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

by

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Introduction

The GOA rock sole stock assessment data and model was reviewed by the Center for Independent Experts (CIE) in April, 2021. This document attempts to respond to some suggestions made during the CIE review as well as other data and model explorations.

One reviewer prioritized the research assessments needs for the GOA rock soles as follows:

"Improvements in modelling growth are necessary to attain better fits to the length distributions in both assessments, though it is more important for the Northern rock sole assessment. The review was able to identify some potential causes based on the data, but a resolution requires further work, both to determine the actual cause and the development of models to facilitate such hypothesis. An appropriate interim measure may be to move to age-based selection using the internally consistent survey age information as the basis.

Selectivities have comparatively few parameters in this model when compared to other models. Despite this there is still some tendency for parameters not to be uniquely identifiable. This could be due to the poor modelling of growth, but the fishery represents a single fleet using trawls within a confined space; so, it is not clear to me why a dome-shaped selection is 'likely' as stated in the assessment report, especially since the survey uses a similar gear and is modelled as a monotonic function. Some efforts to simplify selectivity may still be necessary after growth is modelled more appropriately and definitely required if the latter cannot be adequately resolved.

The survey data for Northern rock sole show some internal inconsistencies with regards to year effects. The model is currently picking those up and interpreting them as residuals so it is not a big issue. However, it may be advantageous to develop a model-based index for this species that might then potentially account / explain why these effects occurred. This would reduce overall model uncertainty and potentially aid convergence further."

The second reviewer made the following suggestions:

"The jitter analysis should be revisited, and it should be verified that for both stocks the model returns estimates of the quantities of interest (spawning stock biomass, fishing mortality, and recruitment) that are the same for all model runs diagnosed as converged (from a number of different starting values). Based on the retrospective runs, the sensitivity runs, and the MCMC diagnostics this is not expected to be a problem (but it should be verified). If it turns out to be a problem, it can likely be isolated to a few parameters, and it should hopefully not be too difficult to identify and solve (restrict or eliminate affected model parameters).

Since the fit to the conditional age-at-length is problematic (as seen in figures 4.18 and 4.33) and there could be more general problems with the use of this data type that extends outside this assessment (Lee et al. 2019) it could be considered to use the age compositions data directly in the assessment model.

The assumed 50/50 split giving the exact same catch series in both assessments, which is further assumed to be without observation noise, does sound problematic. At the very least it will underestimate the added uncertainty originating from split. A first step could be to allow some uncertainties in the catch time series to capture this uncertainty. A long-term goal could be to develop a joint model for the two stocks where the split fraction (process) was estimated internally. Such a model would capture the correlated coupling in the two catches (that they have to sum to the total catch).

The untrawlable areas seem to be an important issue for these assessments. Currently it is assumed that rock sole is equally abundant in trawlable and untrawlable areas in the survey calculation, and again when fixing the catchability parameter to 1 in the model. This is a strong and as far as I have heard, it is an unsubstantiated assumption. Relative abundance in the untrawlable is currently being researched and this research should be encouraged. Further it could be investigated if it is possible to estimate the survey catchability within the model (possibly at the cost of simplifying the models elsewhere). ”

Data

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). Annual rock sole catch statistics are undifferentiated and there is considerable uncertainty about the fraction of annual rock sole catch that is northern or southern rock sole.

Rock sole catch has been variable overtime, with a peak of 8,112 t in 1993 and secondary peak of 7,269 t in 2008 (Figure 1). Catch has averaged 3000 t per year since 2010. On average 97% of the annual catch is caught in NMFS areas 620 and 630, with the majority of the catch from area 630 (around Kodiak). Approximately 3% of the annual catch is from area 610 (Shumagin).

Species-specific fishery length composition data have been available since 1996 and used in the assessment. The raw length composition data from the FMA observer program were used in previous assessments and these data were updated to be extrapolated by the number of hauls. This change was minor (Figure 5 and Figure 6).

Survey

The NMFS Gulf of Alaska groundfish survey conducted by the AFSC’s Resource Assessment and Conservation Engineering (RACE) division was a triennial survey from 1984 until 1999 and then biennial from 2001 until present. The available 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.

Northern rock sole survey biomass in 1996 was 78,845 t and increased to a peak of 102,641 t in 2007 (Figure 2, top left panel). After 2007, survey biomass consistently declined to a low of 389,875 t in 2019 and represents a 61% decline from the 2007 estimate. The peak in total NRS biomass matches the peak in the western GOA, where on average 62% of biomass is found (Figure 2, bottom panel). NRS biomass declined by 58% between 2007 and 2015 and has remained relatively stable as of 2019. Biomass in the Central GOA peaked in 2009 and has declined by 70% as of 2019.

Survey biomass was also estimated using the vector autoregressive spatio-temporal (VAST) program (Thorson and Barnett, 2019). This was encouraged by the CIE reviewers as mentioned in the introduction. The VAST estimates were created using a Poisson-link delta model with a gamma observation error distribution. Density was extrapolated from 750 knots to the entire GOA using a user-defined extrapolation grid. The extrapolation grid excludes regions deeper than 700m, but observations greater than 700m were used to inform edge estimates. Geometric anisotropy was estimated to model the decline in directional correlation.

The mean estimates and overall trends in northern rock sole biomass are similar to the design-based estimate (Figure 3, top panel). The main difference between the two estimators is that the uncertainty is lower from the VAST estimator than the design based index.

Southern rock sole survey biomass in 1996 was 127,390 t and increased to a peak of 191,765 t in 2009 (Figure 2, top right panel). Biomass declined by 37% in 2011 and declined by 48% between 2009 and 2019. The peak in total biomass matches a peak in the central and western GOA, where on average 52% and 43% of southern rock sole biomass is found (Figure 2, bottom right panel). Biomass in the central GOA has remained relatively stable since 2011, whereas biomass increased slightly in the western GOA between 2011 and 2015 and then declined.

The trend in the VAST time series is similar to the design-based estimates between 1996 and 2007 (Figure 3, bottom panel). The two deviate in 2007. The VAST time series peaks in 2007 and the design-based time series peaks in 2009. Both decline to the same point in 2011 and have similar trends between 2011 and 2017. The biggest deviation between the two is in 2019, where the design-based estimate declines and the VAST estimate increases and falls outside of the design-based confidence intervals. The decline in the design-based total biomass time series is driven by the decline in the western GOA (Figure 2, top right panel).

Survey length composition data are shown in Figure 5 and Figure 6. Conditional age-at-length data are also available from the survey and used in the assessment to help estimate the von Bertalanffy growth parameters within the model. These data are shown in Figure 7-Figure 10.

The age error matrix was updated from paired age readings for northern and southern rock sole using the method proposed in Punt et al. (2008). This was implemented using the nwfscAgeingError package in Program R, which is a stepwise model selection program (Thorson et al, 2012). Several models were compared and AIC was used to determine the best model from which the age error matrix was chosen. The models that were considered included: 1.) unbiased estimator with curvilinear standard deviation, 2.) unbiased estimator with constant CV, and 3.) biased with curvilinear standard deviation. The model with the lowest AIC, was unbiased with curvilinear standard deviation for northern rock sole and unbiased with constant CV for southern rock sole. A comparison of the updated age error matrices and those used in previous assessments are shown in Figure 11. The previously used age error matrices assumed a constant CV and the standard deviation increases linearly with age.

Analytical approach

Model structure

The assessment was sex-specific statistical catch at age model implemented in Stock Synthesis3 (SS3, Methot and Wetzel 2013). The age classes included in the model run from 0 to 30, with 30 being a plus group. Age at recruitment is set at 0.

The most recently accepted assessment model (17.1) was a sex-specific, two fleet model (i.e., fishery and survey). Fleet and sex-specific selectivity was modeled using the double-normal function, which allowed for dome-shaped fishery selectivity. Survey selectivity was forced to follow a logistic pattern while using the double-normal function. 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. Survey catchability was set equal to 1.

Growth was assumed to follow the von Bertalanffy growth relationship with separate growth curves for females and males. The parameters were estimated internal to the model using conditional age-at-length data from the survey. Female natural mortality was fixed and equal to 0.2 and male natural mortality was estimated. Age based maturity was a fixed input vector (Figure 4).

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.

Data weighting within the model was according to the specified standard errors or input sample sizes. The survey biomass data were weighted according to the specified standard error from the design-based survey estimates. Input sample for the fishery and survey length composition data was the number of sampled hauls and the input sample size for the survey conditional age-at-length data was the product of the number of samples per length bin and year and the ratio of the total number of hauls per year and samples per year.

Several runs were completed to show the effect of several minor changes to the previously accepted model. These included updated fishery length composition data (17.1a), modified minimal sample size of the conditional age-at length data (17.1b), and the updated age-error matrix (17.1c). The input sample size for the conditional age-at-length data can be less than one. The default minimum input sample size in SS3 is one; therefore, any value less than one was set equal to one in the latest accepted assessment model. This was corrected.

2-area model (Northern rock sole only)

The CIE reviewers noted the relatively poor fit to the overall survey length composition data, a bifurcation in the conditional at-age-length data, and the residual patterns in the fit to the conditional age-at-length data suggesting two growth curves for northern rock sole (Figure 13, Figure 14). A 2-area model with separate growth curves for each area, similar to the GOA rex sole assessment (McGilliard 2017), was explored in an attempt to address these issues.

An evaluation of the age-length data suggest that there are differences in northern rock sole growth and southern rock sole growth between the western and Central GOA (Figure 15 and Figure 16). The fishmethods package (v4.0.5, Nelson, 2021) in Program R was used to externally estimate the von Bertalanffy growth parameters and model selection. The data from Yakutat and SE (for southern rock sole) were combined with Chirikof and Kodiak as part of the central GOA. Several models were considered and included 1.) growth parameters were equal for the two areas, 2.) all growth parameters differed, 3.) asymptotic length was set equal, 4.) the growth coefficient was set equal, and 5.) the theoretical age at which length is zero (t_0) was set equal.

The AIC results are presented in Table 1. The model where all growth parameters differ among areas has the lowest AIC for northern rock sole and given the delta AIC there is strong support for this model for northern rock sole females (Table 1). Differences in growth are also supported for male northern rock sole, but a model with the von Bertalanffy growth coefficient set equal in both areas is also supported. The model with the lowest AIC for southern rock sole is the model where the t_0 parameter is set equal among areas (Table 1); however, the model with overall growth differences among areas and the model where the von Bertalanffy growth coefficient is set equal are also supported. This suggests there is some difference between the areas for southern rock sole. A comparison of the growth curves from model 17.1 and the externally estimated growth curves from the models with lowest AIC are shown in Figure 17. The growth curve estimated by model 17.1 is more similar to the externally estimated relationship in the western GOA for both females and males, while there is a notable difference between the relationships for both female and male northern rock sole in the Central GOA (Figure 17 top panels). The latter is true for southern rock sole as well, while there is a greater difference in the externally estimated relationship in the central GOA for females (Figure 17 bottom panels).

The 2-area, "growth morph" model was explored for only northern rock sole given the magnitude of difference in the growth relationship of this species. The two areas in the model represented the Western GOA and Central GOA and the survey and fishery data were split according to area and input separately in the model. Survey selectivity differed between sexes and the western selectivity mirror survey selectivity in the central GOA. Survey catchability was set equal to 1 for both areas. A time-invariant distribution parameter that specifies the proportion of recruits in each area was estimated.

Additional model runs

Additional model runs included estimating the catchability (171.e), using VAST biomass estimates as a data input in place of the design-based survey biomass estimates (17.1f), as well as an exploration of iterative reweighting approaches (17.1g-j). A summary of model descriptions can also be found in Table 2 and Table 5. Reasons for these model runs are provided in the discussion of the results.

Results

Northern rock sole

Including the updated fishery length composition data (17.1b) led to negligible change relative to model 17.1 (Figure 12). Modifying the input sample size of the conditional age-at-length data resulted in some change, where SSB is slightly higher early in the time series, but well within the confidence intervals of model 17.1. Model 17.1c incorporated the combined changes of 17.1a and 17.1b and model 17.1d was the sames model 17.1c but included an updated age error matrix. The updated age-error matrix had little effect on model results.

2-area model

Initial model runs indicated that when estimating growth, selectivity, and the recruitment distribution parameter, the model estimated the distribution parameter at the lower bound and estimated the western GOA growth parameters with unreasonably large standard errors (i.e., e+02 to e+05). The ability to estimate the recruitment distribution parameter is crucial to this model, since this is how the model distributes the population among the areas. Many subsequent runs were completed and included:

1. Fixing the growth parameters to the external estimates and the distribution parameter to the ratio of survey biomass in the west and survey biomass in the central GOA and estimate selectivity. This was done to obtain selectivity parameter estimates that were fix in the subsequent model runs.
2. Fixing the growth parameters to the external estimates and the selectivity parameters to the estimates from run 1 and estimate the distribution parameter
3. The same as 2 with a normal prior on the distribution parameter. The prior mean was the ratio of survey biomass in the west and survey biomass in the central GOA and the standard deviation was set equal to 3, a weak prior.
4. Run 3, but estimate growth parameters to evaluate whether the growth parameters could be estimated.

The distribution parameter was estimated at the lower bound when freely estimated (run 2), effectively estimating a single area model. The model fits are summarized in Figure 18-Figure 23. Most notably the mean age of the western GOA is grossly underestimated (Figure 23). The model fit to the data were similar for all the above mentioned model runs. When a weak prior was placed on the distribution pattern the parameter estimate moved away from the lower bound, but was still quite low at -2.364, which is equal to approximately 10% of the recruitment is in the western GOA, whereas almost 62% of survey biomass is in this area. When the growth parameters were estimated with a weak prior on the distribution parameter or with the distribution parameter fixed, the growth parameters associated with the western GOA were not estimated. The parameter values did not move from the initial values and the standard errors were unreasonably large. At this time, we cannot move forward with this 2-area model given the aforementioned reasons and the fact that the fits to the data were not improved.

Additional model runs

The CIE reviewers suggested estimating catchability in the model rather than assuming that catchability is equal to 1. This suggestion was made in reference to the uncertainty about rock sole inhabiting untrawlable habitats and are therefore not surveyed; however, the survey estimates are expanded across all habitat. This suggests that catchability is not equal to 1. However, there is evidence that rock sole escape the survey net by swimming underneath the net, more so northern rock sole than southern rock sole. These competing processes could have opposite impacts on the survey catchability. The model was run while freely estimating catchability (17.1e). When estimating catchability in the model, this parameter was estimated to be 2.97, indicating biomass is lower than when assuming catchability is equal to 1. At this time is it difficult to definitively say that catchability should be lower or higher than 1 and the author’s do not recommend estimating catchability at this time.

The CIE reviewers recommended that a model-based index be explored for reasons mentioned in the introduction. A VAST index was developed and the model was run with this input (17.1f). Lastly, the data weighting implemented within the model has been previously questioned, especially for the conditional age-at-length data by the SSC. The McAllister-Ianelli and Francis iterative reweighting approaches were explored for models 17.1d and 17.1f.

The model run with the VAST biomass estimates (17.1f) had a larger RMSE value associated with the fit to the index compared to the other model runs, suggesting a poorer fit to the biomass data (Table 2, Figure 24). This is mainly driven by the poor fit to the peak of the VAST index. Francis re-weighting (17.1h and 17.1j) led to a better fit to the survey biomass estimates with lower RMSE values and survey likelihoods, as would be expected. This led to poorer fit to the conditional age-at-length data; however, the fit to the length composition data improved (Table 2, Figure 25). It should be noted that the total likelihood was generally larger when less weight was placed on the conditional age-at-length data, which includes all model runs other than 17.1a, 17.1c-f.

Survey selectivity was estimated fairly consistently by each model run (Figure 26). Fishery selectivity for both females and males was more variable among the model runs. The peak of the female and male fishery selectivity curves were at a much larger size for model runs using the variance adjustments estimated by the iterative reweighting approaches. Additionally the width of the plateau was greatly reduced for the female fishery selectivity curve model runs using the variance adjustments leading to the selectivity on fish smaller than 60cm was greatly reduced. A similar pattern is seen in the male fishery selectivity curve, reducing the selectivity of fish less than ~45cm. However, the estimated male fishery selectivity by models 17.1g and 17.1h were asymptotic, while all others estimated some doming (Figure 26, right panel).

The estimated growth curves also differed among the model runs. Namely, when the variance adjustments from the reweighting approaches were implemented. This led to lower estimates of asymptotic growth and higher growth coefficient (Figure 27). Female natural mortality is fixed in the model and remains unchanged, while male natural mortality is estimated. Male natural mortality was slightly higher when the variance adjustments were implemented and when the VAST biomass estimates were used as a data input (Table 3).

In general, models with greater weight on the survey biomass and length composition data started and ended with lower SSB and higher fishing mortality than the models placing greater weight on the conditional age-at-length data (Figure 28). This is expected as the models are more closely following the trends in the survey biomass time series. A retrospective analysis was conducted for many of the models. Table 4 and Figure 29 summarize the results for select model runs. The Mohn's rho statistics for the 2017 assessment and models 17.1d and 17.1f are within the acceptable range given the rule of thumb suggested by Hurtado-Ferro et al. (2015). The analysis shows that the retrospective pattern can be improved by better fitting the survey biomass data. Although this was done through data reweighting, this also suggests that better understanding of survey catchability as it relates to escapement and untrawlable habitat is needed.

Southern rock sole

The model that included the updated fishery length composition data (17.1b) better fit the age composition data, while the fit to the length composition data degraded and the fit to the survey data was similar to the 2017 assessment (Table 5). Modifying the input sample size of the conditional age-at-length data resulted in almost no change to the results and the updated age-error matrix had little effect on model results when compared to 17.1b (Table 5Table 6, Figure 30-Figure 35). A model run estimating catchability (17.1e) was completed and catchability was estimated to be 1.2. The resulting model fits to the data, estimated growth and selectivity were similar to 17.1d.

Length-based survey selectivity was consistently estimated among the models (Figure 32). Fishery selectivity was more variable among the models, similar to northern rock sole. The introduction of the updated age error matrix and using VAST biomass estimates shifted the peak of the female fishery selectivity curve to a larger size, whereas for males the selectivity curves were similar for models 17.1-17.2e (Figure 32). Models using the variance adjustment values from the iterative reweighting approaches shifted the peak of both the female and male selectivity curves toward larger sizes and for males they were less domed. Comparing the age composition likelihoods to the length composition likelihoods within individual models, the length composition data were better fit than the conditional age-at-length data when reweighting was used as compared to the base model runs (Table 5). This helps to explain the shift in selectivity and indicates that there is a conflict between these two data sources. The female and male growth curves were similar among model runs 17.1-17.1f (Figure 33). In comparison, the asymptotic length, the length at the minimum age, and the standard deviation at young ages were larger and the growth coefficient and standard deviation at older ages were smaller when the variance adjustments through iterative reweighting were used in the model. Male natural mortality was estimated and was similar among the models.

A retrospective analysis was completed. The Mohn's rho associated with SSB was quite low for all model runs (Table 7). Mohn's rho in SSB was minimized when the VAST biomass estimates were used as a data input, while estimating catchability minimized the Mohn's rho in fishing mortality.

Conclusions

Many model runs were completed for northern and southern rock sole and a 2-area model was explored for northern rock sole. There are obvious differences in growth between the western and central GOA, but at this time it is not feasible to use the 2-area model. We recommend moving forward with the base model 17.1 with the update age error matrix with Francis reweighting for the assessment of northern rock sole. We also recommend using the base model 17.1 with the updated age error matrix and VAST survey biomass estimates for the assessment of southern rock sole. These recommendations are based on the model fit to the data, the likelihood results, as well at the retrospective analysis results.

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Tables

Table 1. AIC results comparing growth models externally estimated from the assessment model.

