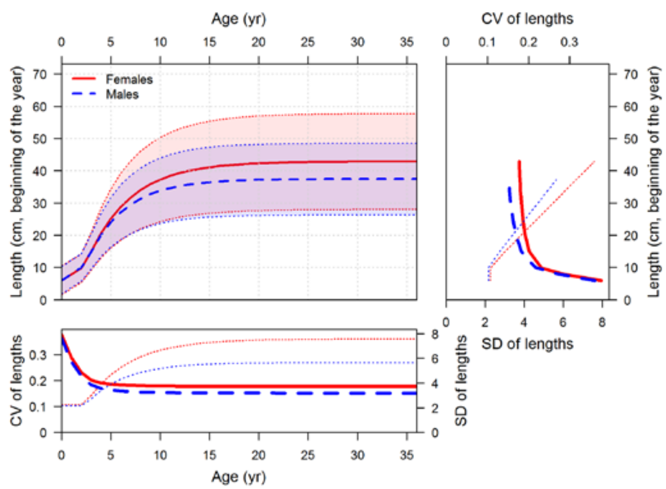
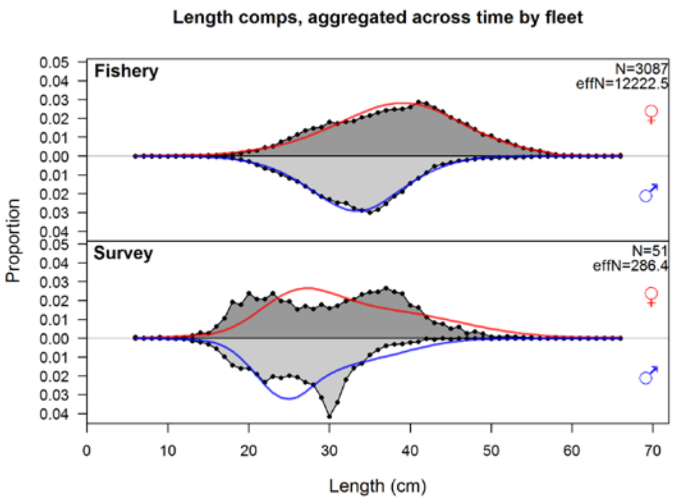
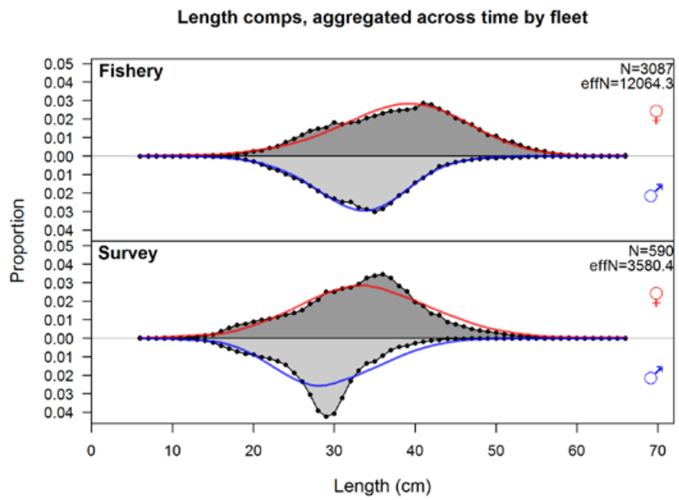


Figure 7. Northern rock sole growth with uncertainty. The red area represents females and the blue area represents males.

Model N15.1



Model N15.2a



Model N15.2b

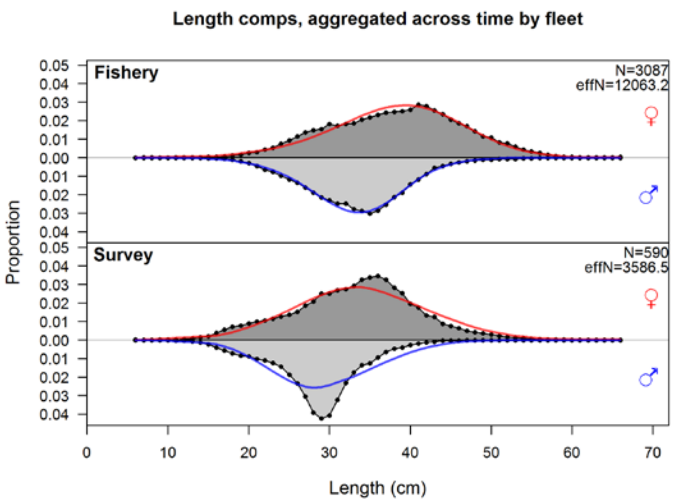
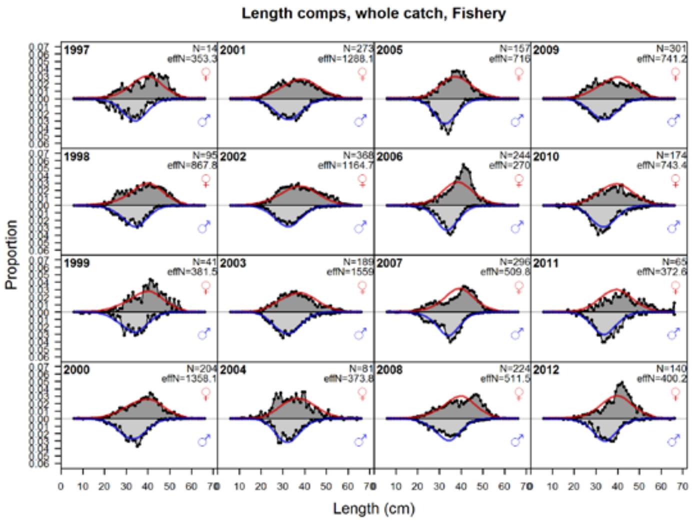
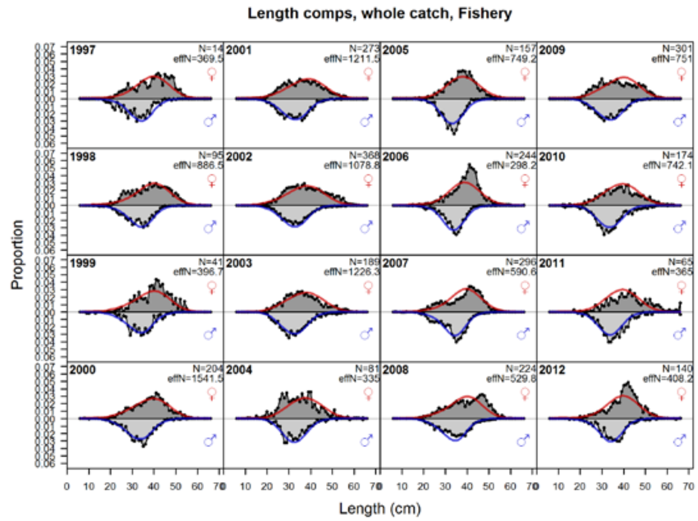


Figure 8. Fits (red line - female, blue line – male) to the northern rock sole fishery and survey size composition data aggregated across years.

Model N15.1



Model N15.2a



Model N15.2b

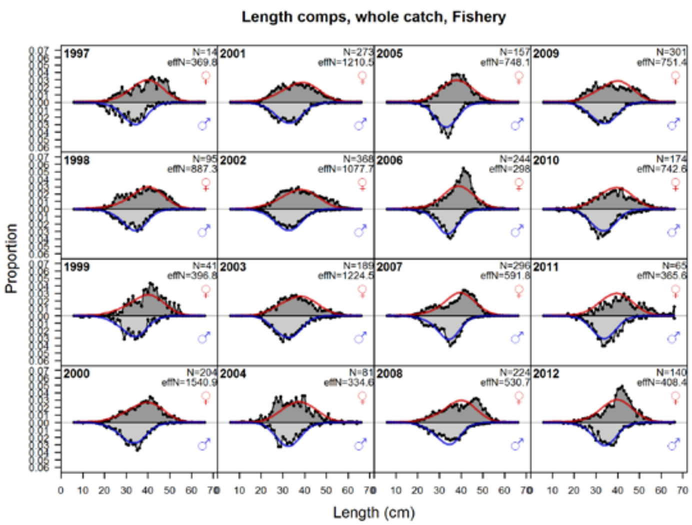
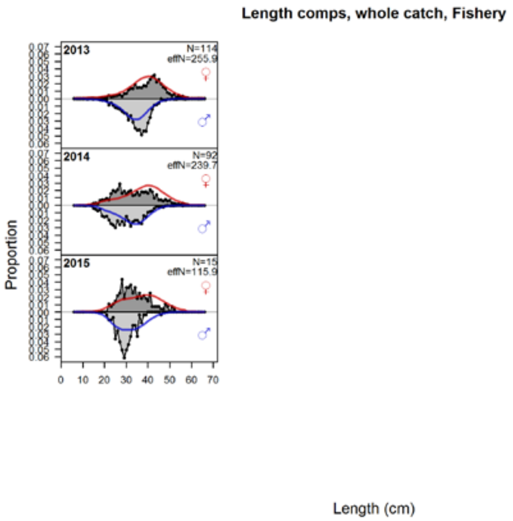
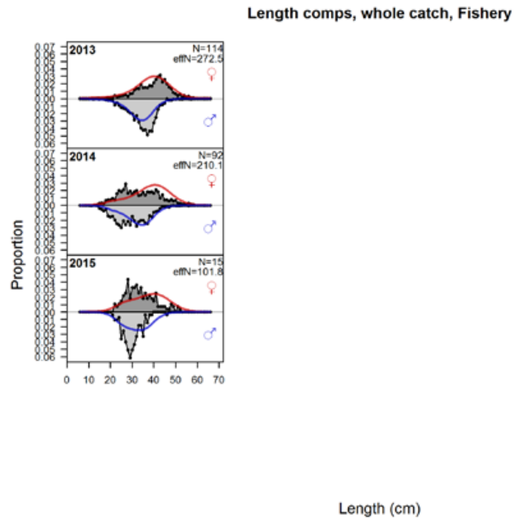


Figure 9. Fits (red line - female, blue line – male) to the northern rock sole fishery size composition data (1997-2012).