Species	Sex	model	rss	AIC	Delta AIC
NRS	Female	**Growth ≠**	**52659.9**	**16395.1**	**-**
		vbK =	53165.0	16420.2	25.2
		t0 =	53256.3	16425.1	30.0
		L∞ =	53258.7	16425.2	30.2
		Growth =	72864.6	17313.3	918.2
NRS	Male	**Growth ≠**	**23270.6**	**10803.3**	**-**
		vbK =	23298.6	10803.7	0.5
		t0 =	23316.7	10805.3	2.0
		L∞ =	23668.6	10836.0	32.7
		Growth =	28958.4	11245.1	441.8
SRS	Female	**t0 =**	**57082.5**	**20420.7**	**-**
		Growth ≠	57069.1	20421.8	1.1
		vbK =	57103.5	20422.0	1.3
		L∞ =	57479.0	20446.0	25.3
		Growth =	63012.7	20777.7	357.1
SRS	Male	**t0 =**	**22945.2**	**11434.5**	**-**
		Growth ≠	22935.9	11435.6	1.1
		L∞ =	22957.6	11435.7	1.2
		vbK =	22965.3	11436.4	1.9
		Growth =	23804.6	11511.6	77.1

Table 2. Northern rock sole: Model run number and description, index RMSE, likelihood components and total likelihood.

			Likelihood					
Model	Model description	Index RMSE	Survey	Age_comp	Catch	Length_comp	Recruitment	Total
17.1	2017 assessment	0.18	-11.92	727.65	0.00	298.59	-11.97	1006.19
17.1a	Minimum sample size fix for CAAL	0.19	-11.25	431.52	0.00	294.60	-12.61	706.06
17.1b	Updated fishery length comp	0.19	-11.17	727.62	0.00	463.72	-11.07	1172.82
17.1c	Combination of a and b	0.20	-10.43	431.99	0.00	459.55	-11.71	873.10
17.1d	Updated age error matrix	0.20	-10.32	430.85	0.00	458.79	-11.54	871.48
17.1e	d plus estimate catchability	0.19	-12.14	436.35	0.00	448.70	-11.40	863.07
17.1f	d plus VAST survey biomass	0.20	-4.74	430.53	0.00	462.06	-7.91	883.80
17.1g	d and McAllister-Ianelli reweighting	0.23	-6.42	1902.14	0.00	839.72	-9.52	2730.67
17.1h	d with Francis reweighting	0.15	-15.47	1503.92	0.00	103.45	-10.65	1584.80
17.1i	f with McAllister-Ianelli reweighting	0.22	0.14	1903.82	0.00	840.69	-6.31	2743.08
17.1j	f with Francis reweighting	0.16	-12.39	1448.91	0.00	98.73	-6.89	1531.98

Table 3. Northern rock sole: Growth parameter and natural mortality estimates for the individual model runs.

Model	Model description	Sex	L_a_Amin	Linf	K	CVmin	CVmax	Natural mortality
17.1	2017 assessment	Female	10.80	42.66	0.23	2.18	7.50	0.20
17.1d	Updated error matrix	Female	11.04	42.73	0.23	2.08	7.27	0.20
17.f	d plus VAST index	Female	10.83	42.16	0.24	2.11	7.14	0.20
17.1g	d and McAllister-Ianelli reweighting	Female	10.41	41.05	0.25	2.46	6.52	0.20
17.1h	d with Francis reweighting	Female	9.45	41.57	0.26	2.97	5.80	0.20
17.1i	f with McAllister-Ianelli reweighting	Female	10.36	41.02	0.25	2.47	6.51	0.20
17.1j	f with Francis reweighting	Female	9.40	41.60	0.26	2.98	5.78	0.20
17.1	2017 assessment	Male	10.55	37.18	0.27	2.23	5.52	0.25
17.1d	Updated error matrix	Male	11.22	37.74	0.26	1.86	5.55	0.25
17.f	d plus VAST index	Male	11.30	37.49	0.26	1.82	5.61	0.26
17.1g	d and McAllister-Ianelli reweighting	Male	10.43	35.10	0.31	2.18	4.78	0.26
17.1h	d with Francis reweighting	Male	9.17	35.72	0.33	2.87	3.99	0.26
17.1i	f with McAllister-Ianelli reweighting	Male	10.39	35.05	0.32	2.18	4.77	0.26
17.1j	f with Francis reweighting	Male	9.15	35.79	0.33	2.88	3.99	0.26

Table 4. Northern rock sole: Mohn's rho statistics from the retrospective analysis. The Mohn's rho values for 17.1d are similar to the 2017 assessment (not reported).

Model	Model description	SSB	Recruitment	Fishing mortality
17.1d	Updated age error matrix	0.24	0.17	-0.15
17.1f	d plus VAST index	0.20	0.20	-0.17
17.1h	d with Francis reweighting	0.11	0.18	-0.04
17.1j	f with Francis reweighting	0.10	0.22	-0.01

Table 5. Southern rock sole: Model run number and description, index RMSE, likelihood components and total likelihood.

Model	Model description	Index RMSE	Age_comp	Catch	Length_comp	Recruitment	Survey	Total
17.1	2017 assessment	0.113	787.11	0.00	189.01	-9.96	-18.70	953.25
17.1b	Updated fishery length composition data	0.116	470.76	0.00	525.00	-10.33	-18.33	973.14
17.1c	b plus corrected CAAL minimum sample size	0.116	470.76	0.00	525.00	-10.33	-18.33	973.14
17.1d	c plus updated age error matrix	0.116	470.27	0.00	524.57	-10.04	-18.28	972.62
17.1e	d plus estimated catchability	0.117	470.95	0.00	524.26	-10.03	-18.22	972.53
17.1f	d plus VAST biomass and standard error	0.089	469.72	0.00	524.84	-10.08	-20.04	970.90
17.g	d and McAllister-Ianelli reweighting	0.146	1927.80	0.00	954.17	-5.74	-13.63	2871.30
17.1h	d plus Francis reweighting	0.137	648.05	0.00	152.84	-9.69	-14.94	782.80
17.1i	f with McAllister-Ianelli reweighting	0.113	1927.47	0.00	954.89	-5.82	-14.51	2871.05
17.1j	f with Francis reweighting	0.107	658.29	0.00	151.81	-9.84	-16.01	791.07
17.1k	e with McAllister-Ianelli reweighting	0.141	1927.69	0.00	956.94	-5.95	-14.31	2875.21
17.1l	e with Francis reweighting	0.136	647.86	0.00	153.65	-9.71	-15.07	784.04

Table 6. Southern rock sole: Growth parameter and natural mortality estimates for the individual model runs.

Model	Model description	Sex	L_a_A1	Linf	K	CVmin	CVmax	Natural mortality
17.1	2017 assessment	Female	12.29	48.06	0.20	3.17	4.83	0.20
17.1b	Updated fishery length composition data	Female	13.65	49.19	0.18	2.89	5.21	0.20
17.1c	b plus corrected CAAL minum sample size	Female	13.65	49.19	0.18	2.89	5.21	0.20
17.1d	c plus updated age error matrix	Female	13.46	49.04	0.18	2.45	5.26	0.20
17.1e	d plus estimated catchability	Female	13.45	49.10	0.18	2.46	5.25	0.20
17.1f	d plus VAST biomass and standard error	Female	13.49	49.01	0.18	2.45	5.26	0.20
17.g	d and McAllister-Ianelli reweighting	Female	12.19	47.17	0.21	3.02	4.42	0.20
17.1h	d plus Francis reqeighting	Female	11.03	46.83	0.23	3.48	4.01	0.20
17.1i	f with McAllister-Ianelli reweighting	Female	12.20	47.16	0.21	3.02	4.42	0.20
17.1j	f with Francis reweighting	Female	11.06	46.83	0.23	3.48	4.01	0.20
17.1k	e with McAllister-Ianelli reweighting	Female	12.15	47.08	0.21	3.02	4.42	0.20
17.1l	e with Francis reweighting	Female	10.98	46.78	0.23	3.49	4.00	0.20
17.1	2017 assessment	Male	13.69	40.34	0.21	2.39	4.49	0.26
17.1b	Updated fishery length composition data	Male	14.86	41.00	0.19	2.05	5.38	0.27
17.1c	b plus corrected CAAL minum sample size	Male	14.86	41.00	0.19	2.05	5.38	0.27
17.1d	c plus updated age error matrix	Male	14.73	40.84	0.19	1.69	5.39	0.27
17.1e	d plus estimated catchability	Male	14.76	40.85	0.19	1.68	5.41	0.27
17.1f	d plus VAST biomass and standard error	Male	14.68	40.82	0.20	1.69	5.36	0.27
17.g	d and McAllister-Ianelli reweighting	Male	13.51	38.48	0.25	2.34	3.71	0.28
17.1h	d plus Francis reqeighting	Male	12.62	38.04	0.27	2.79	3.09	0.28
17.1i	f with McAllister-Ianelli reweighting	Male	13.50	38.48	0.25	2.34	3.71	0.28
17.1j	f with Francis reweighting	Male	12.59	38.04	0.27	2.79	3.09	0.28
17.1k	e with McAllister-Ianelli reweighting	Male	13.44	38.47	0.25	2.36	3.69	0.28
17.1l	e with Francis reweighting	Male	12.55	38.04	0.27	2.80	3.08	0.28

Table 7. Southern rock sole: Mohn's rho statistics from the retrospective analysis.

Model	Description	SSB	Fishing mortality	Recruitment
17.1	2017 assessment	0.01	0.19	-0.13
17.1d	c plus updated age error matrix	0.03	0.13	-0.12
17.1e	d plus estimated catchability	0.03	0.11	-0.11
17.1f	d plus VAST biomass and standard error	0.01	0.12	-0.11
17.1h	d plus Francis reweighting	0.05	0.28	-0.07
17.1j	f with Francis reweighting	0.02	0.26	-0.06
17.1l	e with Francis reweighting	-0.04	0.15	0.03

Figures

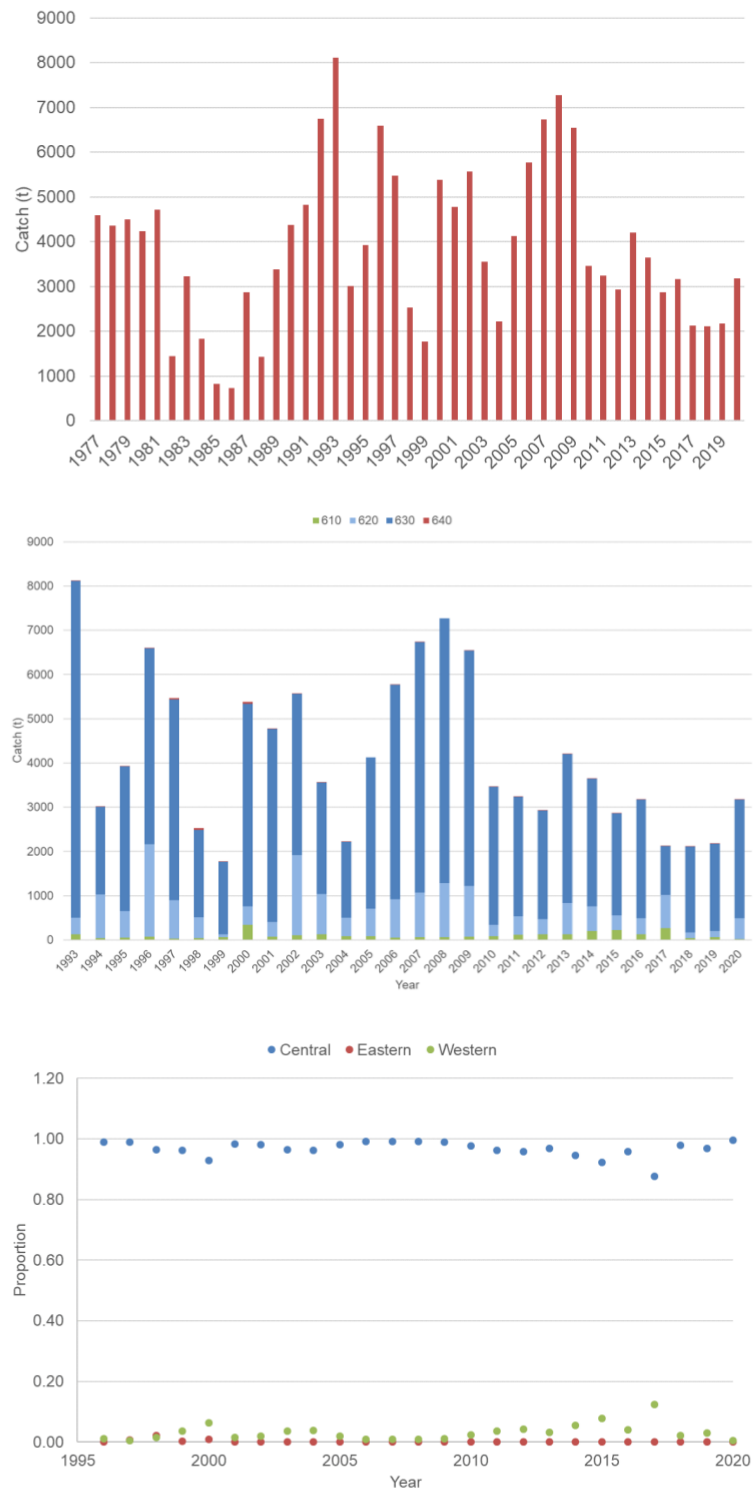


Figure 1. Total rock sole catch (retained + discards) overall (top panel) and by NMFS area (middle panel) and proportion of catch by area (bottom panel). Area 610 represents the western GOA and areas 620 and 630 represent the Central GOA.

Figure 2. Northern rock sole (right panels) and southern rock sole (left panels) survey biomass with 95% confidence intervals (top panels) and proportion of biomass by area (bottom panels). Bars represent the 95% confidence intervals around each point.

Figure 3. Northern rock sole (top) and southern rock sole (bottom) design-based and model estimated (VAST) survey biomass estimates. Lines represent the 95% confidence interval.

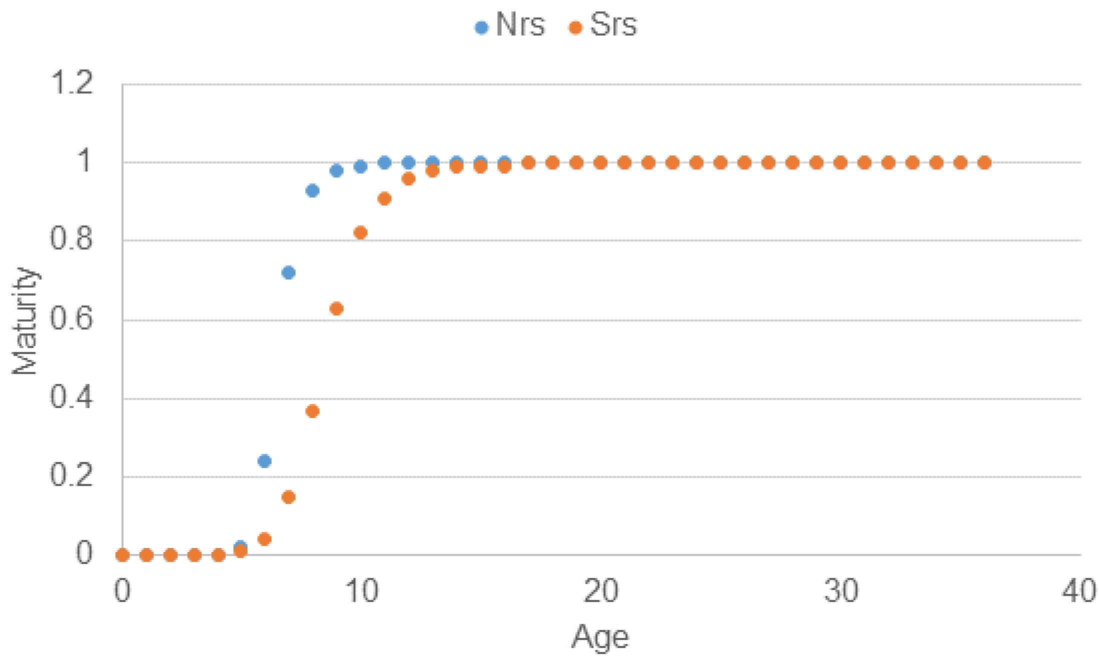
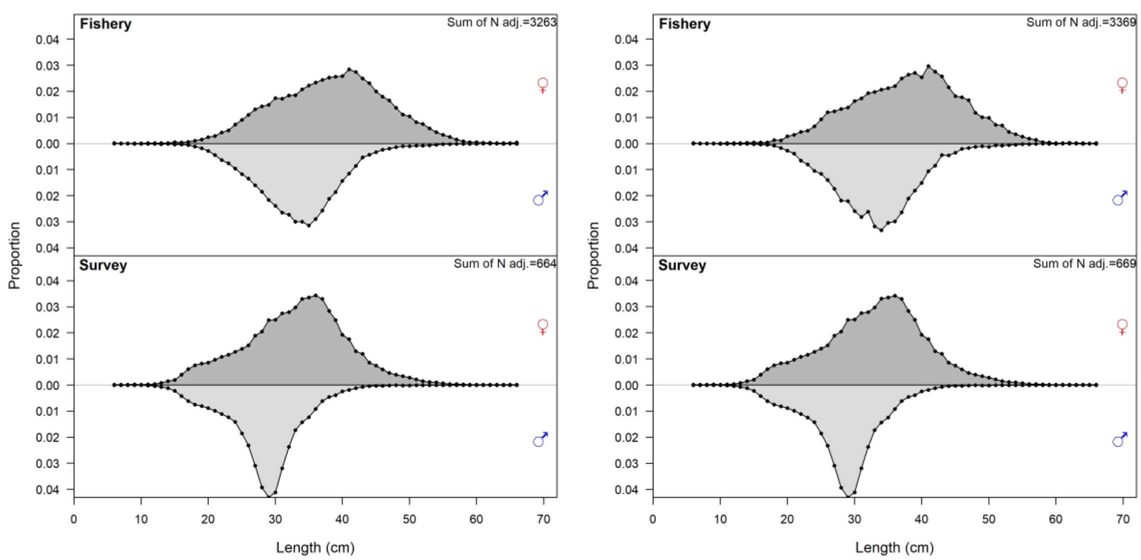


Figure 4. Northern and southern rock sole maturity curves.