Model N15.1



Model N15.2a



Model N15.2b

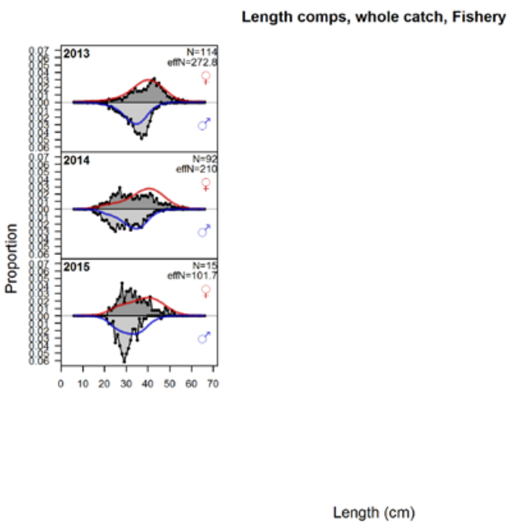
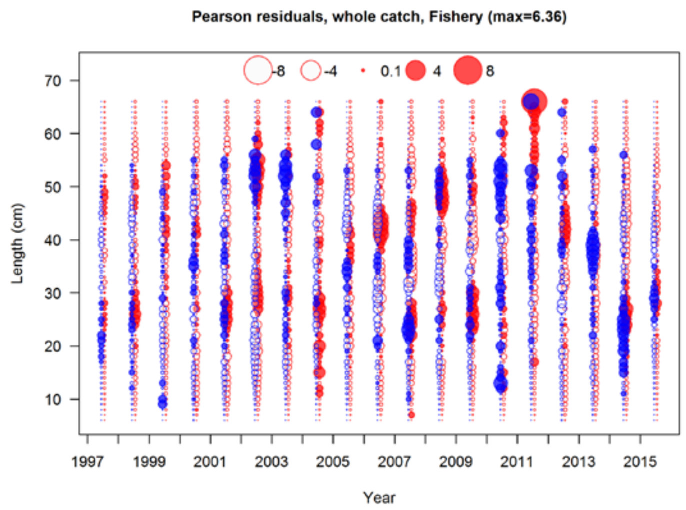
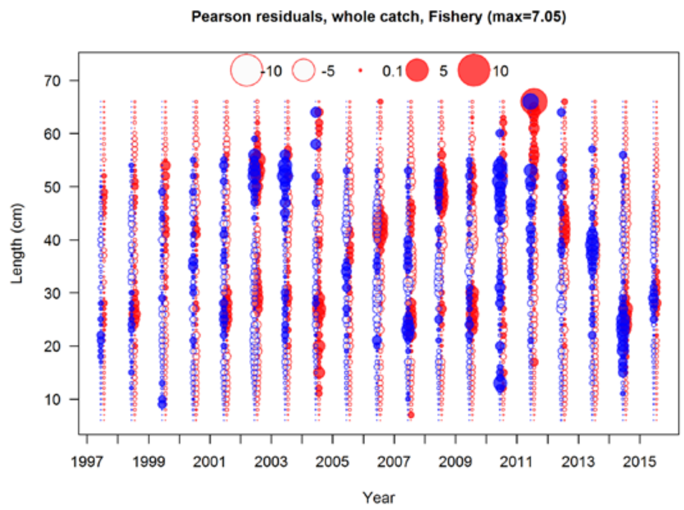


Figure 10. Fits (red line - female, blue line – male) to the northern rock sole fishery size composition data (2013-2015).

Model N15.1



Model N15.2a



Model N15.2b

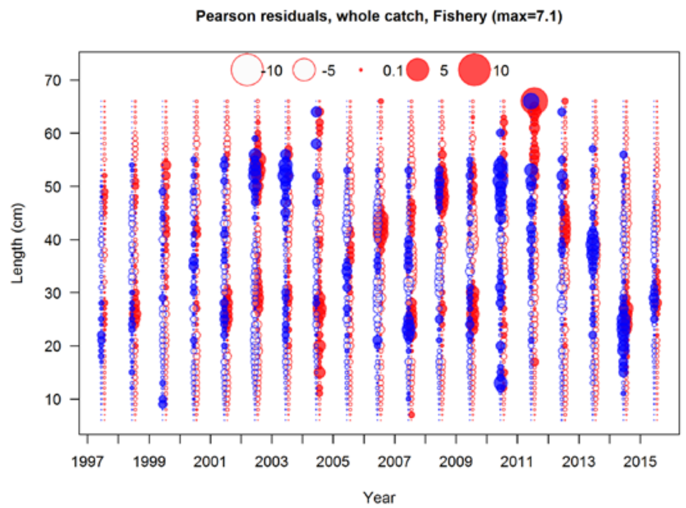
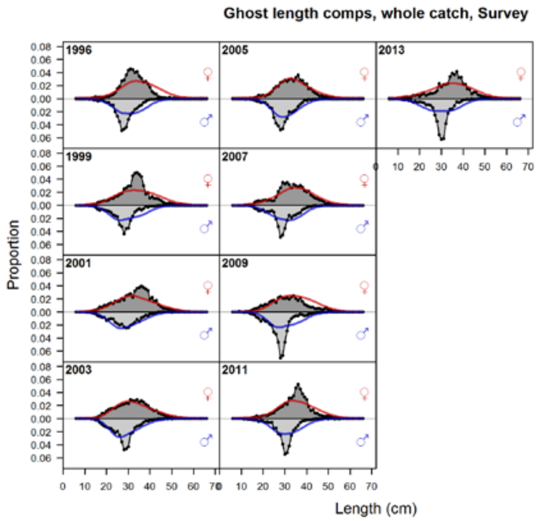
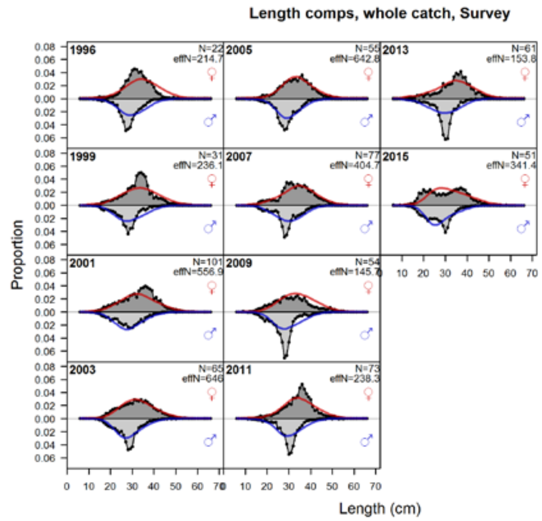


Figure 11. Pearson residuals (red - female, blue – male) for fishery size composition data. Closed bubbles are positive residuals (observed > estimated). Scales differ by model.