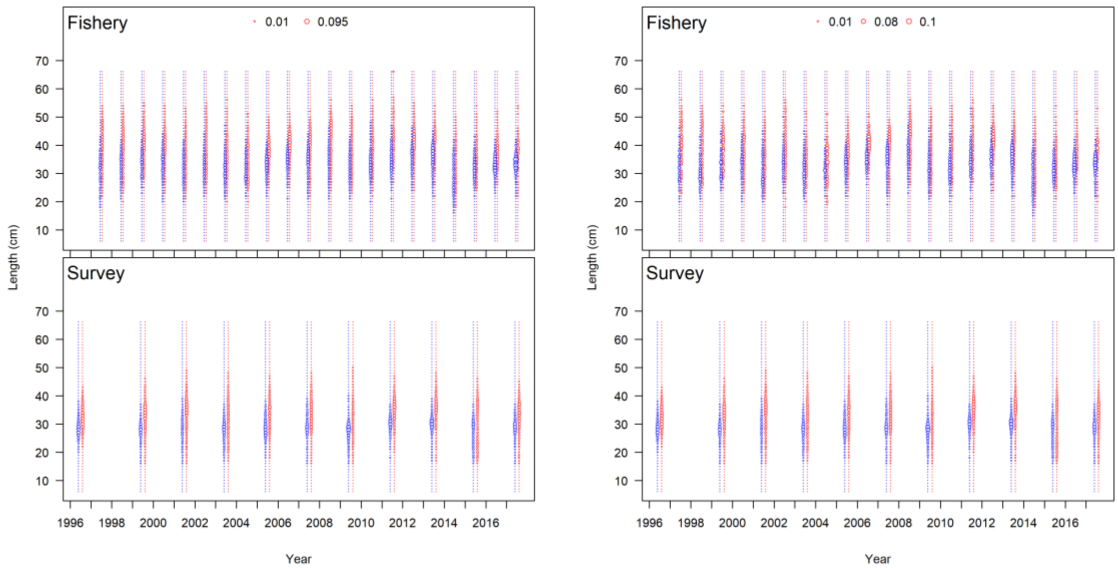
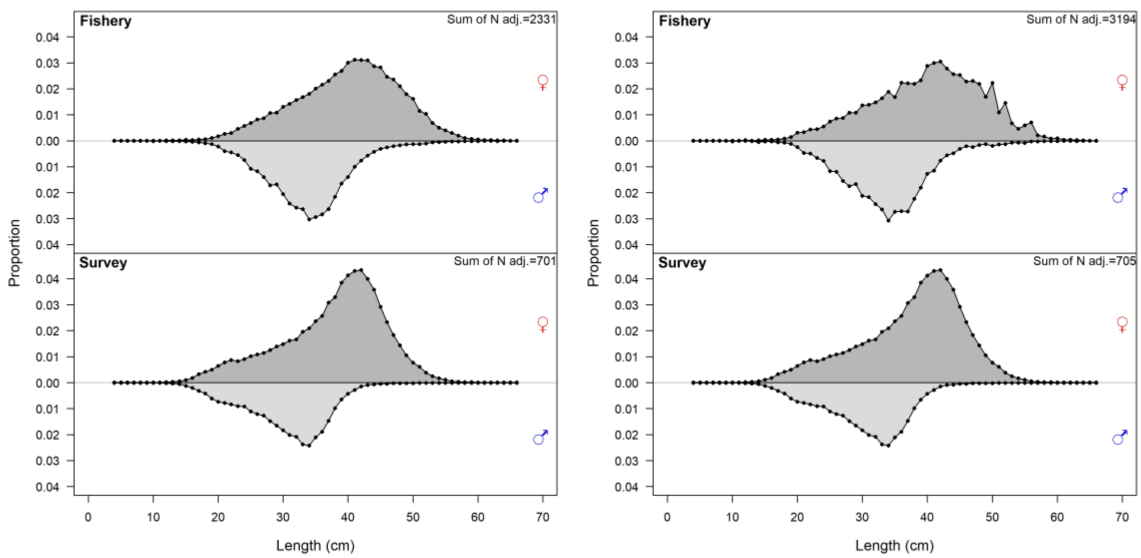


Figure 5. Northern rock sole length composition data (overall, top panels) and by year (bottom panels) from the 2017 assessment (right panels) and this year's update (left panels).



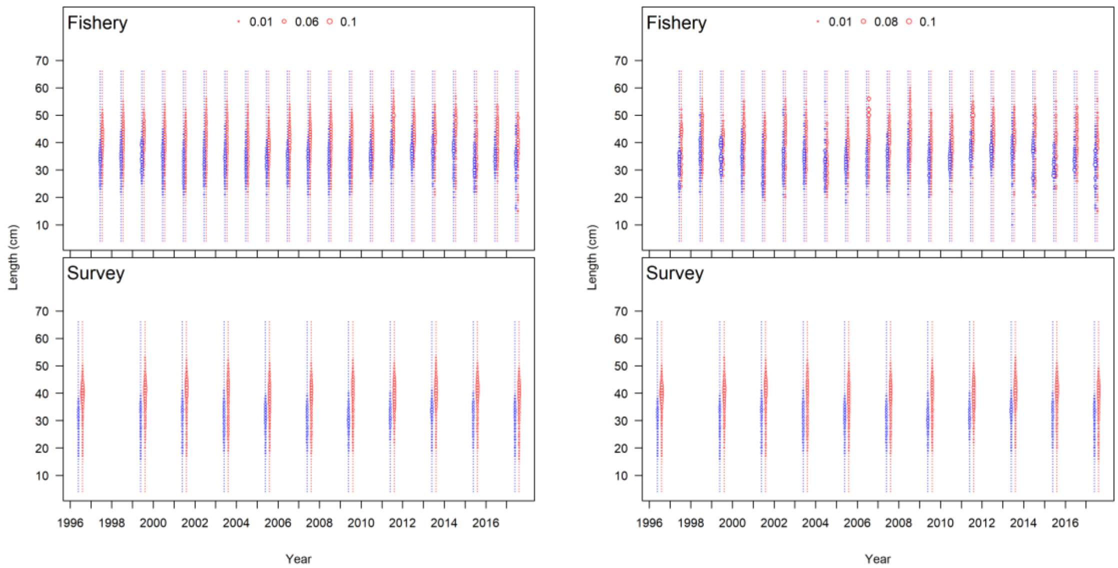


Figure 6. Southern rock sole length composition data (overall, top panels) and by year (bottom panels) from the 2017 assessment (right panels) and this year's update (left panels).

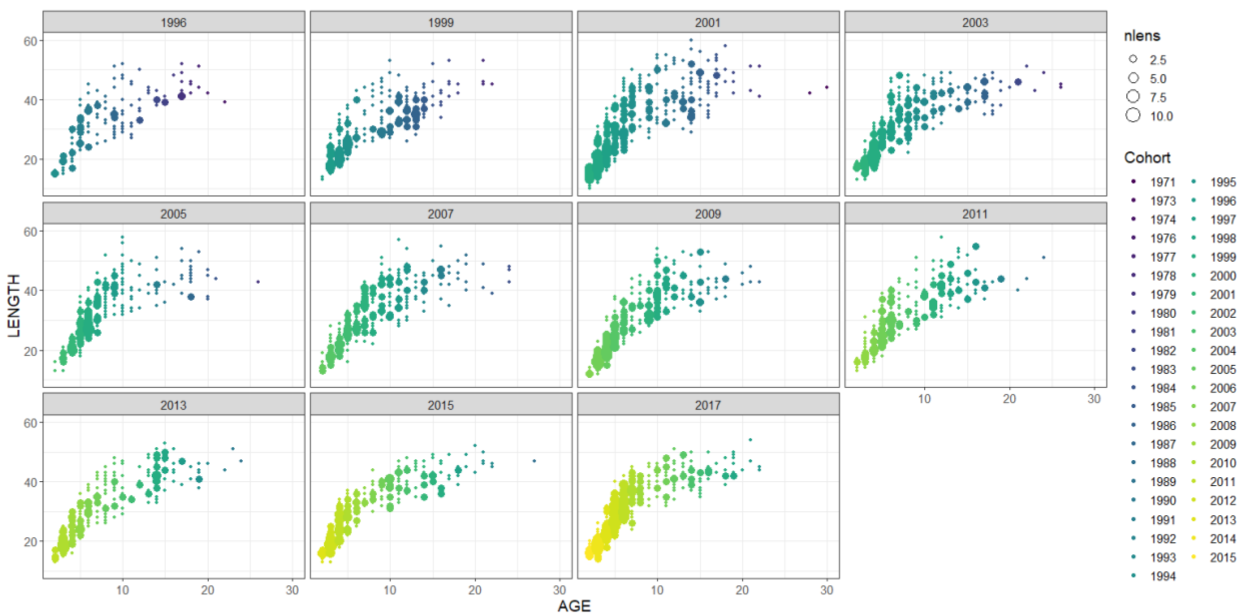


Figure 7. Female northern rock sole age-length data over time and by cohort.

Figure 8. Male northern rock sole age-length data over time and by cohort.

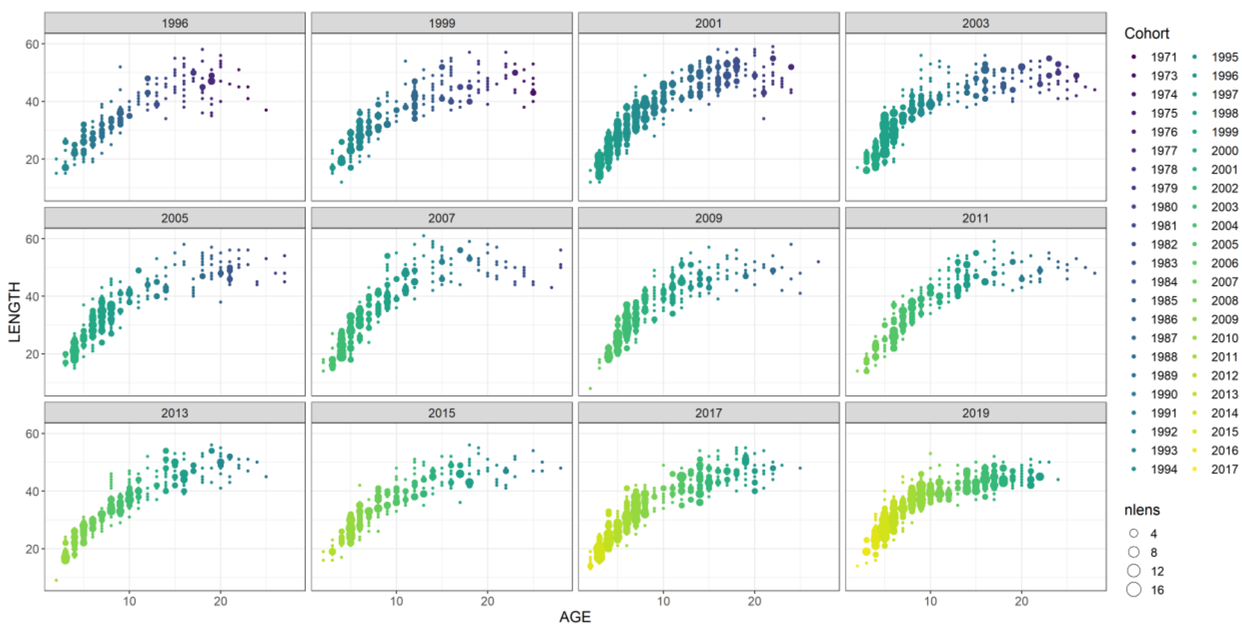


Figure 9. Female southern rock sole age-length data over time and by cohort.

Figure 10. Male southern rock sole age-length data over time and by cohort.

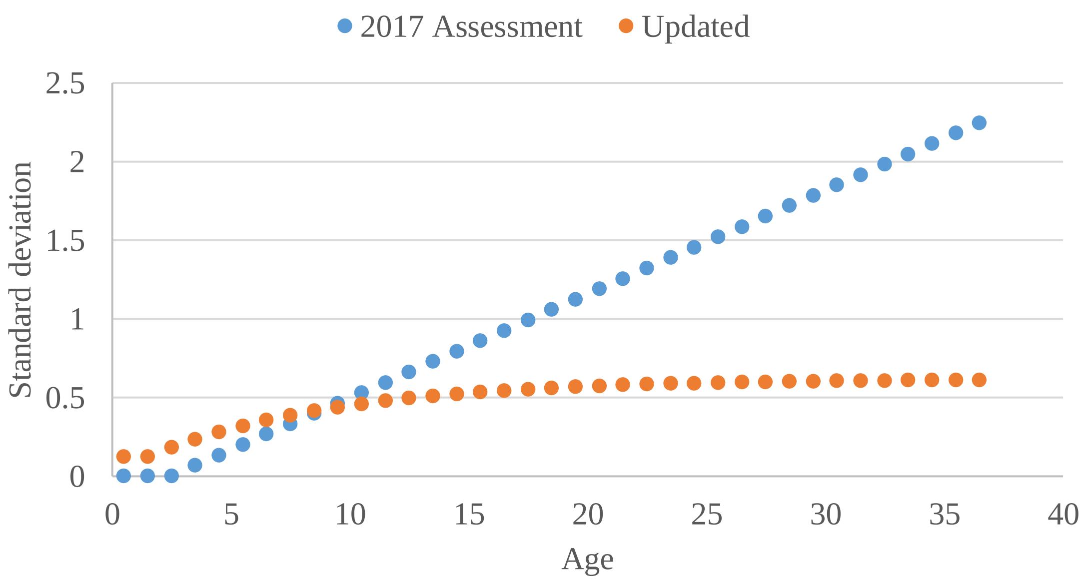


Figure 11. Age error matrix used in previous assessments and an updated age error matrix for northern rock sole (top) and southern rock sole (bottom).

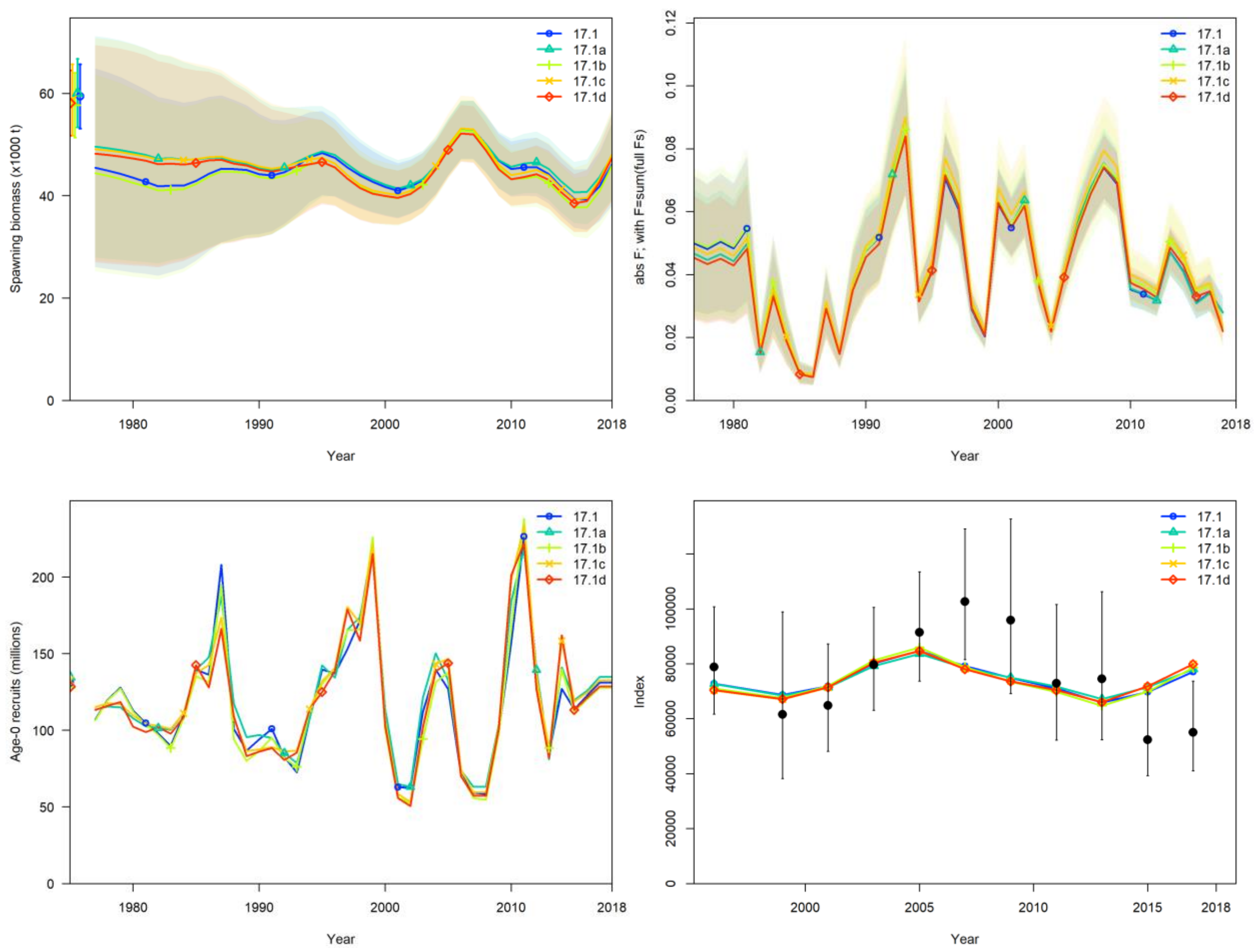


Figure 12. Northern rock sole SSB (t), fishing mortality (F), Age-0 recruits, and fit to the survey index from models 17.1 and 17.1a-d.

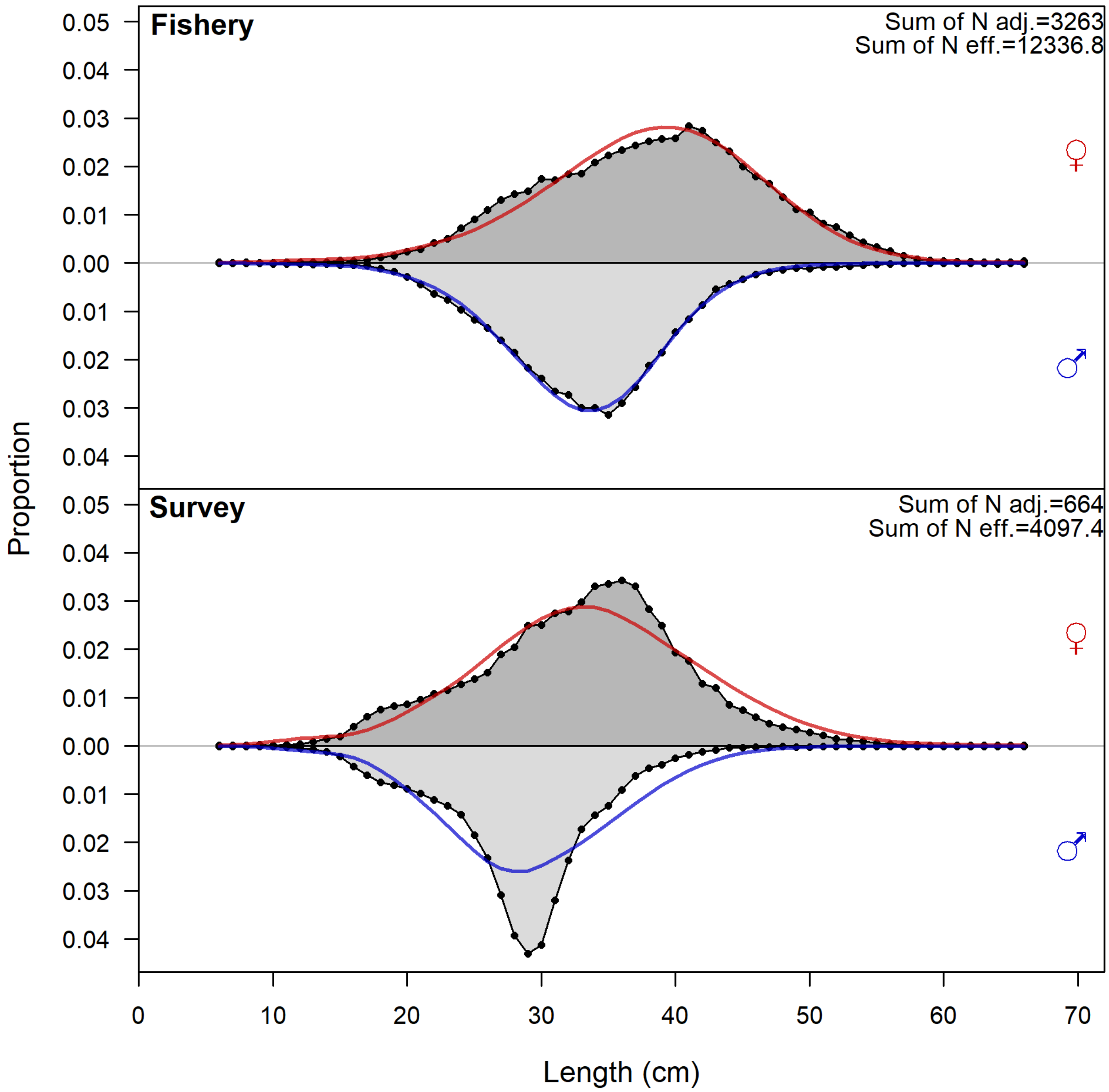


Figure 13. Fishery (top panel) and survey (bottom pane) length composition data in grey and model 17.1 fit to the northern rock sole data, females (red line) and males (blue line).