Model N15.1



Model N15.2a



Model N15.2b

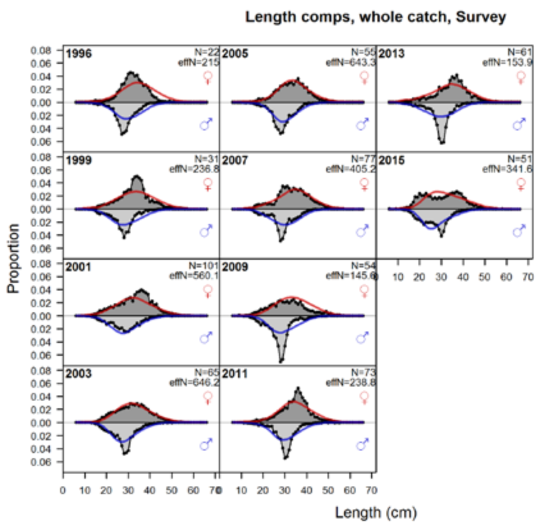
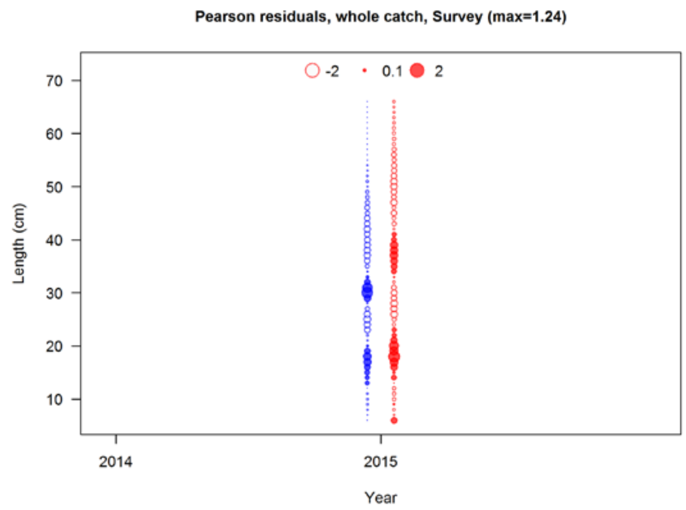
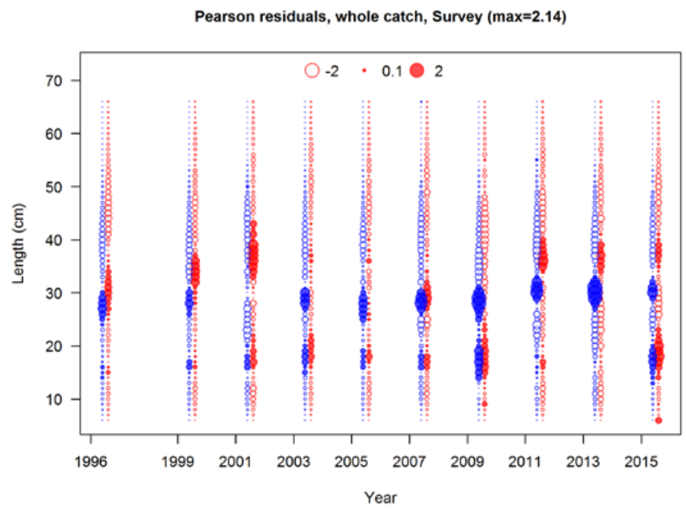


Figure 12. Fits (red line - female, blue line – male) to the northern rock sole survey size composition data (1996-2015).

Model N15.1



Model N15.2a



Model N15.2b

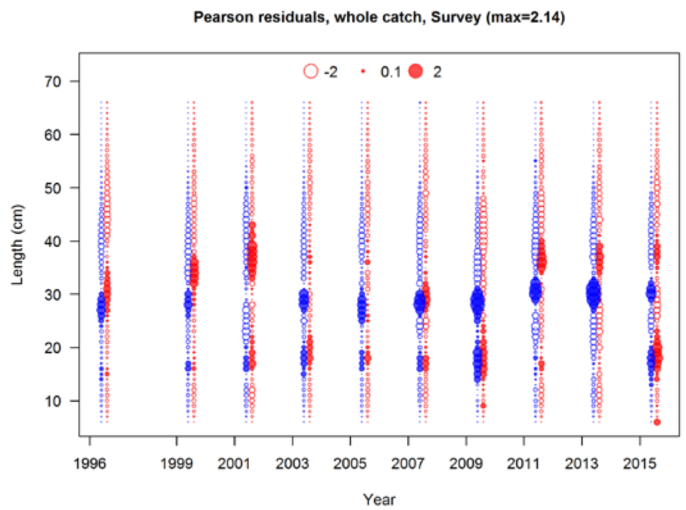


Figure 13. Pearson residuals (red - female, blue – male) for survey size composition data. Closed bubbles are positive residuals (observed > estimated). Scales differ by model.

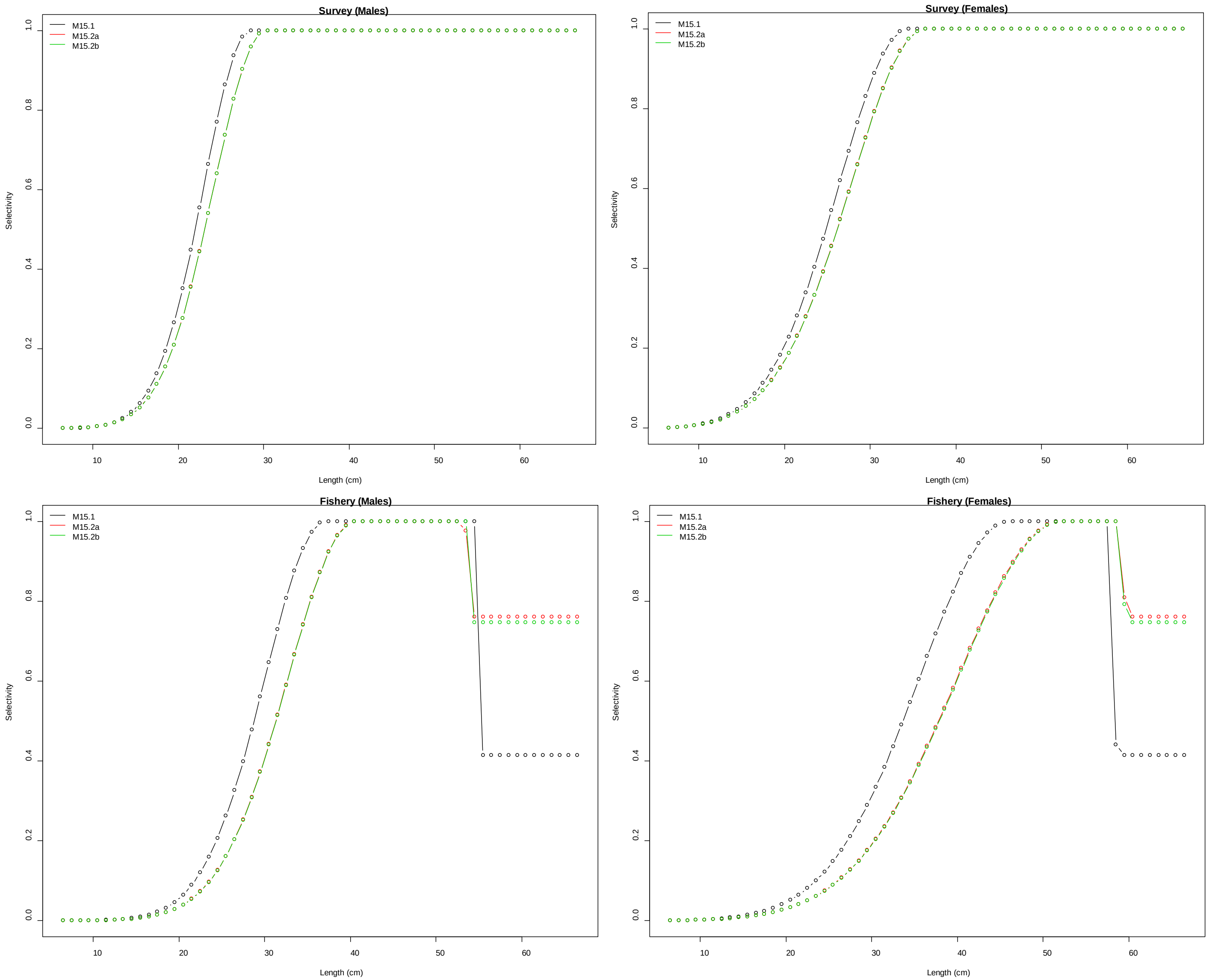


Figure 14. Male (left) and female (right) northern rock sole survey (top) and fishery (bottom) selectivity curves.