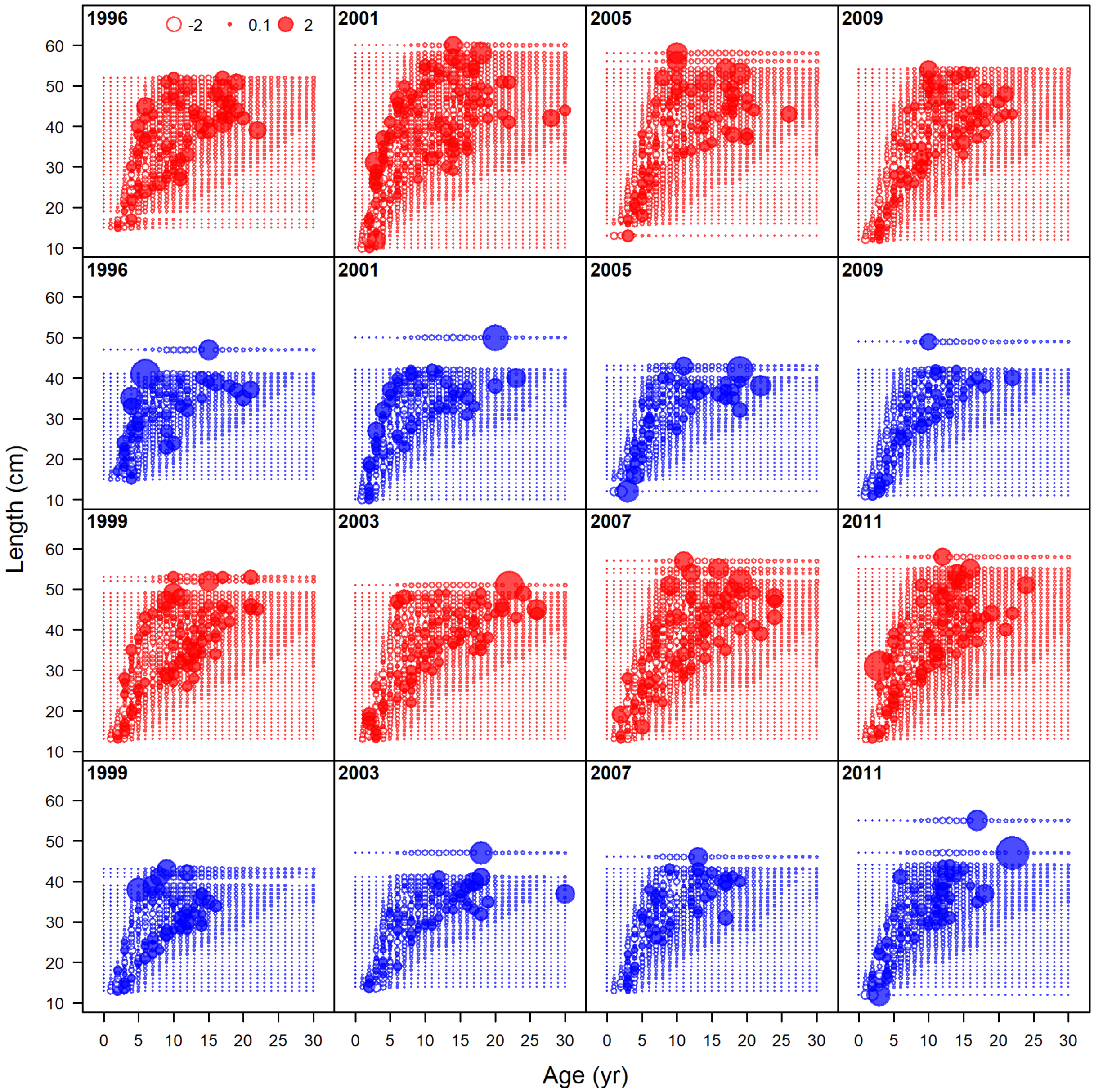


Figure 14. Pearson residuals from model 17.1 fit to the northern rock sole conditional age-at-length data. Red signifies females and blue signifies males

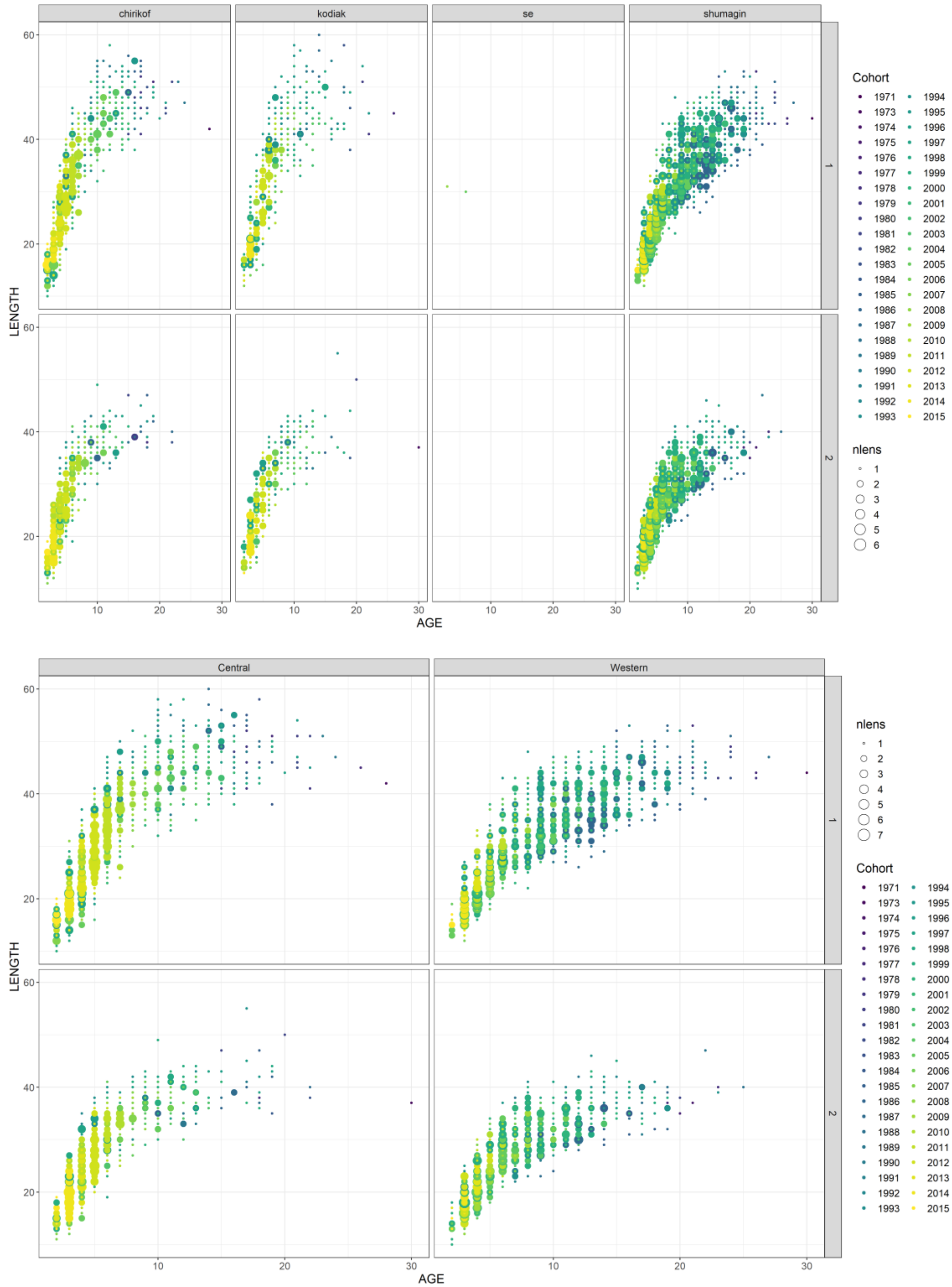


Figure 15. Northern rock sole age-length data by area, cohort, and sex (1=female, 2= male). The top panel shows the data by NMFS area and the bottom panel shows the west (Shumagin) and central (Chirikof and Kodiak aggregated) areas.

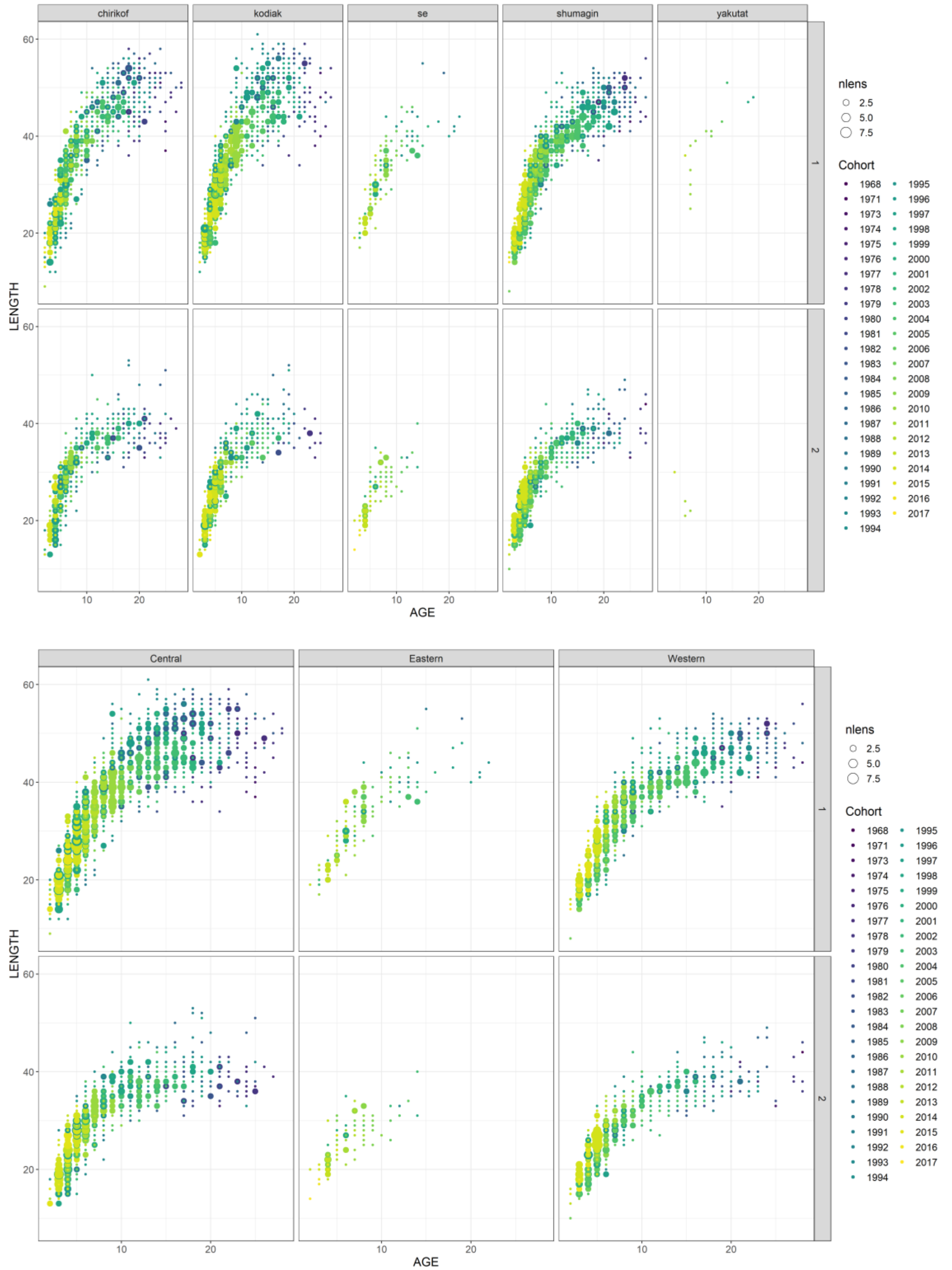


Figure 16. Southern rock sole age-length data by area, cohort, and sex (1=female, 2= male). The top panel shows the data by NMFS area and the bottom panel shows the west (Shumagin) and central (Chirikof and Kodiak aggregated) and eastern (Yakutat and SE) areas.

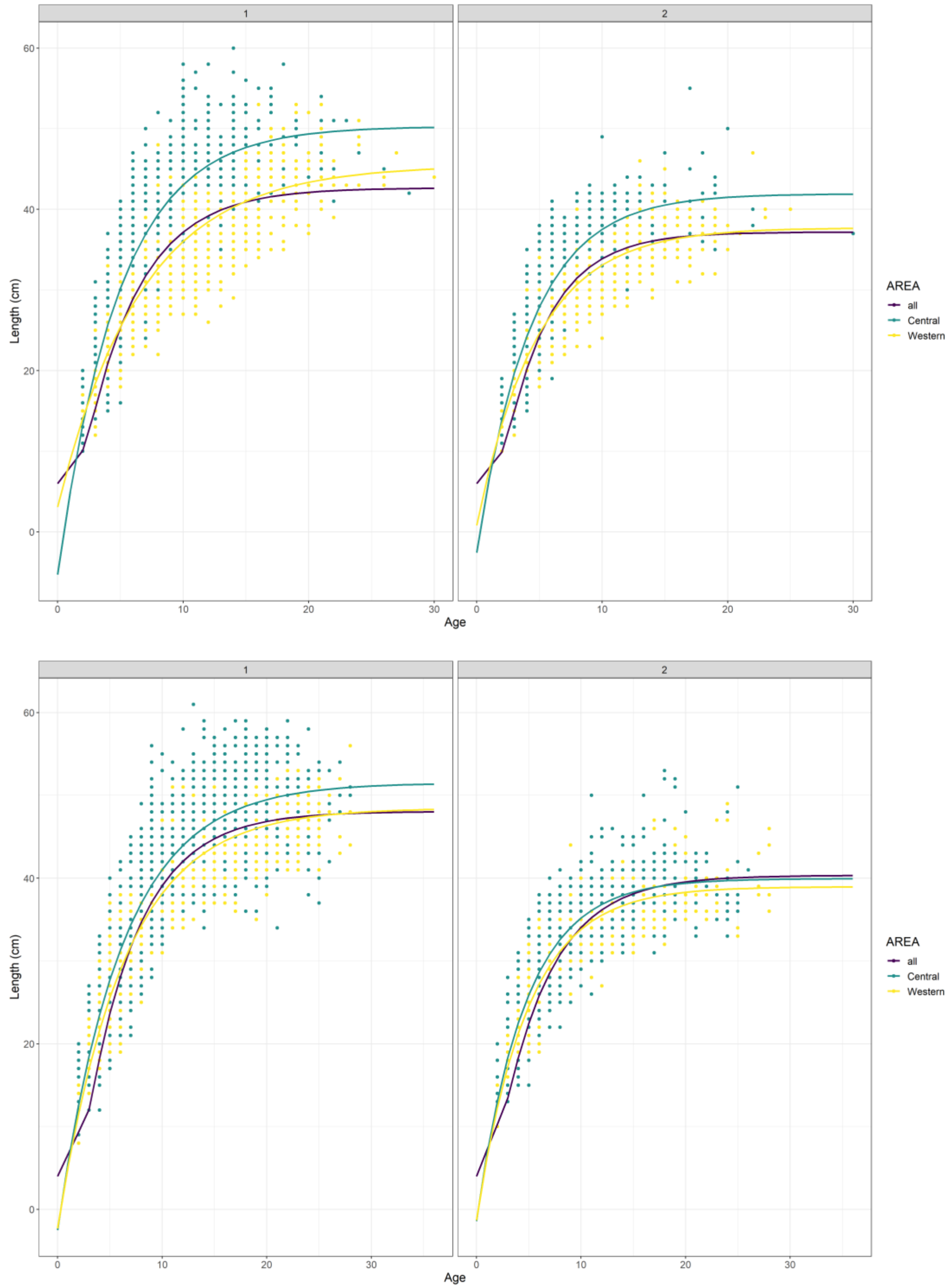
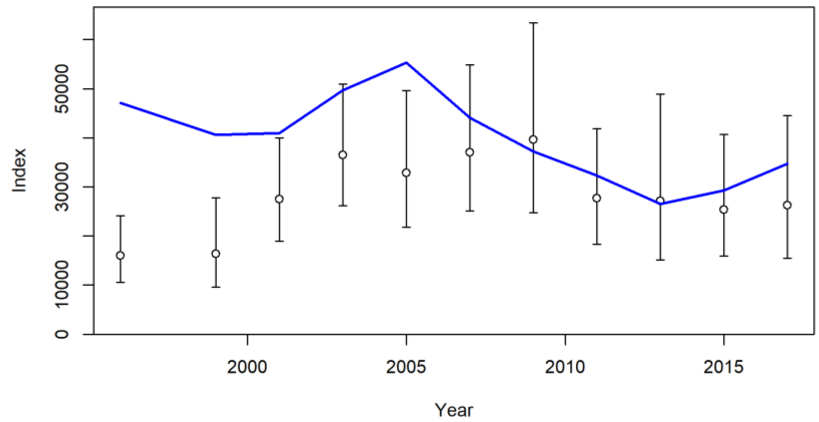
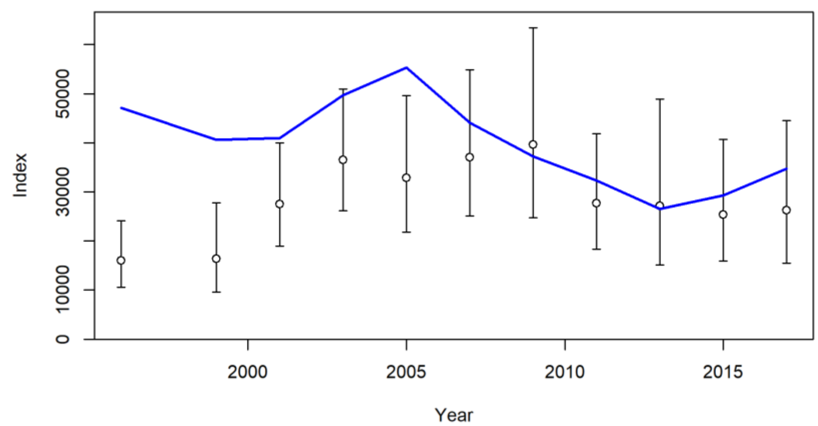


Figure 17. Northern rock sole (top panel) and southern rock sole (bottom panel) female (left panels) and male (right panels) age-length data (colored dots) and the growth curves estimated externally and estimated in by model 17.1 (labeled all under AREA). Area specific curves were derived from external model with the lowest AIC in Table 1.





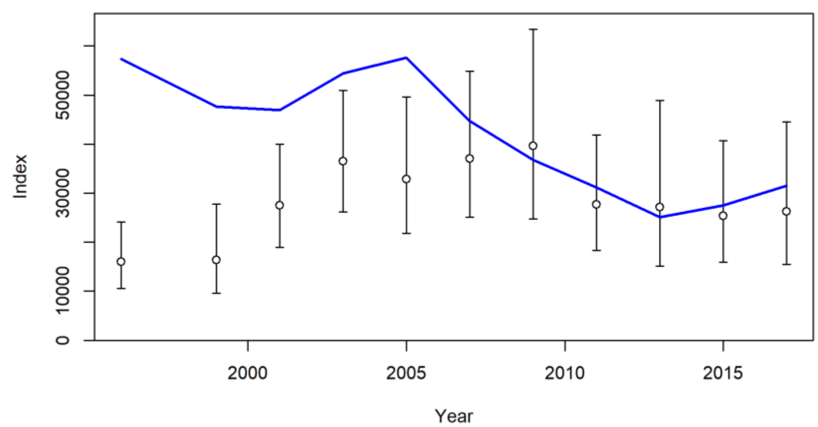


Figure 18. Two area model fit to the central GOA survey northern rock sole biomass: run 2 (top), run 3 (middle), and run 4 (bottom).