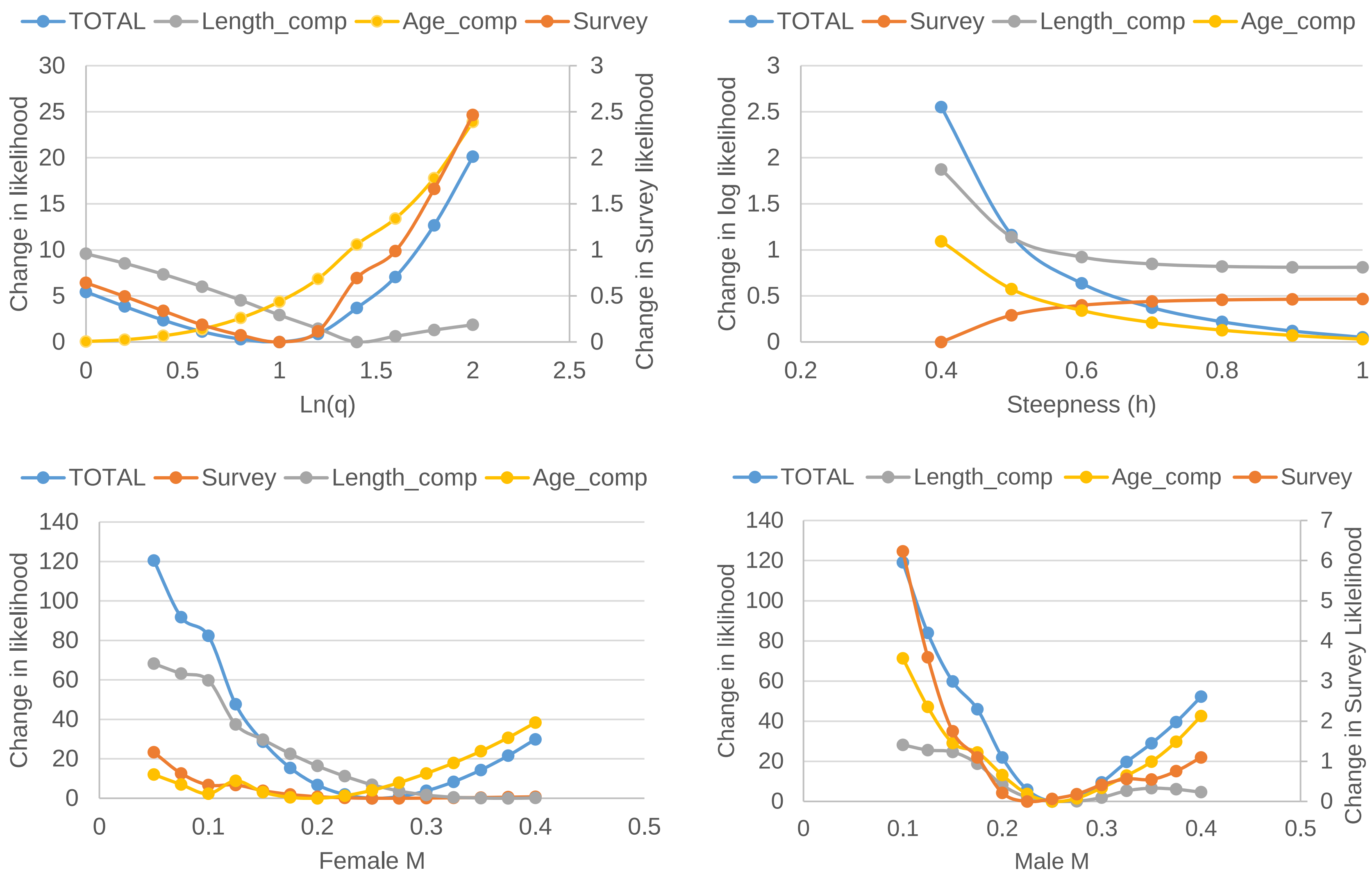


Figure 15. Likelihood profiles for northern rock sole catchability (fixed at 0), steepness fixed at 1), and female (fixed at 0.2) and male natural mortality (M).

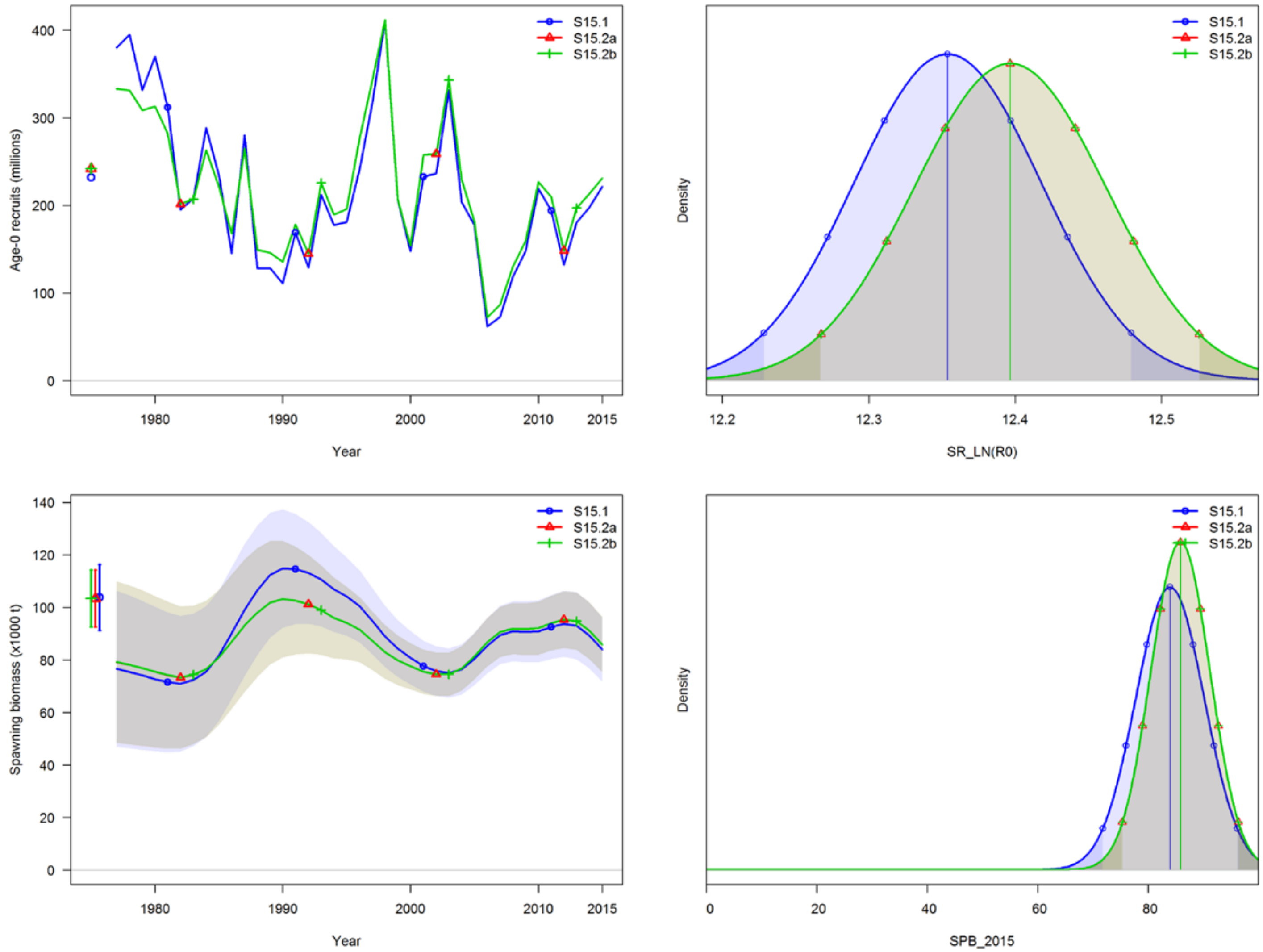
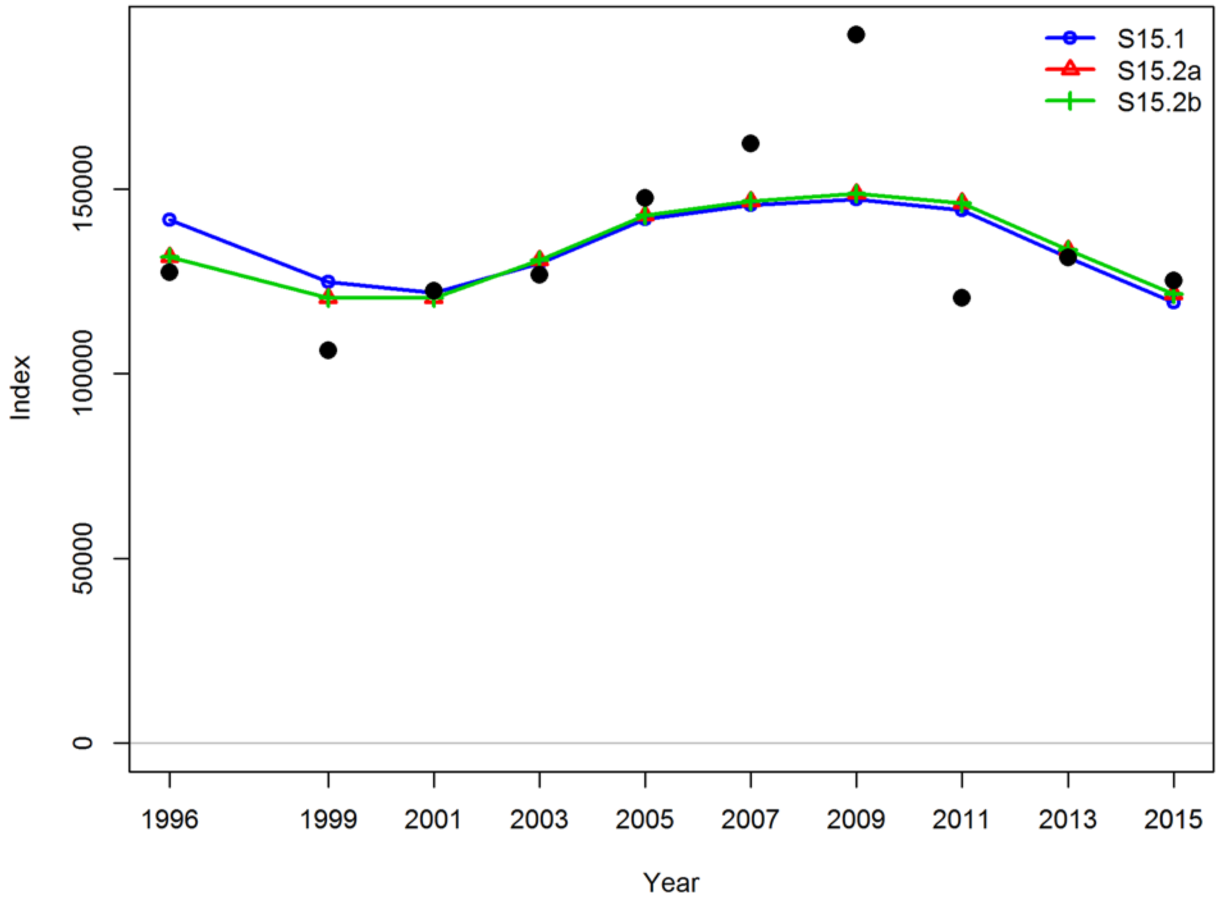


Figure 16. Southern rock sole age-0 recruits, Ln(R_0) density, spawning stock biomass with uncertainty, and spawning biomass density in 2015.