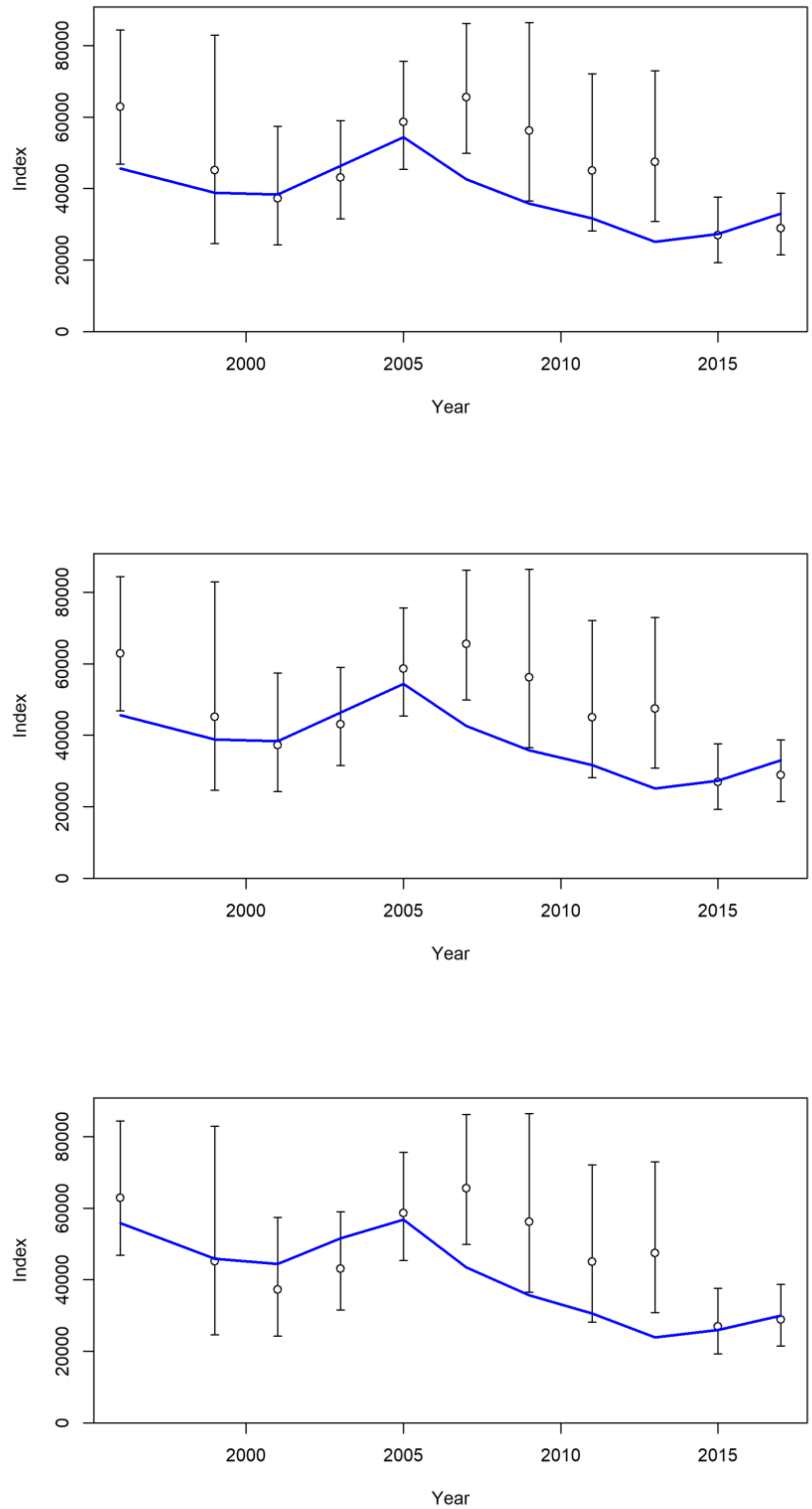


Figure 19. Two area model fit to the western GOA survey northern rock sole biomass: run 2 (top), run 3 (middle), and run 4 (bottom).

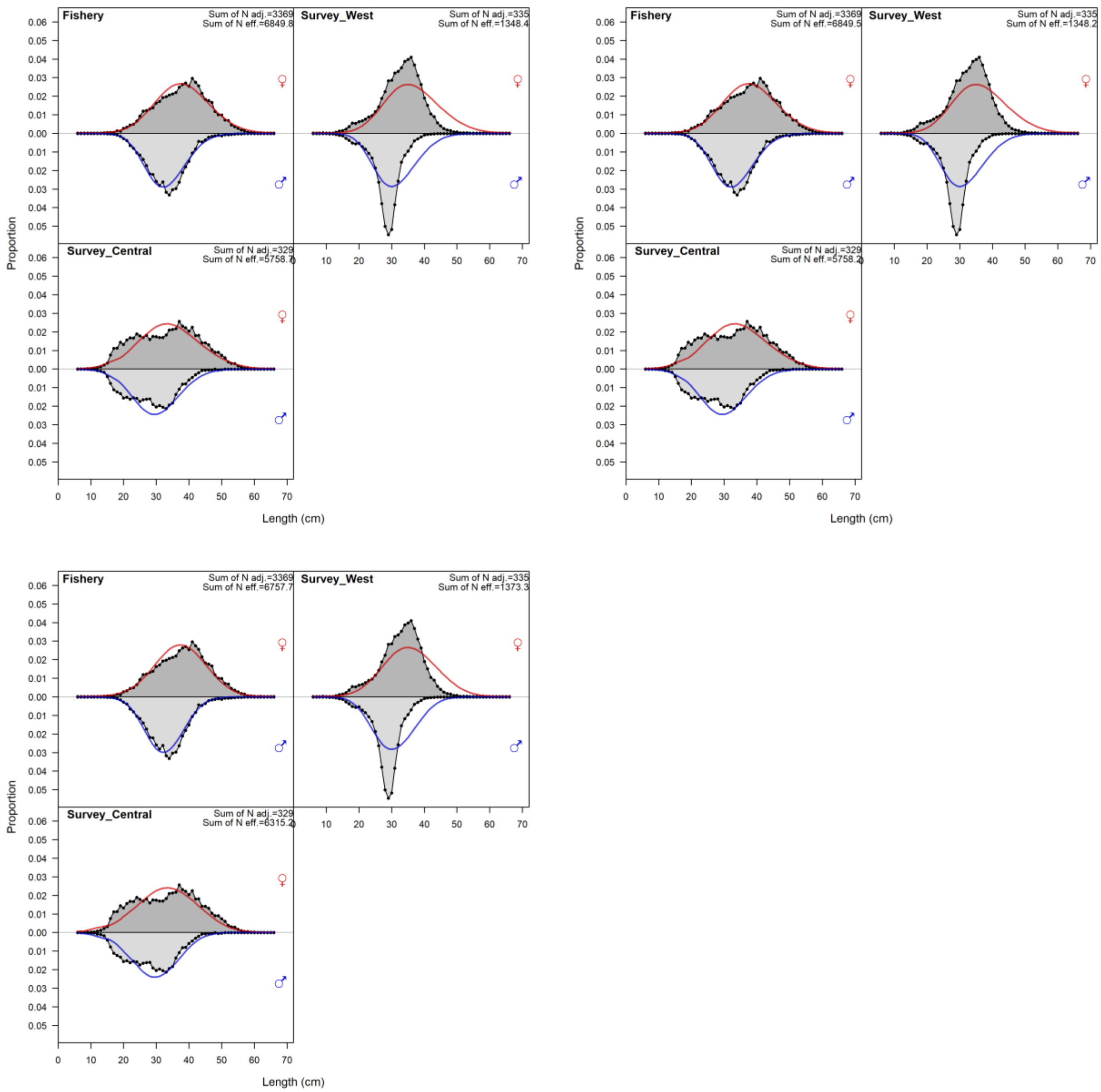


Figure 20. Two area model fit to the northern rock sole length composition data: run 2 (top left), run 3 (top right), and run 4 (bottom left).

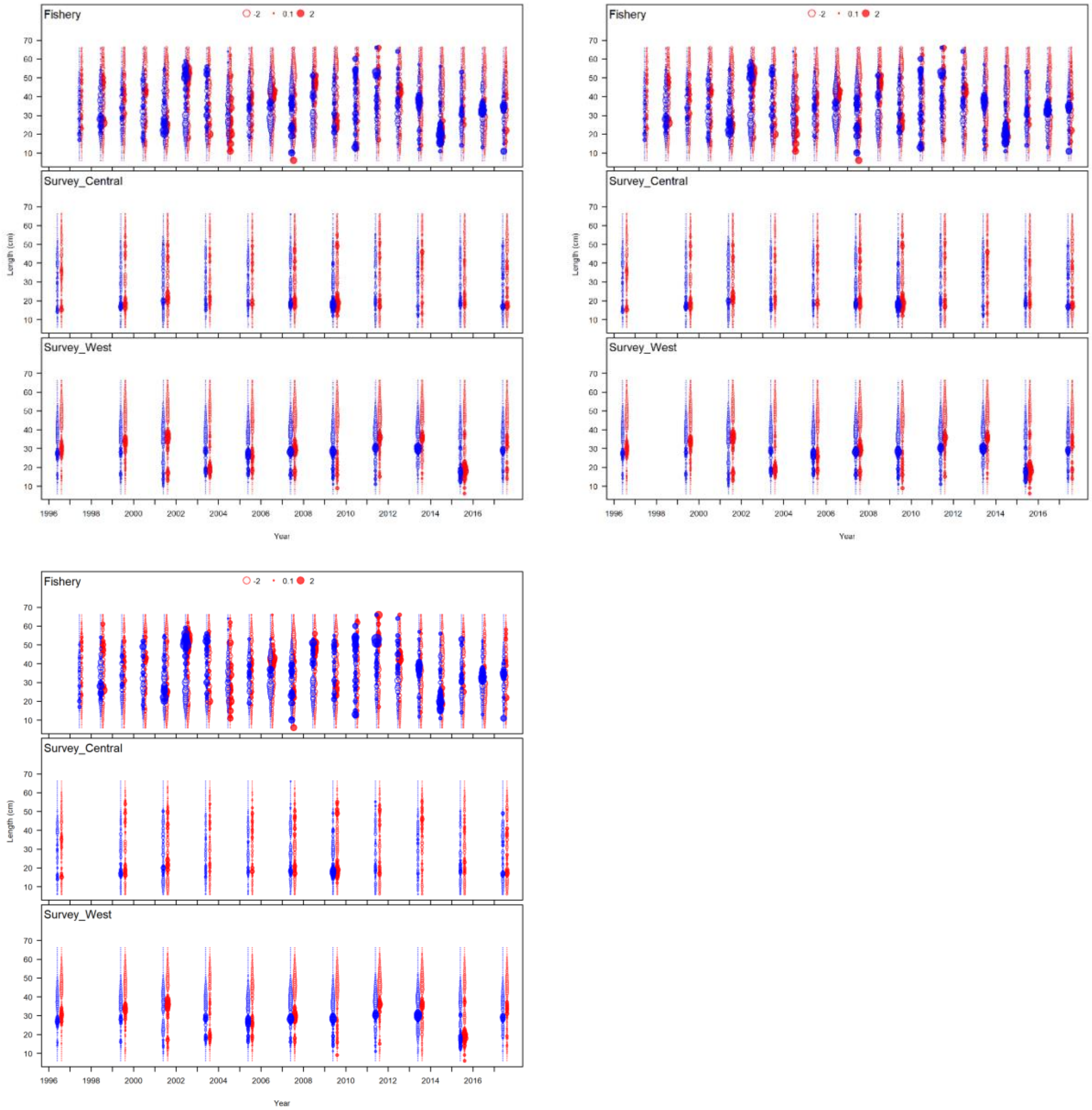


Figure 21. Pearson residuals associated with the northern rock sole length composition data : run 2 (top), run 3 (middle), and run 4 (bottom).

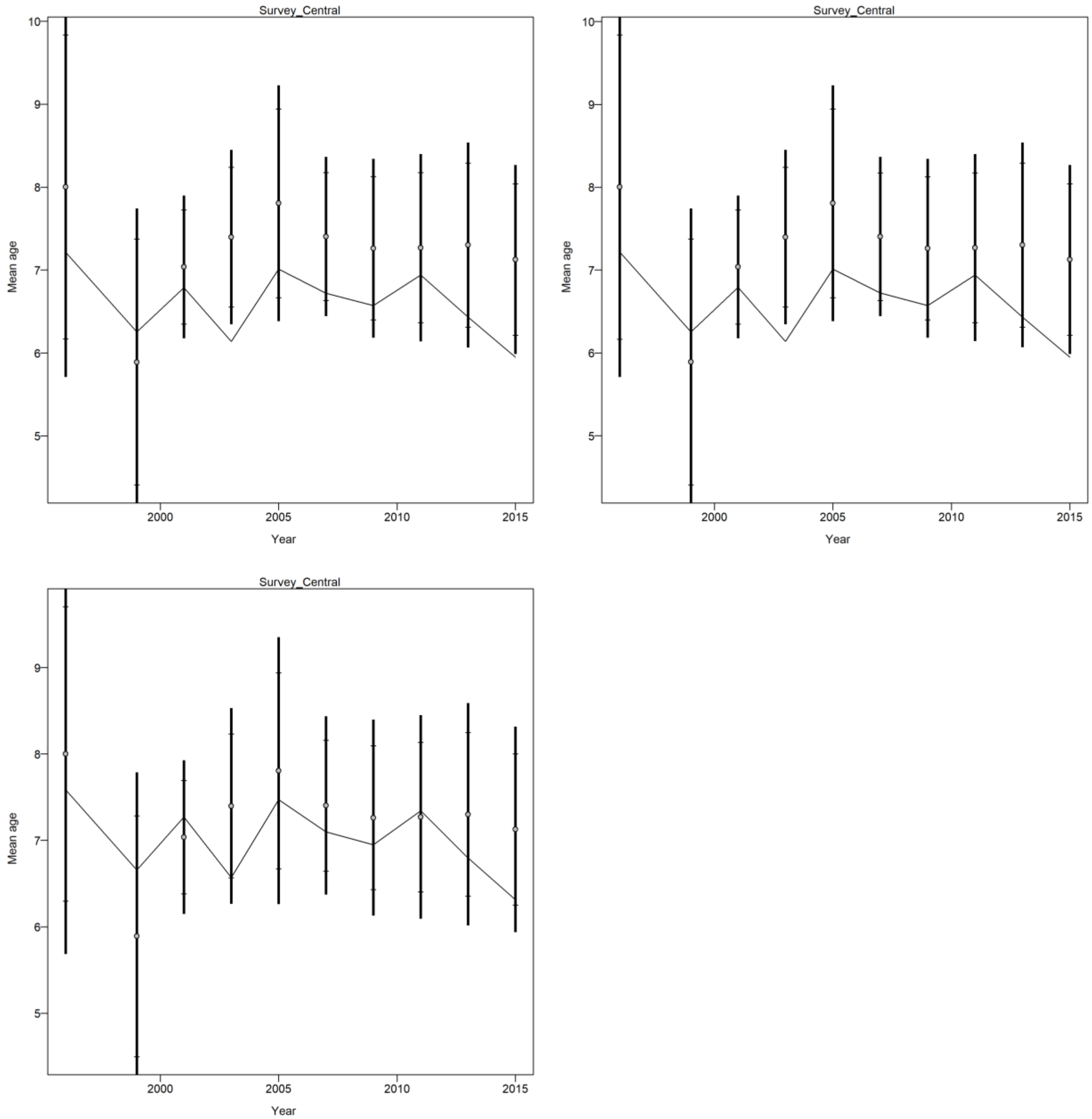


Figure 22. Mean age from the northern rock sole conditional age-at-length data for the central GOA and model fit: run 2 (top left), run 3 (top right), and run 4 (bottom).

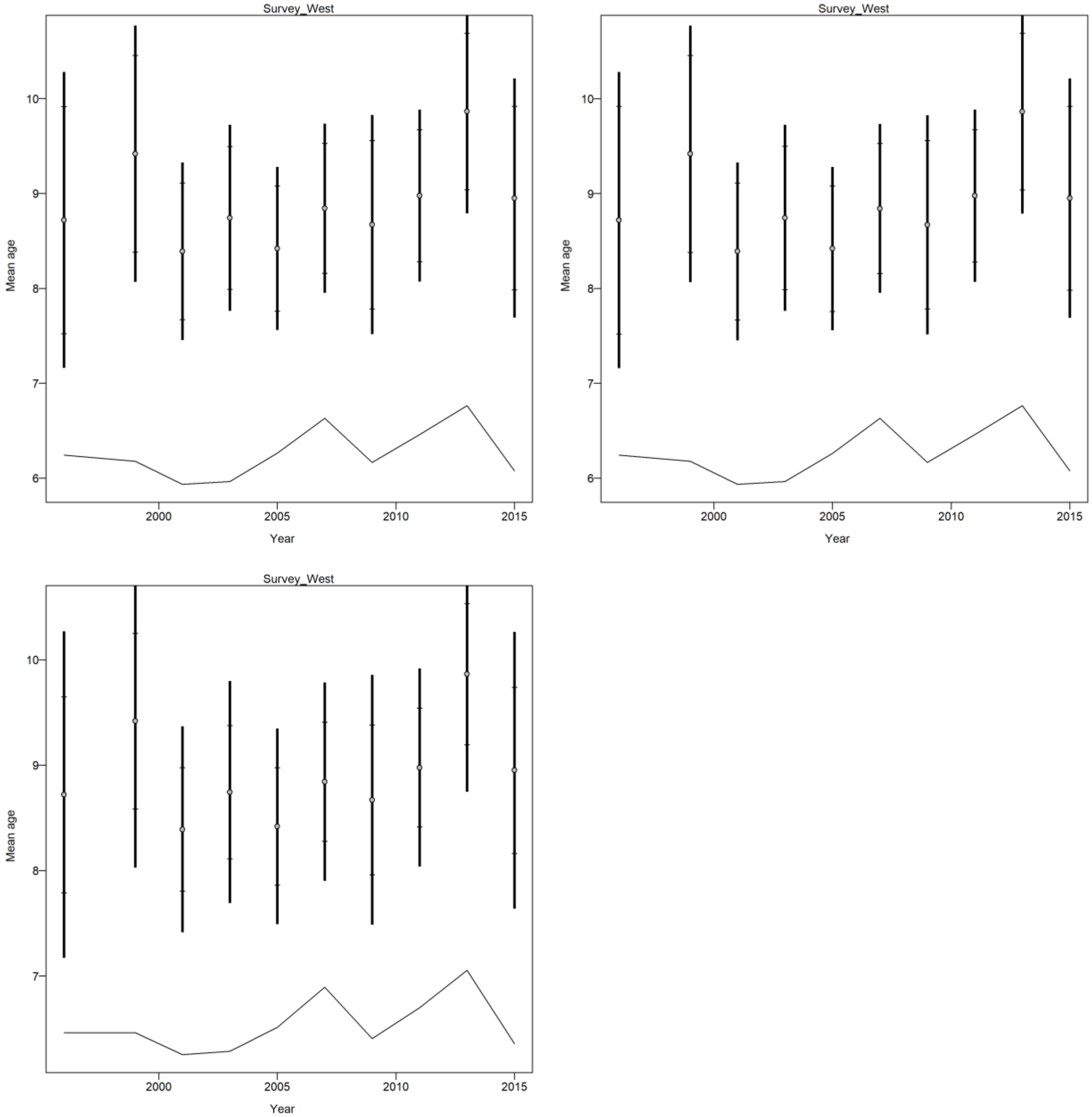


Figure 23. Mean age from the northern rock sole conditional age-at-length data for the western GOA and model fit : run 2 (top left), run 3 (top right), and run 4 (bottom).