Model	RMSE
15.1	0.125
15.2a	0.115
15.2b	0.115

Figure 17. NMFS GOA bottom trawl survey southern rock sole index and model fit comparison.

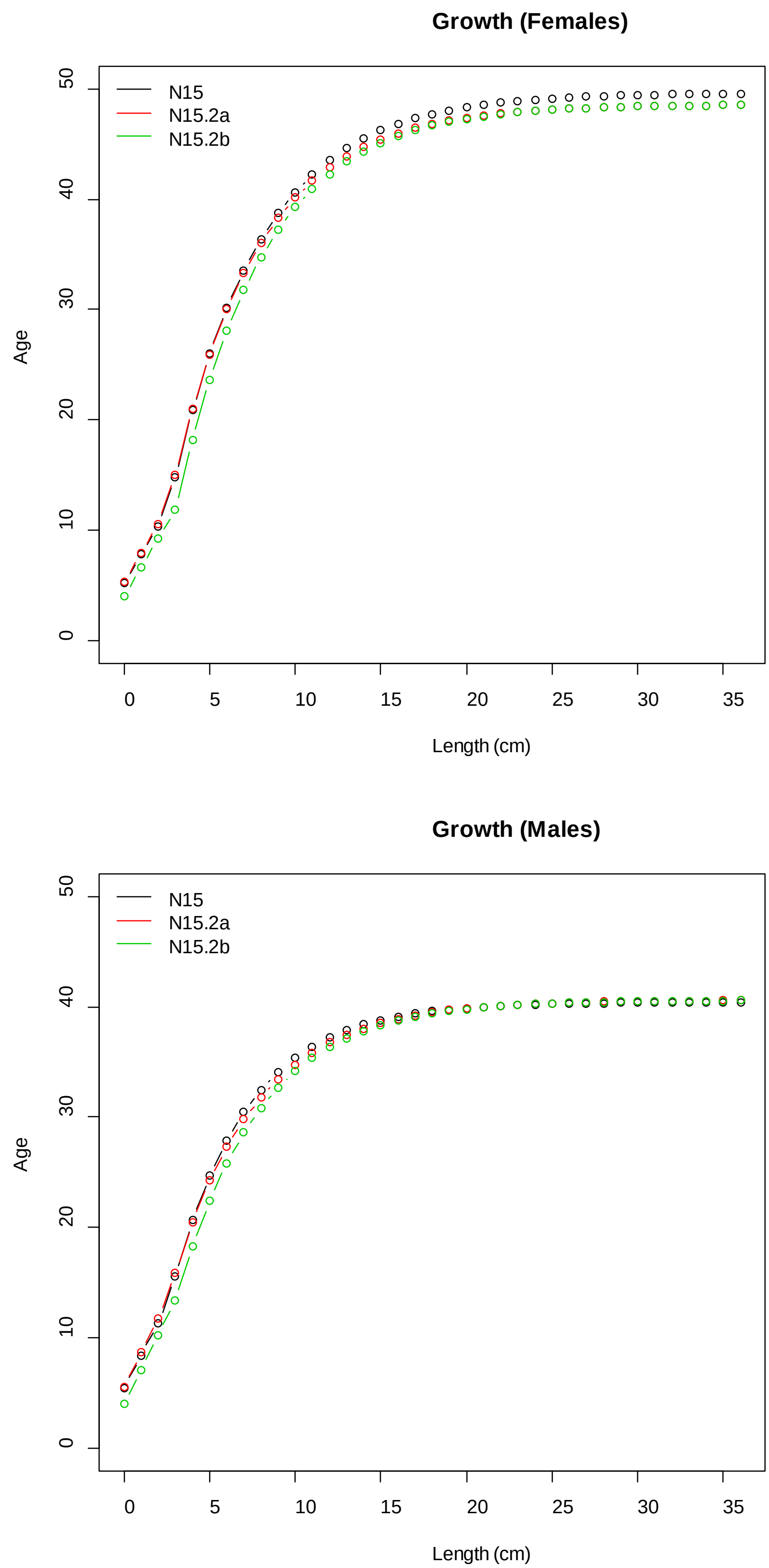
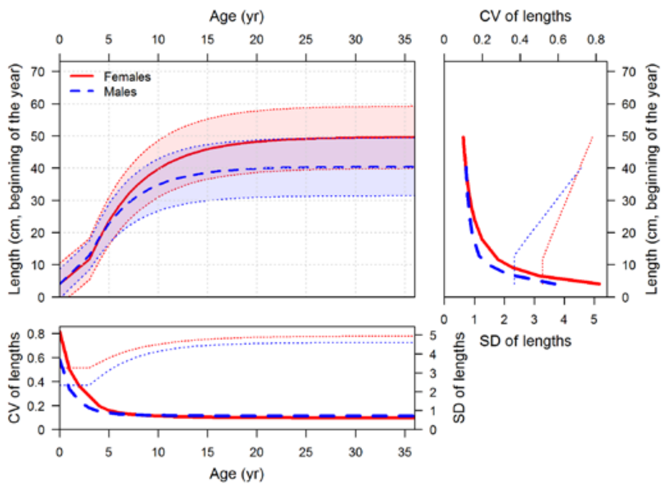
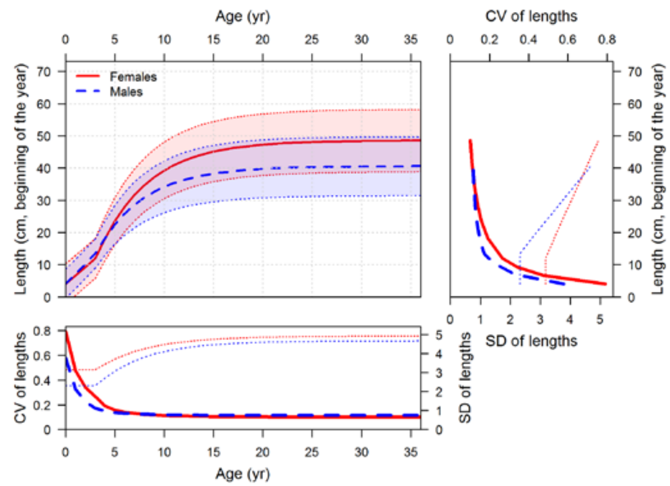


Figure 18. Southern rock sole growth, female (top) and male (bottom).