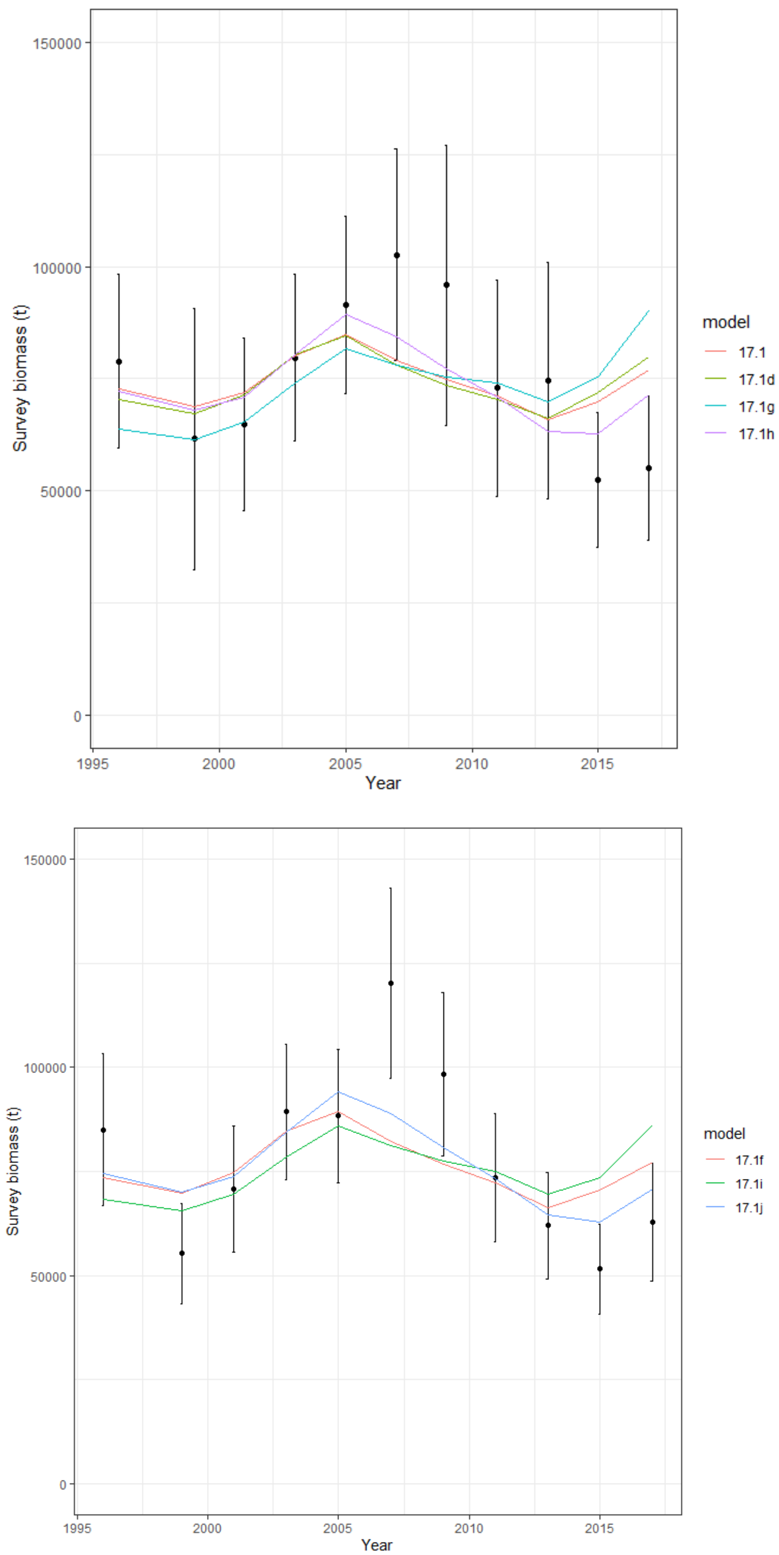


Figure 24. Model fit to northern rock sole survey biomass, design-based index (top) and VAST (bottom).

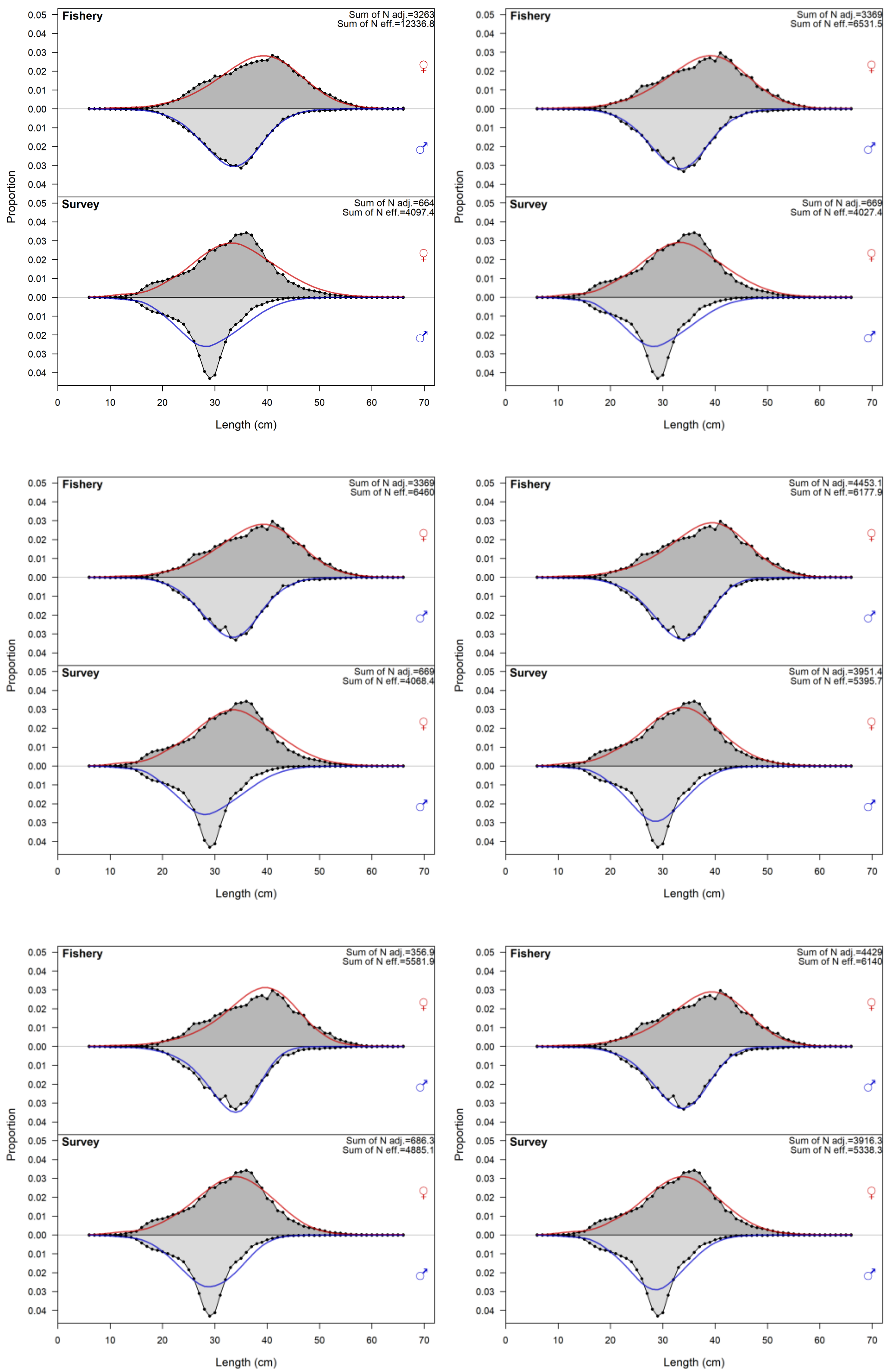


Figure 25. Model fit to northern rock sole length composition data 17.1 (topleft), 17.1e (top right), 17.1f (middle left), 17.1g (middle right), 17.1h (bottom left), 17.1i (bottom right).

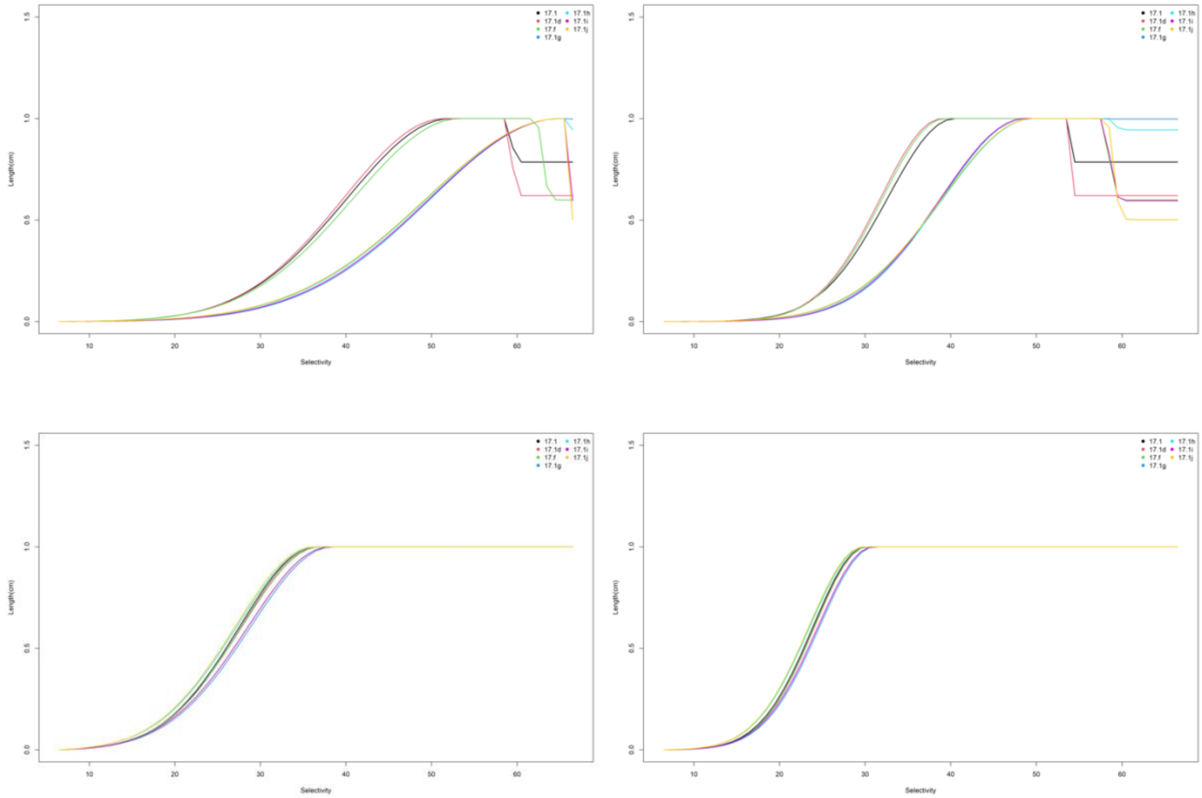


Figure 26. Northern rock sole fishery (top) and survey (bottom) length-based selectivity comparisons among models, females (left) and males (right).

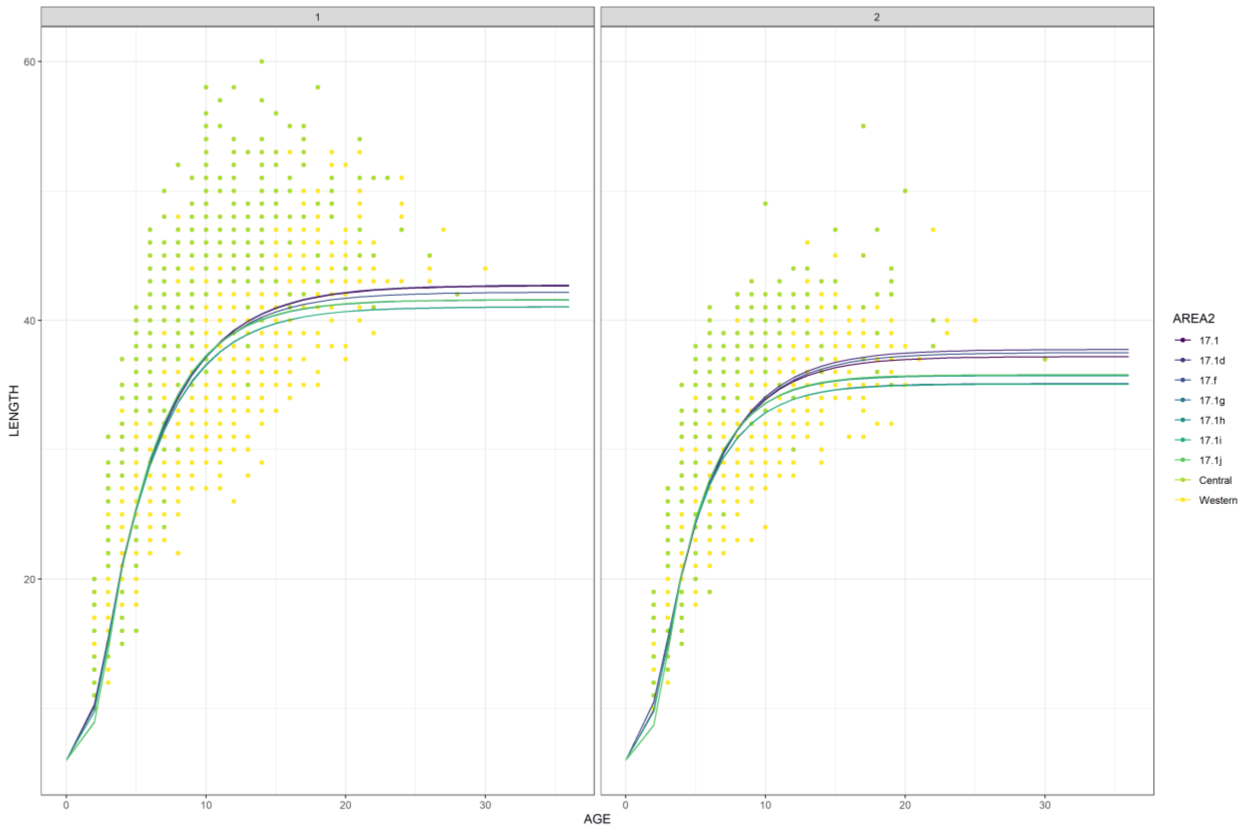


Figure 27. Northern rock sole growth curve comparisons among models, female (right) and male (left). Lighter color dots represent the data and the lines represent the model growth curve estimate.

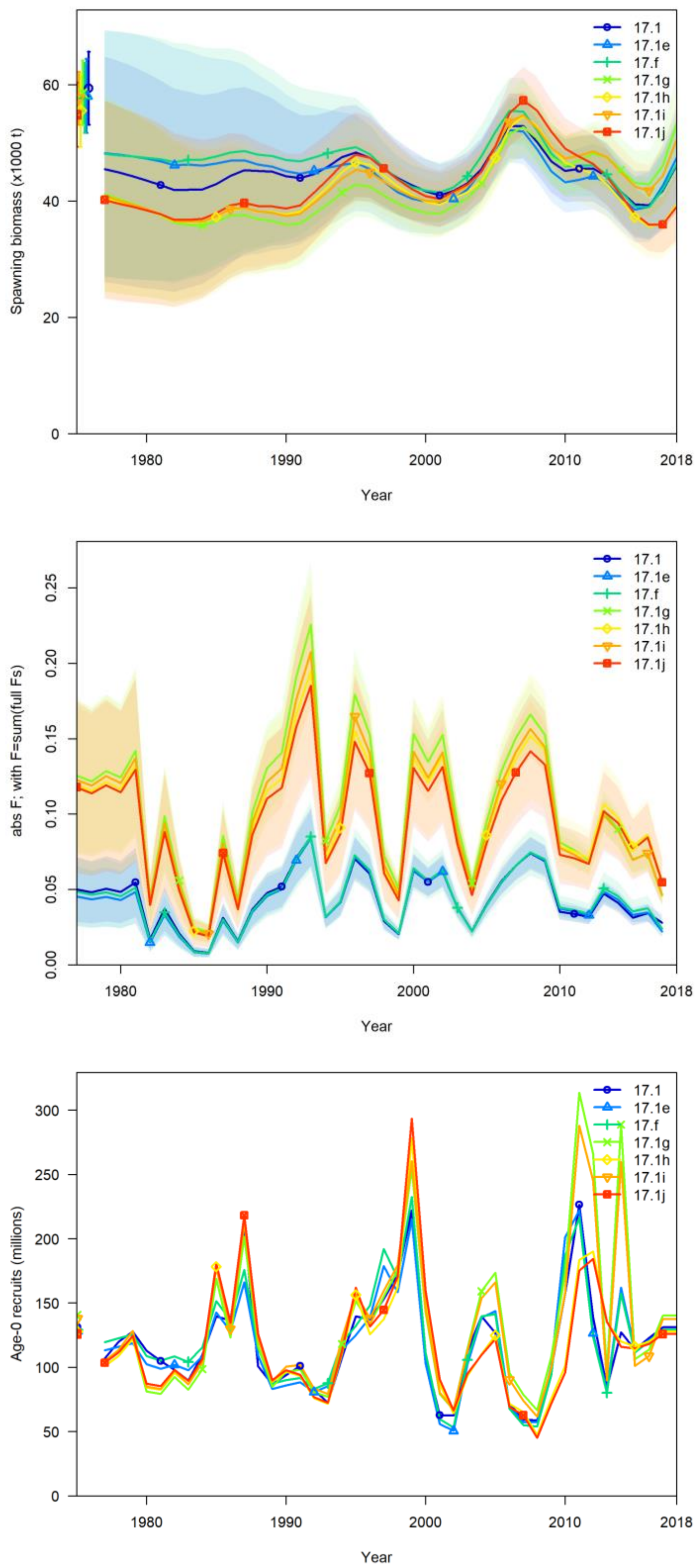


Figure 28. Northern rock sole SSB, fishing morality, age-0 recruits estimates by model.