Model 15.1



Model 15.2a



Model 15.2b

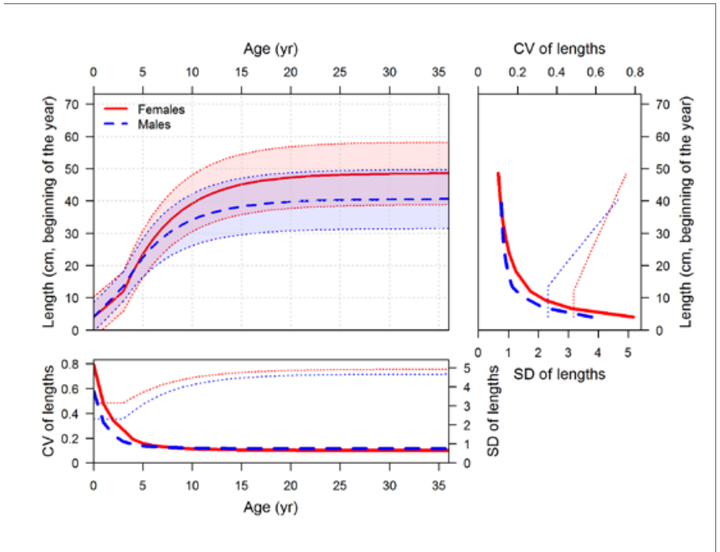
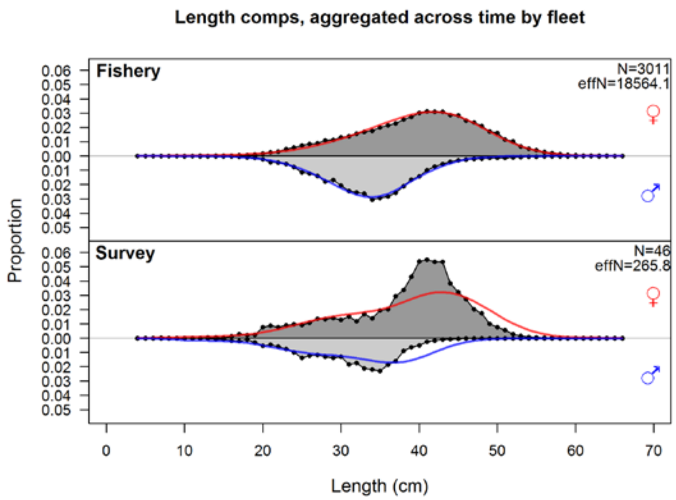
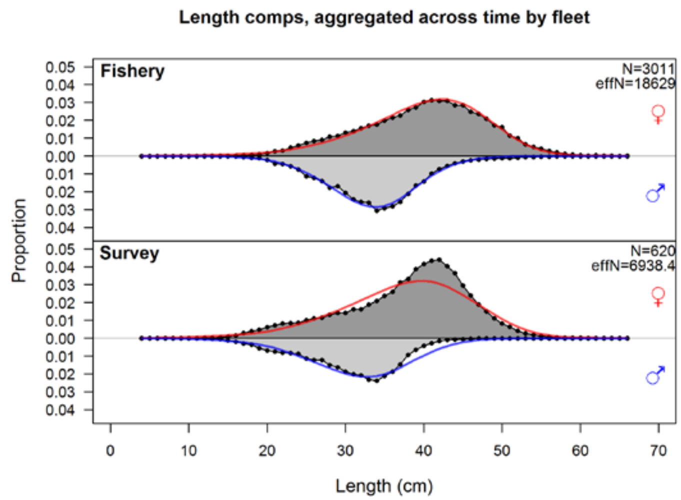


Figure 19. Southern rock sole growth with uncertainty. Red represents females and blue represents males.

Model 15.1



Model 15.2a



Model 15.2b

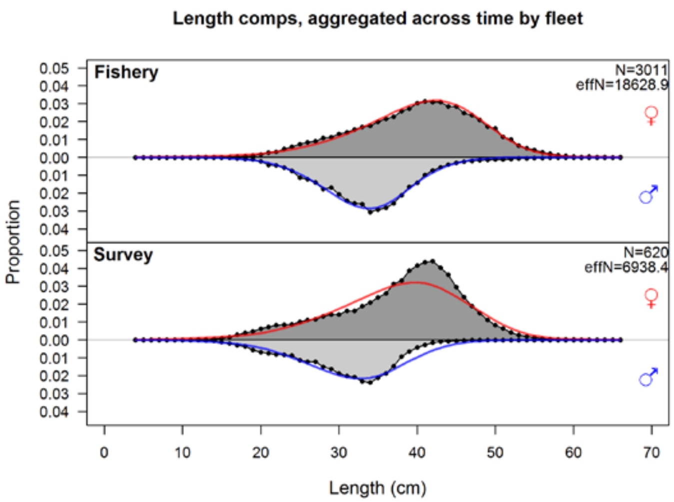
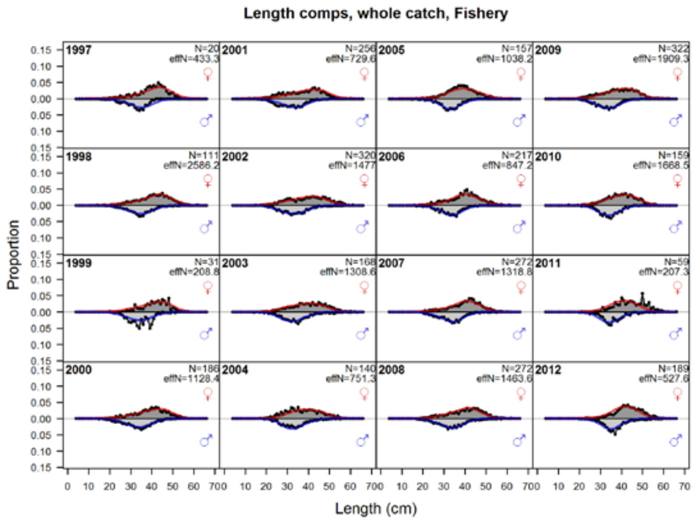
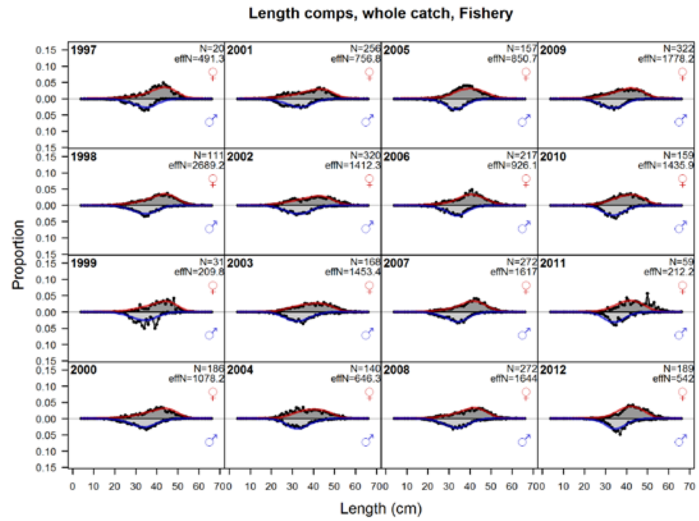


Figure 20. Fits (red line - female, blue line – male) to the southern rock sole fishery and survey size composition data aggregated across years.

Model 15.1



Model 15.2a



Model 15.2b

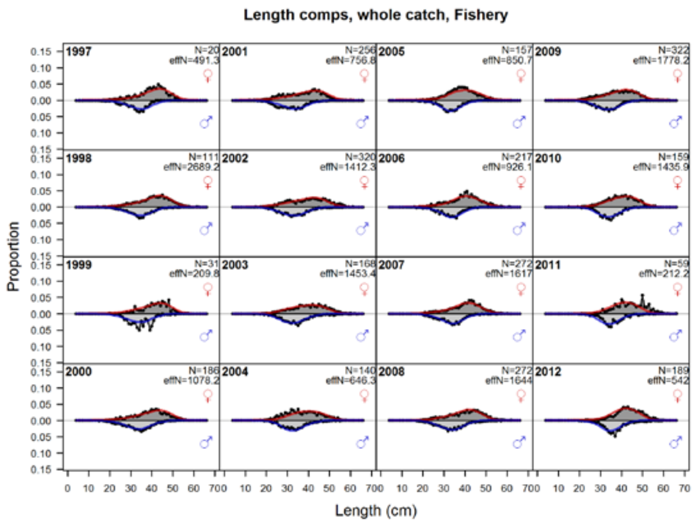
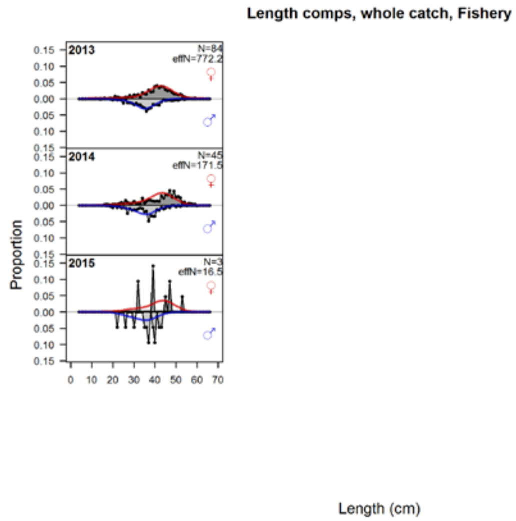
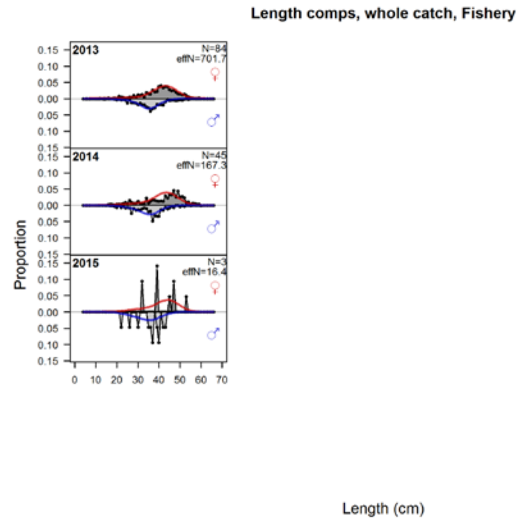


Figure 21. Fits (red line - female, blue line – male) to the southern rock sole fishery size composition data (1997-2012).