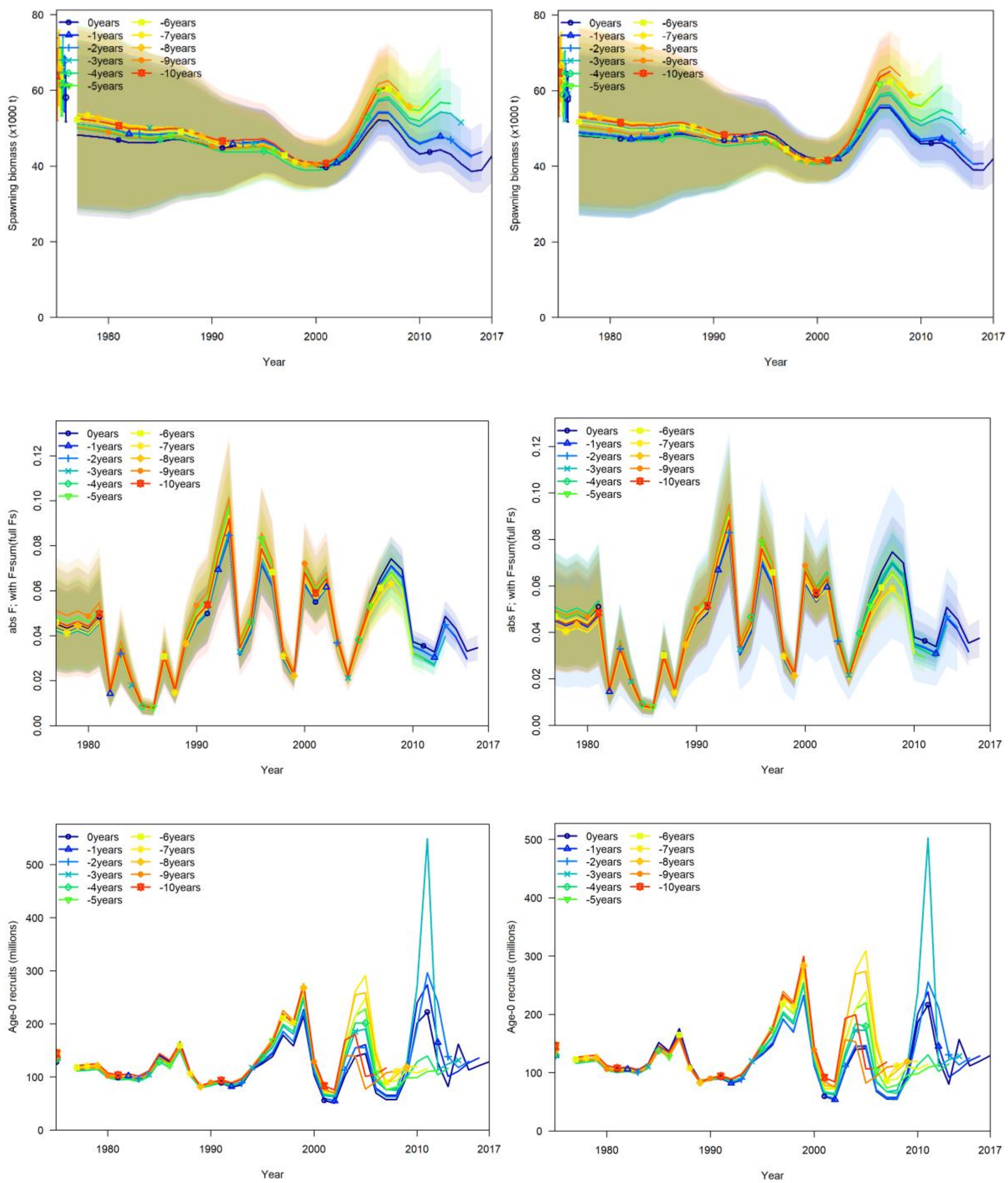


Figure 29. Retrospective plots for northern rock sole SSB, fishing morality, age-0 recruits model 17.1e (left) and 17.1f (right).

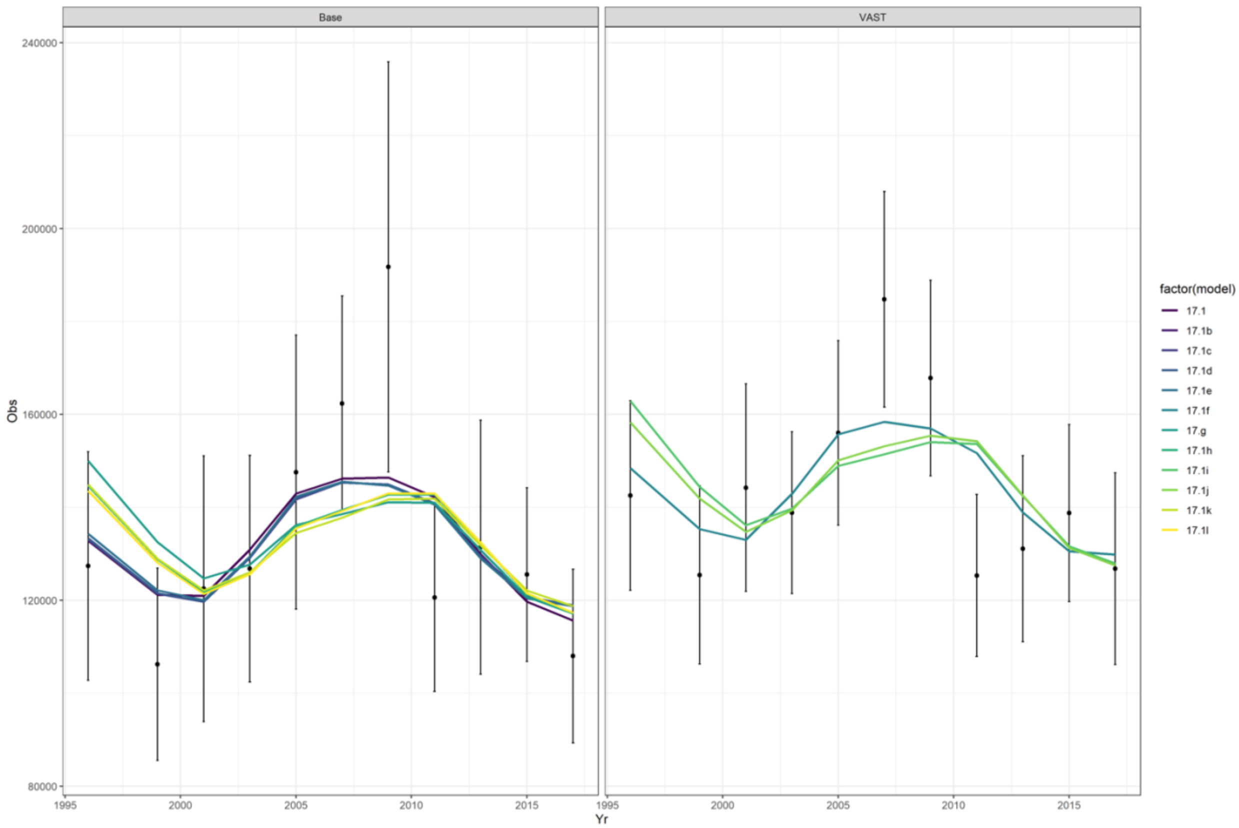


Figure 30. Model fit to southern rock sole survey biomass, design-based index (left) and VAST (right).

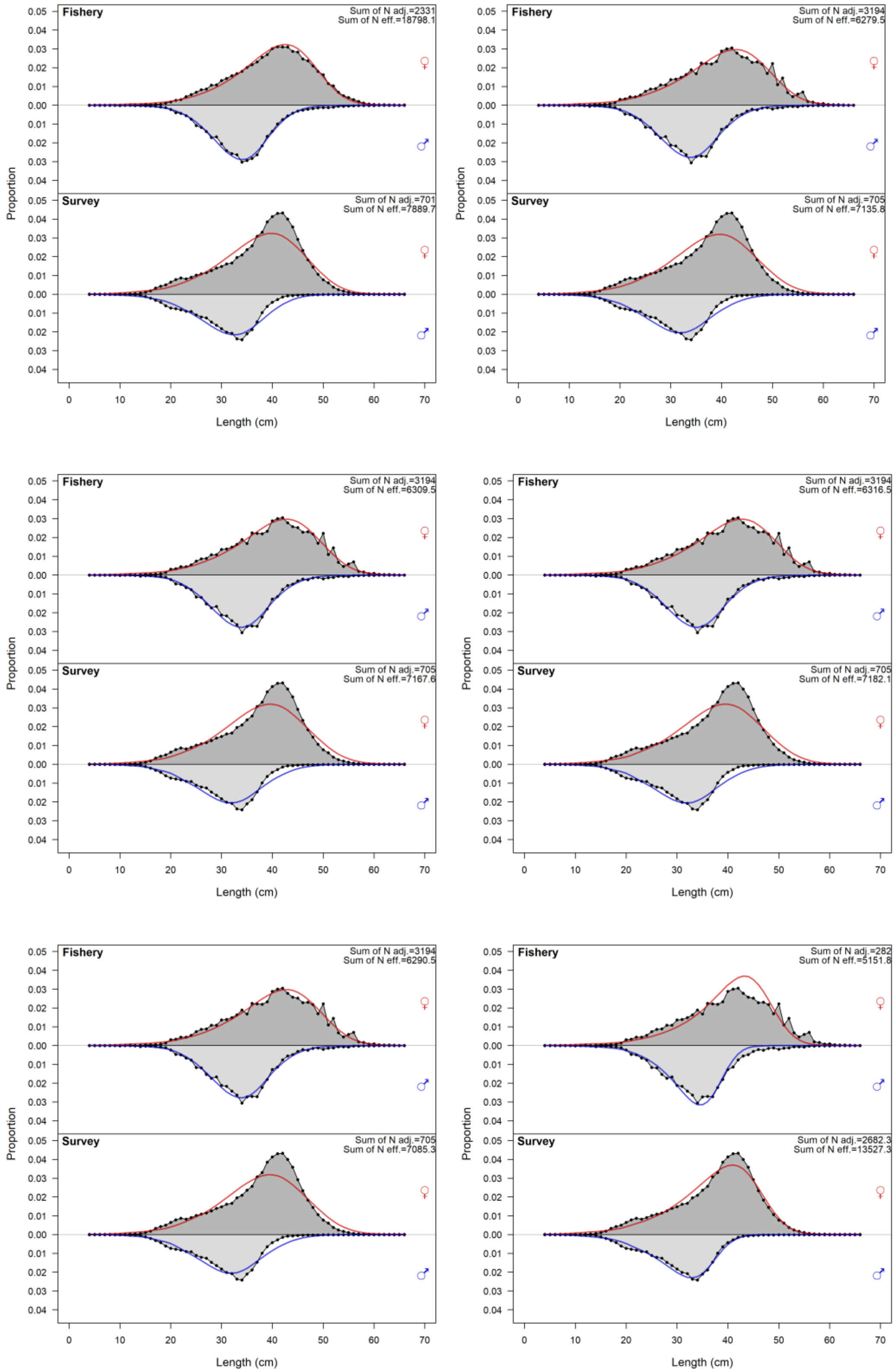


Figure 31. Model fit to southern rock sole length composition data 17.1 (topleft), 17.1c (top right), 17.1d (middle left), 17.1e (middle right), 17.1f (bottom left), 17.1h (bottom right).

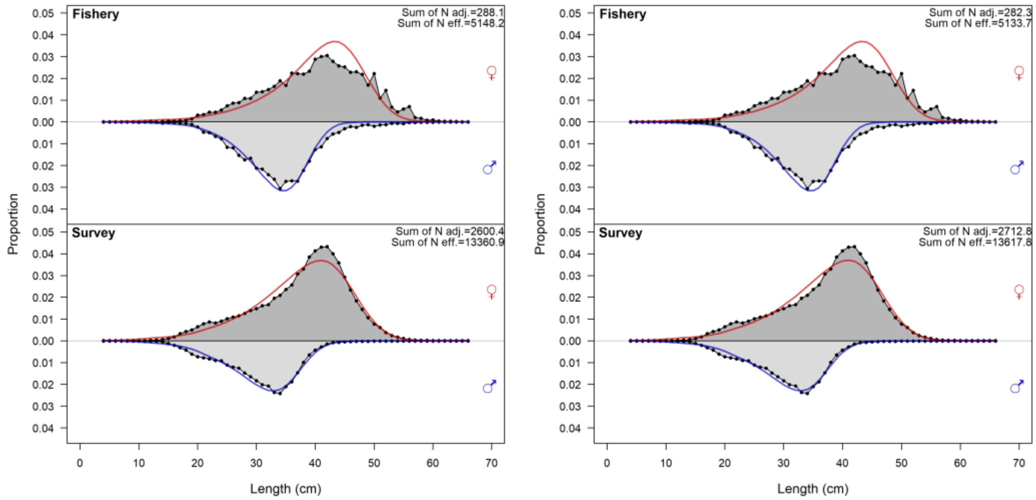


Figure 31 continued. 17.1j (left) and 17.1l (right).

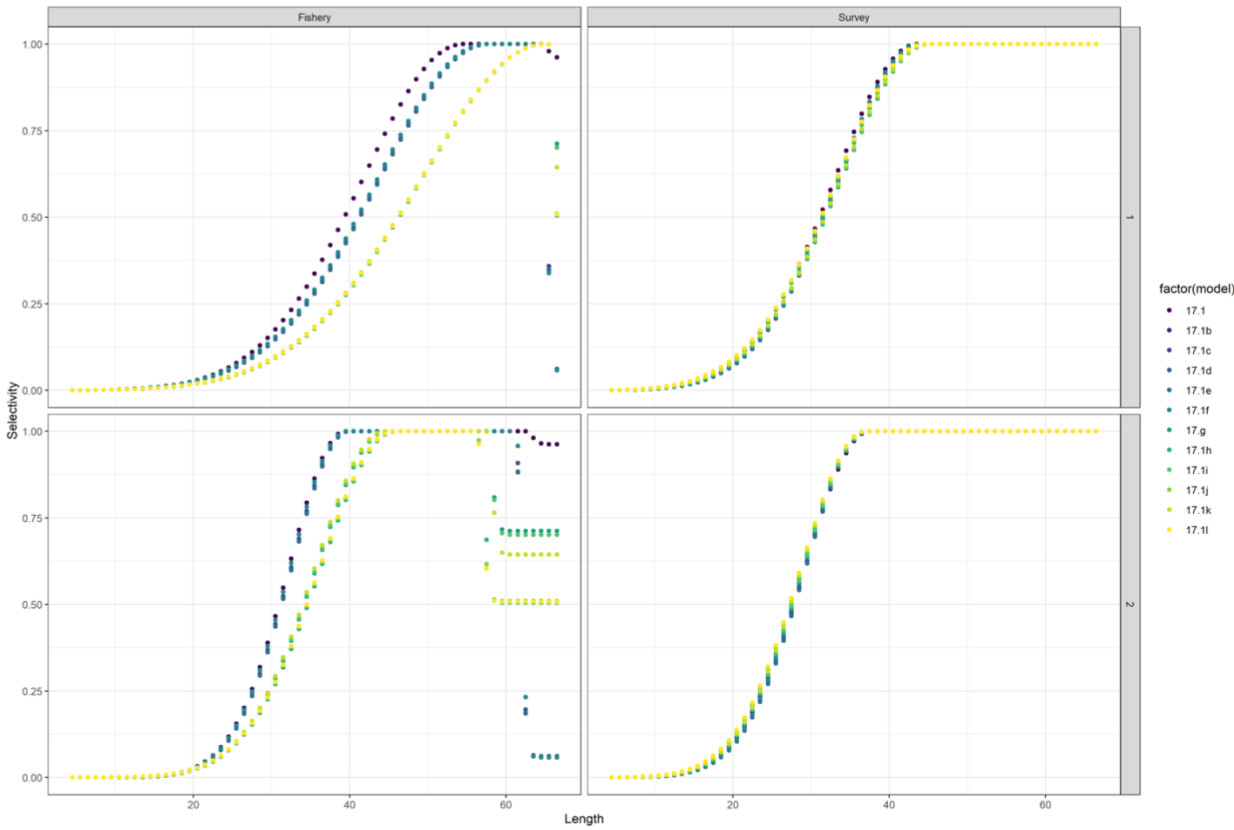


Figure 32. Southern rock sole fishery (left) and survey (right) length-based selectivity comparisons among models, females (top) and males (bottom).

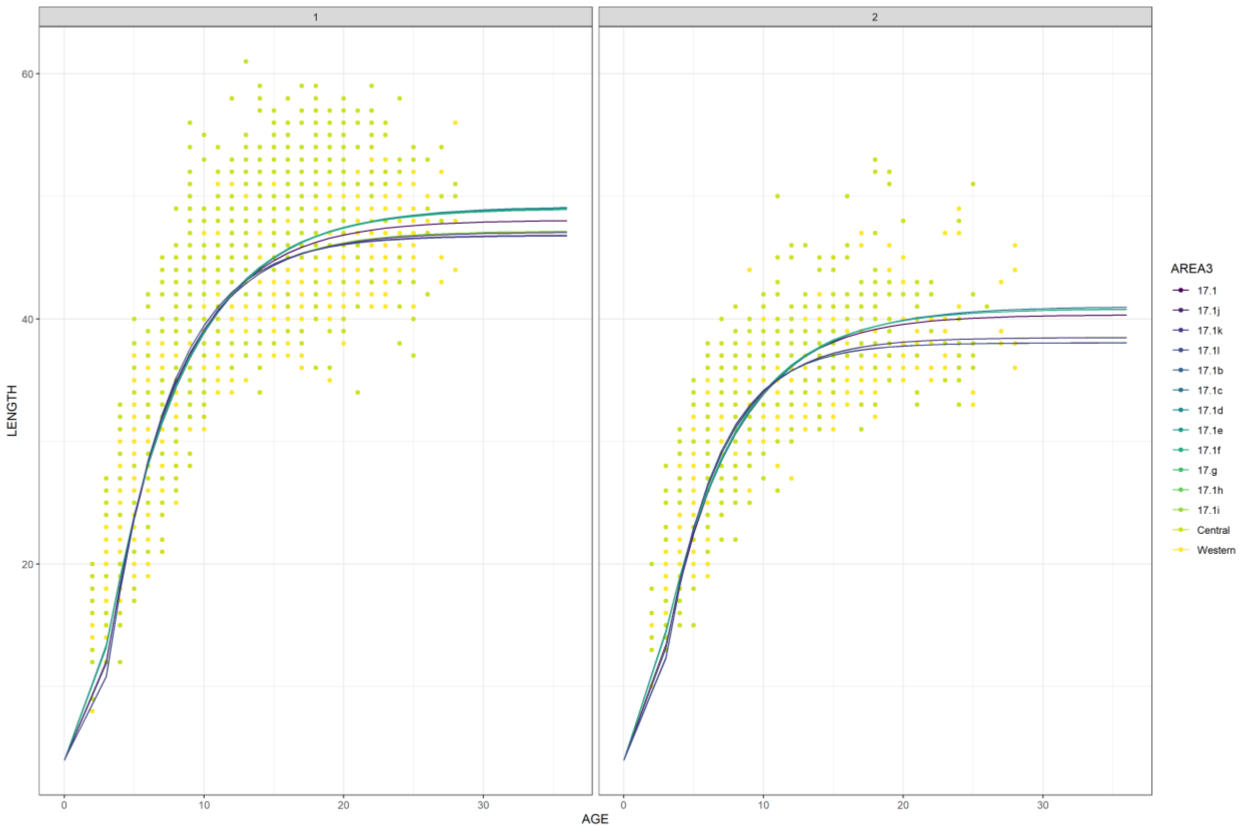


Figure 33. Southern rock sole growth curve comparisons among models, female (right) and male (left). Lighter color dots represent the data and the lines represent the model growth curve estimate.