Model 15.1



Model 15.2a



Model 15.2b

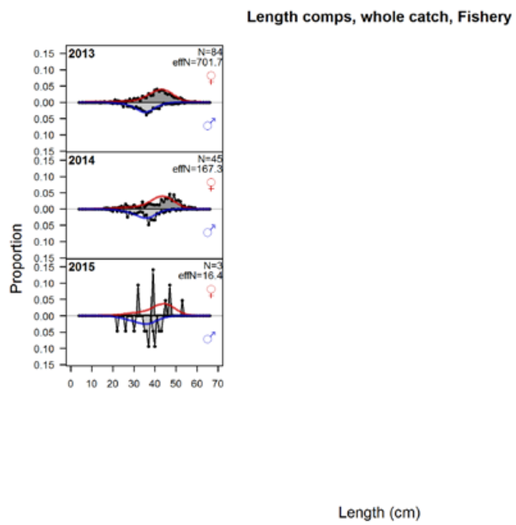
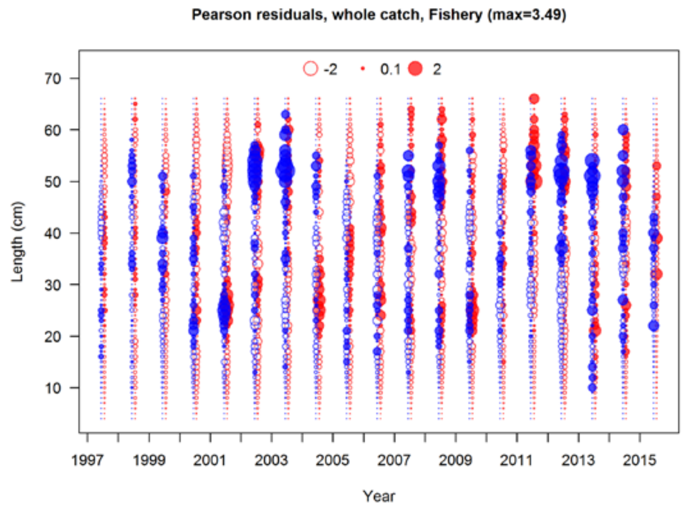
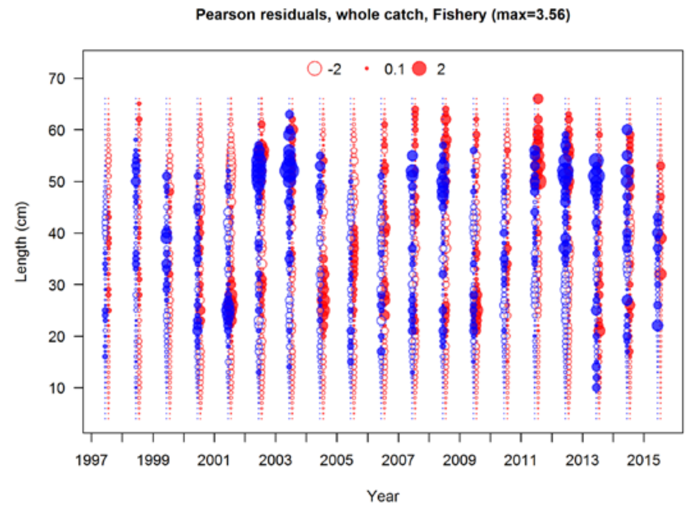


Figure 22. Fits (red line - female, blue line – male) to the southern rock sole fishery size composition data (2013-2015).

Model 15.1



Model 15.2a



Model 15.2b

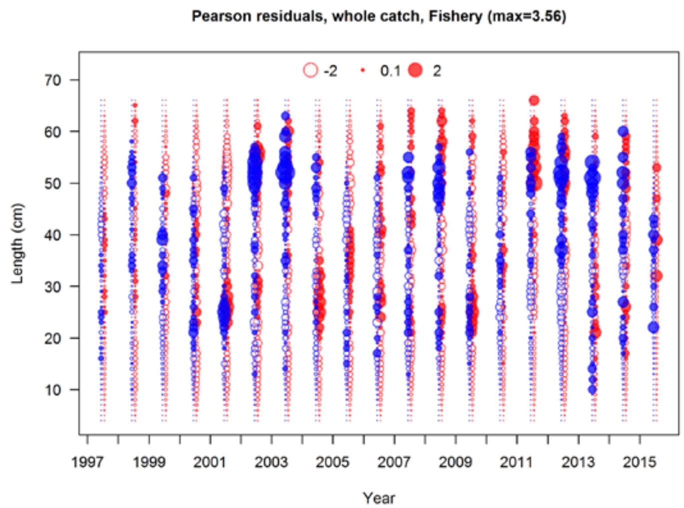
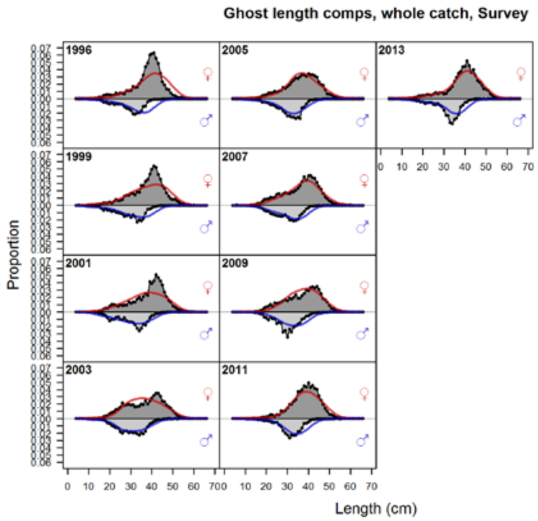
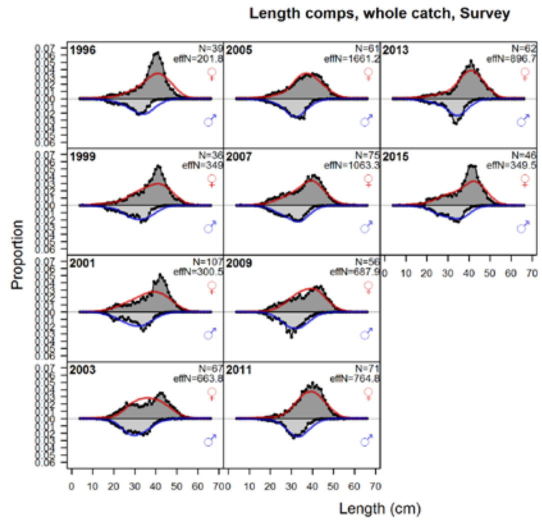


Figure 23. Pearson residuals (red - female, blue – male) for fishery size composition data. Closed bubbles are positive residuals (observed > estimated). Scales differ by model.

Model 15.1



Model 15.2a



Model 15.2b

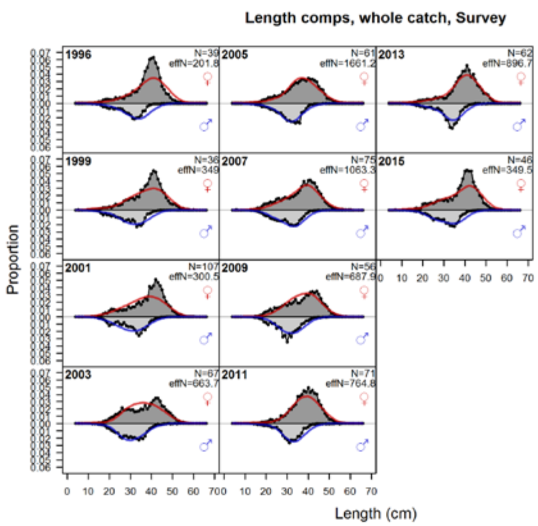
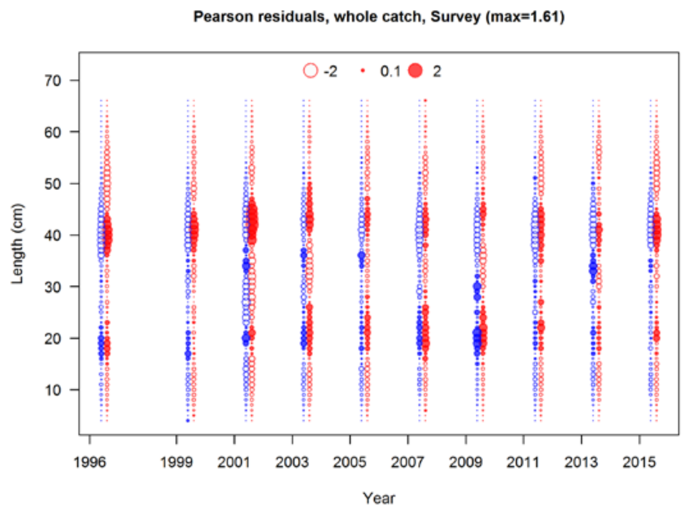


Figure 24. Fits (red line - female, blue line – male) to the southern rock sole survey size composition data (1996-2015).

Model 15.2a



Model 15.2b

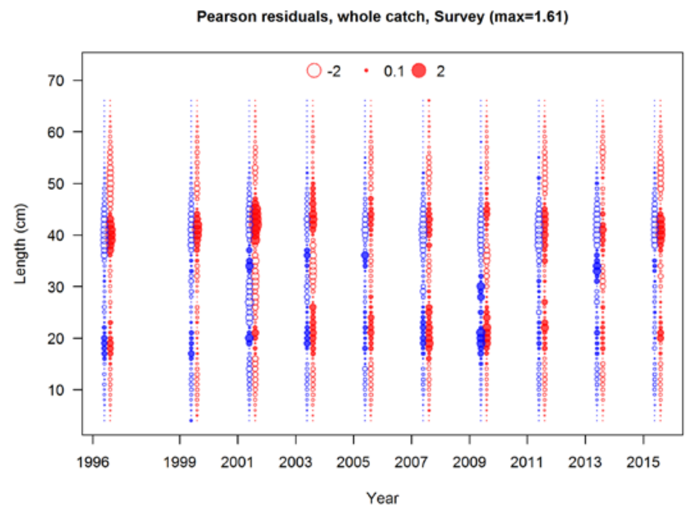


Figure 25. Pearson residuals (red - female, blue – male) for southern rock sole survey size composition data. Closed bubbles are positive residuals (observed > estimated). Scales differ by model. Model 15.1 was not fit to the length composition data, hence the absence of residuals.

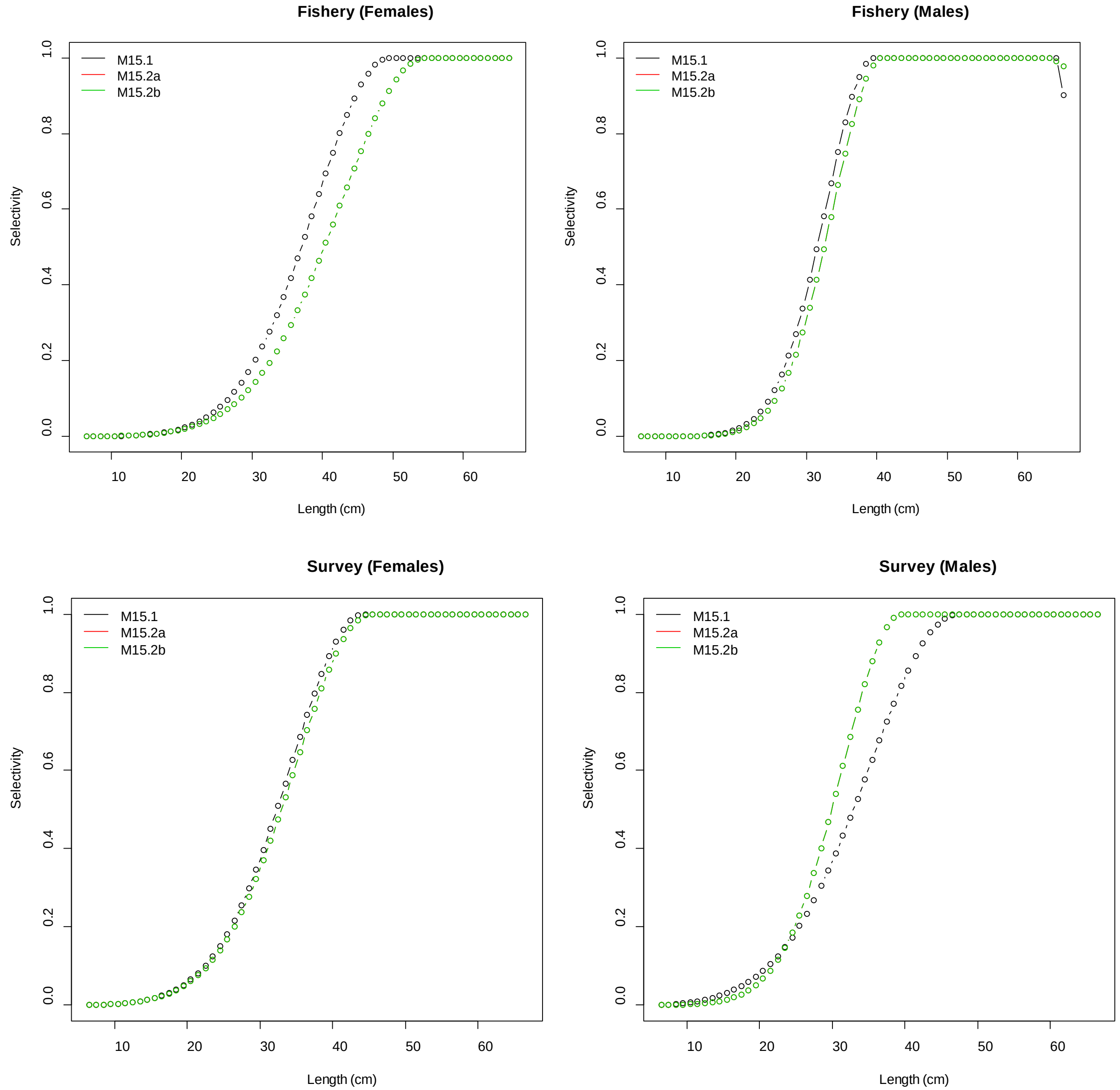


Figure 26. Southern rock sole, female (left) and male (right), fishery (top) and survey (bottom) selectivity.

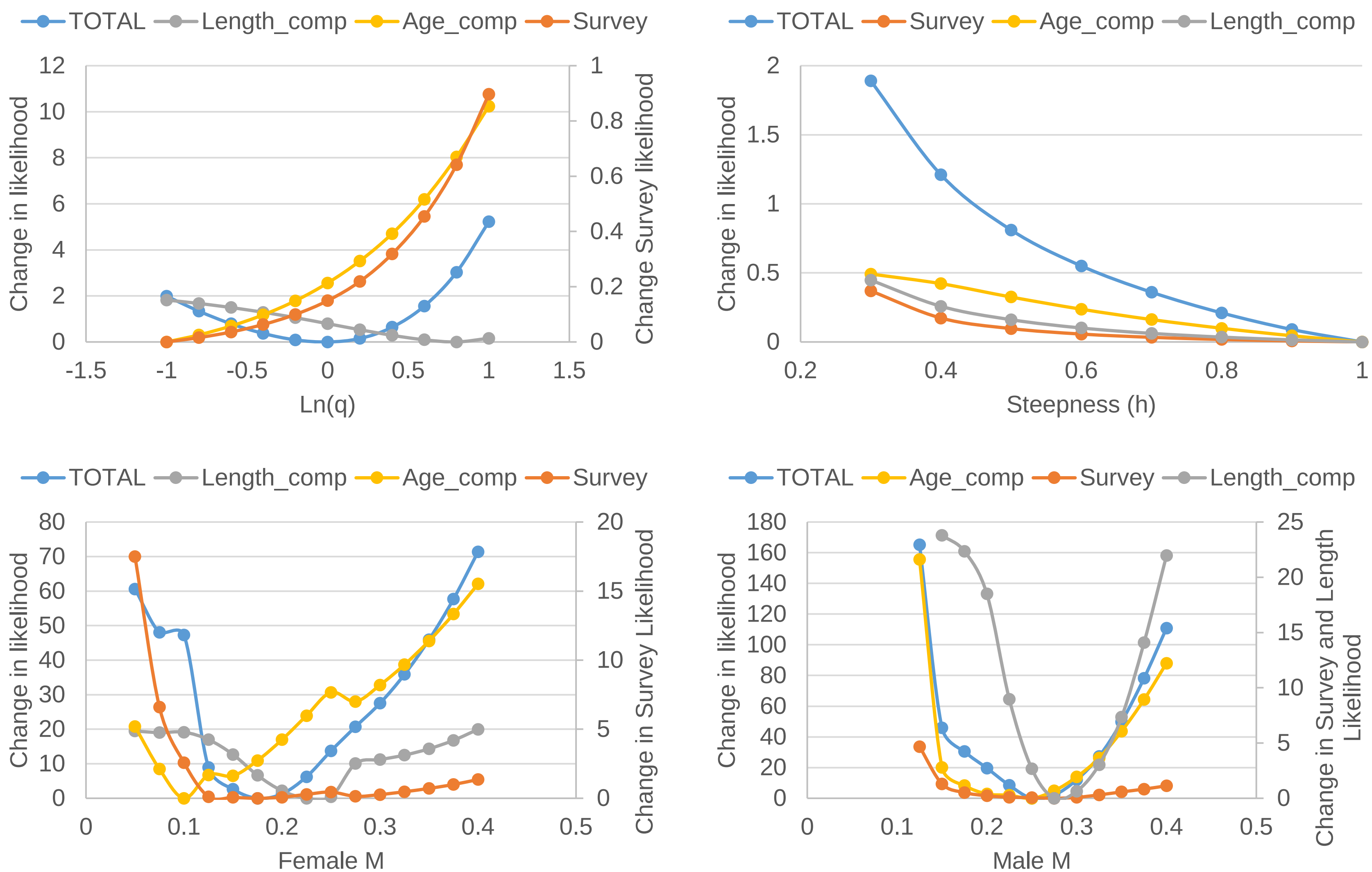


Figure 27. Likelihood profiles for catchability (Ln q), steepness (h), and female and male natural mortality (M).