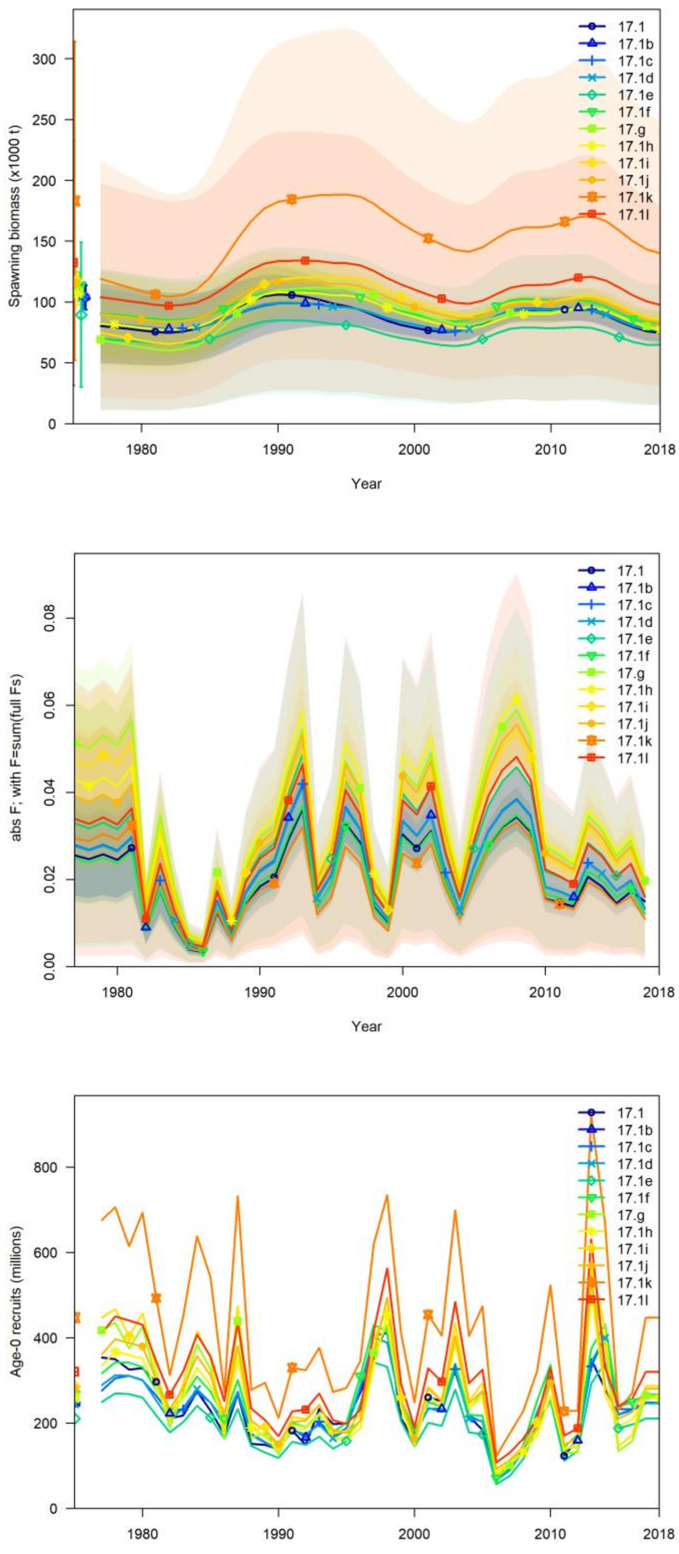


Figure 34 . Southern rock sole SSB, fishing morality, age-0 recruits estimates by model.

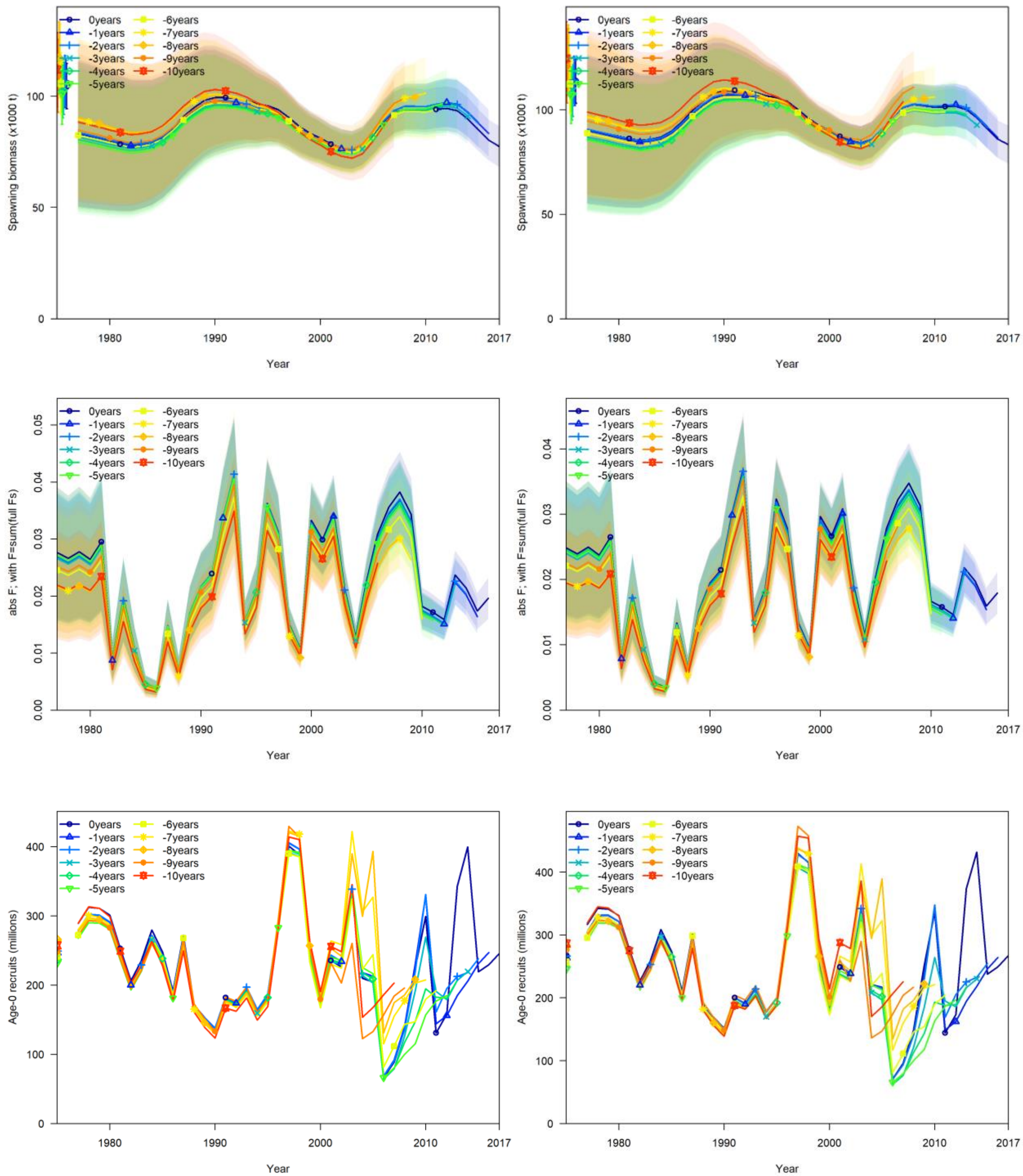


Figure 35 . Southern rock sole retrospective plots of SSB, fishing morality, age-0 recruits for models 17.1d (left) and 17.1f (right).

Appendix

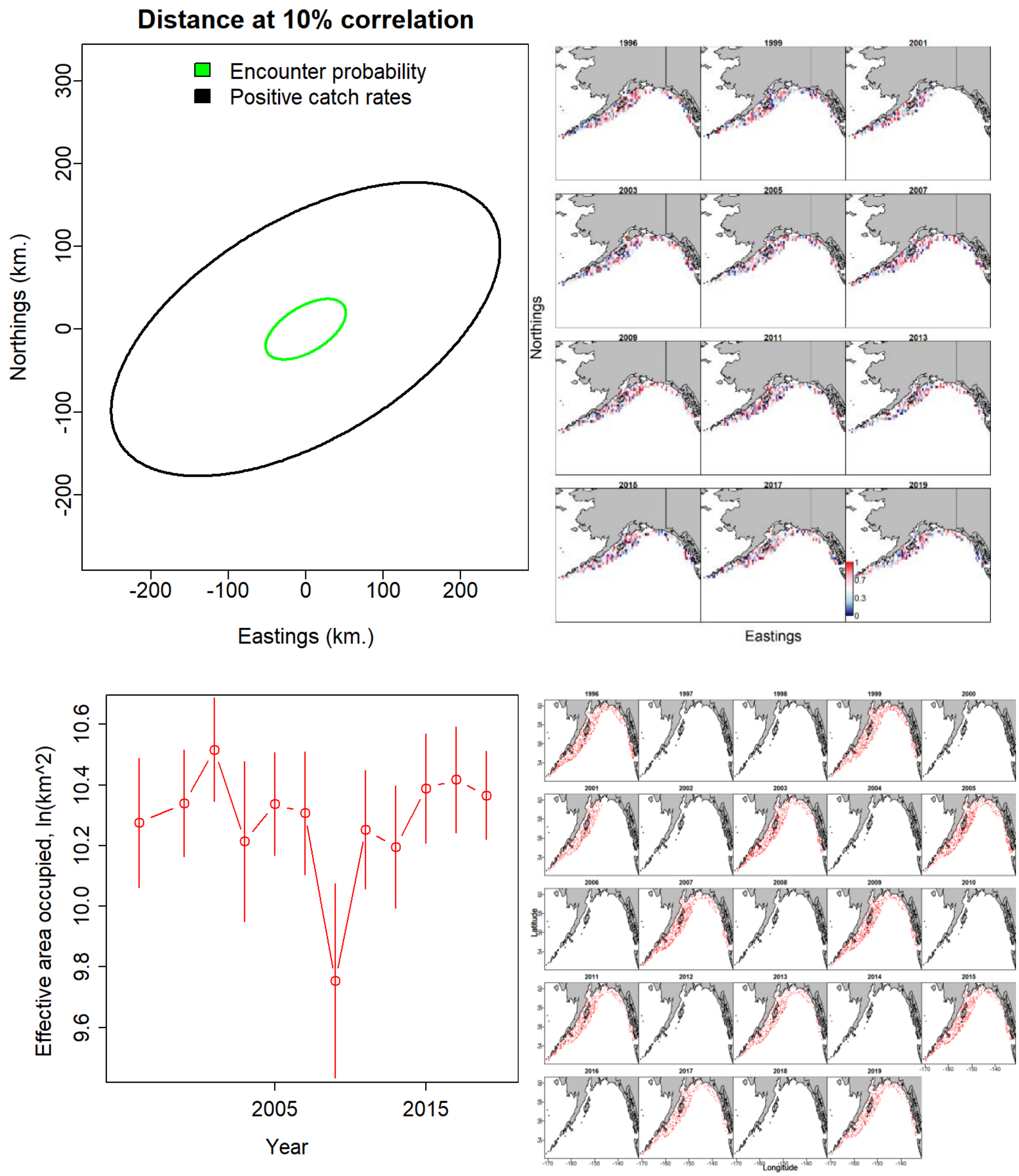


Figure A. 1 VAST diagnostic and data plots for northern rock sole: anisotropy (top left) and quantile residuals (bottom right), effective area occupied (bottom right), data by year (bottom left).

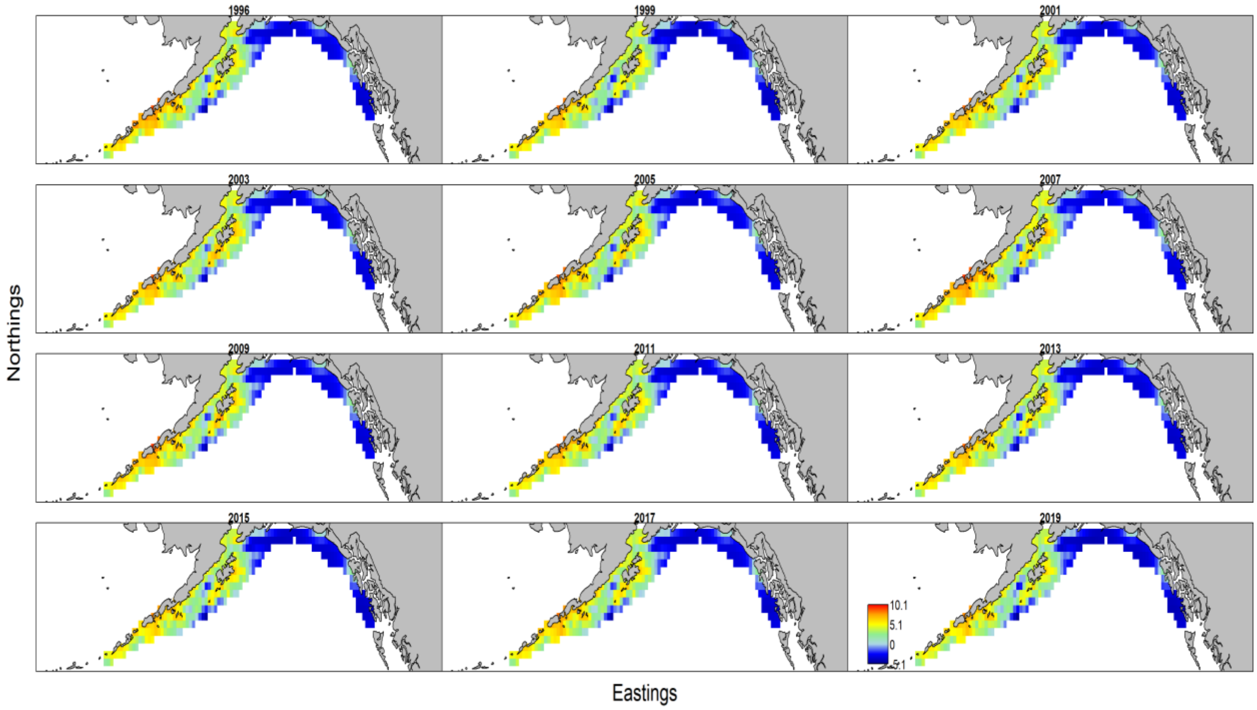


Figure A. 2. Predicted northern rock sole density over space and time.

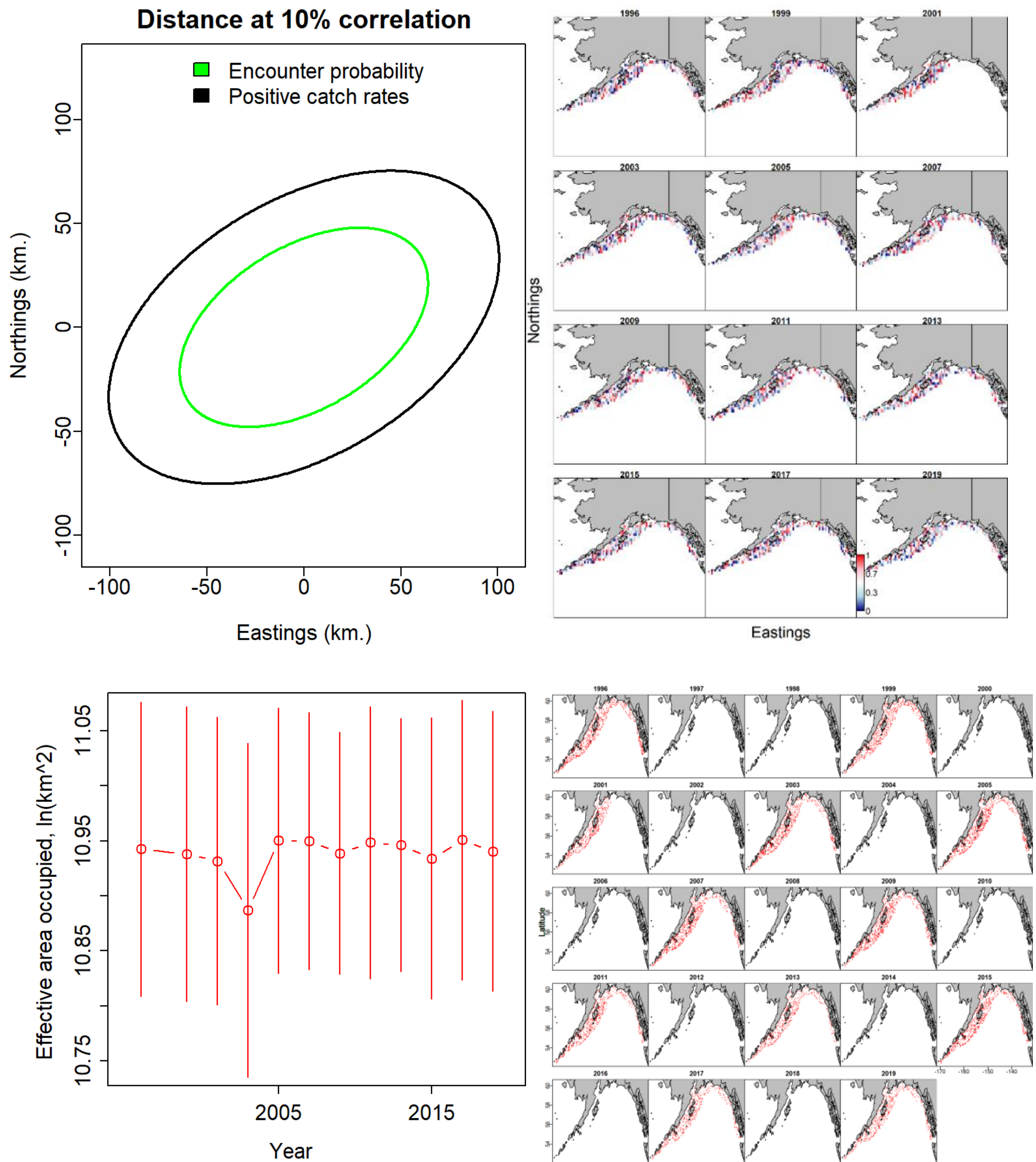


Figure A. 3. VAST diagnostic and data plots for southern rock sole: anisotropy (top left) and quantile residuals (bottom right), effective area occupied (bottom right), data by year (bottom left).

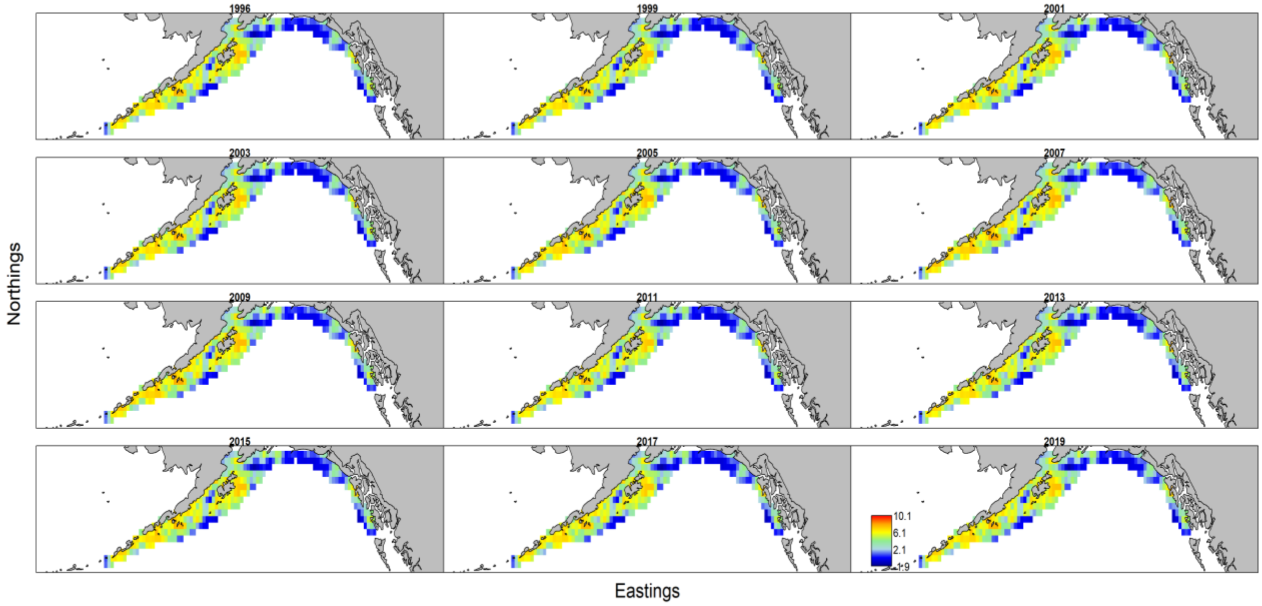


Figure A. 4. Predicted southern rock sole density over space and time.